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Indoor Multipath Wireless Channel Experimental Characterization Utilizing Time Domain Techniques

G. Tatsis and P. Kostarakis

Abstract— **In this paper an experimental characterization of a typical indoor wireless propagation channel is performed. This channel characterization is needed for short range applications (<10m), utilizing Ultra-Wideband Impulse Radio (UWB-IR) techniques. Both the line of sight (LOS) and the non line of sight (NLOS) scenarios are taken into account. The characterization is done using time domain measurements of the transmission-reception path, using very short pulses that are propagating through the wireless channel. In order to obtain the channel's impulse response we utilize the CLEAN algorithm for the time-domain deconvolution technique. The characteristics of the channel that are measured in this study are the path loss, the shadowing effect, the mean excess delay spread, the RMS delay spread and the number of dominant paths.**

Index Terms— **Channel, Deconvolution, Time-domain and Ultra-wideband**

I. Introduction

UWB Impulse Radio is a new promising technology that operates with low transmission power in a very large transmission bandwidth [1], [2]. One of the key elements for accurate transceiver design is the knowledge of the propagation channel. Before UWB Impulse Radio can be implemented for indoor applications, the UWB indoor channel needs to be characterized. A lot of research is going on to characterize the indoor propagation channel [3]-[8]. The importance of accurate channel characterization cannot be ignored, that is why a model for the indoor channel has been released by the IEEE 802.15.3a standardization group [9], [10]. Propagation environments introduce limitations on the performance of wireless communications systems. The existence of multiple propagation paths with different gains and delays produces a transmission channel that is the main cause of performance degradation in wireless communications systems. In this paper an experimental procedure is established in order to obtain the channel's impulse response.

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This is done by using very short pulses, produced by an impulse generator constructed for UWB Impulse Radio techniques. The transmitter sends a pulse repeatedly and the received waveform is processed appropriately in order to extract the multipath gains and delays. The method used is the subtractive deconvolution utilizing the CLEAN algorithm. The purpose of this procedure is to determine both the large scale and the small scale statistics of the channel. The target channel is a typical indoor propagation environment and both LOS and NLOS scenarios are taken into account. The present paper is organized as follows: Section II gives a brief description of the pulse generator and antennas used, in Section III we describe the experimental setup, in Section IV the deconvolution technique is under consideration, Section V provides the results of our research and the paper concludes in Section VI.

II. UWB Impulse Radio Generator and Antennas

Significant work has been done up to now for the generation of very short pulses to be used in UWB Impulse Radio applications. One of the most preferred techniques is based on step recovery diodes (SRD). The rapid transition of this diode from forward to reverse bias generates pulses with the desired UWB spectrum. The transmitter in our case is constructed using an SRD and a differentiation circuit. The produced pulses are measured via an oscilloscope and a spectrum analyzer [11]. Fig. 1 shows the pulse in time domain measured by the oscilloscope. In this measurement a coaxial cable is connected between the transmitter and the oscilloscope. The pulse width is less than 1nsec and the peak to peak amplitude is about 2 Volts. The shape is close to an inversed first derivative of standard Gaussian pulse (monocycle).

To measure the spectrum of those pulses we transmit a pulse train with a repetition rate of 50MHz. The reception antenna output is driven to a spectrum analyzer through a coaxial cable. The result is shown in Fig. 2. One can notice the characteristic spectral lines that occur every 50MHz, the same as the repetition rate of the pulses. The envelope of this graph corresponds to the spectrum of a single pulse. The bandwidth of the pulses is almost 3GHz at -10dB.

The central frequency is about 1.2GHz. The antennas used in our experimental set-up are circular disk monopoles (CDM) fed with a coplanar waveguide [12], [13]. This type of UWB

