Experimental Study of Wideband Propagation Characteristics in an Underground Mall at 5-GHz Band

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1. Introduction

5-GHz band wireless access systems, such as the RLAN (Radio Local Area Network) system of IEEE802.11a, HiSWANa and AWA [1-2], are developed and provide transmission rates over 20 Mbps for indoor use. This band has the merits that it is clear and that it can avoid interference from other radio equipment in comparison to the 2.4-GHz ISM band. Service areas of the 5-GHz access systems will be extended from the office to the so-called hot-spot public areas. Underground shopping malls are one of the anticipated service areas for such a nomadic wireless access service. Broadband propagation characteristics are required for radio zone design in an underground mall environment despite previous results obtained by narrow band measurements [4-3].

This paper presents the results of an experimental study on the propagation characteristics for broadband wireless access systems in an underground mall environment. First, broadband propagation path loss is measured and formulated considering human body shadowing. A ray trace simulation was used to investigate the basic propagation mechanism in such a closed environment. Second, distance dependency of the delay spread during a crowded time period, rush hour, was found to be at most 65 nsec, which is under the permitted maximum value of the present 5-GHz systems.

2. Measurement

The underground mall environment is shown in Fig. 1. It is a part of the Yaesu Underground Shopping Center, which is nearby Tokyo Station. Two long parallel halls, 6-m wide, 3-m high, and 190-m long, are separated by 20 m and several short paths connect them like a ladder. Many shops and small restaurants face the long halls. Most of the side walls that form the halls are open entrances or glass, which enables passersby to see the inside of stores easily. Both the floor and ceiling are concrete. Since crossbeams are affixed to the ceiling about every 20 m, reflected waves from the ceiling exert hardly any influence at the distance over dozens of meters. The densities of passersby are approximately 0.008 persons/m^2 and 0.1 persons/m^2 for a quiet period (early morning, off hour) and a crowded period (lunchtime or rush hour), respectively.

A Base Station (BS) was placed near the end point of the long hall indicated in Fig. 1, and the BS received the signal. For the path loss measurement, a mobile terminal (MT), which was placed on a cart, transmitted a 20-MHz broadband signal of 30 dBm at a 5.2-GHz center frequency. One of the long halls is used as a LOS (Line-of-sight) path and the other is a NLOS (Non-line-of-sight) path. For the delay spread measurement, a sliding correlator with the chip rate of 60 Mcps was used. Both the antennas of the transmitter and receiver were sleeve antennas with the gain of 2 dBi. The heights of the antennas were 2.4 m and 1.2 m for the BS and the MT, respectively.

3. Path Loss Characteristics

At first, measurements during the early morning and ray trace simulations using a uniform flat wall model were carried out to clarify the fundamental characteristics of propagation in this area. A three-dimensional imaging method and UTD (Uniform Geometrical Theory of Diffraction) algorithms [5] were applied to calculate the wall reflection and edge diffraction. Because of the limitations of the computer resources, we took into account only a direct wave, one time diffracted waves, and at most four times reflected waves. A pair of one time reflection and one time diffraction (reflection after diffraction or diffraction after reflection) was also considered. Fig. 2 shows the distance dependency of the measured path loss during off hours in vertical polarization. The measured values are plotted by 10-m section medians and two straight solid lines are logarithmic regression curves in both the LOS and NLOS paths. Fig. 3 shows simulated 10-m section medians of path loss for comparison with the measured data, which are approximated by straight solid lines. In the LOS path, simulated and measured results are in good agreement. In the NLOS path, beyond 20 m, there is a great deal of difference between them. The plotted curves such as reflected and diffracted show distance dependencies of the wave component of each reflected or diffracted wave. Although more wave components such as those with more than five times reflection, more than two times diffraction, and combinations of those are needed for an accurate simulation, the reflected waves traveling along the hall can be regarded as the dominant propagation component in this environment.

For a more actual situation, propagation path loss measurements during rush hours were carried out and the distance dependence of the path loss is shown in Fig. 4. The path loss has an additional loss as the distance increases because of the shadowing effect of passersby. The following formulas consider the shadowing effect for estimating the propagation path loss.

