

# Ultra Wide bandwidth Channel Characterization in Different Environments

Rachid Saadane, Aawatif Hayar & Driss Aboutajdine

**Abstract:** Models of radio channel propagation are indispensable in the analysis and design of wireless communication systems. They are used to predict power and interference levels and analyze other properties of the radio link. In this paper we present a statistical model for the ultra-wideband (UWB) channel. The measurements are provided over channel bandwidth from 3 to 9 GHz in different environments. Based on a set of measurements in Indoor, Corridor and Outdoor conducted recently at Eurecom Institute, we find that the Weibull pdf fits well to experimental measurements. Also, an investigation of UWB channel dispersion properties is given. Finally, we found that the  $\tau_{rms}$ ,  $\tau_m$  values are much smaller than those of conventional narrowband systems.

**Index Terms:** Channel measurements and Modeling, indoor, outdoor environments, Ultra Wide Bandwidth channel model, dispersion properties.

## I. INTRODUCTION

The potential for ultra-wideband (UWB) is to provide wireless communications solutions for the indoor environment like: Indoor residential, Indoor office Outdoor, Industrial environments, Agricultural areas/farms and Body area network (BAN). The development of channel models for UWB communication systems requires extensive data on UWB signal propagation. The well known experimental and simulation techniques can be used to investigate the propagation of UWB signals in different environments. In this work the experimental one is used. Determining such a

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R. Saadane is with, Centre de recherche électronique et capteurs et traitement de l'information the Department of Electrical Engineering, Ecole Hassania des Travaux Publiques, Casablanca, Route d'El Jadida, Km 7, B.P. 8108 -Oasis- Casablanca, Maroc. (e-mail: rachid.saadane@ehp.ac.ma or rachid.saadane@gmail.com)

A. Hayar is with the Department of Mobile Communications, Eurecom Institute, BP 193,F-06904 Sophia Antipolis cedex, France (e-mail: aawatif.hayar@eurecom.fr).

D. aboutajdine is with Laboratoire de Recherche en Informatique et Télécommunications, LRIT-GSCM Faculté des Science de Rabat, University Mohammed V, Maroc (aboutj@ieee.org).

model requires measurements taken in a variety of different environments under various setting like Line-Of-Sight and Non- Line-Of-Sight.

UWB technology, a revolutionary approach to radio communications, allows systems to operate across a range of frequency bands from 3.1 to 10.6 GHz defined and authorized by FCC [1]. In order to develop an efficient UWB system and predict its effects on other communication systems, it is crucial to understand the UWB channel properties first. The literature has reported many measurement campaigns and results for UWB channel models [2]–[8].

Some channel propagation measurements in Indoor deals with UWB channel characterization and modelling have been published [3]–[8]. The primary objective has been to develop channel models that describe the system performance adequately. Successful channel characterizations require extensive and accurate propagation measurements.

The goal of our work is not to formulate a channel model for UWB systems or to provide a universal model for all environments in which UWB devices will be operating, but rather to provide a set of tools that can be used to fairly evaluate the performance of different UWB physical layer proposals in real channels such as for offices, laboratories and industrial environment.

The paper is organized as follows. In section II the measurement setup and environment are described. In section III the measurement scenarios are presented. In section IV the measurement results are given. Conclusion is provided in section V.

## II. MEASUREMENTS SPECIFICATION

### (A) Measurements Configuration

Measurements are performed at spatially different locations under both Line-Of Sight (LOS) and Non Line Of Sight (NLOS). The experiment area is set by fixing the transmitting antenna on a mast at 1 meter above the ground on horizontal linear grid (20 cm) close to VNA and by moving the receiver antenna to different locations on horizontal linear grid (50 cm) in 1 cm steps. The height of receiver antenna was also 1 m above the ground see Fig. 1. This configuration targets peer-to-peer applications. Among all positions, we considered both LOS and NLOS configurations.

## (B) Measurement Environment

Measurements were carried out in Eurecom's Mobile Communication Laboratory, which has a typical laboratory environment (radio frequency equipment, computers, tables, chairs, metallic cupboard, glass windows,...) with plenty of reflective and diffractive objects, as shown in Figs. 3 and 4, rich in reflective and diffractive objects. For the NLOS case, a metallic plate is positioned between the transmitter and the receiver. We have complete database of 4000 channel frequency responses corresponding to different scenarios with a transmitter-to-receiver distance varying from 1 meter to 14 meters.

