Statistical Analysis of Path Loss and Delay Dispersive Parameter of UWB Channel in a Laboratory Environment

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Abstract

This paper presents the results of path loss and delay dispersion parameters of Ultra Wideband (UWB) channel focussing on communication in a laboratory environment. Measurements are performed in frequency domain for the entire 7.5 GHz UWB frequency band (3.1 – 10.6 GHz). A Vector Network Analyser is used to record the channel transfer function. Antennas used for the measurement are Omni-directional micro-strip monopole. Both "Line-Of-Sight" (LOS) and "Non-Line-Of-Sight" (NLOS) scenarios are considered for the measurement. Distance dependent path loss and delay dispersion parameters of the channel are calculated from the measured data. Path loss fluctuation (Large scale fading) is modelled statistically.

Key words: UWB, Channel Model, Path Loss, Delay Dispersion, Large Scale Fading.

I. Introduction

UWB technology is of immense interest among researchers and academia for its low power short range high data rate wireless communication capability. Range of frequency for UWB communication allocated by FCC is 3.1 – 10.6 GHz and maximum spectral power is – 41.3 dBm per MHz [1]. Development of efficient wireless communication system necessitates accurate characterization of different parameters modelling the channel of interest. Characteristic parameters of UWB channel depends highly on the environment. Several researchers have studied the UWB propagation channel in different indoor environments [2] - [6]. There is a potential application of UWB radio in laboratory environments for low power high data rate wireless communications among different equipment and PCs. The scenarios of laboratory environment are different from typical office and residential environment. Main focuses of this study is to statistically characterize the path loss, delay dispersion and large scale fading parameters of UWB channel in laboratory environment.

The paper is organized as follows. Section II describes the details of measurement setup and procedures. Section III presents the results of path loss and large scale fading analysis. Section IV gives the detail findings of delay dispersion parameters and finally section V concludes the paper.

II. Measurement Setup and Procedure

The channel measurement setup used in this work consists of a Rhodes and Schwarz Vector Network Analyzer ZVA 24, a pair of Omni-directional UWB antenna, coaxial cables from Minicircuit, PC with LAN for remotely storing and post processing of data. The selected frequency band for the measurement is from 3.1 GHz to 10.6 GHz with total of 1601 frequency sweep point. Time resolution ($\tau_{res} = 1/BW$) of the measurement setup is 133 picosecond. Table 1 lists the parameters of the measurement setup

Table 1: Measurement parameters

Parameter	Value
Frequency Band	3.1 – 10.6 GHz
Bandwidth	7.5 GHz
No of points	1601
Sweep time	3.2 sec
IF bandwidth	1 KHz
DANL(avg. Noise floor)	- 120 dBm
Transmitted power	10 dBm

Measurements were performed in a typical laboratory environment of size (11.5 x 9 meter) consisting of different laboratory instrument, computers, work benches, bookshelves, tables, chairs etc. Measurements were conducted at two different scenarios one in pure Line-Of-Sight (LOS) and other one in Non-Line-Of-Sight (NLOS) environment. In both cases, T_x antenna is fixed at one position and R_x antenna position is changed from nearest to the farthest position in steps of 0.5 meter. At each spatial point 16 channel responses were recorded on a (4 X 4) square grid to remove small scale fading effect from the measurement. Grid points are separated by 5cm (λ/2) to make sure of independent fading [7]. The process is repeated for a large number of different receiver-transmitter positions. Heights of transmit and receive antenna were kept at 1.05 meter above the floor. All measurements were performed during night time or holidays to get guarantied static channel during measurement. Figure 1 and Figure 2 below shows the measurement setup and measurement plane respectively.

