

NEAR GROUND WIDEBAND CHANNEL MEASUREMENT

IN 800 -1000 MHz[†]

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Abstract – Frequency domain channel propagation measurements in the 800-1000 MHz band have been performed with ground-lying antennas. The range of path-loss exponent and shadowing variance for indoor and outdoor environment were determined. The range of these values roughly agree with those measured for higher elevation antennas. Frequency selectivity of the RF channel was also characterized by means of determining average coherence bandwidth (CBW). It was observed that there is a relationship between CBW and distance between transmitting and receiving antennas.

I. INTRODUCTION

Near ground close range RF propagation conditions arise in wireless sensor networks. These novel networks are the focus of successful research efforts at UCLA (1,2). Wireless sensor networks aim to interface the analog physical world with existing communication and data networks. In these systems tasks of sensing, signal processing, and communications are combined on one or very few ICs.

The sensor node that results from this design solution is a stand alone unit capable of two-way radio communication with its peers. The radio environment for this kind of wireless RF transmission consists of small range propagation with very low elevation antennas (less than one meter height). The 900 MHz ISM band is one possible operating frequency band for the wireless sensor network.

The nodes are envisioned to use binary FSK modulation,

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slow frequency hopping with non-coherent reception. Symbol rates of up to 10 Ksymbols/second, transmit powers of less than 1 mW, and node separations of up to 30 meters are expected. Sensor nodes are battery operated, and thus are limited both in the total energy and instantaneous peak current available.

The propagation conditions arising from this mode of communication have not been studied before to the best of knowledge of the authors. In order to optimize our system performance, it is important to have a model for the RF environment.

Assuming time-invariant channels (nodes do not move), frequency domain measurements were performed to determine complex frequency responses for the channel. From this response, path loss, shadowing parameters, and coherence bandwidth of the channel for various indoor and outdoor environments were calculated.

This paper is organized as follows: in Section II the measurement procedure and equipment are described. Measurement results and data processing methods are presented in Section III along with discussion of results. Conclusion of our observations is included in Section IV.

II. MEASUREMENT METHOD

Since the sensor nodes do not move and we are interested in characterizing the effect of local geometry on the channel, it is reasonable to assume the channel of interest is slowly time-varying. The equipment setup and measurement approach used is very similar to the one used in (3). Figure 1 gives a description of the measurement system. The laptop was used to remotely control the network analyzer and to act as data storage.

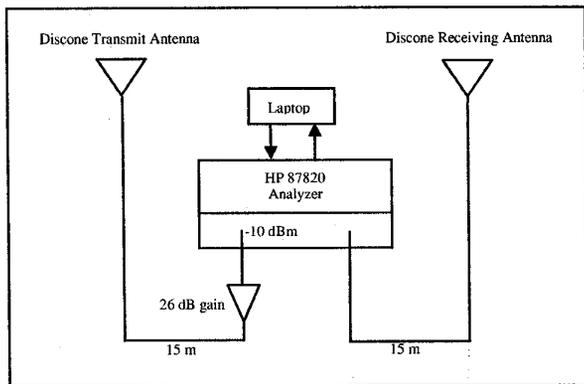


Figure 1. Diagram of the measurement system.

At various sites, both indoors and outdoors, the frequency response of the channel was measured at regular intervals of transmitter receiver separation. In each site one or more fixed locations for the transmitter antenna were chosen. A long track starting at the transmitter location was determined along which the receiver antenna would be placed. The receiver antenna was then placed at regularly increasing distances from the transmitter, and for each such distance m local snapshots of the complex frequency response of the channel were made along a local track. These local snapshots would then be averaged in amplitude to give an average frequency response for the specific separation.

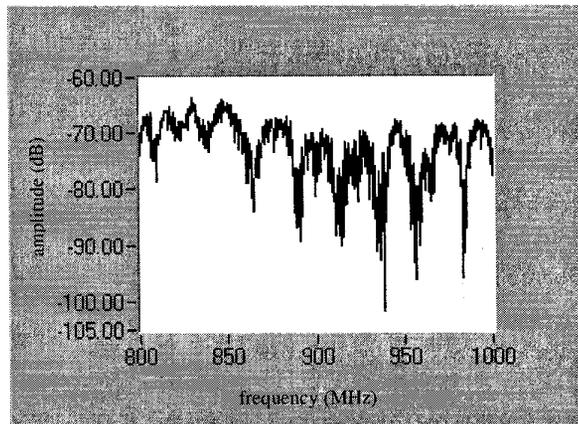


Figure 2. Amplitude of frequency response at 10 m separation, Parking Lot.

The measurements were done in a 200MHz band centered at 900MHz. Each snapshot was a collection of 801 points of received signal amplitude and phase in complex format. Frequency separation was 250KHz. The discone (3) antenna used was designed to operate in the band of

interest to us and had height of approximately 15 cm. Antennas were placed directly on the surface in each location, i.e. either on the ground or on the floor at each site. Figure 2 gives the amplitude of a sample snapshot.

