Channel Propagation Models for PAP02: Wireless Communications for the Smart Grid – Task 6

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1. The channel propagation model

This document gathers channel propagation models[1] for a host of environments. The model parameters were extracted from the data collected in a series of measurement campaigns conducted by the RF Fields Group in the Electronics and Electrical Engineering Laboratory at NIST. The models can be used for evaluating the performance of wireless communication technologies in application to the Smart Grid. In this study, we concentrate on the 2.4 GHz and 5 GHz unlicensed bands common to many technologies.

The environments considered are categorized according to the placement of the transmitter-receiver pair as indoor-indoor, outdoor-outdoor, and outdoor-indoor. The channel propagation path between the pair is characterized by the dual-slope path loss model. It is more flexible than the single-slope model and so can reflect a wider range of environments. The deterministic component of the path loss PL (dB) is a function of the distance d (m) between the transmitter and receiver and is defined as follows:

$$PL(d) = PL_0 + \begin{cases} 10n_0 \log_{10}(d/d_0), & d \le d_1 \\ 10n_0 \log_{10}(d_1/d_0) + 10n_1 \log_{10}(d/d_1), & d > d_1 \end{cases}$$

where PL_0 (dB) is the reference path loss at $d_0 = 1$ m and d_1 (m) is the breakpoint where the path loss exponent adjusts from n_0 to n_1.

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The path loss model with shadowing PL_S (dB) includes the stochastic shadowing parameter S (dB) which varies according to a zero-mean Normal distribution with standard deviation σ:

$$PL_S(d) = PL(d) + S,$$
$$S \sim N(0, \sigma)$$

Figure 1 shows the extraction procedure of the model from the data points. The PL in red is fit to the blue data points collected in an indoor-indoor residential environment at f_c = 5 GHz. The deviation of the data points from the line represents the shadowing effect.

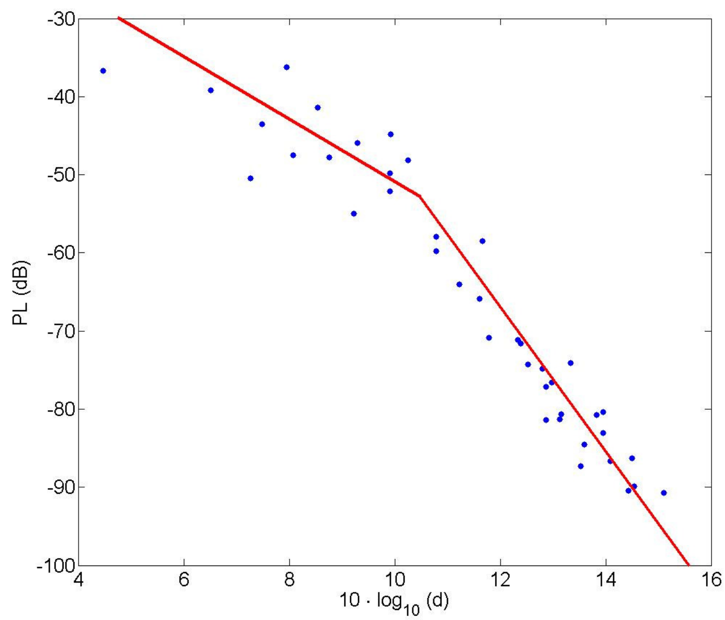

Figure 1: The dual-slope path loss model in an indoor-indoor residential environment at f_c = 5 GHz

2. Extracted model parameters

a. Indoor-indoor environments

We have gathered indoor-indoor data for *residential*, *office*, *industrial*, and *cinder block* environments. The details of the measurement system, procedure, and campaign are described in [1,2]. The five model parameters are listed in Table 1. Each environment is further differentiated into line-of-sight (LOS) and non-line-of-sight (NLOS) conditions. Note that in some environments the dual-slope model simply collapses to the single-slope model by setting $n_1 = n_0$ and arbitrarily choosing $d_1 = d_0$.

