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Indoor Radio Propagation Model Analysis Wireless Node Distance and Free Space Path Loss Measurements and Using Ultra-wideband (UWB) Technology

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ABSTRACT
Ultra wide bandwidth (UWB) signals are commonly defined as signals that have a large relative bandwidth (bandwidth divided by the carrier frequency) or a large absolute bandwidth. Typical indoor environments contain multiple walls and obstacles consisting of different materials. The RF ultra wideband (UWB) system is a promising technology for indoor localisation owing to its high bandwidth that permits mitigation of the multipath identification problem. The work proposed in this paper identifies exact position of transmitter and receiver wireless nodes, calculates free space path loss and distance between two nodes by considering frequency bandwidth using 2-point and 3-point Gaussian filter. Also in the 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- FSPL Gaussian, Path loss exponent, LOS, NLOS, ROI, RSS, WPAN

I. INTRODUCTION

The 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.

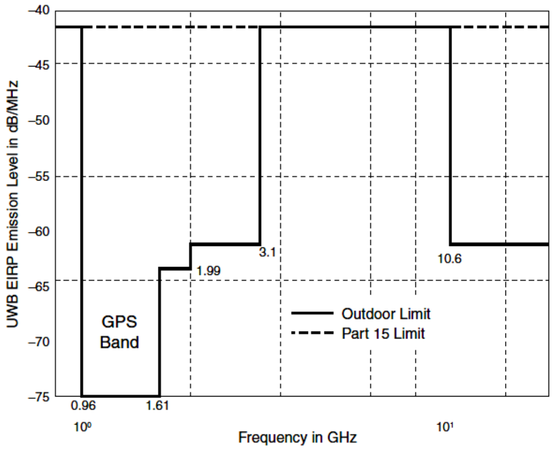


Fig.1: FCC spectrum mask for UWB [1]

UWB characteristics can be analyzed according to the Shannon capacity *(C)* formula. For an AWGN channel 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 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.

Fig. 2 shows the capacity comparison of UWB technology with IEEE WLAN and Bluetooth standard. [3]

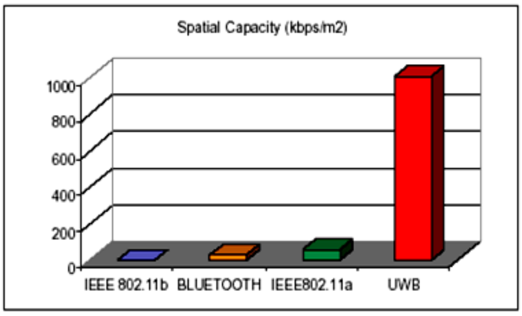


Fig.2: Spatial capacity comparison of UWB with other technology [3]

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. In this paper, the free space path loss of UWB communications is studied. The Friis' formula is extended in the complex frequency transfer function. The ideal and Gaussian filters are used for filtering the specific frequency bandwidth. The UWB free space path loss is derived based on average power and peak power losses. The simulations of the proposed parameter are done in visual studio and results are compared and commented with the help of various graphs and figures in the entire paper.

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.

The combined effects of reflection, diffraction, and scattering cause multipath. Multipath results when the transmitted signal arrives at the receiver by more than one path. The multipath signal components combine at the receiver to form a distorted version of the transmitted waveform. The multipath components can combine constructively or destructively depending on phase variations of the component signals. The destructive combination of the multipath components can result in a severely attenuated received signal.

One goal of our work is to characterize how the indoor radio channel affects the performance of the wireless nodes such as 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 FSPL and node distance. The frequency bandwidth (f_b) can be change with the dial to obtain different value of FSPL in the entire range of UWB spectrum. 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. INDOOR RADIO PROPAGATION MODEL AT UWB FREQUENCY

The performance of the wireless system depends heavily on the characteristics of the indoor radio channel. Excessive path loss within the home can prevent units from communicating with one another. Thus, it is useful to attempt to predict path loss as a function of distance within the home [22].

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.

Moreover, the ranges involved need to be of the order of 100 meters or less. Typically, multipath propagation is very important in indoor environments. Simple empirical propagation models are therefore not sufficient. The indoor propagation models are suitable for wireless devices designed for indoor application to approximate the total path loss an indoor wireless link may experience. The indoor propagation models can be used for picocell in cellular network planning.