To express the path loss underground in convolutions of free space loss and excess loss, path loss $L(x)$ is defined as follows:

$$L(x) \equiv -10\log\left\{\left(\frac{l}{4px}\right)^{a} \cdot L_h(x)\right\} + \mathrm{C} \qquad \cdots (1)$$

where $L_h(x)$ is the excess loss from shadowing by passersby. It is expressed as

$$dL_h(x) = -L_h(x) \cdot d \cdot dx \qquad \cdots (2)$$

where d is the constant number of the shadowing loss per unit distance related to the passersby. The undefined integral of

$$L_h(x) = \exp(-d \cdot x) + C_i \qquad \cdots (3)$$

where C_i is integral constant. When $x = 0$, there are no shadowing losses,

$$\begin{aligned} &L_h(0) = 1 \\ &\therefore C_i = 0 \end{aligned} \qquad \cdots (4)$$

So we can unify the Path loss model as

$$L(x) = -10\log\left\{\left(\frac{l}{4px}\right)^{a} \cdot \exp(-d \cdot x)\right\} + C \qquad \cdots (5)$$

The solid lines in Fig. 4 are calculated by the above equations and parameters in Table 1.

4. Delay Spread Characteristics

IEEE802.a and HiSWANa systems, which use the OFDM (Orthogonal Frequency Division Multiplexing) scheme, permit the maximum delay spread of about 250 nsec[6]. The median values of the r.m.s. delay spread that was calculated from the delay profile acquired every 102.3 msec using a 5.2-GHz band sliding correlator was measured at several fixed points in both the LOS and NLOS paths. As the measurement period for one data set was 10 seconds, 97 delay profiles were obtained at each position. In order to avoid error caused by noise, data points in a delay profile, which were 6-dB greater than the noise level, were selected for calculating a delay spread value.

Fig. 5 shows two delay profiles, one is the highest delay spread case and the other is measured at the farthest point from the BS (Point B in Fig. 1). These two points were situated on the NLOS path. The highest value was obtained at the second farthest point. This indicates that traveling waves along the LOS-hall, which arrive at the farthest point by taking a roundabout way, inject power into a short time range of the delay profile. As the roundabout way becomes longer than that of the farthest point, the delay spread value increases at the second farthest point.

Fig. 6 shows the distance dependency of the delay spread during rush hours for both the LOS and NLOS paths. The maximum value is obtained at around the 150-m point, which is the second farthest point. We found that the maximum delay spread, about 65 nsec, is lower than the permitted value of the present systems.

5. Conclusion

We measured the path loss and delay characteristics for 5-GHz broadband wireless access systems in the Yaesu Underground Shopping Center and obtained the following results.

(1) A propagation path loss model was derived considering the crowd in the shopping mall. The influence of the shadowing caused by passersby can be reflected by an exponential term that includes the density of the passersby.

(2) The maximum delay spread value during the rush hours is at most 65 nsec, which is lower than the permitted value, 250 nsec, of present wireless access systems.

References

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Table 1. Parameters of Modeled Path Loss Function in Yaesu Underground Mall

	LOS			NLOS		
	α	δ	C	α	δ	C
Off-hour	2.0	0	5	3.4	0	-20
Rush-hour	2.0	0.015	5	3.4	0.015	-20