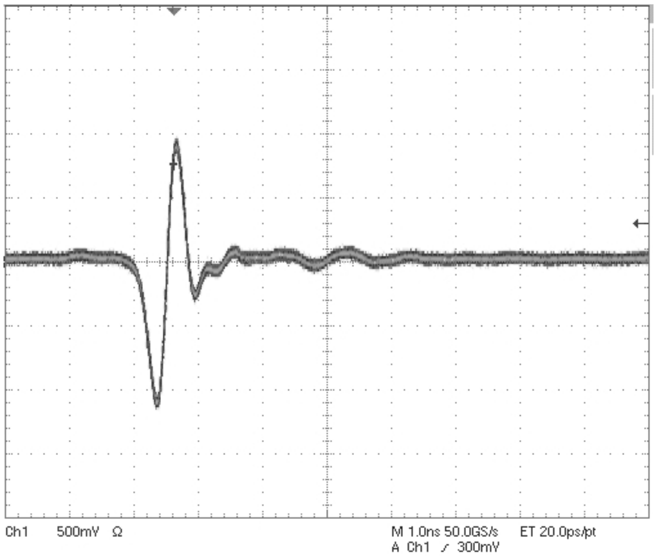

Fig. 1. Generated ultra short pulse of the transmitter, measured with oscilloscope.

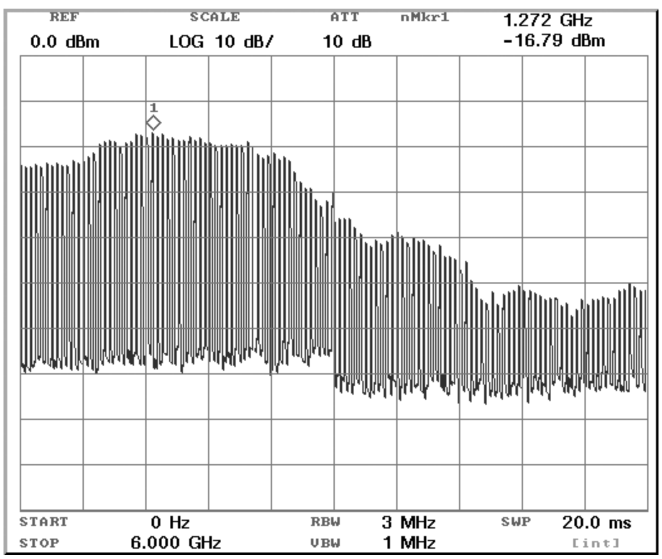

Fig. 2. The spectrum of pulse train of the transmitter at rate of 50MHz, measured with spectrum analyzer.

antenna is low cost, small size, simple to construct and has a very good omni-directionality, that is a desired property in our case, as it will be explained in the next section.

III. Experimental Setup

In order to measure the channel characteristics we realized the experimental setup that is shown in Fig. 3. The technique we follow is channel sounding. The data recording processing is done completely in time domain. In order to avoid pulse overlapping due to reflections the pulse generator is programmed to repetition rate of 2.5MHz that is to send one pulse every 400nsec through the antenna (TX). The generator also triggers the oscilloscope, through a coaxial cable, indicating the start time of the pulses. On the receiver side, a digital oscilloscope is used to sample the received waveforms and a personal computer stores the digital data. The sampling rate of the oscilloscope is 20Gs/sec. A low noise amplifier (LNA) is used after the receiver antenna (RX) to amplify the signal. Also we take advantage of the oscilloscope's property to average sequential captured frames in order to significantly reduce the additive noise. The oscilloscope is configured to sample 200 frames, of the same waveform, and it computes the average of the samples. This is a useful process in order to reduce the noise level since the noise is a significant factor of data distortion. The two antennas are connected with 8m long coaxial cables and are free to move within these limits. Both antennas are placed on a distance of 1.5m from the floor and 1.7m from the ceiling. The whole experiment was conducted in our laboratory, a view of which is shown in Fig. 4.

Using this set-up we have taken measurements with different locations of antennas covering distances of 1m to 10m both for LOS and NLOS scenarios. In the first scenario (LOS) we place the receiver antenna (RX) in the middle of the room (point A) and afterwards near to one of the corners of the room (point B), whereas the transmitter's antenna (TX) changes position, within the same room using small steps of 30cm, covering about the whole area of the laboratory. In the case of NLOS, we place the transmitter's antenna (TX) at the positions named C, D and E as shown in the diagram, whereas the receiver's antenna is placed at several positions inside the laboratory.

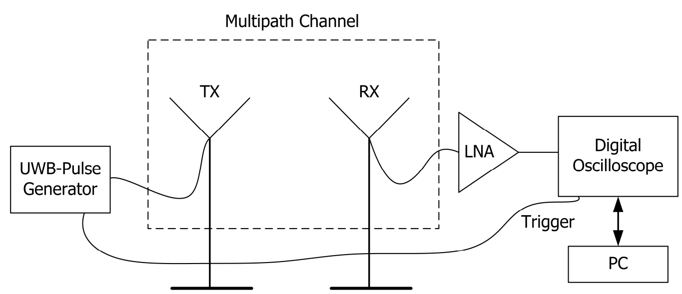

Fig. 3. Schematic diagram of the experimental setup.