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 3.1-3.3 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. below.

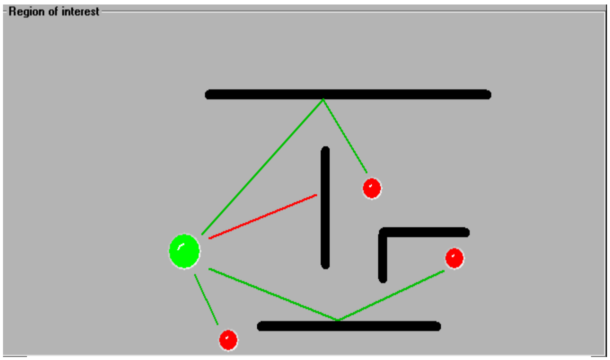


Fig. 3. Indoor wireless standard environment with obstruction in between to create multipath

In the Fig. 3 above 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.

All the large scale path loss models require free space path loss to be calculated by using friss transmission equation calculated in section 3.1.1.

2.1 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 (2) below,

$$\overline{PL}(d) = \overline{PL}(d_0) + 10n\log\left(\frac{d}{d_0}\right) \quad (2)$$

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 3.1.1. 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. above 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.

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

(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

Thus, the log-distance model is a combination of a modified power-distance law and a log normal fading model.

2.2 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,

$$PL(dB) = \overline{PL}(d_0) + 10n_{sf}\log\left(\frac{d}{d_0}\right) + FAF \quad (3)$$

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

(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

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.

2.3 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

$$PL(d) = PL(d_0) + 10n\log(d) + kF \tag{4}$$

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, (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

2.4 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:

$$PL(d) = \overline{PL}(d_0) + 10n\log\left(\frac{d}{d_0}\right) + X_\sigma \tag{5}$$

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 1.63 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.

2.4.1 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,

(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

2.4.2 Log-normal shadowing (Non-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,

(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

2.5 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]

$$P_r(d) = P_0 - 10\gamma \log_{10} d + S \quad (6)$$

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 $\sigma_{s.}$ [23].

Table 5: Calculation of Received signal strength (RSS) with LOS and NLOS condition

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

III. FREE SPACE PATH LOSS MEASUREMENTS

3.1 Free Space Path Loss (FSPL) based on free space model

This model is used to predict the signal strength when the transmitter and the receiver have a clear, unobstructed line of sight (LOS) path between them. It predicts that the received power decays as a function of Transmitter-Receiver distance raised to some power – typically to the second power [25]. The Free Space model [25], also known as Friis propagation model, calculates the average radio signal attenuation over distance d. When assuming isotropic propagation of waves this relates to a quadratic loss of signal power over distance given in [24]. It basically represents the communication range as a circle around the transmitter. The angle of attack (AOA) is calculated as a relative angle between transmitter and receiver and displayed in seven segment LED display panel. The typical RF transmission system for free space model is shown in figure below.

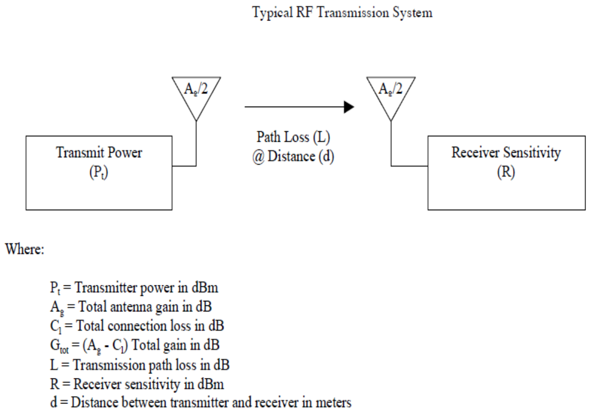


Fig.4: Typical RF transmission system [25]

In wireless communications, such as shown in Fig.4, as the distance between source and destination i.e. (d) increases, the minimum energy required to successfully transmit a data packet between them also increases. This is due to the fact that the strength of the received signal decreases as a function of d. By using the inverse power law (d^{-n}), one can model the decrement in the received signal strength in which n is the path loss exponent. The average path loss for an arbitrary separation is expressed as a function of distance by using path loss exponent ' n'

PL =10 n log (d) (7)

Where d is the distance between the transmitter and receiver and n is the path loss exponent whose value ranges between 2 to 4, For free-space propagation model, n is 2 (d^{-2} power loss with distance) and n is 4 for the two-ray ground propagation model (d^{-4} power loss) [26].

