Effect of People Moving near Short-Range Indoor Propagation Links at 2.45 GHz

Ali Kara and Henry L. Bertoni

Abstract: **Measurement results are presented for the effects of people moving near and across short-range indoor propagation links at 2.45 GHz (ISM band). Excess loss due to scattering and blockage by human bodies in the vicinity of one terminal were measured for different radio links in an office environment. Statistics on fades due to human body motion are given. Polarization coupling (depolarization) for various radio links was measured, and correlation of polarization components is discussed as a basis for using polarization diversity reception in short-range indoor systems.**

Index Terms: **Bluetooth, body shadowing, indoor propagation, indoor radio, interference, polarization diversity, wireless local area network (WLAN).**

I. INTRODUCTION

The measurements of indoor radio channel characteristics primarily examine the channel characteristics for medium to large propagation distances. Some research efforts have dealt with the characterization of short-range channels for low power wireless systems such as Bluetooth. Understanding local environmental conditions near the terminals is important for determining system performance and possible interference in small enterprises or home offices. Objects like desks and cabinets scatter the radio waves and thereby cause spatial fading as a result of multipath [1]–[5], as well as shadowing due to blockage. When people move in the vicinity of the link they cause additional fading, which may be the result of body blockage or multipath interference due to body scattering. On line of sight (LOS) links body blockage is found to produce deep fades, while on obscured links the effect of body scattering are found to be most significant. This difference is observed both in the time dependence of the excess path loss as people move, and in the statistical distribution of the fading.

In this letter, we present measurement results for people moving near one end of short radio links at 2.45 GHz (ISM band). The measurement system and the environment are described in Section II. Section III presents the results for the shadowing effects of human body, polarization coupling, and correlation of polarization components for various link conditions. A short discussion of the results is given in Section IV.

II. MEASUREMENT SYSTEM AND ENVIRONMENT

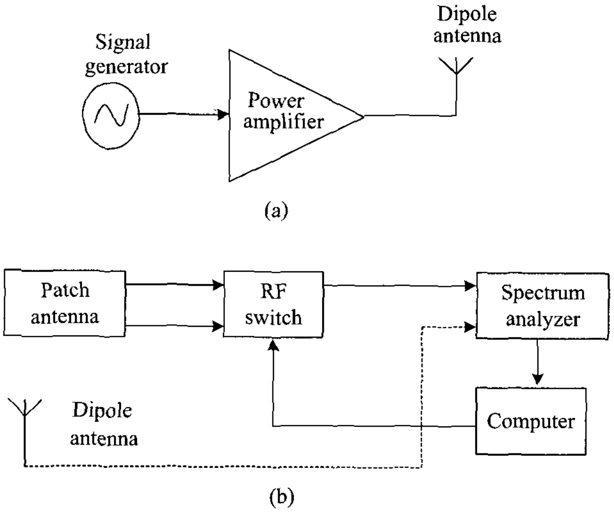

Fig. 1. Measurement system: (a) Transmitter, (b) receiver.

The measurement system consisted of a transmitter and a receiver configured as shown in Fig. 1. The transmitter was an RF signal generator tuned to 2.45 GHz, connected to a power amplifier with 20 dB gain, to feed a vertically polarized dipole of 5.1 dBi gain as depicted in Fig. 1(a). Two different receiver setups were used. The first one had a dual polarized patch antenna of gain 7.1 dBi feeding a spectrum analyzer through an RF switch, so as to measure the polarization components (vertical and horizontal) at the receiver as depicted in Fig. 1(b). In this setup, the portable computer both collects the received power from the spectrum analyzer over a GPIB bus and controls the RF switch via a DAQ card for polarization change. For the second, a vertically polarized dipole (dashed line in Fig. 1(b)) identical to the one in the transmitter side, was moved along a horizontal circle of height 1.5 m in order to find excess path loss. For this purpose, the receiving antenna was attached on a pipe forming the top bar of a 'T.' The bottom of the 'T' was mounted on a rotator so that the antenna could be moved around a circle of radius 40 cm. The excess path loss is used to characterize the degree to which the radio link is obscured by wall and furniture. The output power of the power amplifier was kept at its maximum (20 dBm) in order to prevent measurement errors for low signal levels measured over links of heavy blockage, and also to reduce possible interference from nearby systems operating at the same band though there was no known high power interferers in the environment. Preliminary calibration measurements were made in a large open area outdoors. Indoor measurements were made in a laboratory room of the Electrical Engineering Department of Polytechnic University. Fig. 2 shows a top view of the rooms with the transmitter and receiver locations, and indicates the path lengths of the links. The rooms have no win-

