MEASUREMENTS OF PCS MICROWAVE PROPAGATION IN BUILDINGS

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ABSTRACT

The indoor environments, which have not yet been generally characterized are critically important to PCS propagation. This paper describes measurements in different indoor environments and the application of a novel indoor loss-distance model. The dynamic effects of indoor activities by people are also examined.

I. INTRODUCTION

To provide reliable Personal Communication Services (PCS) using radio media, knowledge of the propagation characteristics of the service area is required. The indoor propagation environments, which have not yet been generally characterized are critically important to PCS.

Many works have been dedicated to indoor propagation. Some in narrowband context [2], [3], [5]-[7], and others in wideband [1], [4], [8]. When it comes to slow fading, all have chosen a linear loss distance model. This effort and related work [9], [10] are proposing some nonlinear loss-distance models.

The propagation in buildings depends on the type of structure, the interior layout, obstructions, and materials. Two building layout features that will be important in PCS applications are hallways and large closed-in areas (e.g., factories). As a consequence, this effort addresses each of these topics.

While fast fading has been routinely studied, study of fading caused by activities by people to an essentially fixed indoor radio link has not been seen in open literature. In our experiments, we have observed fades of more than 10-dB. The knowledge of this type of fading is also very important in order to design a reliable system. Measured results and analysis of this dynamic effect are also included in this paper.

II. MEASUREMENTS

A. Measurement Setup

Figure 1 shows the measurement system. The transmitter produces a 31-dBm CW signal at 1905 MHz. The AGC output of the FM demodulator in the receiver is calibrated to measure the power seen at the input of the LNA, which provides an indication of received power with 70-dB dynamic range and less than ±0.5 dB error.

Automated data acquisition is achieved using an HP PC and an HP PC Instrument Digital Multi-Meter (DMM) module. A GW-BASIC program is used to measure, calibrate and record the data into files. The DMM module samples at the rate of 12.5 samples/sec. Laboratory constructed vertically polarized microstrip array antennas, which have a synthesized omnidirectional horizontal pattern and a low vertical gain were used in the measurements. The measurement setup is loaded on two carts, with antennas mounted at 2 meters above the ground.

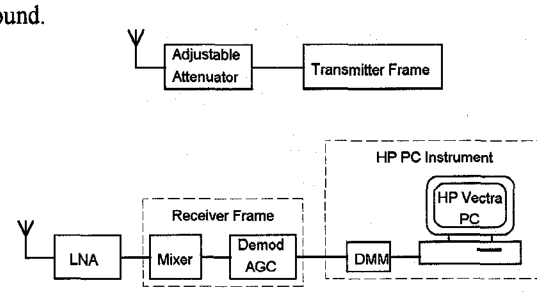

Figure 1 Block diagram of the measurement setup

B. Hallway Measurement

Measurements were performed in hallways in Nedderman Hall at the University of Texas at Arlington. At each location, 350 data points were collected in a 30 second period, during which the cart with receiver was moved from side to side across the hallway to collect a good sample set. Figure 2 shows the fast fading caused by the movement of the receiver.

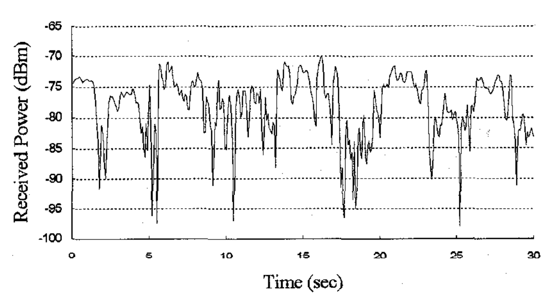

Figure 2 Hallway signal level in 30 seconds

Figure 3 shows the average received power, the best linear fit and the model prediction [10] for one of the hallways. The correlation coefficient between the data and the linear fit is 0.982. The correlation coefficient between the data and the theoretical prediction is 0.991.

The hallway is defined by the following parameters:

Width $W = 9.3$ ft,

Height $h = 9.7$ ft,

and Openings

$\{d_k\} = \{13.2, 19.2, 37.0, 39.0, 64.0, 88.2, 108.8, 108.8\}$ ft,

$\{w_k\} = \{7.0, 7.0, 5.3, 7.0, 13.3, 13.3, 7.0, 7.0, 7.0\}$ ft.

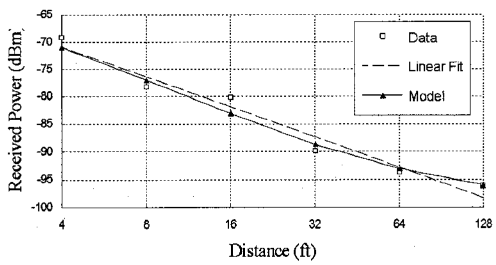

Figure 3 Average signal level in hallway

C. Measurement in Closed-in Areas

Measurements were conducted in the lobby of Nedderman Hall. The lobby is about 180 ft long, 55 ft wide and 40 ft tall. The lobby environment includes couches, bulletin stands, plants, and students sitting and walking. In the measurements, every point of reception had a LOS path to the transmitting antenna. Forty 1-minute Measurements were performed with five different antenna separations. During each 1-minute run, the cart with the receiver was pushed back and forth around the point of reception and 750 readings were collected and saved into a data file.