3.1.1 Free Space Path Loss Calculation

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.

$$FSPL = \left(\frac{4\pi d}{\lambda}\right)^2 \quad (8)$$

$$FSPL = \left(\frac{4\pi d f}{\lambda}\right)^2 \quad (9)$$

Where, λ is the signal wavelength (in metres), f is the signal frequency (in hertz), d is the distance from the transmitter (in metres), c is the speed of light in a vacuum, 3×10^8 metres per second.

For typical radio environment; Frequency is in MHz; Distance is in Km, hence [23],

$$FSPL(dB) = 20\log_{10}(d) + 20\log_{10}(f) + 32.45 \quad (10)$$

For UWB, WPAN applications; Frequency is in MHz; Distance is in m, hence,

$$FSPL(dB) = 20\log_{10}(d) + 20\log_{10}(f) - 27.44 \quad (11)$$

The free space path loss, FSPL, is an essential basic parameter for many RF calculations. It can often be used as a first approximation for many short range calculations. Alternatively it can be used as a first approximation for a number of areas where there are few obstructions. As such it is a valuable tool for many people dealing with radio communications systems.

3.1.1.1 Free Space Path loss formula frequency dependency

Although the free space loss equation given above seems to indicate that the loss is frequency dependent. The attenuation provided by the distance travelled in space is not dependent upon the frequency. This is constant. The reason for the frequency dependence is that the equation contains two effects:

1. The first results from the spreading out of the energy as the sphere over which the energy is spread increases in area. This is described by the inverse square law.
2. The second effect results from the antenna aperture change. This affects the way in which any antenna can pick up signals and this term is frequency dependent.

As one constituent of the path loss equation is frequency dependent, this means that there is a frequency dependency within the complete equation.

3.1.1.2 Free Space Path loss formula distance dependency

Dependency of the FSPL on distance is caused by the spreading out of electromagnetic energy in free space and is described by the inverse square law, i.e. [23]

$$S = P_t \frac{1}{4\pi d^2} \quad (12)$$

Where,
S is the power per unit area or power spatial density (in watts per meter-squared) at distance d, P_t is the equivalent isotropic radiated power (in watts).

