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Project	IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)	
Title	**Channel Model Parameterization of the Indoor Residential Environment**	
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Re:	[Response to Call for Contributions on 15.4a Channel Modeling Subgroup.]	
Abstract	[This document summarizes the important channel parameters reported in the literature based on the UWB channel measurements in indoor residential environment. A set of unique channel parameter suitable for simulation is recommended.]	
Purpose		
Notice		
Release		

I. INTRODUCTION

The aim of this document is to summarize the important channel parameters reported in the literature based on the UWB channel measurements in indoor residential environment. A set of unique channel parameter suitable for simulation is recommended based on the generic channel model as proposed in [1].

II. PATH LOSS AND SHADOWING

A. *Distance Dependence*

The path loss in dB as a function distance is given by

$$PL(d) = PL_0 + 10n\log_{10}\left(\frac{d}{d_0}\right) + S; \quad d \geq d_0 \tag{1}$$

where d_0 is the reference distance i.e. $d_0 = 1m$ and PL_0 is the free-space path loss in the far-field of the antennas at a reference distance d_0. PL_0 is the interception point and usually is calculated based on the mid-band frequency, f_c. n is the path loss exponent and S is the shadowing fading parameter that varies randomly from one location to another location within any home. It is a zero-mean Gaussian distributed random variables (in dB) with standard deviation σ_S which is also in dB. Table 1 lists the path loss and shadowing parameters extracted from the measurement data. Note that, unless otherwise stated, μ and σ represent the mean and standard deviation of the corresponding parameter. For example, μ_n and σ_n represent the mean and standard deviation of the path loss exponent, respectively.

B. *Frequency Dependence*

The frequency dependency of the path loss can be modeled by [1]

$$\log_{10}\left(PL(f)\right) = \alpha\exp(-\delta f) \tag{2}$$

or

$$\sqrt{PL(f)} \propto f^{-m}. \tag{3}$$

δ was reported to be varying between 0.6 and 1.2 in the indoor residential high rise-apartments [2] and [3]. Its statistics is characterized by its mean, μ_δ and standard deviation, σ_δ. Table 2 lists the frequency decaying factor parameters extracted from the measurement data.

III. Temporal Domain Parameters

The *mean excess delay*, τ_m is defined as the first moment of the power delay profile (PDP) and is defined as [4]

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

where a_k, τ_k and $P(\tau_k)$ are the gain coefficient, delay and PDP of the k^{th} multipath component (MPC), respectively. The *rms delay spread*, τ_{rms} is the square root of the second central moment of the PDP and is defined to be [4]

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

where

$$\overline{\tau_m^2} = \frac{\sum_k a_k^2 \tau_k^2}{\sum_k a_k^2} = \frac{\sum_k P(\tau_k)\tau_k^2}{\sum_k P(\tau_k)}. \tag{6}$$

$NP10dB$ is defined as the number of dominant MPCs that arrive within 10 dB of the strongest path for each of the PDP. Table 3 lists the temporal domain parameters extracted from the measurement data.

IV. Saleh-Valenzuela Multipath Channel Parameters

The main structure of the IEEE 802.15.4a multipath channel model is detailed in [1] and will be based on the conventional Saleh-Valenzuela (S-V) clustering channel model [5]. As described in Section III of [6], there are 5 key parameters that define the S-V multipath channel model:

- Λ is the cluster arrival rate
- λ is the ray arrival rate, i.e. the arrival rate of path within each cluster
- Γ is the cluster exponential decay factor
- γ is the ray exponential decay factor
- σ_a is the standard deviation of the lognormal fading term (dB).

Table 4 lists the S-V multipath channel parameters extracted from the measurement data.

V. SMALL-SCALE AMPLITUDE FADING STATISTICS

The small-scale amplitude fading statistics is proposed to be modeled by Ricean or Nakagami distribution for each delay bin in [1]. The two distributions are transformed into each other via the following relationship

$$m = \frac{\left(K_r + 1\right)^2}{\left(2K_r + 1\right)} \tag{7}$$

and

$$K_r = \frac{\sqrt{m^2 - m}}{m - \sqrt{m^2 - m}} \tag{8}$$

where K_r and m are the Rice and Nakagami-*m* factor, respectively.

Measurement results reported in [2] and [3] suggested that either lognormal, Nakagami or Weibull distributions can fit the small-scale amplitude fading statistics of the measurement data reasonably well, with their corresponding parameters remain almost constant across the excess delay. Table 5 lists the small-scale amplitude fading channel parameters extracted from the measurement data.

VI. RECOMMENDED CHANNEL PARAMETER SET

Based on the measurement results reported in the literature, a set of unique channel parameters is recommended for the simulation purposes. This parameter set is the average of their corresponding channel parameters given in Table 1 to Table 5. Table 6 lists the recommended simulation parameter set of the IEEE 802.15.4a channel model for the indoor residential environment under both line-of-sight (LOS) and non-LOS (NLOS) scenarios.