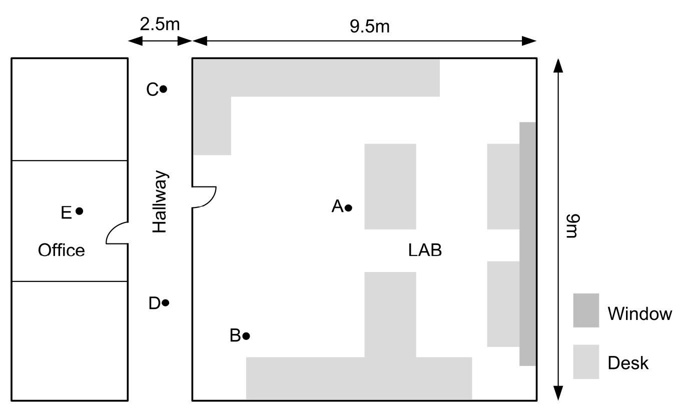

Fig. 4. Schematic diagram of the propagation environment for the experimental measurements.

The corresponding number of samples in each of those cases is shown in Table I. The total number of measurements for all the above cases is 693 samples. The estimation of the channel is based on a template pulse that we measure at a reference distance between TX-RX at 1m, at the far field, comparing with the small antenna dimensions (~5cm). The received waveform of a single pulse measured at 1m distance is shown in Fig. 5. The presence of the channel does not affect the received pulse because the nearest path except the line of sight path is the reflection from the floor which is about 2.1m longer than the first path resulting a 7nsec time delay. Therefore we may assume that there is no pulse interference for the first path, and thus no channel effect. This is the waveform that we use as a template for pulse detection. This waveform is the result of convolution of the transmitted pulse with both antennas, cables, LNA and the oscilloscope. This effect of pulse distortion is assumed to be the same always and the only variable is the propagation channel. Of course the different positions and angles of the antennas cause different received pulse shape but in our case this difference is measured to be small as shown in Fig. 6 and Fig. 7. We place the antennas with vertical polarization and with their planes parallel. We keep the transmitter's antenna steady while we rotate the receiver's antenna. Fig 6. shows the received waveform of a pulse while the receiver antenna is rotated in the horizontal plane, around its vertical axis. The pulse shapes are almost identical in cases where the planes of the antennas are at angles of 30, 60 and 90 degrees. Fig. 7. depicts the received pulse shape while we rotate the receiver antenna in the vertical plane. For 30 and 60 degrees the difference is small but near 90 degrees the received pulse is significantly distorted and reduced. This is a rather rare event to receive at this direction. In this experiment we consider as template waveform the one at 0deg.

IV. Deconvolution and Clean Algorithm

In order to determine the time dispersive characteristics of the target channel we must estimate the gains and delays of the channel's paths. The method we follow is the subtractive deconvolution utilizing the CLEAN algorithm [4], [6]. We adopt the modification made in [4], by adding zeros in dirty map update. By this we keep a reasonable resolution in time domain searching for resolvable paths. Depending on the form of our reference pulse we must have an estimate of the minimum space between paths that can be estimated with better accuracy. Therefore a simulation process is created to obtain a measure of that space. The steps of the simulation process we follow are given below,

1. Create random channel with tap space equal to N samples.
2. Perform convolution of channel with the measured reference pulse.
3. Add noise with specific signal to noise ratio.
4. Apply the CLEAN algorithm [6].
5. Calculate the square error of estimated channel compared to initial one.