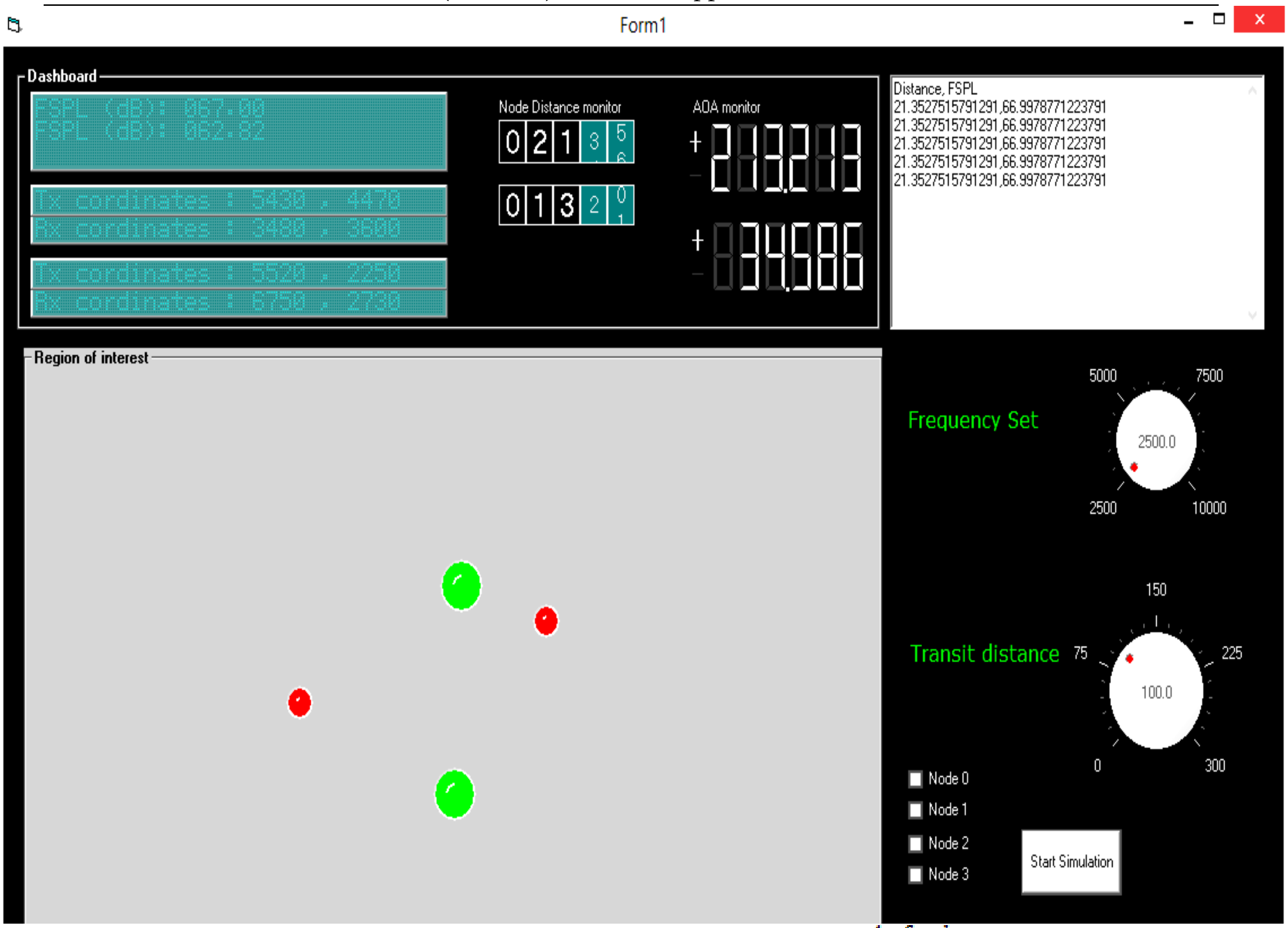
3.2 Free Space Path loss of UWB communication:

For UWB communications, the free space path loss can be defined in the two meanings. The first is based on the average power loss of the signal spectrum in the specific frequency bandwidth. The second is based on the peak power loss of the signal waveform in the specific frequency bandwidth. Conveniently, the ideal filter is used for filtering the specific frequency bandwidth. Unfortunately, the ideal filter is not causal. Therefore, in this paper the Gaussian filter is additionally analyzed and the frequency bandwidth is considered on positive frequency axis.

The Friis' free space path loss is extended in the complex frequency transfer function for considering the frequency bandwidth instead of only single frequency. That is (13)

$$H_f(f,d) = \frac{c}{4\pi f d} e^{-2\pi f_d/c} \quad (13)$$

The ideal and Gaussian filters are used for filtering the specific frequency bandwidth. The frequency transfer functions of ideal and Gaussian filters are respectively defined as



$$H_i(f) = \begin{cases} 1 & f_l \le f \le f_h \\ 0 & elsewhere \end{cases} \quad (14)$$

$$H_g(f) = e^{-\pi^2 d_e^2 (f-f_c)^2} \quad (15)$$

Where d_e is the $1/e$ characteristic decay time and has the relation on the reference level l_r that is used to consider the frequency bandwidth. The relation between d_e and l_r is

$$d_e = \frac{2}{\pi f_b}\sqrt{\frac{-l_r}{20\log(e)}} \quad (16)$$

3.2.1 Free Space Path loss based on average power loss

The free space path loss based on average power loss is considered as the average power loss of the signal spectrum in the specific frequency bandwidth. The ideal and Gaussian filters are considered.

3.2.1.1 Ideal filter

The free space path loss based on average power loss by using ideal filter in dB can be evaluated from

$$PL_{a,i}(d) = -10log\left[\frac{\int_{f_l}^{f_h} |H_f(f,d)|^2 |H_i(f)|^2 df}{\int_{f_l}^{f_h} |H_i(f)|^2 df}\right] \quad (17)$$

This equation can be derived in the closed form, that is

$$PL_{a,i}(d) = 20log\left[\frac{4\pi f_{a,i} d}{c}\right] \quad (18)$$

Where,

$$f_{a,i} = \sqrt{f_L f_H} \quad (19)$$

Fig. 5 Simulation environment created with provision to change frequency bandwidth, node distance, number of nodes. Parameters displayed are FSPL, node distance on real time basis

This free space path loss formula corresponds with that proposed by IEEE 802.15.3a [27].