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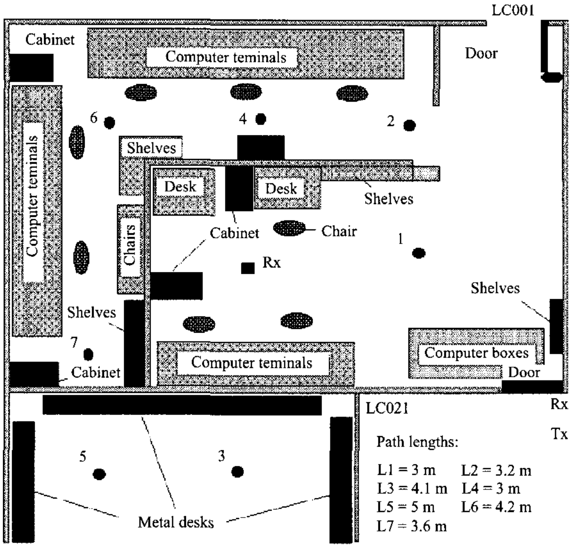

Fig. 2. Floor plan of the laboratory environment. Receiver (Rx) and transmitter (Tx) locations with corresponding path lengths are indicated.

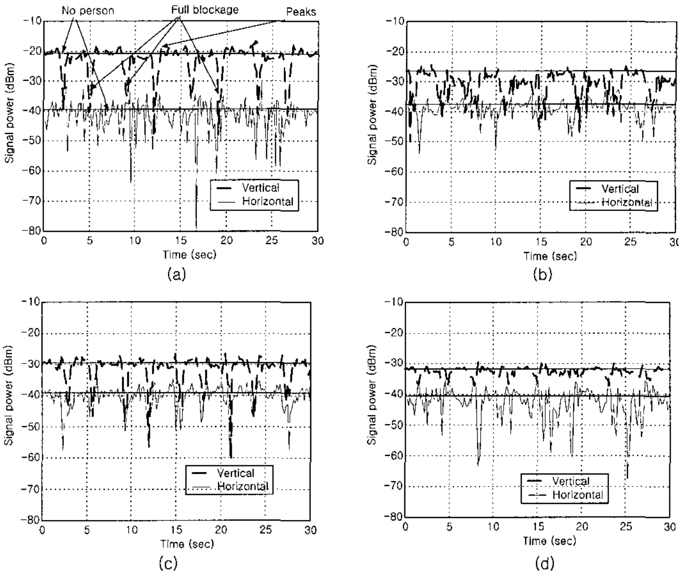

Fig. 3. Signal variation as a person periodically cross the link of different paths: (a) LOS (#1), (b) lightly obstructed (#2), (c) obstructed (#6), (d) heavily obstructed (#7).

dows, their walls are made of plasterboard on metal studs, and the floors are concrete. The main room (LC001) is 6.5 m by 8.5 m with ceiling height of 3 m. The room is furnished with movable partitions of height 1.75 m, together with wooden and metal shelves of height 2 m as illustrated. It has two doorways, one of which was open while the other was always closed during measurements. The neighboring room (LC021) has only metal desks that are located next to the walls.

Radio links or receiver positions are chosen such that each would simulate a situation in real environments. For example, the path for transmitter location 2 in Fig. 2 is mildly obstructed by a movable partition and wooden shelves while location 6 represents blockage by partition and high metal/wooden shelves. The transmitter was stationary during the measurements. The description of the radio links corresponding to the transmitter locations in Fig. 2 is listed in the Table 1. There were seven radio links to simulate real office environments. The transmitting antenna was mounted at heights (h_t) of 0.75 m and 1.5 m while the receiving antenna was at the height of 1.5 m.

III. MEAUREMENT RESULTS

Excess path loss is used here as a measure of the degree to which the radio link is obscured by walls and furniture. The excess loss was found by removing the range dependent free space loss from the "small area averaged" received signal obtained by moving the receiving antenna along a horizontal circle and averaging the recorded [6], [7] are listed in Table 1. On the LOS path the excess loss is less than 1 dB. Its next lowest value of 1.6 dB was found for the lightly obstructed link blocked by low partitions and low metal cabinets near the transmitter. Other paths having excess loss between 4.9 and 6.2 dB are obstructed by movable partitions, wood and metal shelves and plaster board walls. The highest value of excess loss of 12.7 dB is for a link that has heavy obstruction by metallic shelves together with some partitions.