Figure 4 shows the average received power, the best linear fit and the theoretical prediction [10] in the lobby. The correlation coefficient between the data and the linear fit is 0.993. As a contrast, the correlation coefficient between the data and the model prediction is 0.999.

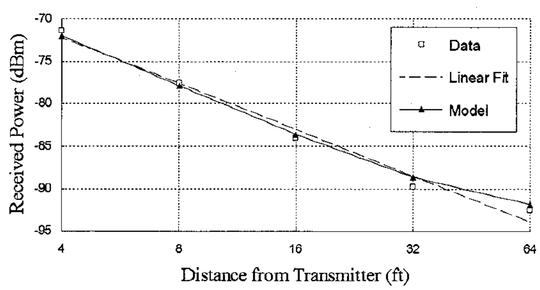

Figure 4 Signal level in lightly furnished lobby

D. Dynamic Effects of Activities by People

Six 10-minute data sets were collected in the lobby of Nedderman Hall with 80-ft antenna separation. Some data were recorded during class hours, with less people activity in the lobby; and others were recorded during inter-class period, with more activity. During each 10-minute run, the carts were at fixed locations and 7500 samples were saved into a data file.

Figure 5 shows a typical set of data collected in 5 minutes, in which we can clearly see fades with magnitude of more than 10 dB caused by the movement of people around the radio link.

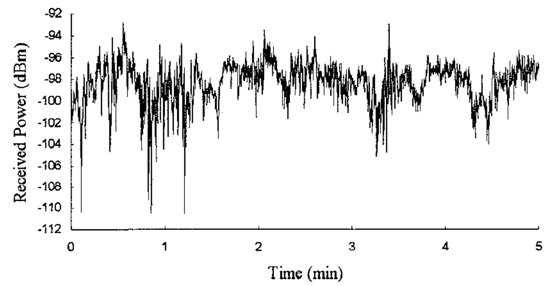

Figure 5 Dynamic fading due to people activity

Table 1 lists the basic statistics of the six 10-minute dynamic data sets. The standard deviation of data seems to correlate with people activities.

Table 1 Statistics of dynamic data

	record 1	record 2	record 3	record 4	record 5	record 6
People Activities	less	less	less	less	more	more
Maximum (dBm)	-92.1	-90.8	-92.7	-89	-88.7	-86.9
Minimum (dBm)	-99.3	-101.2	-103.0	-100.8	-105.2	-100.8
Mean (dBm)	-96.3	-96.5	-97.8	-96.0	-96.9	-94.5
Std. (dBm)	1.1	1.7	1.6	1.8	2.6	2.6

Figure 6 shows the cumulative distribution function (cdf) of record 1, and that of log-normal distribution. As we can see, the data fits log-normal distribution very nicely. Table 2 lists the correlation coefficients of the all six records of data when fitted to log-normal distribution.

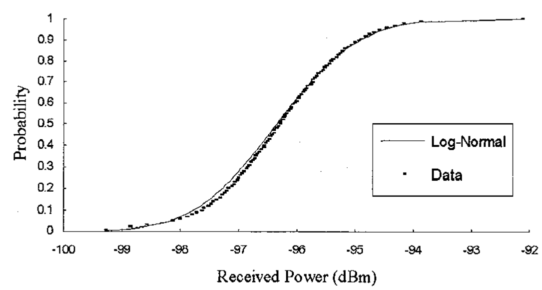

Figure 6 Cdf of data and log-normal distribution

Table 2 Correlation coefficients between cdf's of data and that of log-normal distribution

	record 1	record 2	record 3	record 4	record 5	record 6
corre. coefficient	0.99958	0.99916	0.98941	0.99731	0.99732	0.99952

Fading rate, which is a measure of the rate of change of the received signal level, is an important parameter in the system design of PCS radio. Figure 7 shows the dynamic data in a 20-second period. Each marker indicates a data sample. We can see that the sample rate (12.5 samples/sec) was fast enough to catch the details of fading, therefore the difference signal which is the power ratio between the consecutive samples in dB can be derived from the dynamic data and will contain the statistical information of the fading rate.

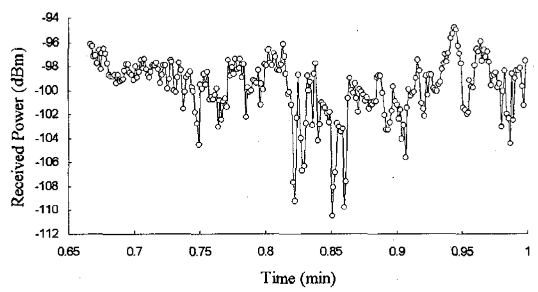

Figure 7 Time expanded plot of dynamic data

Figure 8 shows a typical set of difference data and Table 3 lists the basic statistics of the difference data and the standard deviation of the fading rate.