3.2.1.2 Gaussian filter

The free space path loss based on average power loss by using Gaussian filter in dB can be evaluated from

$$PL_{a,g}(d) = -10log\left[\frac{\int_{f_l}^{f_h} |H_f(f,d)|^2 |H_g(f)|^2 df}{\int_{f_l}^{f_h} |H_g(f)|^2 df}\right] \quad (20)$$

This equation cannot be directly derived in the closed form. Therefore, the Gaussian integration formula [24] is used to estimate this equation. The closed form formula obtained from 2- and 3-point Gaussian integration formulas respectively are

$$PL_{a,g,2}(d) = 20log\left[\frac{4\pi f_{a,g,2}d}{c}\right] \quad (21)$$

$$PL_{a,g,3}(d) = 20log\left[\frac{4\pi f_{a,g,3}d}{c}\right] \quad (22)$$

Where,

$$f_{a,g,2} = \frac{12f_c^2 - f_b^2}{2\sqrt{36f_c^2 + 3f_b^2}} \quad (23)$$

$$f_{a,g,3} = \frac{1}{2}\sqrt{\frac{4 + 5e^{-0.2\pi^2 d_e^2 f_b^2}}{\frac{1}{f_c^2} + 25\frac{20f_c^2 + 3f_b^2}{(20f_c^2 - 3f_b^2)^2}e^{-0.2\pi^2 d_e^2 f_b^2}}} \quad (24)$$

Above formulas are implemented at typical UWB frequency range from 3.1GHz to 10.6 GHz. The ROI is considered two transmitters and receivers nodes are taken and frequency and distance are kept variable to obtain multiple values of path loss. The environment created is shown in Fig. above.

The values obtained of the free space path loss are tabulated as below and graph is plotted to have clear view of FSPL by considering different filters. UWB free space path loss is studies by setting the centre frequency *fc* to be 6:85 GHz. That is the centre frequency of UWB bandwidth for communications. The frequency bandwidth *fb* is considered from 500 MHz to 7:5 GHz which corresponds with minimum to maximum UWB bandwidth. The T-R separation distance *d* is set to be 1 m.

Table 6: FSPL based on average power loss by using ideal, -3 dB and -10 dB bandwidth Gaussian filters

Frequency (GHz)	Free space path loss (dB)		
	Ideal Filter	-3 dB bandwidth Gaussian filter	-10 dB bandwidth Gaussian filter
0.5	49.14	49.14	49.16
1	49.12	49.12	49.12
1.5	49.09	49.11	49.15
2	49.05	49.09	49.1
2.5	49	49.05	49.1
3	48.94	49	49.12
3.5	48.86	48.94	49.11
4	48.77	48.86	49.09
4.5	48.67	48.8	49
5	48.56	48.7	48.9
5.5	48.44	48.6	48.8
6	48.3	48.5	48.75
6.5	48.15	48.4	48.65
7	47.99	48.32	48.59
7.5	47.82	48.2	48.49

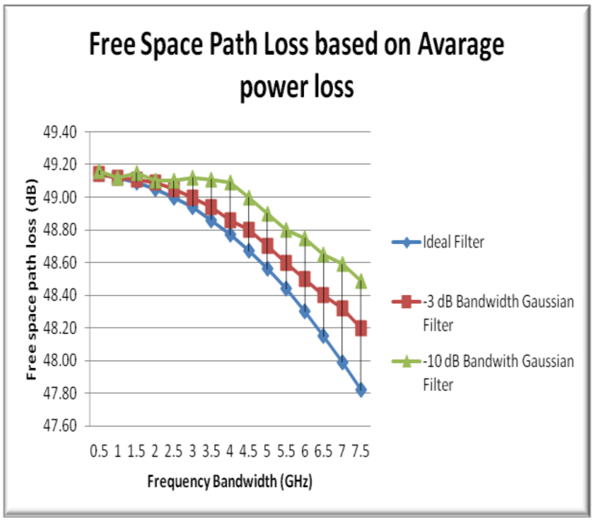


Fig.6 Free space path losses based on average power loss with centre frequency is *fc* = 6.85 GHz and T-R separation distance is *d* = 1 m along frequency bandwidth *fb* from 500 MHz to 7.5 GHz.