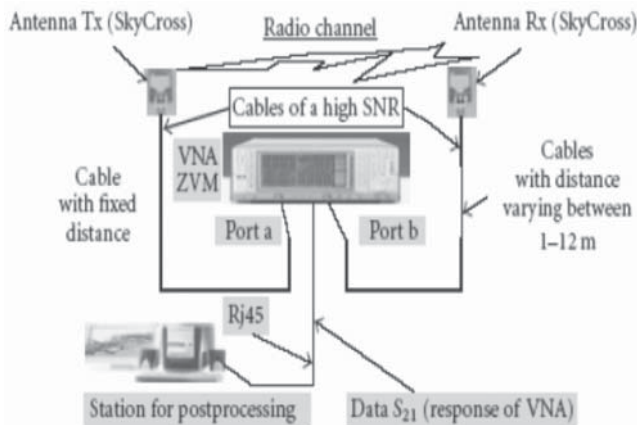


Fig. 1: The Channel Measurements in Frequency Domain

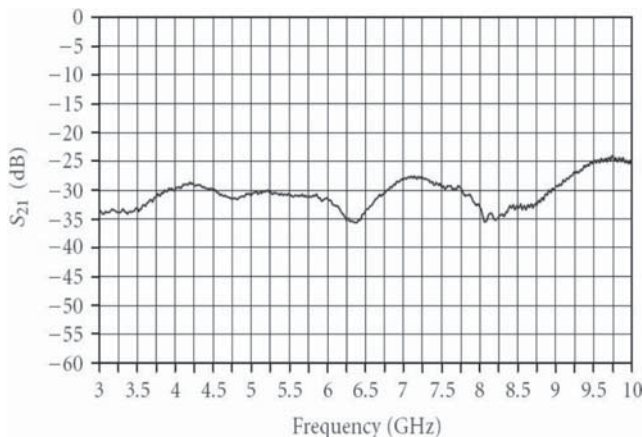


Fig. 2: The Antenna S<sub>21</sub> Parameter

Fig. 2 shows the S<sub>21</sub> response of the UWB antenna used in the channel measurements campaigns. The S<sub>21</sub> presents a late response over frequency range; this is a very important characteristic of UWB antenna.

## III. SCENARIOS

### (A) Scenario I

For the LOS and NLOS Scenarios the measurement are performed at night, the medium is the laboratories Mobile Communication (radio frequency) and (UMTS labs), in the

two rooms we find different elements (chair, Screen of computer, central processing units, plastic table, vector network analyzer, cable for computer and electrical connection, the walls, the windows of glass, . . .) a metallic cupboard is used to create NLOS settings. The cupboard does not leave last the rays. As the environment has different elements go well influencing the channel behavior in frequency and time, such as the reflection and path-loss and diffraction phenomenon.



Fig. 3: A Part of Laboratory of Mobile Communications where the UWB Channel Measurements are Conducted



Fig. 4: The Corridor where the UWB Channel Measurements are Conducted

### (B) Scenario II

In the Corridor configuration, only channel measurements in the LOS setting are carried. The measurements are performed at night; the medium is the Corridor of Fig. 4.

### (C) Scenario III

The Outdoor LOS measurements are taken in the out of the Eurecom Institute. The used setup is the same one used in the scenarios previously described. It was full by the objects which size is larger compared to the size of UWB wave.

### (D) Scenario III

This scenario is static (the antenna are fixed for all points of measurement). Measurements carried out to examine the influence of the displacement of the antennas. The setup and environment are the same as for scenario I.

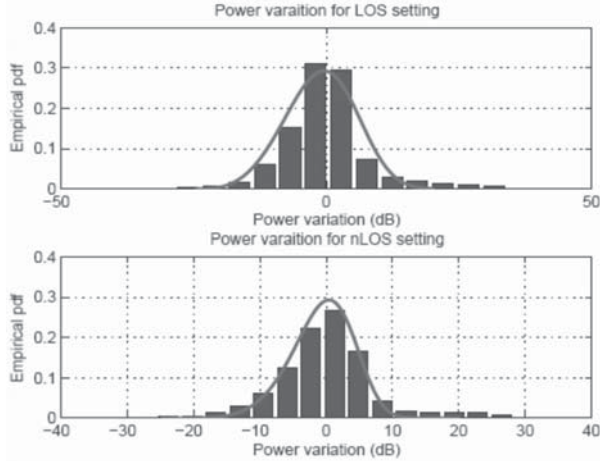


Fig. 5: Probability Density Function of the Power Variations (LOS) and NLOS

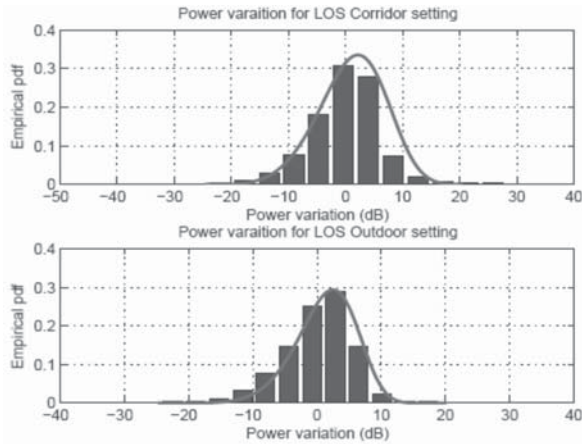


Fig. 6: Probability Density Function of the Power Variations Corridor (LOS) and Outdoor (LOS)