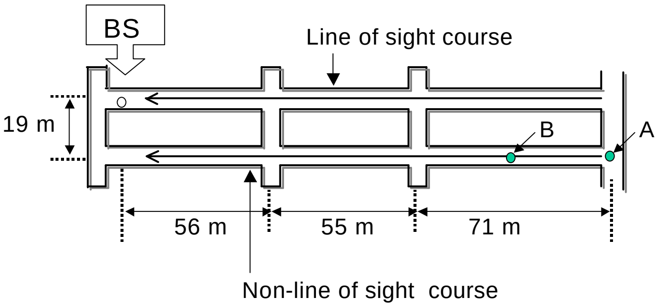

Figure 1. Underground mall environment

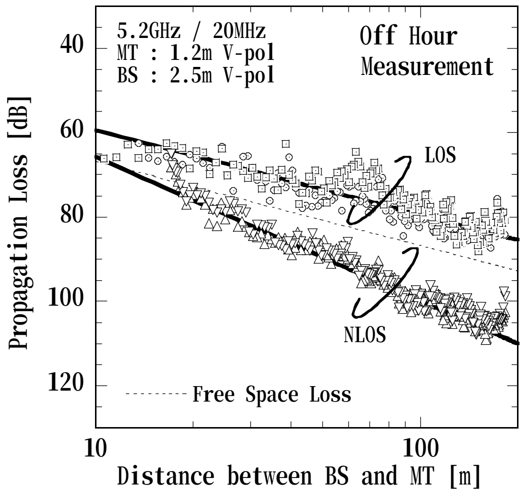

Figure 2. Path loss in off hours

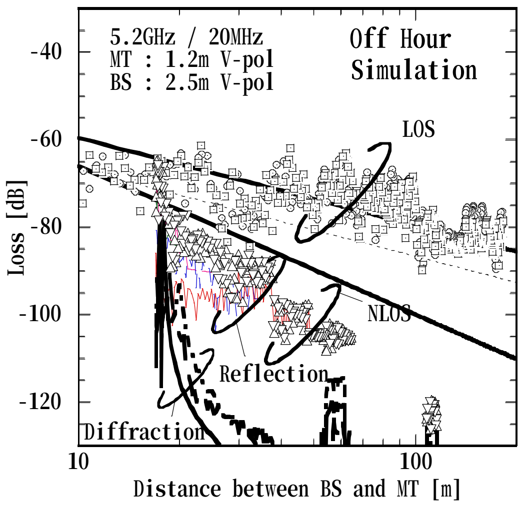

Figure 3. Path loss by simulation

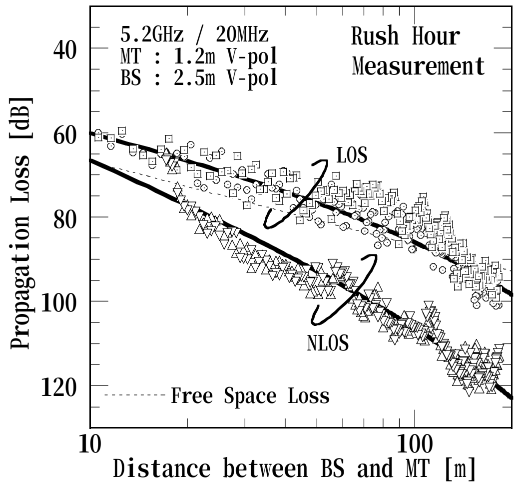

Figure 4. Path loss in crowded hours

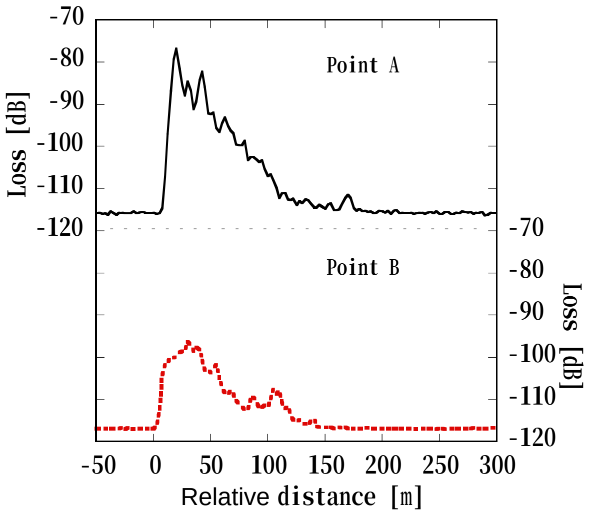

Figure 5. Examples of delay profile

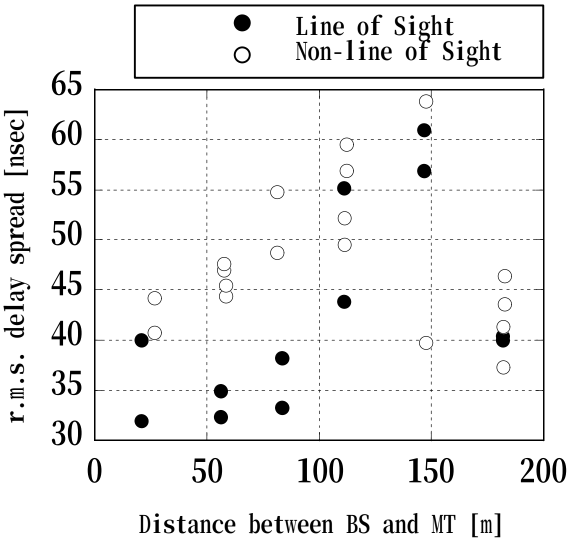

Figure 6. Distance dependency of delay spread