Fig.6 show the free space path losses based on average power loss. The ideal and Gaussian lters with *lr* = -3dB and -10dB are considered. In this case, the free space path loss obtained from the Friis' formula is constant about 49.16 dB which almost the same with each UWB free space path loss at the frequency bandwidth about 500 MHz.

Each free space path loss is decreased when the frequency bandwidth is wider. The free space path loss with ideal filter is lowest and it is higher when uses the -3dB and -10dB bandwidth Gaussian filters, respectively.

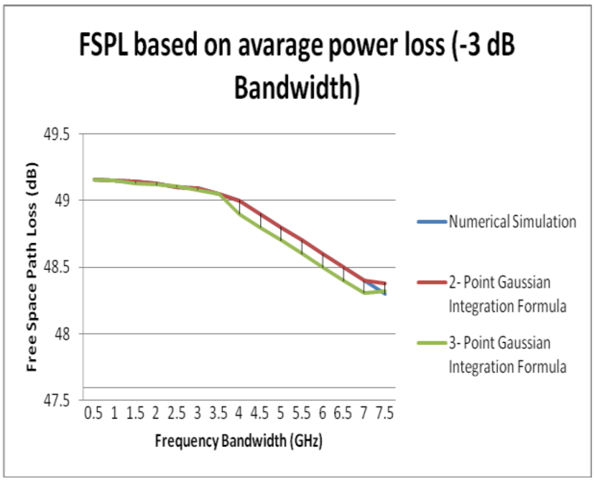


Fig.7 Free space path losses based on average power loss with centre frequency is *fc* = 6.85 GHz and T-R separation distance is *d* = 1 m along frequency bandwidth *fb* from 500 MHz to 7.5 GHz.

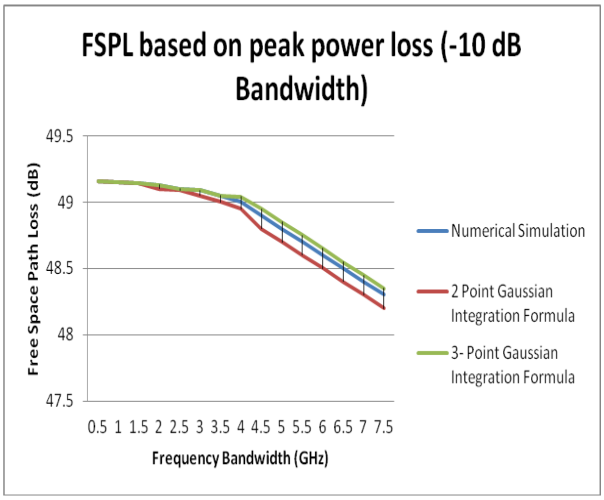


Fig.8 Free space path losses based on average power loss with centre frequency is f_c = 6.85 GHz and T-R separation distance is d = 1 m along frequency bandwidth f_b from 500 MHz to 7.5 GHz.

Fig. 7 and 8 shows the free space path losses based on average power loss. The formula of the -10dB bandwidth has the error more than that of the -3dB bandwidth. For the -3dB bandwidth, the maximum errors of 2- and 3-point Gaussian formula are about 0.08 dB and 0.01 dB, respectively. For the -10dB bandwidth, the maximum errors of 2- and 3-point Gaussian formula are increased to about 0.51 dB and 0.10 dB, respectively.

3.2.2 Free Space Path loss based on peak power loss

The free space path loss based on peak power loss is considered as the peak power loss of the signal waveform in the specific frequency bandwidth. The ideal and Gaussian filters are considered.

3.2.2.1 Ideal Filter

The free space path loss based on peak power loss by using ideal filter in dB can be evaluated from

$$PL_{p,i}(d) = -20log\left[\frac{\int_{f_l}^{f_h}|H_f(f,d)H_i(f)|df}{\int_{f_l}^{f_h}|H_i(f)|df}\right] \quad (25)$$

This equation can be derived in the closed form, that is

$$PL_{p,i}(d) = 20log\left[\frac{4\pi f_{p,i}d}{c}\right] \quad (26)$$

Where,

$$f_{p,i} = \frac{f_b}{\ln\left(\frac{f_H}{f_L}\right)} \quad (27)$$

This free space path loss formula corresponds with that proposed in [28]-[29].