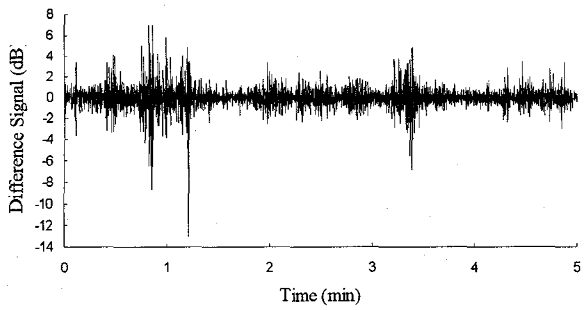

Figure 8 Difference signal in 5 minutes

Table 3 Statistics of difference data

	record 1	record 2	record 3	record 4	record 5	record 6
Maximum (dB)	6.44	7.10	6.94	10.56	20.23	11.56
Minimum (dB)	-5.24	-9.31	-13.05	-8.72	-14.83	-11.31
Mean (dB)	5.9e-4	-1.9e-4	4.5e-4	2.4e-4	2.7e-5	-4.4e-4
Std. (dB)	0.7	0.8	0.8	1.1	1.6	1.1
σ of f.r. (dB/sec)	8.75	10.0	10.0	13.75	20.0	13.75

As we can see, the difference signal is essentially a zero mean random process. Interestingly, there is some obvious symmetry in the envelope of the signal, which can be interpreted as that the radio link tending to return to the undisturbed condition.

The distribution of the difference signal was found in our study to best fit that of the Laplacian distribution. Table 4 lists the correlation coefficients between the cdfs of the difference signal and that of the Laplacian distribution.

Table 4 Correlation coefficients between cdfs of difference signal and that of Laplacian distribution

	record 1	record 2	record 3	record 4	record 5	record 6
corre. coefficient	0.9997	0.9997	0.9997	0.9999	0.9997	0.9985

III. CONCLUSION

In small scale indoor propagation environments, where a LOS path exists between the transmitting and receiving antennas, the received power varies slower than r^{-2} due to the additional random power contribution. Measurements and theory presented elsewhere [10] show that received power in the heavily furnished factory or lobby environment varies at a rate greater than r^{-2}.

People in indoor propagation environments can cause a substantial amount of fading to the received signal. Fades with more than 10-dB magnitude were observed in our measurements. The standard deviation of the fading signal correlates with the amount of people activity in the region of propagation. The distribution of the fading signal can be modeled with log-normal distribution. As a consequence, deeper fades are more likely to be observed when there is more people activity, which is exactly what we have seen.

The instantaneous fading rate, an important temporal parameter for radio design, was found in our measurements to be a Laplacian random process with a standard deviation in the order of 10 dB/sec.

REFERENCES

[1] M. Saleh, et al., "A statistical model for indoor multipath propagation," *IEEE J. Select. Areas Commun.*, vol. SAC-5, pp. 128-137, Feb. 1987.

[2] S. E. Alexander, "Characterizing buildings for propagation at 900 MHz," *Electronics Letters*, vol. 18, No. 21, Oct. 1982, pp 913-914.

[3] Cox, et al., "800-MHz attenuation measured in and around suburban houses," *B.S.T.J.*, pp. 921-954, Jul.-Aug. 1984.

[4] J. Devasirvatham, "Multipath time delay jitter measured at 850 MHz in the portable radio environment," *IEEE J. Select. Areas Commun.*, vol. SAC-5, pp. 855-861, Jun. 1987.

[5] C. Bultitude, et al., "A comparison of indoor radio propagation characteristics at 910 MHz and 1,75 GHz," *IEEE J. Select. Areas Commun.*, vol. SAC-7, pp. 31-39, Jan. 1989.

[6] T. S. Rappaport and C. D. McGillum, "UHF fading in Factories," *IEEE J. Select. Areas Commun.*, vol. SAC-7, pp. 40-48, Jan. 1989.

[7] J. M. Keenan and A. J. Motley, "Radio coverage in buildings," *British Telecom Technology*, vol. 8, No. 1, Jan 1990.

[8] T. S. Rappaport and D. A. Hawbaker, "Wide-band microwave propagation parameters using circular and linear polarized antennas for indoor wireless channels," *IEEE Trans. Commun.*, vol. COM-40, pp. 240-245, Feb. 1992.

[9] Yuqiang Tang, "Study of Microwave Propagation for Personal communication Systems," Ph.D. Proposal, University of Texas at Arlington, Oct. 1992.

[10] Yuqiang Tang and Harold Sobol, "Modeling of Indoor Microwave Propagation for PCS System," ICC'93, May 1993.