IEEE P802.15
Wireless Personal Area Networks

Project	IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)	
Title	**Channel Model Parameterization of the Indoor Residential Environment**	
Date Submitted	1 September, 2004	
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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		
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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]

$$\log_{10}\left(PL(f)\right) = \alpha\exp\left(-\delta_1 f\right) \tag{2}$$

or

$$\sqrt{PL(f)} \propto f^{-\delta_2}. \tag{3}$$

Its statistics is characterized by its mean, i.e. μ_{δ_1} and μ_{δ_2}, and standard deviation, i.e. σ_{δ_1} and σ_{δ_2} in [2]. 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 [3]

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

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 [3]

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

where

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

$NP10dB$ 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 [4]. As described in Section III of [5], 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 including the mean number of cluster, $\overline{L}$. As shown in [2], the number of MPCs within a cluster,

K_l can be modeled by an exponential PDF, $f(K_l)$. The mean values of $f(K_l)$, μ_{K_l} are also listed in Table 4.

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] 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. The parameters of these distributions i.e. well fitted a lognormal distribution. 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	Freq. Range (GHz)	Distance (m)	LOS					NLOS				
			n		PL_0 [dB]	S [dB]		n		PL_0 [dB]	S [dB]	
AT&T [6]-[8]	4.375-5.625 (BW=1.25)	1-15	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 [9]	2-8 (BW=6)	0.8-10.5	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 [10]	2-6 (BW=4)	1-17	1.67		-	-		4.97[1]		-	-	
								7.24[2]				
Intel [11]	2-8 (BW=6)	1-20	1.72		-	1.48		4.09		-	3.63	
Samsung/SAIT [2], [12]	3-10 (BW=7)	1-25	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 [13], [14]	2-6 (BW=4)	1-17	1.67		-	4.0		5.13[1]		-	4.0	
								7.25[2]				

Table 1: Path loss and shadowing parameters.

Source	**Freq. Range (GHz)**	**Distance (m)**	**LOS**				**NLOS**			
			δ_1 [dB/Oct]		δ_2 [dB/Oct]		δ_1 [dB/Oct]		δ_2 [dB/Oct]	
			μ_{δ_1}	σ_{δ_2}	μ_{δ_2}	σ_{δ_2}	μ_{δ_1}	σ_{δ_2}	μ_{δ_2}	σ_{δ_2}
Samsung/SAIT [2]	3-10 (BW=7)	1-25	0.14^3	0.01^3	1.25^3	0.14^3	0.08^3	0.03^3	1.54^3	0.39^3
			0.08^4	0.09^4	0.98^4	0.09^4	0.10^4	0.02^4	1.51^4	0.25^4

Table 2: Frequency decaying factor parameters.