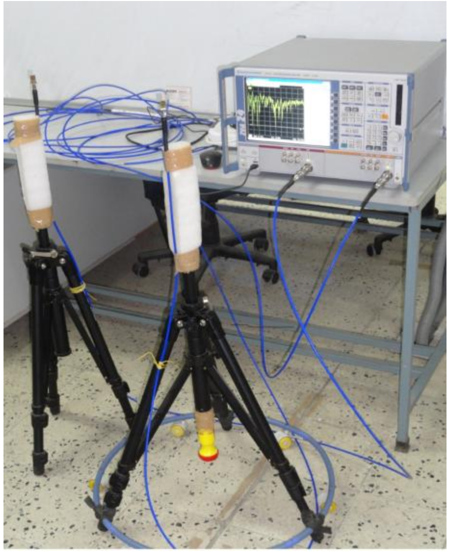

Figure 1: Snapshot of the measurement setup

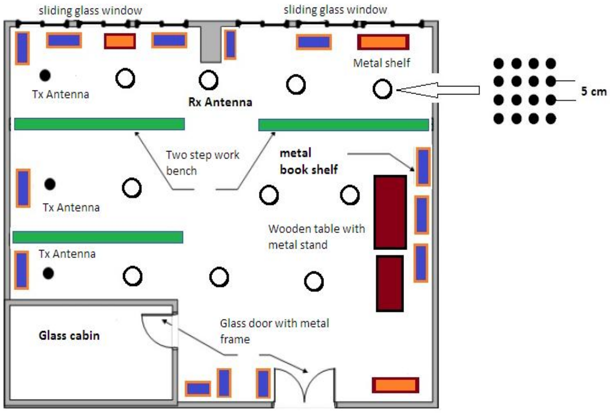

Figure 2: A sketch of the measurement plane

Antenna pair used for the measurement is a rectangular micro-strip monopole with Omni-directional radiation pattern in azimuth (H) plan. This antenna structure has been designed, fabricated and tested in the laboratory. The design is based on [8] with slight modification. Specifications of the antenna are listed in Table 2.

Table 2: Antenna specifications

Parameter	**Specification**
Frequency range	3 – 10.6 GHz
VSWR	< 2:1 across 3 – 10.6 GHz
Polarization	Linear
Radiation pattern	H plane Omni
Feed impedance	50 Ω
Assembly PCB	12 mm × 18 mm

III. Path Loss and Large scale Fading Analysis

Path loss refers the decay of received power with distance. Since UWB signal has extremely high bandwidth, different frequency components have different effect on the received power. Generally for UWB system, frequency dependence and distance dependence of path loss are treated independently [9].

$$PL(f,d) = PL(f).PL(d)............(1)$$

Several researchers have studied the frequency dependency of channel. P. Pagani et all [10] reported that a theoretical frequency loss of ***– 20 log(f)*** can be used for a modelling of frequency dependent UWB path loss. In our study we have considered the distance dependency of the channel. This frequency average path loss is modelled as [11]

$$\overline{PL}_{dB}(d) = \overline{PL}_{dB}(d_o) + 10n\log\left(\frac{d}{d_o}\right).............(2)$$

Here, $\overline{PL}_{dB}(d_o)$ is the mean path loss at a reference distance $\boldsymbol{d_o}$, $\boldsymbol{n}$ is the path loss exponent which depends on the specific environment. Reference distance is so chosen that it satisfies the far field requirement. Normally in indoor UWB channel measurement this is taken as 1 meter. In our measurement, received power at each measurement point is calculated from the channel transfer function as [12].

$$\overline{PL(d)} = -10\log_{10}\left(\frac{1}{16}\sum_{k=1}^{16}\left(\frac{1}{1601}\sum_{i=1}^{1601}\left|H_k\left(d, f_i\right)\right|^2\right)\right)........(3)$$

Received power calculated from Eqn. 3 is plotted against $\boldsymbol{10\log_{10}(d/d_o)}$. Figure 3 and Figure 4 below show the path loss for LOS and NLOS environment respectively. A linear regression line is fitted to the measured data by least square method to get the path loss exponent.