A. Body Shadowing

Human body shadowing was studied when a person periodically crosses the link about 0.7 m from the receiving antenna for the radio links in Table 1. The speed of the person, crossing the link in a direction perpendicular to the path, was adjusted in accordance with the switching speed of the receiver for polarization change. Recordings of the signal received on both polarizations were made over 30 second intervals. The fades are somewhat correlated with the blocking rate of the person. The radio links illustrated below are LOS (#1), lightly obstructed (#2), obstructed (#6), and heavily obstructed (#7). The time dependent received signal measured for a transmitter height of 1.5 m for each link is shown in Fig. 3.

The solid horizontal lines (labeled "No person" in Fig. 3(a)) in Fig. 3 show the signal level when the person is not present. The deep fades correspond to the position of full blockage by the person as indicated in Fig. 3(a) ("Full blockage"). It should be noted that the signal level exceeds the average level when the person is close to the link but not blocking it. This is due to the fact that the direct signal and the signal scattered from the body add constructively resulting in the peaks seen next to the deep fades as indicated in Fig. 3(a) ("Peaks"). It is also observed that the received signal occasionally drops about 20 to 30 dB from the average signal level for obstructed and heavily obstructed links. The relative strength of the cross polarized (horizontal) field component increases from about 20 dB on the LOS link to about 8 dB on the heavily obstructed link.

Cumulative distribution functions (CDF) of the fading due to human body motion are shown in Fig. 4. The horizontal axis indicates the fading that were determined by subtracting the instantaneous signal power from the average signal power for a period of 30 seconds at each location for Fig. 3. Therefore, negative values represent the signal values higher than the average

Table 1. Link description and excess loss.

Location No.	Link description	Excess loss (dB)
1	Un-obstructed line of sight (LOS)	< 1
2	Lightly obstructed by low partition and metal cabinets	1.6
3	Obstructed by plasterboard wall	4.9
4	Obstructed by partition and wooden shelves	5
5	Obstructed by wall and high metal shelves	5.5
6	Obstructed by partition and partly by high shelves	6.2
7	Heavily obstructed by partition and high metal shelves	12.7

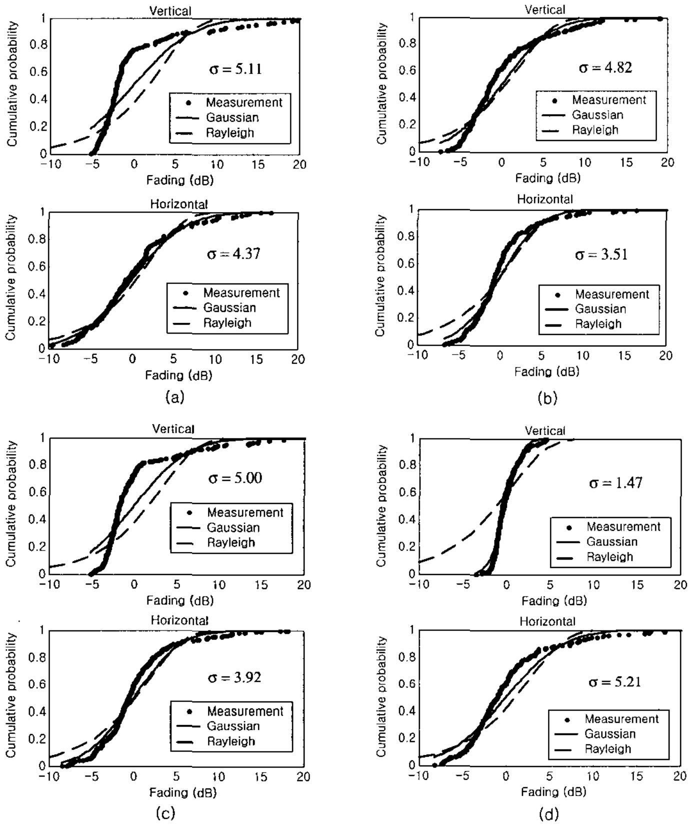

Fig. 4. CDF of shadowing fades for the locations in Fig. 3: (a) LOS, (b) lightly obstructed, (c) obstructed, (d) heavily obstructed.

Table 2. Polarization coupling and power cross-correlation coefficients.

