Outdoor-to-Indoor Channel Measurements & Models

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This document reports on wireless channel measurements and models for outdoor to indoor propagation environments. Although there have been a number of publications that have recently appeared on this topic, e.g., [1], [2], and references therein, the amount of work that has been published is far less than that regarding traditional cellular (outdoor-to-outdoor) and indoor channels. In addition, as far as we are aware, no standardized models for this type of channel yet exist. In this brief report we provide an initial channel model based upon field-test measurements.

A number of researchers have collected data on building penetration loss (attenuation), but this report concerns channel impulse response (CIR) data and models. Researchers from the National Institute of Standards and Technology (NIST) and Ohio University collected channel transfer function measurements using a vector network analyzer in two public safety bands: 725-800 MHz, and 4.9-5 GHz. This work was funded by the NIST Public-Safety Communications Research Lab. The settings included the following:

1. urban: downtown Denver, CO, financial district 17th Street
2. campus: NIST, Boulder, CO (Two different office buildings and one storage building)
3. low-rise apartment building (11 floors): Horizon West, Boulder, CO
4. high-rise office building (66 floors): Republic Plaza, Denver
5. large arena: Denver Convention Center

For each of these settings, the transmit antenna was outside the building, with antenna height of approximately 1.7 m. In some cases the transmit antenna was omni-directional, while in cases where no nearby objects were present to induce multipath, directional antennas were used to increase gain in the direction of transmission. Distances from transmitter to building ranged from 10-30 m in order to simulate an emergency response scenario. The receiver was moved to discrete locations inside the various buildings, with link distances up to approximately 100 m (slightly larger for Republic Plaza). For both the low-rise apartment building and the high-rise office building, a significant fraction (~1/2 for the high-rise to all for the low-rise) of the receiver locations included locations on floors above the ground floor. For one of the NIST campus buildings, some receiver locations were also in the basement.

The data include both line of sight (LOS) and non-LOS (NLOS) conditions, where LOS conditions prevail when the receiver was nearest the transmitter, and propagation was through large windows or banks of glass doors. Fewer than one-third of the locations were LOS (the Denver urban and some convention center). The receive antenna height above ground (or “above floor” when the receiver was not on the ground floor) was identical to that of the transmitter, and the receive antenna pattern was also omni-directional. Scatterers in these environments included the buildings themselves, human beings, and for the Denver urban data, moving vehicles on the streets. Each transfer function measurement was made over a duration less than the minimum channel coherence time, computed assuming single-bounce scattering from vehicles at their maximum velocity. Although transmit antenna heights were low (unlike cellular), our results can mimic small outdoor base station heights, used in some urban "picocells." In addition, if coupling into buildings is primarily through a number of apertures on one side of a building, the outdoor antenna height may not strongly affect delay dispersion characteristics.

The measurements reported on here were single-input/single-output (SISO). Yet some of the measurements were made by moving the transmitter antenna to nine positions on a grid of size 0.5 m by 0.5 m, with the "local" transmitter and receiver positions fixed. This should enable us to apply some basic spatial processing that will yield statistics on angle of arrival, for a pseudo-multiple-input/single-output (MISO) channel. This will be done in the near future.

From the channel transfer functions, we obtained power delay profiles (PDPs) via inverse Fourier transformation. The PDPs were delay aligned, noise thresholded, filtered, and averaged. Several delay dispersion statistics were compiled. In addition, we employed the time of arrival estimation algorithm of [3] to estimate the number of multipath components in the average PDP. These results enable us to devise a model for the average PDP, in the form of an exponentially decaying function.

The vast majority (nearly all) of the PDPs for these measurements are of the "single-cluster" variety, in contrast to the multiple cluster form often found for outdoor-to-outdoor urban propagation. The multiple cluster PDPs are also well established for indoor-to-indoor propagation [4], and these multiple cluster PDPs are also modeled with exponential decays in power for each cluster.

The average PDPs for the two frequency bands are shown in Figures 1 and 2. Over 100 PDPs were used for each average. As also found in [5], profiles for the two frequency bands are quite similar. Table 1 compiles the delay dispersion statistics for these average profiles. The RMS delay spread is widely used. The delay window is the duration that contains 90% of the CIR energy [6]. The last delay domain dispersion measure that we list is the delay interval [6], defined as the duration of the CIR containing all impulses above X dB down from the largest impulse, where here we use X=25. Exponential fits for the average PDPs $P(\tau)$ are of the form

$$P(\tau)=a\,exp(-b\tau). \qquad (1)$$

Coefficients for the fits appear in Table 2. Equation (1) and Table 2 constitute our model.

Table 1. Summary delay dispersion statistics for outdoor-indoor average PDPs (all values in ns).

Band	**RMS Delay Spread**	**Delay Window 90% Energy**	**Delay Interval 25 dB**
700 MHz	80	244	396
4900 MHz	90	258	405

Table 2. Exponential fit parameters for the average PDPs of Figures 1 and 2.