## IV. RESULTS

### (A) Time Domains Analysis

To characterize the probability density function of the power variations we plot on figures (5) for LOS and NLOS and (6) for Corridor (LOS) and Outdoor (LOS) the histogram's measurement data respectively. The power variations are fitted with an analytical probability density function (pdf) approximation, namely a Weibull pdf. The general formula for the Weibull pdf is given by:

$$f(x) = \frac{\gamma}{\alpha} \left( \frac{x-\mu}{\alpha} \right)^{(\gamma-1)} \exp \left\{ - \left( \frac{x-\mu}{\alpha} \right)^\gamma \right\} \quad (1)$$

where  $\alpha, \gamma, \alpha \in \mathbb{R}, \alpha, \gamma > 0$  and  $x \geq \mu$ ,  $\alpha$  is the scale parameter,  $\gamma$  is the shape parameter, and  $\mu \in \mathbb{R}$  is the location parameter.

From our measurements, we obtain the values summarized in table I. It can be observed how the Weibull pdf fits well with the experimental measurements.

### (B) Multipath Indoor Radio Channel

The multipath indoor radio propagation channel is normally modeled as a complex low pass equivalent impulse response given by:

$$h(t) = \sum_{l=0}^{l=L} a_l p(t - \tau_l) \quad (2)$$

Where  $L$  the number of multipath components, and  $a_l$  and  $\tau_l$  are the complex attenuation and propagation delay of the  $l^{\text{th}}$  path, respectively, while the multipath components are indexed so that the propagation delays  $\tau_l, 0 \leq l \leq L-1$  are in ascending order. As a result,  $\tau_0$  in the model denotes the propagation delay of Direct LOS. Taking the Fourier transform of (2), the frequency-domain channel response can be expressed as

$$H(f) = \sum_{l=0}^{l=L} a_l P(f) e^{-2j\pi f \tau_l} \quad (3)$$

The parameters  $a_l$  and  $\tau_l$  are random time-variant functions because of the motion of manipulator and equipment in and around buildings. However, since the rate of their variations is very slow compared the measurement time interval, these parameters can be treated as time-invariant random variables within one snapshot of measurement. The phase of the complex attenuation  $\theta_l$  is normally assumed random from one snapshot to another with a uniform probability density function  $U(0, 2\pi)$  [16]. On the other hand, these parameters are frequency-dependent since they are related to radio signal characteristics such as shown in [17]. For frequency bands used in this paper, these parameters can be assumed frequency-independent. In our analysis we assume that the  $p(t) = \delta(t)$  in equation (2). Therefore, we obtain for the following equation for the  $h(t)$  function:

$$h(t) = \sum_{l=0}^{l=L} a_l \delta(t - \tau_l) \quad (4)$$

TABLE I  
PDF Shape Parameter

Parameter/Setting	LOS	NLOS	Corridor	Outdoor
$\gamma$	6	4	5	6.5
$\alpha$	26	26	28	28.5

### (C) UWB Channel Dispersion Properties

The dispersive properties of UWB channel can be considered

As an extension of the large scale study of the channel. There are two parameters to be characterized for concluding about channel and large scale. These parameters are the mean excess delay  $\tau_m$  and delay spread  $\tau_{ms}$ . The mean excess delay  $\tau_m$  and  $\tau_{ms}$  delay spread are two important parameters use to

characterize the temporal dispersive properties of the multipath channels. These are useful as single number descriptions of the channel to estimate the performance and potential for inter symbol interference (ISI). These values tend to increase with greater Tx/Rx separation. The mean excess delay  $\tau_m$  is defined as the first moment of the power delay profile (PDP) and is defined as:

$$\tau_m = \bar{\tau} = \frac{\sum_{l=0}^{L-1} \tau |a_l|^2}{\sum_{l=0}^{L-1} |a_l|^2}$$

with  $P(a_l) = a_l^2$ .

where  $a_l$  and  $P(a_l)$  are the gain coefficient, delay and PDP of the  $l^{th}$  multipath component. The  $\tau_{rms}$  delay spread,  $P(\tau_{rms})$  is the square root of the second central moment of the PDP and is defined to be:

$$\tau_{rms} = \sqrt{\bar{\tau^2} - \tau_m^2} \quad \text{and} \quad \bar{\tau^2} = \frac{\sum_{l=0}^{L-1} \tau^2 |a_l|^2}{\sum_{l=0}^{L-1} |a_l|^2}$$

$\tau_{rms}$  is seen to be the second centralized moment of the normalized power delay profile.