Location No.	Polarization coupling (dB) $h_t = 1.5$ m	Cross-correlation coefficient $h_t = 1.5$ m	Cross-correlation coefficient $h_t = 0.75$ m
3	-18	0.46	0.14
4	-16	0.7	0.29
5	-10	0.35	0.48
6	-7	0.24	-0.09
7	> -5	0.03	0.07

while the positive values represent signal values less than the average. We have also plotted in Fig. 4 the CDF for a Gaussian (in dB) distribution function having the same mean and standard deviation (as indicated in dB) as the experimentally derived distribution. Finally, we have plotted the CDF of Rayleigh (in volts) distribution.

Only for co-polarization (vertical) in a heavily obstructed environment does the Gaussian give a significantly better fit to the distribution of measured values. In general, one or both the Gaussian and Rayleigh CDF's can be used to fit the distribution of measured values for cross polarization (horizontal), but are rather poor fits for the co-polarization (vertical).

Conventional wisdom holds that when the scatterers are stationary and the receiving or transmitting antenna is moved, variations of the received signal will exhibit statistics that are close to those of a Rayleigh or Rician distribution. What we see from Fig. 4 is that when the scattering/shadowing object moves close to one end of a link with stationary antennas, the statistics of the signal variation will differ significantly from a Rayleigh distribution.

B. Polarization Coupling and Correlation

Polarization coupling was measured with the dual polarized patch antenna placed at heights of 1.5 m and 0.75 m, and pointed in the direction of the transmitting antenna. At each location over 300 values of the coupling were obtained during the time a person moved in the vicinity of the radio link. Polarization coupling (in dB) is given as the difference between the co-polar and the cross-polar components of the received signal powers in dB. The average of the measured polarization couplings for the radio links of Table 1 are shown in Table 2. For heavy blockage, the measured polarization coupling was stronger than -5 dB, and occasionally the cross-polar components were measured to be higher than the co-polar components (coupling greater than 0 dB).

Cross-correlation between the fading of the two polarization components is an important parameter for evaluating polarisation diversity [8]–[10]. For the transmitting antenna heights of 1.5 m and 0.75 m, the cross-correlation coefficients were calculated, and are listed in Table 2. It should be noted that a negative correlation coefficient was measured for the link of the location number 7, for which the transmitting antenna was at 0.75 m. A correlation factor of 0.7 (or less) has been reported to be enough to obtain a polarization gain for outdoor and some indoor channels at lower frequencies of UHF band [9], [10]. The values determined here for the ISM 2.54 GHz band are relatively smaller than this factor as shown in Table 2.

IV. CONCLUSION

Environmental blockage, such as by furniture and human bodies in the vicinity of the receiver and/or transmitter, cause deep fades that might limit the range and the performance of short-range wireless systems, e.g., Bluetooth. It is also important for possible interference of co-located systems operating at the same band, such as Bluetooth and wireless local area networks (WLAN). Fading values of 20 dB to 30 dB were measured for some links due to human body/furniture blockage in an office environment. Polarization components measured at the receiver were also dependent on the blockage of the links. The correlation coefficients of polarization components were found to be less than 0.5 for moderately and highly obstructed links. The results could be valuable for determining the feasibility of polarization diversity reception for short-range indoor systems.

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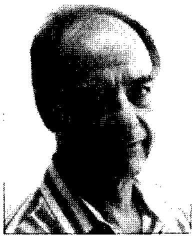
Ali Kara was born in Amasya, Turkey, on November 10, 1972. He received the B.Sc. degree in Electronics Engineering and the M.Sc. and the Ph.D. degrees in Electrical and Electronics Engineering from Erciyes University, Cukurova University and Hacettepe University in 1992, 1996, and 2002, respectively. From January 1999 to June 2000, he was at Polytechnic University (NY, USA) where he conducted research on theoretical and experimental investigation of radio propagation for indoor and urban environments. He has been with Atilim University since 2002. His major interests are radio propagation, channel characterization, RF issues for short range wireless systems, and UWB radio applications.



Henry L. Bertoni has conducted leading edge research of radio channel characteristic in modern wireless application for over 20 years. He was the first to explain the wave processes underlying the measured properties of cellular mobile radio signals. This work has been incorporated into computer design tools for cellular and PCS systems, and earned him the 2003 James R. Evans Avant Garde Award for Contributions to Standard Propagation Models for the Wireless Telecommunications Industry of the IEEE Vehicular Technology Society. He has developed computer tools based on ray tracing within site-specific building environments for predicting channel characteristics. He has authored or co-authored over 35 journal papers and 8 book chapters on wireless topics as well as the book Radio Propagation for Modern Wireless Systems, Prentice Hall PTR, 2000. He is currently the director of the wireless Internet center for advance technology (WICAT) at Polytechnic University.