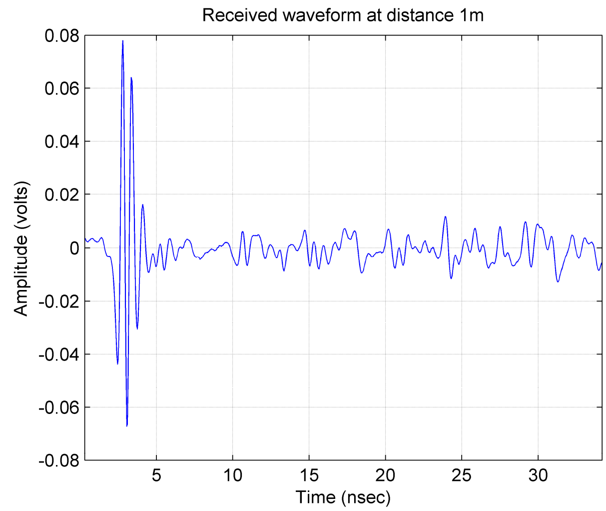

Fig. 5. Received waveform of one transmitted pulse measured at a distance of 1m.

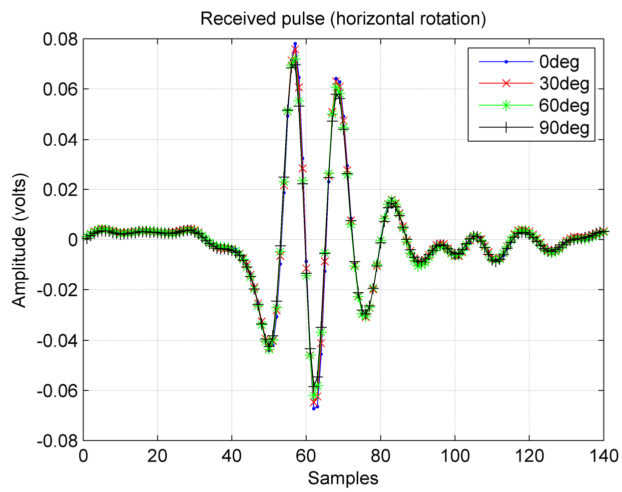

Fig. 6. Received pulses for different angle of rotation at horizontal plane (angle of azimuth).

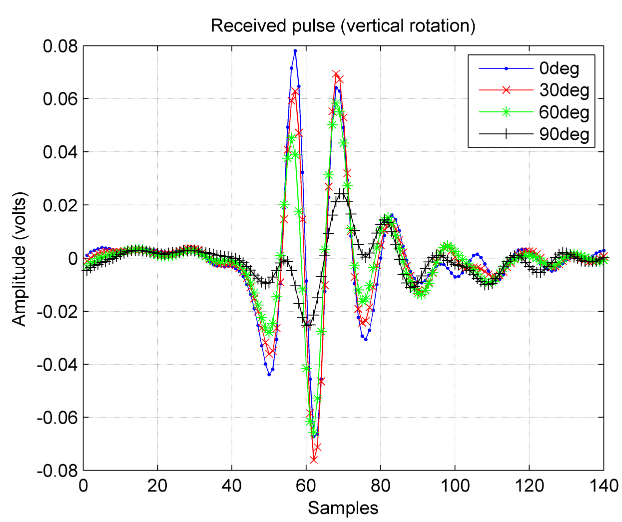

Fig. 7. Received pulses for different angle of rotation at vertical plane (elevation angle).

The above process is repeated 1000 times to produce the final mean square error (MSE) of the estimation procedure. The overall simulation process is performed for different numbers of samples N and the result is shown in Fig. 8. It is obvious that the accuracy is better when the channel is relatively sparse and worse when it is dense. Using the result obtained by the above mentioned simulation, shown in Fig. 8, we have chosen a reasonable value of resolvable space to be 25 samples. Measurements have shown that the signal to noise ratio (SNR) of our measurements is above 10dB. We try to keep the space between channel taps as low as possible. The difference of our algorithm compared with the one in [4], beside that we don't use multiple templates, is that in the updated dirty map we insert zeros corresponding to the 25 samples (1.25nsec) and not the whole reference pulse that we used which is about 40 samples long, corresponding to 2nsec width. The transmitted pulse became wider especially because of the limited analog bandwidth of the oscilloscope which has a nominal value of 1.5GHz. The algorithm used is defined as follows,

1. Initialize the dirty map with $d(t) = r(t)$ (received waveform) and the clean map with $c(t) = 0$.
2. Form the correlation coefficient function $\Gamma(\tau) = p(t) \star d(t)$, where $p(t)$ is the reference pulse (normalization is understood and ($\star$) denotes correlation).
3. Find peak, Γ_i, and its position, τ_i in $\Gamma(\tau)$.
4. If $\Gamma_i < threshold$, go to step 8.
5. Clean the dirty map by $d(t) = d(t) - \Gamma_i p(t - \tau_i)$ and then insert zeros in place of detected component.
6. Update the clean map by $c(t) = c(t) + \Gamma_i \delta(t - \tau_i)$.
7. Go to step 2.
8. The impulse response is estimated as $\hat{h}(t) = c(t)$.