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Source	LOS					NLOS				
	n		PL_0 [dB]	S [dB]		n		PL_0 [dB]	S [dB]	
AT&T [7]-[9]	μ_n	σ_n	47.0	μ_S	σ_S	μ_n	σ_n	51.0	μ_n	σ_n
	1.70	0.30		1.60	0.50	3.50	0.97		2.70	0.98
AT&T [10]	μ_n	σ_n	47.2	μ_S	σ_S	μ_n	σ_n	50.4	μ_n	σ_n
	1.82	0.39		1.50	0.60	3.34	0.73		2.60	0.90
	2.01		45.9	3.20		3.12		50.3	3.80	
CEA-LETI [11]	1.67		-	-		4.97[1]		-	-	
						7.24[2]				
Intel [12]	1.72		-	1.48		4.09		-	3.63	
Samsung/SAIT [2], [3], [13]	1.18[3]		50.1[3]	0.93[3]		2.18[3]		52.2[3]	1.43[3]	
	2.48[4]		49.7[4]	1.50[4]		2.69[4]		52.7[4]	4.69[4]	
U.C.A.N [14], [15]	1.67		-	4.0		5.13[1]		-	4.0	
						7.25[2]				

Table 1: Path loss and shadowing parameters.

Source	LOS		NLOS	
	μ_δ [dB/Oct]	σ_δ [dB/Oct]	μ_δ [dB/Oct]	σ_δ [dB/Oct]
Samsung/SAIT [2], [3]	0.5903[3]	0.0993[3]	0.7431[3]	0.2145[3]
	0.8434[4]	0.1324[4]	1.1695[4]	0.3842[4]

Table 2: Frequency decaying factor parameters.

Source	LOS						NLOS					
	τ_m, [ns]		τ_{rms}, [ns]		$NP10dB$		τ_m, [ns]		τ_{rms}, [ns]		$NP10dB$	
	μ_{τ_m}	σ_{τ_m}	$\mu_{\tau_{rms}}$	$\sigma_{\tau_{rms}}$	μ_{NP10dB}	σ_{NP10dB}	μ_{τ_m}	σ_{τ_m}	$\mu_{\tau_{rms}}$	$\sigma_{\tau_{rms}}$	μ_{NP10dB}	σ_{NP10dB}
AT&T [9]	-	-	-	-	-	-	10.83[5]		8.43[5]		60[5]	
							12.40[6]		11.5[6]		82[6]	
AT&T [9], [16]	-	-	4.70[7]	2.30[7]	-	-	-	-	8.20[7]	3.30[7]	-	-
AT&T [17]	2.15	-	3.55	1.65	-	-	6.93	-	7.35	3.45	-	-
CEA-LETI [11]	6.53	-	11.45	-	3.4	-	-	-	-	-	-	-
Intel [18]	4.01	-	8.88	-	7	-	17.36	-	14.53	-	35	-
Intel [12], [18]	3.06[8]	-	7.39[8]	-	6[8]	5	9.96[8]	-	12.81[8]	-	28[8]	30
	3.09[9]		7.93[9]		6[9]		10.06[9]		13.22[9]		29[9]	
	4.01[10]		8.88[10]		7[10]		17.36[10]		14.53[10]		36[10]	
	3.95[11]		9.13[11]		7[11]		17.25[11]		15.0[11]		37[11]	
Samsung/SAIT [2], [3], [13]	5.88[3]	1.25[3]	14.00[3]	1.53[3]	4.04[3]	1.53[3]	36.09[3]	15.48[3]	38.61[3]	8.03[3]	19.58[3]	7.64[3]
	5.01[4]	0.64[4]	12.48[4]	1.87[4]	5.97[4]	1.96[4]	24.95[4]	8.47[4]	26.51[4]	5.22[4]	23.51[4]	10.75[4]
Time Domain [19]	4.95	4.14	5.27	3.37	24.0	-	10.04[12]	6.26[12]	8.78[12]	4.34[12]	36.1[12]	-
							14.24[13]	5.97[13]	14.59[13]	3.41[13]	61.6[13]	
U.C.A.N [14], [15]	7.52	1.94	12.15	1.88	3.82	2.43	7.74[1]	2.27[1]	9.94[1]	1.52[1]	16.71[1]	9.44[1]
							14.48[2]	3.03[2]	12.94[2]	1.38[2]	31.27[2]	16.86[2]

Table 3: Temporal domain parameters.