Description of Sites

We were interested in measuring channel behavior in a variety of locations where our communications nodes would be placed. This fact and ease of access and possibility of transporting our measurement equipment to the sites were important factors in determining the sites. The following list gives short descriptions of the sites for which data are presented in this paper:

- 1) Engineering I: multi leveled building. This is an old brick structure, with wide hallways, and large lab-like rooms on either side of hallways. Heavy equipment and machinery in some of the labs are present in some labs.
- 2) Apartment Hallway: commercial apartment complex. This is a building with wood-frame and narrow hallways. A first floor long hallway was our measurement site.
- 3) Parking Structure: concrete and steel parking structure on UCLA campus. It has 6 levels and open sides.
- 4) One-sided corridor: a corridor on the side of a modern multi-floored, steel and concrete building. On one side it is open (similar to a long balcony).
- 5) One-sided patio: very large patio without roof and having only one wall on the 2nd floor of modern steel and concrete building.
- 6) Concrete canyon: wide alley between large metal frame 7-8 storied structures which comprise the engineering complex on UCLA campus.
- 7) Plant fence: a thick growth of leafy plants about 1 m high, used as a fence in a garden.
- 8) Small boulders: a wall of crushed limestone, similar to a surf-break. Antennas were placed on top of the wall.
- 9) Sandy flat beach: Santa Monica Beach.
- 10) Bamboo: small bamboo jungle located in the UCLA Botanical Garden. Used as a model for tropical forests.
- 11) Dry tall under-brush: tall grassy fields, with few tall bushes.

III. RESULTS

As mentioned earlier, each channel snapshot is a collection of 801 complex data points. Each complex number is the S_{21} parameter of the channel at a fixed frequency in the frequency band of interest. After correcting for the effect of the amplifier inserted in the signal path, the resulting signal is the channel frequency

response over the range 800-1000 MHz. Standard data analysis was performed on the raw data collected at each location to determine power loss laws of the wireless channel and to characterize channel frequency selectivity. The model used for power loss is described in (4) where the path loss at distance d between transmitter and receiver is given as:

$$PL(d) = PL(d_0) + 10n \log_{10}\left(\frac{d}{d_0}\right) + X_{\sigma} \text{ [dB]}$$

This formula deals with average path loss at a given separation between transmitter and receiver at a fixed frequency. Linear regression is used to fit our raw data to this model.

Table 1. Ranges for power loss exponent and shadowing variance over the measurement band.

Location	Path Loss Exponent	Shadowing Variance (dB)
Engineering I	$1.4 < n < 2.2$	$5.7 < \sigma^2 < 13.0$
Apartment Hallway	$1.9 < n < 2.2$	$3.0 < \sigma^2 < 11.0$
Parking Structure	$2.7 < n < 3.4$	$2.4 < \sigma^2 < 17.0$
One-sided Corridor	$1.4 < n < 2.4$	$4.0 < \sigma^2 < 16.0$
One-sided Patio	$2.8 < n < 3.8$	$1.0 < \sigma^2 < 9.2$
Concrete Canyon	$2.1 < n < 3.0$	$4.8 < \sigma^2 < 20.0$
Plant Fence	$4.6 < n < 5.1$	$2.8 < \sigma^2 < 5.0$
Small Boulders	$3.3 < n < 3.7$	$8.8 < \sigma^2 < 18.2$
Sandy Flat Beach	$3.8 < n < 4.6$	$2.2 < \sigma^2 < 10.0$
Dense Bamboo	$4.5 < n < 5.4$	$0.4 < \sigma^2 < 46.0$
Dry Tall Underbrush	$3.0 < n < 3.9$	$4.2 < \sigma^2 < 16.0$

Note that we are interested in a range of frequencies and therefore the values of parameters of interest, namely " n ", $PL(d_0)$, and σ^2 , variance of X_{σ} , were found for the entire measurement bandwidth. Over the 200MHz band there are some variations in these parameters. The data given in tables 1 and 2 give the dynamic range of these parameters over the measurement bandwidth. For example, the power loss exponent for Parking Structure at some frequency f_x will have a value between 2.7 and 3.4 depending on the value of the frequency, and has an average value of 3.0. Generally, the path loss exponent agrees with results obtained for other types of channels. The interesting part however, is the fact that the onset of channel behavior is at much closer ranges compared to other channels. The results for 1m path loss values indicate this point.

Table 2. Range of path loss at reference distance over the measurement band.