The *threshold* is defined at -25dB of maximum amplitude of correlation coefficient.

V. Results

Using the measurements that took place at the aforementioned environment, we determine one of the most important large-scale characteristic of the channel, the path loss (PL) [14], which is defined as follows,

$$PL(dB) = 10\log\left(\frac{P_t}{P_r}\right) \tag{1}$$

where, P_t is the transmitted power and P_r is the received power at a specific location of antennas. The transmitted power is calculated from the measured pulse in Fig. 1. The received power is calculated from the data records of the database in which the received waveform has been truncated at 200nsec in all measurements to have a constant duration and to reduce the extra noise sampled at the end of the measurements.

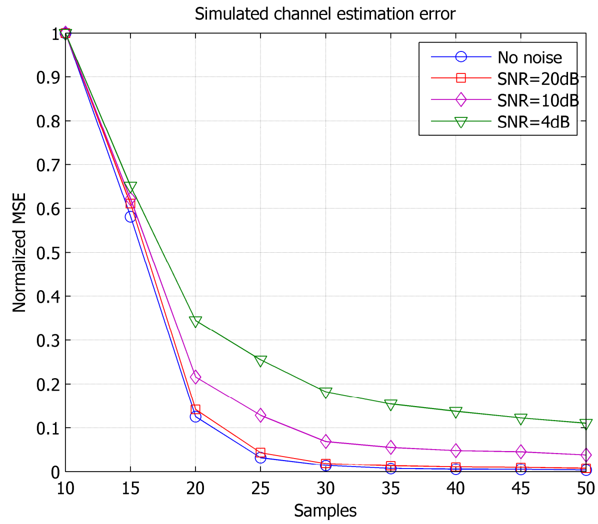

Fig. 8. Simulated normalized mean square error of channel estimation against multipath resolution in samples via simulations.

It is observed that the multipath components after 200nsec, can not be distinguished from noise. The model that is used to describe the dependency of the PL from distance is expressed as follows,

$$PL(d) \propto \left(\frac{d}{d_0}\right)^n \tag{2}$$

where, d is the distance in meters between TX and TX , d_0 is the reference distance of 1m and n is the path loss exponent of the exponential model. Of course in the case of free space propagation this exponent equals to 2, as the Friis formula indicates. Therefore, the expression above can be formed as follows,

$$PL_{dB}(d) = PL_0 + 10n\log\left(\frac{d}{d_0}\right) + X_{sh} \tag{3}$$

where, PL_0 is the path loss at the reference distance $d = d_0 = 1m$ and the term X_{sh} expresses the shadowing effect which causes different values of PL at different locations even with the same distance d. This term is a random variable with zero mean and normal distribution in dB, with standard deviation σ_{sh}, i.e. $X_{sh} \sim N(0, \sigma_{sh}^2)$. Equation (3) is used to calculate the exponent n the PL_0 and the shadowing standard deviation using the scattered data from the measurements and by performing the least squares linear regression on them. Fig. 9 to Fig. 13 show the results of the measured path loss for the five cases described in Section III. These results are grouped in Table I. In the graphs the theoretical free-space path loss line is depicted. The results are separated according to LOS and NLOS scenarios and the specific location of the RX or TX in each of the five cases. The shadowing effect is much stronger in NLOS scenario than LOS and the exponent is greater too. Also one can notice that the exponent (slop) in most cases, even under NLOS, don't exceed the value of 2 (free-space) except the case where the TX is placed at point D. This shows that the propagating power in indoor environment, like the one is used, decreases with a relatively slow rate, at least at the experiment's range (1m-10m).

Shadowing on the other hand has strong dependency, whether there is the line of sight or not. The worse case, as someone could assume, is that where between TX-RX there are two walls (point E) and consequently under NLOS.

The next step is the determination of the time-spreading characteristics of the wireless channel. This is accomplished by estimating first the channel's impulse response using the subtractive deconvolution technique described above. The time dispersive properties of wideband multipath channels are most commonly quantified by their mean excess delay and RMS delay spread [14].