Typical values for the  $\tau_{rms}$  delay spread for indoor channels have been reported to be between 10 ns and 50 ns, and mean values between 20 and 30 ns for 5 to 30 m antenna separations were reported in [13]. In addition, the multipath delay spread has been found to increase with increasing separation between the receiving and transmitting antennas, and the mean increases with the threshold level [14]. Tables II presents the main values of  $\tau_m$  and  $\tau_{rms}$  for different channel settings.

Figs. 7 and 8 show the cumulative distribution of  $\tau_m$  and  $\tau_{rms}$  respectively, calculated from measured data. These figures show that the CDF of to parameters is fitted by a normal CDF.

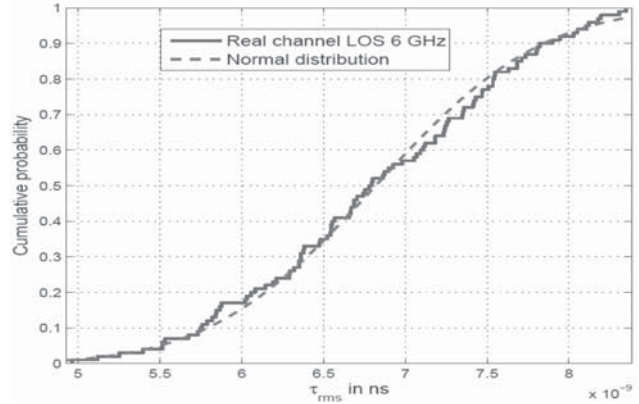
All the summarized values of  $\tau_m$  and  $\tau_{rms}$  in the Table II can be considered a dispersive properties of channel in indoor environments. To illustrate these properties in an outdoor environment,  $\tau_m$  and  $\tau_{rms}$  are calculated for a threshold of 10 dB. The Table (III) presents main statistics of  $\tau_m$  and  $\tau_{rms}$  for indoor LOS setting.

**TABLE II**  
Table of Averages Delay Statistics in the Time Domain, with Windowing

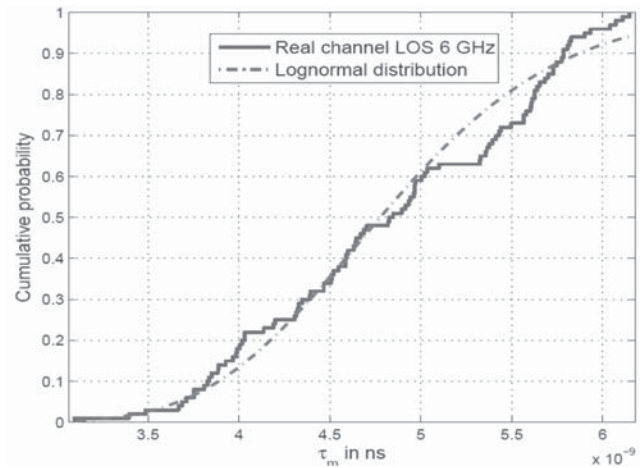
Scenarions parameters	$\tau_{rms}$ in ns (20 dB)	$\tau_m$ in ns (20 dB)
LOS CM1 (6 meters, grig)	6.8179	4.8366
LOS CM2 (6 meters, grig)	13.769	17.699
NLOS CM1 (6 meters, grig)	15.186	24.285
NLOS CM2 (6 meters, grig)	13.769	17.7699
LOS CM2 (9 meters, grid)	12.033	35.065
LOS CM2 (6 meters, Fix)	7.6730	6.4861
LOS CM1 (7 meters, grid)	7.16	35.06
LOS Corridor (7 meters, grid)	9.7673	5.2105

where

- CM1: Indoor Configuration 1.
- CM2: Indoor Configuration 2.



Figs. 7 and 8 Show the Cumulative Distribution of  $\tau_{rms}$



Figs. The Cumulative Distribution of  $\tau_m$ .

**Table III**  
Main Stastics of  $\tau_m$  and  $\tau_{rms}$  for Indoor LOS Setting

Mean	Std $\tau_m$	Max $\tau_m$	Mean $\tau_{rms}$	Std $\tau_{rms}$	Max $\tau_{rms}$
2.6 ns	.93 ns	9.9 ns	3.6 ns	1.6 ns	16 ns

## V. CONCLUSION

We have investigated ultra wide bandwidth propagation channels in different environments, and established a statistical model that describes the behavior of the channel. We found that the power variation can be well described by a Weibull distribution model (with model parameters given in Table I).

Finally, the  $\tau_{rms}$  delay spread was found to be about between 3.6 ns and 15.2 ns for LOS and about between 9.6 ns and 15.6 ns for NLOS. This value is much smaller than that of conventional narrowband systems.

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