Location	Path Loss at 1 m (dB)
Engineering I	$-50.5 < PL(d_0) < -39.0$
Apartment Hallway	$-38.2 < PL(d_0) < -35.0$
Parking Structure	$-36 < PL(d_0) < -32.7$
One-sided Corridor	$-44.2 < PL(d_0) < -33.5$
One-sided Patio	$-39.0 < PL(d_0) < -34.2$
Concrete Canyon	$-48.7 < PL(d_0) < -44.0$
Plant Fence	$-38.2 < PL(d_0) < 34.5$
Small Boulders	$-41.5 < PL(d_0) < -37.2$
Sandy Flat Beach	$-40.8 < PL(d_0) < -37.5$
Dense Bamboo	$-38.2 < PL(d_0) < -35.2$
Dry Tall Underbrush	$-36.4 < PL(d_0) < -33.2$

Table 3. Mean power loss, and shadowing variance.

Location	Mean Path Loss Exponent	Mean σ^2 (dB)
Engineering I	1.9	5.7
Apartment Hallway	2.0	8.0
Parking Structure	3.0	7.9
One-sided Corridor	1.9	8.0
One-sided Patio	3.2	3.7
Concrete Canyon	2.7	10.2
Plant Fence	4.9	9.4
Small Boulders	3.5	12.8
Sandy Flat Beach	4.2	4.0
Dense Bamboo	5.0	11.6
Dry Tall Underbrush	3.6	8.4

The relatively small value for the shadowing parameter is mostly due to the fact that our measurements were done in LOS conditions. The exception is the dense bamboo growth area, where indeed extreme signal absorption and scattering occurs. The unexpected high shadowing in the concrete canyon is probably due to high levels of reflected energy off the walls. Relatively little shadowing is observed in wide-open areas. Power loss exponent which has a maximum of 5.4 is comparable with power loss exponent in channels with higher antenna heights.

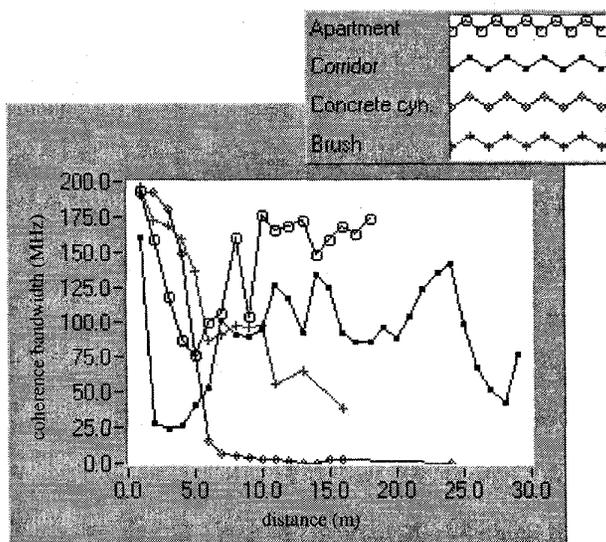


Figure 3. Variation of coherence bandwidth with distance in various sites.

Channel coherence bandwidth (CBW) was also determined for each snapshot. We define the CBW as the -3dB bandwidth of the magnitude of the complex auto-correlation function of the frequency response of the channel. Our definition of the complex auto-correlation function follows that of (5). For each site, the CBW was calculated for all the snapshots at a specific distance, and averaged. The average CBW was then plotted as a function of distance. Based on our observations, it was found that in general, the average CBW tends to decrease with distance between transmitter and receiver. An intuitive explanation for this phenomenon is that, as the separation is increased, a larger portion of the transmitted energy that arrives at the receiver will have been reflected or scattered on its way, and therefore there is higher possibility of destructive interference at some frequencies. This destructive interference results in appearance of nulls in the amplitude of the channel frequency response, which then contributes to smaller CBW calculated for each snapshot.

Needless to say, the specific behavior of channel selectivity is closely related to the geometry of the measurement environment and the physical properties of the reflecting surfaces in the vicinity of the transmitter and receiver antennas. Figure 3 shows these results.

Note that CBW does not follow the same trend in hallways. Unlike open areas, in hallways we see a roughly oscillating relationship with increasing distance for average CBW. Hallways provided another interesting phenomenon also. It was found that the power loss exponent in long, enclosed spaces is smaller than those

observed in open spaces. This can be described as a result of a wave-guide like effect. The same principle may also be responsible for the CBW behavior.

IV. CONCLUSIONS

Prior to our experiments, there were no data available characterizing radio channels with low-lying antennas in the 800-1000 MHz band. The results of our experiments have to some degree, shed light on the channel behavior with near-ground antenna heights. Generally the power law follows those of other types of channels where antenna heights are higher. However the scale of the channel behavior is different. That is, the power starts to drop off with higher exponents at smaller distances than for channels with higher antennas. While it has long been known that reduction of antenna height could lead to such effects, experimental validation was necessary for the complicated conditions of interest.

Channel frequency selectivity on average, and except in hallways, increases with transmitter receiver separation. The hallways exhibit unique behavior. More complicated models in the future must be used to describe channel behavior in hallways.

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