TABLE I
PATH LOSS RESULTS OF INDOOR PROPAGATION

Scenario - Location	n	$PL_0\ (dB)$	$\sigma_{sh}\ (dB)$	Samples
LOS – A	1.328	40.288	0.723	150
LOS – B	1.625	38.521	0.685	130
NLOS – C	1.517	49.390	1.402	151
NLOS – D	2.107	43.107	1.746	125
NLOS – E	1.723	46.282	2.185	137

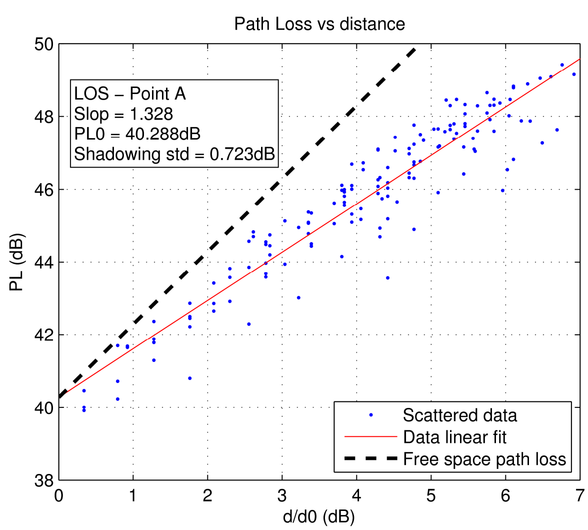

Fig. 9. Path loss vs distance for LOS scenario with RX located at point A

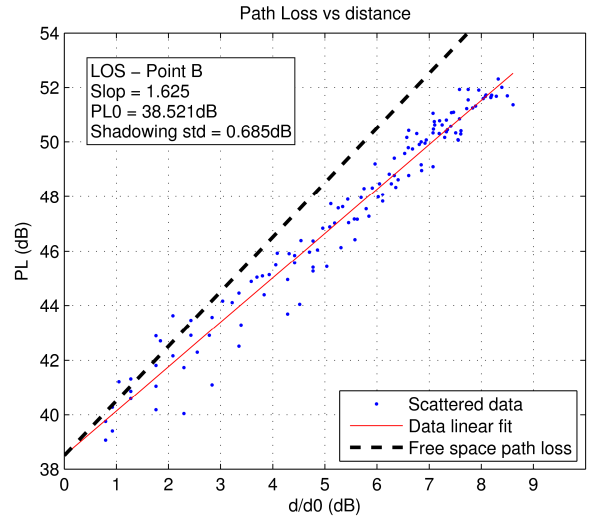

Fig. 10. Path loss vs distance for LOS scenario with RX located at point B

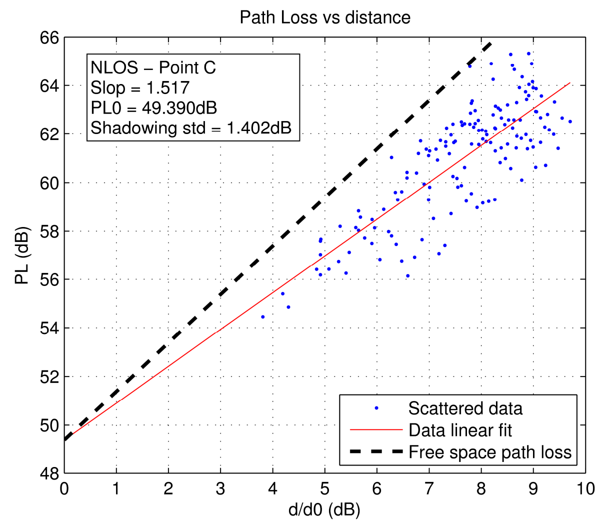

Fig. 11. Path loss vs distance for NLOS scenario with TX located at point C

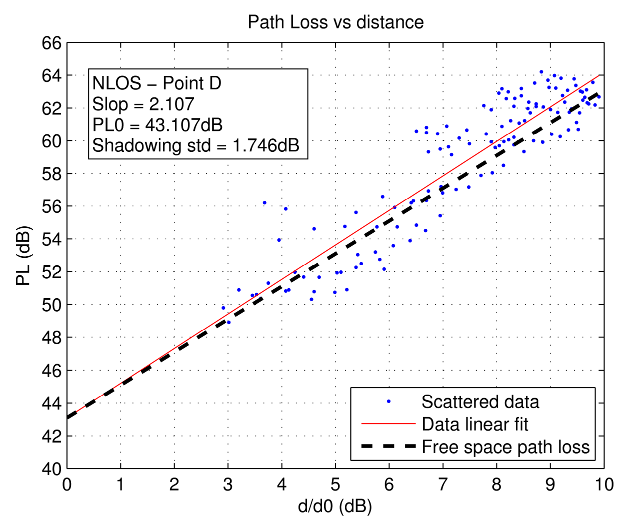

Fig. 12. Path loss vs distance for NLOS scenario with TX located at point D

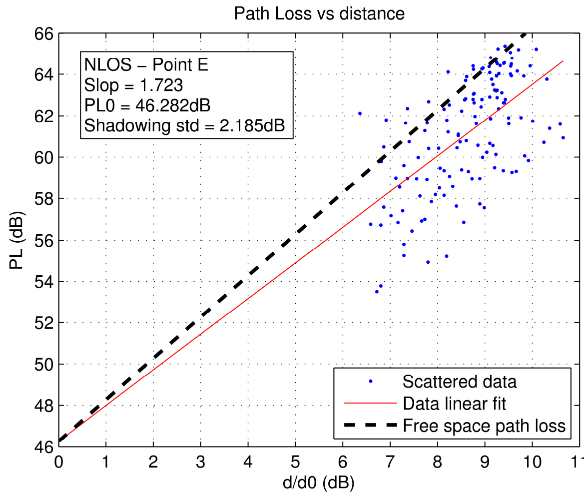

Fig. 13. Path loss vs distance for NLOS scenario with TX located at point E

The mean excess delay is the first moment of the power delay profile and it is defined as follows,

$$\tau_m = \frac{\sum_k a_k^2 \tau_k}{\sum_k a_k^2} \tag{4}$$

where, a_k and τ_k are the gain coefficients and the delays of the multipath components respectively.

The RMS delay spread is the square root of the second central moment of the power delay profile and it is defined as follows,

$$\tau_{rms} = \sqrt{\overline{\tau^2} - (\tau_m)^2} \tag{5}$$

where, the term $\overline{\tau^2}$ is defined as follows,

$$\overline{\tau^2} = \frac{\sum_k a_k^2 \tau_k^2}{\sum_k a_k^2} \tag{6}$$