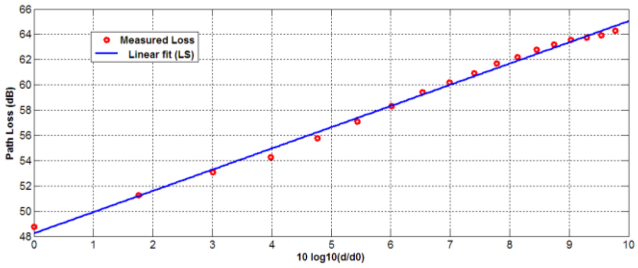

Figure 3 Scatter plot of path loss for LOS

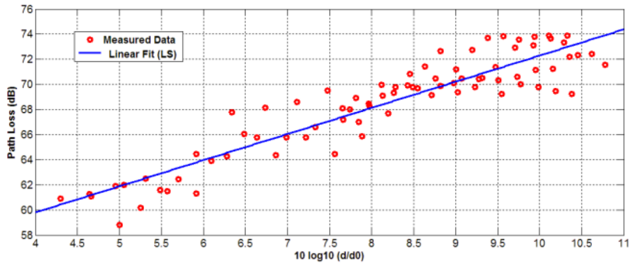

Figure 4 Scatter plot of path loss for NLOS

Fitted line gives the estimation of path loss at a distance ***d***. Slope of the fitted line gives the estimation of path loss exponent ***n*** and the point of interception of the line to Y axes gives the estimation of path loss at reference distance. From the analysis the path loss exponent ***n*** is found to be **1.7** and **2.08** for LOS and NLOS environment respectively. Reference path losses are found to be **48 dB** and **51.45 dB** respectively for LOS and NLOS.

When there is no direct path between Tx and Rx antenna (NLOS), then received power deviates from the linear regression line which is termed as large scale fading. This fading is a random parameter and hence the path loss expression Eqn. 3 modifies to

$$PL(d) = PL(d_o) + 10n\log\left(\frac{d}{d_o}\right) + X_\sigma \text{...........}(4)$$

Deviations of points from the estimated line are calculated to estimate the X_σ. Mean and standard deviation of X_σ are found to be **0** and **1.5** respectively. To verify the distribution followed by X_σ we have performed the Kolmogorov Smirnov test on X_σ with simulated normally distributed CDF of same mean and standard deviation. Test shows that our observations are from the same distribution with a significance level of **α = 0.05.** Figure 5 shows the histogram of large scale fading. Figure 6 represents the cdf of measured X_σ and simulated cdf. Large scale fading is found to be Lognormally distributed in linear scale which is normal in log scale.

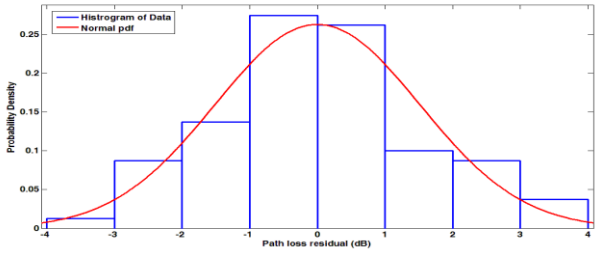

Figure 5 Histogram of large scale fading (dB)

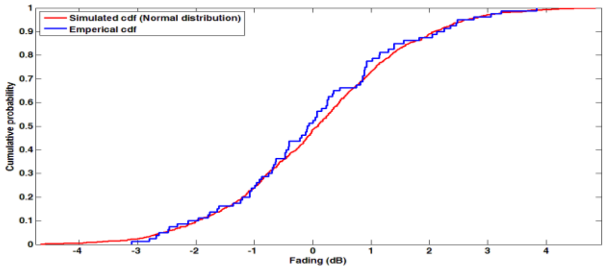

Figure 6 CDF of large scale fading

IV. Analysis of Delay Dispersion Parameters

In time domain a channel is described by its impulse response. Recorded channel transfer functions are converted to time domain impulse response by taking IFFT in matlab. A Hamming window is applied to frequency domain data to reduce side lobe in time domain. Squared impulse response gives the Power Delay Profile (PDP) which describes the power contained in each multipath component. PDP has been computed from impulse response as [13],

$$p(\tau) = \frac{1}{16}\left(\sum_{k=1}^{16}\left|h_k(\tau)\right|^2\right)\text{...........}(5)$$

This gives the PDP at a spatial point averaged over 16 local points. $\boldsymbol{h_k(\tau)}$ is the impulse response at kth measurement. Delay dispersion parameters are quantified by the Mean excess delay, RMS delay and Maximum excess delay. These dispersion parameters are defined with reference to a threshold value set from the maximum peak power. To calculate the delay parameters we have shifted the time axes of each Small Scale Average PDP (SSAPDP) such that first multipath component above the threshold appears at zero. There after we have normalized the SSAPDP such that total multipath power became unity.

Mean Excess Delay

Mean excess delay represents the point in delay domain where most of multipath powers are concentrated. Mean excess delay (τ_m) is calculated from SSAPDP as

$$\tau_m = \frac{\sum_k p(\tau_k)\tau_k}{\sum_k p(\tau_k)} \text{............}(6)$$

Empirical CDF of mean excess delay with different threshold value for LOS and NLOS environments are shown in figure 7 and figure 8 respectively. Mean of mean excess delay and standard deviation for LOS and NLOS environment are given in Table 3 and Table 4 below.