Band	***a***	***b***
700 MHz	0.612	0.018
4900 MHz	0.710	0.043

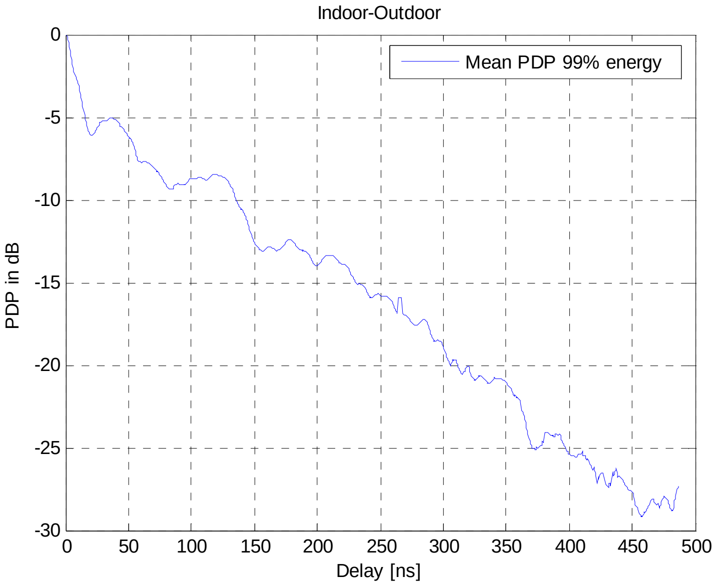

Fig. 1. Average PDP for 700 MHz band, all outdoor-indoor data.

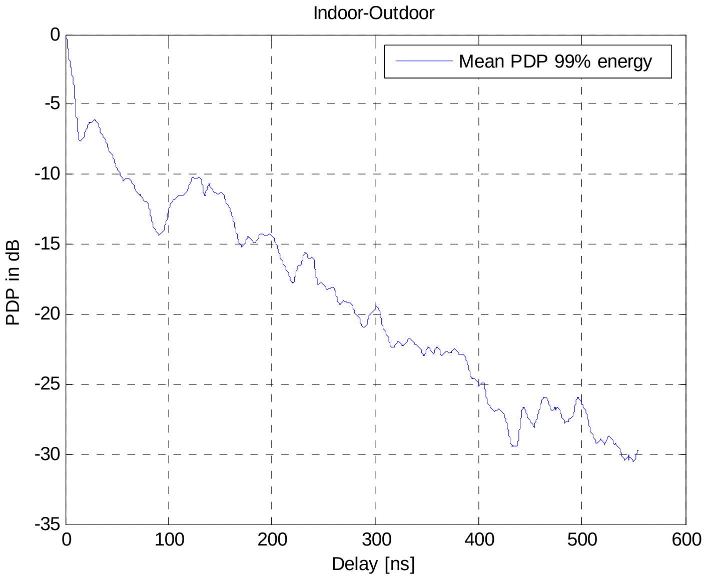

Fig. 2. Average PDP for 4900 MHz band, all outdoor-indoor data.

Since the single delay dispersion values provide only information on the "average" PDP, in Figure 3 we show cumulative distribution functions for the RMS delay spread for both bands. Median values of RMS delay spread are between 45 and 60 nanoseconds, and 90th percentile values are between 100 and 120 nanoseconds. These results are between those of [1] and [2], found for the 4.9 GHz and lower VHF/UHF bands (~200, 500 MHz), respectively.

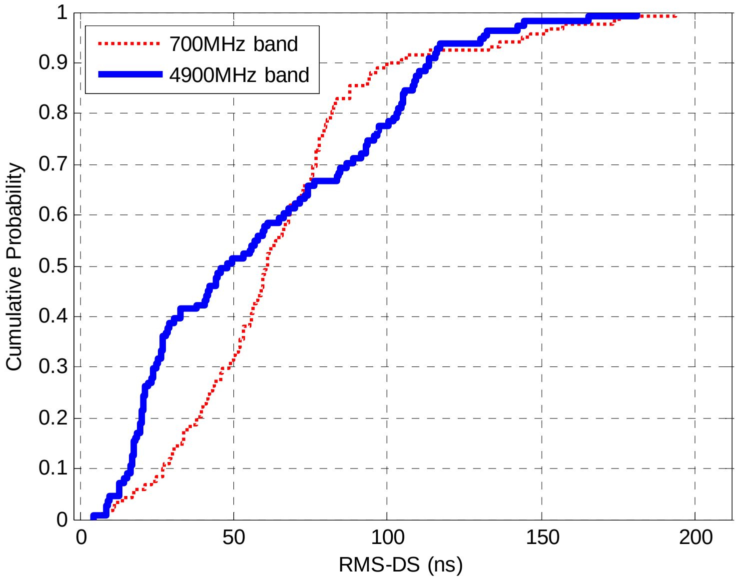

Fig. 3. Cumulative distribution functions of RMS delay spread for the two bands.

Finally, via the algorithm in [3], we found that for the 700 MHz band, typically only 5-7 multipath components are present within our delay resolution (< 1 nanosecond), whereas in the 4900 MHz band, 14 or more components may be present.

References

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