Source	Freq. Range (GHz)	Dist. (m)	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 [8]	4.375-5.625 (BW=1.25)	1-15	-	-	-	-	-	-	10.83^{5}		8.43^{5}		60^{5}	
									12.40^{6}		11.5^{6}		82^{6}	
AT&T [8], [15]	4.375-5.625 (BW=1.25)	1-15	-	-	4.70^{7}	2.30^{7}	-	-	-	-	8.20^{7}	3.30^{7}	-	-
AT&T [16]	2-8 (BW=6)	0.8-10.5	2.15	-	3.55	1.65	-	-	6.93	-	7.35	3.45	-	-
CEA-LETI [10]	2-6 (BW=4)	1-17	6.53	-	11.45	-	3.4	-	-	-	-	-	-	-
Intel [17]	2-8 (BW=6)	1-20	4.01	-	8.88	-	7	-	17.36	-	14.53	-	35	-
Intel [11], [17]	2-8 (BW=6)	1-20	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], [12]	3-10 (BW=7)	1-25	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 [18]	3-5 (BW=2)	1-10	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 [13], [14]	2-6 (BW=4)	1-17	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	Freq. Range (GHz)	Dist. (m)	LOS							NLOS						
			$\overline{L}$	μ_{K_l}	Λ [1/ns]	λ [1/ns]	Γ [ns]	γ [ns]	σ_a [dB]	$\overline{L}$	μ_{K_l}	Λ [1/ns]	λ [1/ns]	Γ [ns]	γ [ns]	σ_a [dB]
CEA-LETI [10]	2-6 (BW=4)	1-17	-	-	0.007	1.27	30	10	5.5-1.0[14]	-	-	-	-	-	-	-
Intel [17]	2-8 (BW=6)	1-20	-	-	0.017	2.0	16	1.6	4.8	-	-	0.091	2.86	16	8.5	4.8
U.C.A.N [13], [14]	2-6 (BW=4)	1-17	-	-	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]
Samsung/ SAIT [2]	3-10 (BW=7)	1-25	3[3]	24.10[3]	0.115[3]	1.96[3]	22.10[3]	14.27[3]	0.87[3]	4[3]	87.19[3]	0.047[3]	1.39[3]	51.47[3]	38.62[3]	0.94[3]
			3[4]	30.47[4]	0.085[4]	1.16[4]	23.95[4]	30.77[4]	0.85[4]	3[4]	117.36[4]	0.064[4]	1.79[4]	36.86[4]	27.40[4]	0.89[4]

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]	0.022[3]	0.23[3]	0.68[3]	0.28[3]	0.24[3]	0.19[3]	0.02[3]	0.25[3]	0.67[3]	0.28[3]	0.25[3]	0.19[3]
	0.036[4]	0.27[4]	0.68[4]	0.35[4]	0.24[4]	0.23[4]	0.05[4]	0.27[4]	0.69[4]	0.28[4]	0.23[4]	0.18[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 $c = 3 \times 10^8$ ms^{-1}	
n	1.79	4.58
S [dB]	2.22	3.51
Frequency Decaying Factor[15]		
$\delta_2 :\ \mu_{\delta_2}$ [dB/Oct]	1.12	1.53
σ_{δ_2} [dB/Oct]	0.12	0.32
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		
$\overline{L}$	3	3.5
μ_{K_l}	27.29	102.28
Λ [1/ns]	0.047	0.12
λ [1/ns]	1.31	2.11
Γ [ns]	22.61	26.27
γ [ns]	12.53	17.50
σ_a [dB]	2.75	2.93
Small-Scale Amplitude Fading Channel Parameters		
$m_L :\ \mu_{m_L}$	0.68	0.68
σ_{m_L}	0.32	0.28

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

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[1] Analysis for 45 different TX-RX positions with distance between 9-13 m under NLOS scenario [10], [13], [14].
[2] Analysis for 109 different TX-RX positions with distance between 7-17 m under NLOS scenario [10], [13], [14].
[3] Analysis for 3-bedroom apartment [12].
[4] Analysis for 4-bedroom apartment [12].
[5] Analysis based on 30 dB threshold level for 50% of the NLOS locations [8].
[6] Analysis based on 30 dB threshold level for 90% of the NLOS locations [8].
[7] τ_{rms} is Gaussian distributed over all homes with mean, $\mu_{\tau_{rms}}$ and standard deviation, $\sigma_{\tau_{rms}}$ [8], [15].

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[8] Analysis based on passband analysis, frequency domain Hamming windowing and 0.17 ns bin size [11].

[9] Analysis based on complex baseband analysis, frequency domain Hamming windowing and 0.17 ns bin size [11].

[10] Analysis based on passband analysis, frequency domain rectangular windowing and 0.17 ns bin size [11].

[11] Analysis based on complex baseband analysis, frequency domain rectangular windowing and 0.17 ns bin size [11].

[12] Analysis for TX-RX positions with distance between 0-4 m under NLOS scenario [18].

[13] Analysis for TX-RX positions with distance between 4-10 m under NLOS scenario [18].

[14] Decrease with delay [10].

[15] The frequency decaying factor is modeled by equation (3).