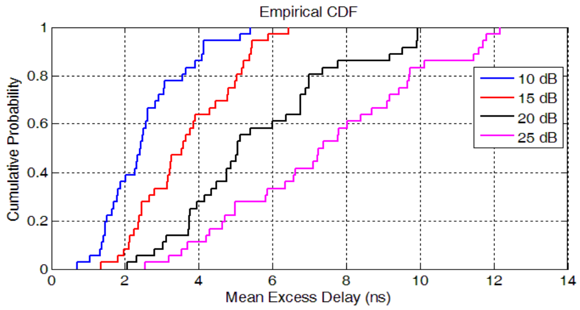

Figure 7: CDF of mean excess delay (LOS)

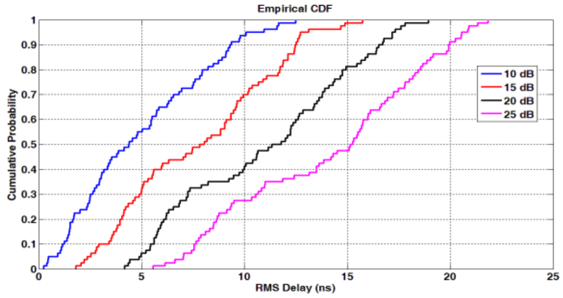

Figure 8: CDF of mean excess delay (NLOS)

Table 3: Mean Excess delay (LOS)

Sl. No	Threshold	Mean of Mean Excess Delay (ns)	Std. dev. of Mean Excess delay (ns)
1.	10 dB	2. 54	1. 12
2.	15 dB	3. 67	1. 32
3.	20 dB	5. 62	2. 21
4.	25 dB	7. 42	2. 10

Table 4: Mean Excess delay (NLOS)

Sl. No.	Threshold	Mean of Mean Excess delay (ns)	Std. dev. of Mean Excess delay (ns)
1.	10 dB	7. 16	5. 10
2.	15 dB	10. 11	5. 79
3.	20 dB	12. 54	6. 07
4.	25 dB	14. 50	6. 67

RMS Delay (τ_{rms})

RMS delay spread is the square root of second central moment of multipath power intensity profile. This represents the temporal spread of multipath power in delay domain. This parameter determines the symbol rate of a communication system. We have computed RMS delay spread as

$$\tau_{\mathrm{rms}} = \sqrt{\tau_{m2} - \tau_m} \text{............}(7)$$

Where τ_{m2} is given by

$$\tau_{m2} = \frac{\sum_k p(\tau_k)\tau_k^2}{\sum_k p(\tau_k)} \text{............}(8)$$

Empirical cdf of τ_{rms} with different threshold value for LOS and NLOS environment are shown in Figure 9 and Figure 10 respectively. Mean of τ_{rms} and standard deviations with different thresholds values are given in Table 5 and Table 6 below for LOS and NLOS.

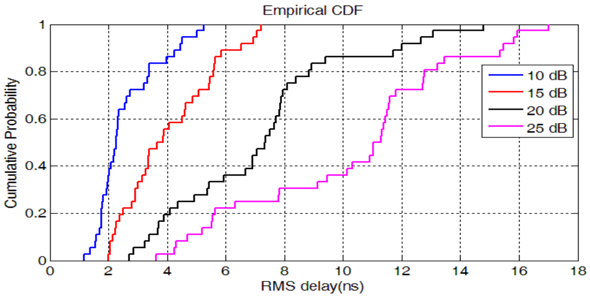

Figure 9: CDF of RMS delay (LOS)

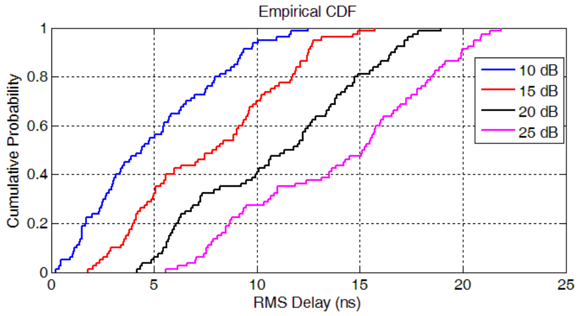

Figure 10: CDF of RMS delay (NLOS)