3.2.2.2 Gaussian Filter

The free space path loss based on peak power loss by using Gaussian filter in dB can be evaluated from

$$PL_{p,g}(d) = -20log\left[\frac{\int_{f_l}^{f_h}|H_f(f,d)H_g(f)|df}{\int_{f_l}^{f_h}|H_g(f)|df}\right] \quad (28)$$

This equation cannot be directly derived in the closed form. Therefore, the Gaussian integration formula [24] is used to estimate this equation. The closed form formula obtained from 2- and 3-point Gaussian integration formulas respectively are

$$PL_{p,g,2}(d) = 20log\left[\frac{4\pi f_{p,g,2}d}{c}\right] \quad (29)$$

$$PL_{p,g,3}(d) = 20log\left[\frac{4\pi f_{p,g,3}d}{c}\right] \quad (30)$$

Where,

$$f_{p,g,2} = \frac{12f_c^2 - f_b^2}{12f_c} \quad (31)$$

$$f_{p,g,3} = \frac{4 + 5e^{-0.15\pi^2 d_e^2 f_b^2}}{\frac{4}{f_c} + \left(\frac{100f_c}{20f_c^2 - 3f_b^2}\right)e^{-0.15\pi^2 d_e^2 f_b^2}} \quad (32)$$

Table 7: FSPL based on peak power loss by using ideal, -3 dB and -10 dB bandwidth Gaussian filters.

Frequency (GHz)	Free space path loss (dB)		
	Ideal Filter	-3 dB bandwidth Gaussian filter	-10 dB bandwidth Gaussian filter
0.5	49.16	49.16	49.18
1	49.15	49.15	49.18
1.5	49.14	49.14	49.18
2	49.13	49.13	49.18
2.5	49.1	49.12	49.15
3	49.09	49.1	49.14
3.5	49.05	49.09	49.11
4	49	49.05	49.09
4.5	48.9	49	49.08
5	48.8	48.9	49.06
5.5	48.7	48.8	49
6	48.6	48.7	48.9
6.5	48.5	48.6	48.8
7	48.4	48.5	48.7
7.5	48.3	48.4	48.6

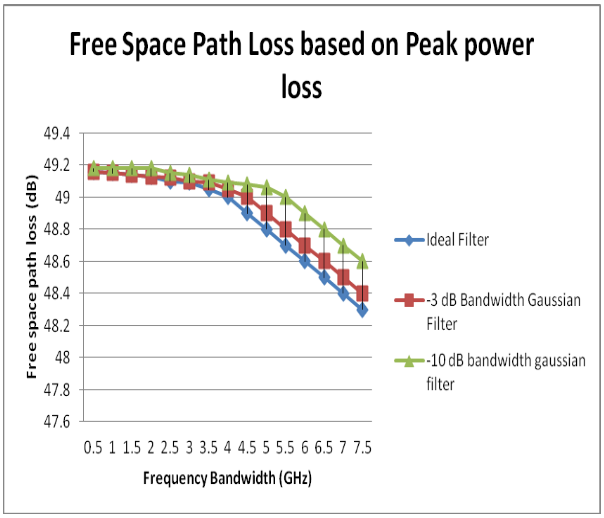


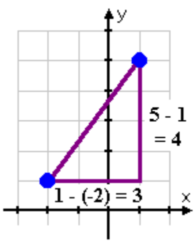
Fig.9 Free space path losses based on peak power loss with centre frequency is *f*c = 6.85 GHz and T-R separation distance is *d* = 1 m along frequency bandwidth *f*b from 500 MHz to 7.5 GHz.

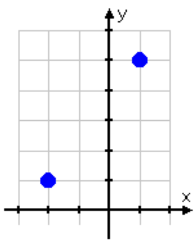
From Fig.9 it is seen that the free space path losses based on the average power loss are lower than that based on the peak power loss. The free space path loss with ideal filter is lowest and it is higher when uses the -3dB and -10dB bandwidth Gaussian filters, respectively.

