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Title	**UWB Channel Characterization in Outdoor Environments**	
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Re:	[Response to Call for Contributions from 15.4a Channel Modeling Subgroup]	
Abstract	[This document describes the UWB channel measurement results in outdoor (office) environments. At the end of this document, a set of unique channel parameters, which are suitable for studying the performances of 15.4a PHY proposals in outdoor office environments, is recommended based on the generic channel model proposed in [22].]	
Purpose	[]	
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1. INTRODUCTION

In this document, we briefly describe the model [22, 23] adopted by the 15.4a channel modeling subgroup and summarize the parameters extracted from our channel measurement campaign. Details of the extraction processes for various parameters can be found in [20], [21] and [25]. One of our main aims in this channel modeling activity is to keep our model simple and at the same time, to make sure that it reflects a real environment as close as possible.

Various institutes and industries have performed extensive UWB channel measurements and modeling [1-25]. However, most of these results are done for indoor environments. The published results for outdoor environments are very limited. Since the Infocomm Development Authority (IDA) of Singapore has declared the Science Park II in Singapore as "UWB friendly zone", we have performed some extensive measurements for both LOS and NLOS environments and the results are reported in this document. Some of these results are published in [20], [21] and [27].

At the end of this document, a set of unique channel parameters, that are suitable for studying the performances of 15.4a PHY proposals in indoor office environments, is recommended based on the generic channel model proposed in [22].

2. LARGE-SCALE PARAMETERS

The distance dependent path loss (in dB), at a distance *d,* is given by

$$PL(d) = \left[PL_0 + 10\nu \log_{10}\left(\frac{d}{d_0}\right) \right] + S; \qquad d \geq d_0 \tag{1}$$

Where,

- d_0 is a reference distance, e.g., $d_0 = 1$ m.
- PL_0 is the intercept and ν is the path loss exponent.
- S (in dB) is the shadowing component.
- ν is the path loss exponent

S is generally assumed to be a zero-mean Gaussian random variate with standard deviation σ_S.

The frequency dependent path loss *PL(f)* is modeled by the following equation:

$$PL(f) \propto \left[\frac{f}{1GHz} \right]^{-r} \tag{2}$$

In (2), r denotes the frequency dependent path loss exponent. Keignart et. al. [28], have reported that $\nu = 2.45$ for outdoor LOS environment and in our measurements campaigns [20], $\nu = 1.76$ for outdoor LOS environment.

3. TEMPORAL PARAMETERS

Mean excess delay, τ_m and root square mean excess delay, τ_{rms} can be calculated from the following equations:

$$i^{th} \text{ order moment: } \tau^i = \frac{\sum_{l=0}^{L} \sum_{k=0}^{K} a_{k,l}^2 \tau_{k,l}^i}{\sum_{l=0}^{L} \sum_{k=0}^{K} a_{k,l}^2}$$

$$\tau_m = \tau^1, \quad \tau_{rms} = \sqrt{\tau^2 - (\tau^1)^2} \tag{3}$$

In [26], Win et. al have done some outdoor NLOS measurements for 1.3 GHz band. They estimated the temporal parameters over various distances and the average values for τ_m and τ_{rms} are 30.46 ns and 38.02 ns, respectively. In our measurements [21, 27], τ_m = 24.1 ns and τ_{rms} = 55.1 ns for the LOS case, and τ_m = 83.5 ns and τ_{rms} = 97.8 ns for the NLOS case.

4. SALEH-VALENZUELA MULTIPATH PARAMETERS

802.15.4a channel modeling sub-committee adopted the following discrete-time model for the channel measurements campaign:

$$h(t) = \sum_{l=0}^{L} \sum_{k=0}^{K} a_{k,l} \delta(t - T_l - \tau_{k,l}) \tag{4}$$

Where,

- T_l: Delay of the l^th^ cluster
- $\tau_{k,l}$: delay of the k^th^ MPC of the l^th^ cluster
- $a_{k,l}$: amplitude of the k^th^ MPC in the l^th^ cluster
- K: Total number of MPCs in a cluster
- L: Total number of clusters
- $\tau_{0,1} = T_0 = 0$

The cluster and ray arrival times are respectively described by the following Poisson processes:

$$\begin{aligned} p(T_l|T_{l-1}) &= \Lambda \exp[-\Lambda(T_l - T_{l-1})], l>0 \\ p(\tau_{k,l}|\tau_{k,l-1}) &= \lambda \exp[-\lambda(\tau_{k,l} - \tau_{k,l-1})], k>0 \end{aligned} \tag{5}$$

Where,

- Λ: Cluster arrival rate
- γ: Ray arrival rate

Average PDP (Power Delay Profile) at $T_l + \tau_{k,l}$ is described by the following exponential function:

$$E\{|a_{k,l}|^2\}=E\{|a_{0,0}|^2\}\exp\left[-\frac{T_l}{\Gamma}\right]\exp\left[-\frac{\tau_{k,l}}{\gamma}\right] \tag{6}$$

An S-V model is characterized by the following parameters:

- Γ: Cluster decay factor
- γ: Ray decay factor
- Λ: Cluster arrival rate
- λ: Ray arrival rate

5. SMALL-SCALE AMPLITUDE STATISTICS

The small-scale amplitude statistics are generally modeled by log-normal [3,10,18], Nakgami [14,15,20] or Weibull distributions [3,11,19]. However our results in [20] and the results in [14,15] suggest that Nakagami distributions give the best fit to the amplitude statistics very well.

In [14,15], it is reported that Nakagami m-factor decreases (from 6 to 1) with increasing delay. However, this phenomenon was not observed in our measurement campaign. Instead, we observed that the m-factors for all the scenarios fit well into a log-normal cdf [20].

6. CONCLUSIONS

Based on the results reported in the literature, we recommend a unique set of channel parameters for UWB indoor office environments for simulation purposes in table (1). Corresponding simulated values of the parameters (from a Matlab program) are given in table (2).

7. REFERENCES

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Parameters	**LOS**	**NLOS**
Large-scale Parameters		
ν	1.76	2.5*
σ_S (dB)	0.83	2*
PL_0 (dB)	43.29	
r (μ_r , σ_r)	(0.64, 0.0066)	
Multipath Parameters		
Γ (ns)	31.7	104.7
γ (ns)	3.7	9.3
Λ (1/ns)	0.0048	0.0243
λ (1/ns)	0.27	0.1395
NP10dB	2.56	
Temporal Parameters		
Mean Excess Delay, τ_m (ns)	24.1	83.5
RMS Delay Spread, τ_{RMS} (ns)	55.1	94
Amplitude Statistics		
Amplitude Statistics	Nakagami Distribution	Nakagami Distribution
m-factor: Mean (dB)	0.77	0.56
m-factor: Variance (dB)	0.78	0.25

Table (1): Recommended values for parameters (from the measured data)

Parameters	**LOS**	**NLOS**
τ_m (ns)	24	85.7
T_{rms} (ns)	29	98
NP10dB	7.5	10.6

Table (2): Simulated values (from Matlab)

** Assumed values*