Table 5: RMS delay (LOS)

Sl. No.	Threshold	Mean of RMS delay (ns)	Std. dev. of RMS delay (ns)
1.	10 dB	2. 59	1. 06
2.	15 dB	4. 07	1. 57
3.	20 dB	7. 17	3. 00
4.	25 dB	10. 25	3. 71

Table 5: RMS delay (NLOS)

Sl. No.	Threshold	Mean of RMS delay (ns)	Std. dev. of RMS delay (ns)
1.	10 dB	4. 91	3. 21
2.	15 dB	7. 75	3. 67
3.	20 dB	10. 96	4. 21
4.	25 dB	14. 06	4. 63

V. Conclusions

This paper presents the empirical results of Path Loss, Large Scale Fading and Delay Dispersion parameters of UWB channel in a laboratory environment. Path Loss exponents are found to be **1.7** and **2.08** for LOS and NLOS scenarios respectively. Large Scale Fading is modeled as lognormal with mean **0** and standard deviation of **1.5**. Mean excess delay and RMS delay spreads are calculated for different threshold values and their mean and standard deviations are reported.

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References

[1] Federal Communications Commission, “First report and order 02-48,” 2002.

[2] A. F. Molisch, D. Cassioli, Chia-Chin chong, S. Emami, A. Fort, B. Kannan, J. Karedal, J, kunisch, H. G. Schantz, K. Sowiak, Moe Z. Win, “A comprehensive standardized model for Ultrawideband Propagation Channels,” IEEE Transactions on Antenna and Propagation, vol. 54, No. 11, November 2006.

[3] A. Muqaibel, A. Safaai-Jazi, A. Attiya, B.Woerner, and S. Riad, “Path-loss and time dispersion parameters for indoor uwb propagation,” IEEE Transactions on Wireless Communications,, vol. 5, no. 3, pp. 550 – 559, March 20

[4] Ranjan Bose, “ULTRA WIDEBAND INDOOR CHANNEL MODELING FOR PERSONAL AREA NETWORKING,” Proceeding, ‘EuCAP 2006’ Nice, Franch, 6 – 10 November 2006.

[5] J. Kunisch, J.Pamp, “Measurement results and modelling aspects for the UWB radio channel,” IEEE conf. On Ultra Wideband systems and Technologies, pp 19 – 23, May 2002.

[6] R. Saadane, D. Aboutajdine, “Ultra wide bandwidth indoor channel model based on measurements and physical approach,” Int. J. Ultra Wideband Communications and Systems, Vol. 2, No. 1, 2011.

[7] Andreas F. Molisch, “Ultrawideband propagation channels- theory measurement, and modeling,” IEEE Transactions on Vehicular Technology, special issue on UWB, winter 2005.

[8] Mohammad Ojaroudi, Changiz Ghobadi, and Javad Nourinia, “Small Square Monopole Antenna With Inverted T-Shaped Notch in the Ground Plane for UWB Application,” IEEE Antennas and Wireless Propagation Letters, Vol. 8,

[9] R. Saadane, M. Wahbi, A. Hayar, and D. Aboutajdine, “Path loss analysis based on uwb channel measurements,” in IEEE/ACS International Conference on Computer Systems and Applications, 2009. AICCSA May 2009, pp. 970 –974.

[10] P. Pajusco and P. Pagani, “Frequency dependence of the UWB indoor propagation channel,” in The Second European Conference on Antennas and Propagation, 2007. EuCAP 2007., nov. 2007, pp. 1 –7.

[11] Aawatif Menouni Hayer, Giorgio M. Vitetta, “Channel Model for Ultra-Wideband Communications: An Overview,” 14th Mobile & Wireless Communication Summit, EURASIP IST Summit, June 19-23, 2005, Dresden, Germany

[12] H. Li, M. Juan, L. ShuRong, and Z. Zhen, “Uwb channel measurement and data analysis in offshore oil platform,” in International Conference on Communications and Mobile Computing, 2009. CMC ’09. WRI, vol. 1, jan. 2009, pp. 476 –480.

[13] P. Pagani and P. Pajusco, “Statistical modeling of the ultra wide band propagation channel through the analysis of experimental measurements,” Comptes Rendus Physique, vol. 7, no. 7, pp. 762 – 773, 2006.