Table II shows the results of the temporal parameters. The aforementioned parameters are calculated for each location of the antennas and then we calculate the mean value and the standard deviation of them. Also the number of significant paths are given separated in two categories, one has the strongest paths which have power greater than -10dB of maximum (NP_{10dB}) and the other has the paths that capture the 85% of the total channel's energy. In the two expressions above the time delay of the first path is $\tau_0 = 0$. In both LOS and NLOS scenarios the time corresponding to distance between RX-TX has been subtracted from all the measurements. Also the difference in transmission through the antenna cables and the trigger cable is removed.

VI. Conclusion

In this paper an experimental characterization of the indoor ultra-wideband multipath channel is accomplished. The channel's impulse response is estimated using measurements of channel sounding with the subtractive deconvolution technique utilizing the CLEAN algorithm. The characteristics of the channel that was measured are the path loss, the shadowing effect, the mean excess delay spread, the RMS delay spread and the number of dominant paths. The experimental results are presented.

TABLE II
TIME DISPERSION PARAMETERS OF CHANNEL MEASUREMENTS

Scenario Location	τ_m (nsec)		τ_{rms} (nsec)		NP_{10dB}		$NP_{85\%}$		Samples
	mean	std	mean	std	mean	std	mean	std	
LOS A	6.80	2.33	10.95	2.39	8.91	4.28	32.49	15.65	150
LOS B	6.26	2.45	9.99	2.73	8.75	3.19	31.51	14.06	130
NLOS C	16.64	4.13	15.92	2.50	29.06	9.34	88.90	16.62	151
NLOS D	11.95	6.38	14.05	4.44	19.63	10.20	64.62	23.92	125
NLOS E	17.87	6.90	17.74	3.88	32.04	14.43	91.50	27.04	137

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