Source	**LOS**					**NLOS**				
	Λ [1/ns]	λ [1/ns]	Γ [ns]	γ [ns]	σ_a [dB]	Λ [1/ns]	λ [1/ns]	Γ [ns]	γ [ns]	σ_a [dB]
CEA-LETI [11]	0.007	1.27	30	10	5.5-1.0[14]	-	-	-	-	-
Intel [18]	1/60	1/0.5	16	1.6	4.8	1/11	1/0.35	16	8.5	4.8
U.C.A.N [14], [15]	0.01	0.18	21	6	4	0.01[1]	3[1]	18[1]	5[1]	4[1]
						0.4[2]	1.5[2]	9[2]	8[2]	4[2]

Table 4: S-V multipath channel parameters.

Source	LOS						NLOS					
	σ_L [dB]		m_L		b_L		σ_L [dB]		m_L		b_L	
	μ_{σ_L}	σ_{σ_L}	μ_{m_L}	σ_{m_L}	μ_{b_L}	σ_{b_L}	μ_{σ_L}	σ_{σ_L}	μ_{m_L}	σ_{m_L}	μ_{b_L}	σ_{b_L}
Samsung/SAIT [2], [3]	0.99[3]	0.26[3]	0.55[3]	0.22[3]	1.33[3]	0.26[3]	1.02[3]	0.36[3]	0.55[3]	0.17[3]	1.33[3]	0.31[3]
	0.99[4]	0.27[4]	0.52[4]	0.16[4]	1.30[4]	0.26[4]	1.00[4]	0.26[4]	0.90[4]	0.33[4]	1.61[4]	0.24[4]

Table 5: Small-scale amplitude fading channel parameters

CHANNEL PARAMETERS	LOS	NLOS
Path Loss and Shadowing		
PL_0 [dB]	$PL_0 = 10\log_{10}\left(\frac{4\pi f_c}{c}\right)$ where f_c : mid-band frequency $c = 3\times10^8$ ms^{-1}	
$n:\ \mu_n$	1.75	4.49
σ_n	0.35	0.85
$S:\ \mu_S$ [dB]	1.84	3.18
σ_S [dB]	0.55	0.94
Frequency Decaying Factor		
$\delta:\ \mu_\delta$ [dB/Oct]	0.72	0.96
σ_δ [dB/Oct]	0.12	0.30
Temporal Domain Parameters		
$\tau_m:\ \mu_{\tau_m}$ [ns]	4.56	14.98
σ_{τ_m} [ns]	1.99	6.91
$\tau_{rms}:\ \mu_{\tau_{rms}}$ [ns]	8.82	14.46
$\sigma_{\tau_{rms}}$ [ns]	2.10	3.83
$NP10dB:\ \mu_{NP10dB}$	7.42	38.14
σ_{NP10dB}	2.73	14.94
S-V Multipath Channel Parameters		
Λ [1/ns]	0.011	0.17
λ [1/ns]	1.15	2.45
Γ [ns]	22.33	14.33
γ [ns]	5.87	7.17
σ_a [dB]	4.02	4.27
Small-Scale Amplitude Fading Channel Parameters		
$\sigma_L:\ \mu_{\sigma_L}$ [dB]	0.99	1.01
σ_{σ_L} [dB]	0.27	0.31
$m_L:\ \mu_{m_L}$	0.54	0.73
σ_{m_L}	0.19	0.25
$b_L:\ \mu_{b_L}$	1.32	1.47
σ_{b_L}	0.26	0.28

Table 6: Recommended simulation parameter set of the IEEE 802.15.4a channel model for the indoor residential environment.

[1] Analysis for 45 different TX-RX positions with distance between 9-13 m under NLOS scenario [11], [14], [15].
[2] Analysis for 109 different TX-RX positions with distance between 7-17 m under NLOS scenario [11], [14], [15].
[3] Analysis for 3-bedroom apartment [13].
[4] Analysis for 4-bedroom apartment [13].
[5] Analysis based on 30 dB threshold level for 50% of the NLOS locations [9].
[6] Analysis based on 30 dB threshold level for 90% of the NLOS locations [9].
[7] τ_{rms} is Gaussian distributed over all homes with mean, $\mu_{\tau_{rms}}$ and standard deviation, $\sigma_{\tau_{rms}}$ [9], [16].
[8] Analysis based on passband analysis, frequency domain Hamming windowing and 0.17 ns bin size [12].
[9] Analysis based on complex baseband analysis, frequency domain Hamming windowing and 0.17 ns bin size [12].
[10] Analysis based on passband analysis, frequency domain rectangular windowing and 0.17 ns bin size [12].
[11] Analysis based on complex baseband analysis, frequency domain rectangular windowing and 0.17 ns bin size [12].
[12] Analysis for TX-RX positions with distance between 0-4 m under NLOS scenario [19].
[13] Analysis for TX-RX positions with distance between 4-10 m under NLOS scenario [19].
[14] Decrease with delay [11].