Table I: Indoor-indoor environments

environment		f_c = 2.4 GHz					f_c = 5 GHz				
		PL_0	n_0	d_1	n_1	σ	PL_0	n_0	d_1	n_1	σ
LOS	*residential*	16.3	2.2	1	2.2	2.4	17.9	1.7	1	1.7	1.5
	office	22.8	1.2	1	1.2	1.7	17.5	1.9	1	1.9	1.1
	industrial	22.4	1.1	1	1.1	2.1	15.2	1.8	1	1.8	1.2
	cinder block	24.2	1.5	1	1.5	2.8	12.7	2.5	1	2.5	1.6
NLOS	*residential*	12.5	2.2	11	5.6	3.0	20.2	2.4	11	5.4	3.3
	office	26.8	2.2	10	6.7	3.7	26.0	2.3	10	8.1	4.0
	industrial	29.4	1.4	1	1.4	6.3	27.5	1.7	1	1.7	6.7
	cinder block	9.1	4.9	1	4.9	6.7	7.8	5.3	1	5.3	7.7

b. Outdoor-outdoor environments

We have gathered outdoor-outdoor data for *oil refinery* and *urban-canyon* environments. The details of the measurement system, procedure, and campaign are described in [3,4]. The model parameters are listed in Table 2. In the *oil refinery* environment, the propagation paths before the breakpoint were in LOS, while those after the breakpoint traversed dense metal piping. This explains the large discrepancy between n_0 and n_1 there.

Table 2: Outdoor-outdoor environments

environment	f_c = 2.4 GHz					f_c = 5 GHz				
	PL_0	n_0	d_1	n_1	σ	PL_0	n_0	d_1	n_1	σ
urban-canyon / LOS	6.9	1.7	1	1.7	2.4	15.2	1.6	1	1.6	2.7
urban-canyon / NLOS	21.3	1.6	1	1.6	7.4	20.7	2.1	1	2.1	7.5
oil refinery	16.8	0.4	87	12.2	2.3	3.0	1.3	87	12.9	3.3

c. Outdoor-indoor environments

We have gathered outdoor-indoor data for *office*, *high-rise building*, *convention center*, and the *Greathouse mine tunnel* environments. The details of the measurement system, procedure, and campaign are described in [3]. The model parameters are listed in Table 3. By virtue of the outdoor-indoor environment, all parameters are for non-line-of-sight conditions. In the *office* environment, measurements were not available at 5 GHz. Also, since no data points were collected there before d_1 = 70 m, we just assumed free space (n_0 = 2.0) for distances before the breakpoint. In the *mine-tunnel* environment, the propagation paths before the breakpoint were in LOS, while those after were in NLOS where penetration is difficult given the thickness and density of the mine walls. This explains the very large discrepancy between n_0 and n_1 there.

Alternatively, an outdoor-indoor environment can be composed from an indoor-indoor segment, an outdoor-outdoor segment, and a fixed penetration loss to account for the transition through the building material. Reference [5] provides an extensive list of penetration losses at a number of center frequencies.

Table 3: Outdoor-indoor environments

environment	f_c = 2.4 GHz					f_c = 5 GHz				
	PL_0	n_0	d_1	n_1	σ	PL_0	n_0	d_1	n_1	σ
office	0.2	2.0	70	4.2	3.3	NA	NA	NA	NA	NA
high-rise	8.8	2.2	1	2.2	5.6	9.2	3.3	1	3.3	4.8
convention center	4.2	0.6	100	3.7	4.6	15.5	0.8	100	7.6	3.6
mine tunnel	5.7	0.7	70	18.3	5.8	1.3	0.2	70	23.4	4.3

3. References

[1] C. Gentile, S.M. Lopez, and A. Kik, "A Comprehensive Spatial-Temporal Channel Propagation Model for the Ultra-Wideband Spectrum 2-8 GHz," *IEEE Global Telecommunications Conf.,* pp. 1-6, Dec. 2009.
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[3] W.F. Young, K.A. Remley, J. Ladbury, C.L. Holloway, C. Grosvenor, G. Koepke, D. Camell, S. Floris, W. Numan, A. Garuti, "Measurements to Support Public Safety Communications: Attenuation and Variability of 750 MHz Radio Wave Signals in Four Large Building Structures," *Natl. Inst. Stand. Technol. Note 1552*, Aug. 2009.
[4] D.W. Matolak, K.A. Remley, C. Gentile, C.L. Holloway, Q. Wu, and Q. Zhang, "Ground-Based Urban Channel Characteristics for Two Public Safety Bands," *Submitted to IEEE Trans. on Antennas and Propagation*, Dec. 2009.
[5] T.S. Rappaport, "Wireless Communications," *Prentice-Hill, Inc.*, pp. 124-125, 1996.