3.3 Wireless Node distance

Distance between wireless nodes in typical indoor environment is important parameter to be calculated to estimate the free space path loss in decibels. In typical wireless environment with ROI within 30m according to UWB consideration, the distance between two wireless nodes can be calculated by using basic formulas of Pythagoras theorem.

Transmitter and Receiver nodes are separated by distance. The X-coordinates and Y-coordinates are measured for transmitter and receiver. The Distance Formula is a variant of the Pythagorean Theorem that you used in geometry. Suppose there are two points (–2, 1) and (1, 5), and to find how far they are:





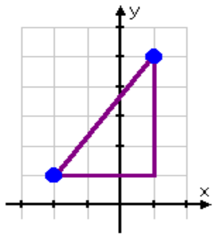


Fig.10 Wireless node distance calculation

The above geometry Fig.10 and method is applied in the paper to find distance between wireless transmitter and receiver at any given points within ROI. Based on above discussion the formula for the distance calculation is:

$$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \quad (33)$$

3.3.1 Free Space Path Loss Variation with frequency variation for different values of node distance

Table 8: Variation of FSPL with distance change at different frequencies (a) f=3.1GHz (b) f=5GHz (c) f=7GHz (d) =10.6GHz

(a)

Frequency of 3.1GHz	
Node distance (m)	**Free space path loss (dB)**
3	51.92
5	56.36
7	59.28
9	61.47
15	65.9
20	68.4
25	70.34
30	71.9

(b)

Frequency of 5 GHz	
Node distance (m)	**Free space path loss (dB)**
3	56.08
5	60.51
7	63.44
9	65.62
15	70.06
20	72.56
25	74.49
30	76.08

(c)

Frequency of 7 GHz	
Node distance (m)	**Free space path loss (dB)**
3	59
5	63.44
7	66.36
9	68.54
15	72.98
20	75.48
25	77.42
30	79

(d)

Frequency of 10.6 GHz	
Node distance (m)	**Free space path loss (dB)**
3	62.6
5	67.04
7	69.96
9	72.15
15	76.58
20	79.08
25	81.02
30	82.6

As seen from the above table 8 the variation in FSPL is obtained with different values of node distance at a particular UWB frequency range. As the simulated results shows at a frequency of 5GHz, by changing node distance between transmitter and receiver from 3m to 30m and it was found that FSPL is increasing from 56.08dB to 76.08dB. The simulation results are plotted in Fig. 11 for various frequency ranges within UWB range.

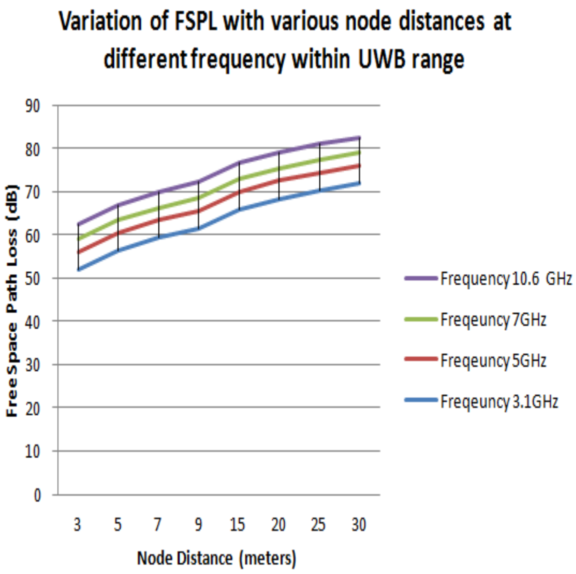


Fig. 11: Variation of FSPL at different frequency range and distances between transmitter and receiver

IV. RESULTS 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. 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 2.2 considers the floor attenuation factor (FAF) based on number of floors between transmitter and receiver. 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 2.3 additional attenuation factor path loss model is discussed. 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 2.4 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.

In section 2.5 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 5 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.

V. CONCLUSION

Several conclusions can be drawn from the indoor propagation study. The most obvious 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 the later section free space path loss of UWB communication was investigated In this paper, the free space path loss of UWB communications is studies. 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. When the frequency bandwidth is increased, the UWB free space path loss is lower than that obtained from Friss' formula. The free space path loss with ideal filter is lowest and it is higher when uses the -3 dB and -10 dB bandwidth Gaussian filters, respectively.

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