CHANNEL CHARACTERIZATION IN HIGH-RISE APARTMENTS AT 5 GHz

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1. Introduction

The deployment of Wireless Local Area Networks (WLANs) [1-3] at home has changed the philosophy of home communications. Nowadays, the number of WLAN systems deployed at home environments increases rapidly. Hence, understanding the propagation mechanisms in home environments becomes essential for calculating the link budget and predicting coverage for the deployment and performance evaluation of WLANs. Many indoor channel measurements have been reported in the literature. However, the measurement environments in the reported work are different from normal home environments in South Korea, which is built up with high-rise apartments. Therefore, these models may not directly help. For this purpose, we performed channel measurements at 5 GHz in three typical apartments with different dimensions, in Daegu of South Korea. This paper presents the channel measurement and modeling results of our experiments. The objective of our campaign is to measure the main characteristics of indoor propagation, e.g. the path loss, the rms delay spread and the coherence bandwidth, in typical home environments of high-rise apartments in South Korea, where 802.11a WLANs are being deployed. The chosen apartments are of typical large, medium and small size. The results provided in this paper are useful for design and deployment of communication systems operating in the 5 GHz band, like those compliant with IEEE 802.11a and HIPERLAN2 wireless standards.

2. Measurement Setup and Environments

A. Measurement Setup

The measurements were conducted using an Agilent S-Parameter Network Analyzer, model 8722ES. A pair of identical dipole antennas optimized for the 5 GHz band was used for all measurements. The antennas were manufactured by the SAIT (Samsung Advanced Institute of Technology). The measurements were performed by transmitting 1601 continuous wave tones over the chosen frequency range from 5.15 GHz to 5.83 GHz, which includes the two sub-bands of 802.11a WLAN. The resulting frequency step is 0.425 MHz, which provides a time resolution of 1.5 ns. The maximum excess delay spread is 2300 ns.

B. Measurement Environments

The environments, chosen for our measurements, are three typical modern high-rise apartments in South Korea. These apartments, denoted as A, B and C respectively, are different in size and structure. Apartment A has a size of 287 m^2 with 5 bedrooms; the 4-bedroom apartment B is 152 m^2 and apartment C has a size of 120 m^2 with 3 bedrooms. Apartments B and C have a similar architecture to that of apartment A. Among the three apartments, only B is fully furnished. The height of the ceiling in all apartments is about 2.5 meters. During our measurements in each apartment, the transmit antenna was located at the center of the living room, which is approximately the center of the corresponding apartment, while the receive antenna was placed at many locations within the apartment. Normally, 2 or 3 reception points were selected in each individual room, while more points were selected in larger rooms, such as in living room and kitchen. At each receiver point, data were acquired in 100 different time snapshots for temporal averaging purposes. Both line-of-sight (LOS) and non-line-of-sight (NLOS) scenarios are examined in the apartments. Every apartment has a main corridor. In order to inspect whether there is hallway effect in home environments, we also measured the channel along the corridor of each apartment. This was done by positioning the transmit antenna at one end of the corridor and moving the receive antenna to successive positions along the corridor. All measurements conducted in corridors correspond to LOS channels. During our measurements, both transmit and receive antennas were placed 1.2 meters above the floor. Moreover, all doors (made of wood) were closed and there were no movements of people or objects, in order to preserve the quasi-stationary condition of the environment.

With the aid of Labview®, the acquired channel frequency responses were saved in a laptop for post data processing. From the measurement data, we can derive the path loss. By applying IFFT to the measured frequency

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response, the power delay profile (PDP) can be obtained and, hence, the rms delay spread as well as the coherence bandwidth of the channel.

3. Characterizations of Indoor Channels

A. Path Loss

Our measurements aim at developing a path loss (*PL*) model for high-rise apartments, so as to accurately predict the coverage and to reduce the interference of WLANs for home users. Here, we use *PL* to denote the temporal-average received signal power, relative to the received signal power at a reference distance from the transmitter in free space. A general *PL* model that has been demonstrated through measurements [2], [4] uses a parameter, *n*, to denote the power law relationship between distance and received power. As a function of distance *d*, *PL* (in dB) is represented as

$$PL(d) = PL(d_0) + 10n\log(d/d_0) + X_\sigma \tag{1}$$

where $n=2$ for free space, the term $PL(d_0)$ simply gives *PL* at a known close in reference distance d_0, which is in the far field of the transmitting antenna (1 meter for our model). X_σ denotes a zero mean Gaussian random variable that reflects the variation in average received power, which naturally occurs when a *PL* model of this type is used. The precision of a *PL* model is measured by the standard deviation σ of the random variable X_σ, with a smaller value of σ reflecting a more accurate *PL* prediction model.

B. Temporal Characteristic

Time dispersion varies widely in a mobile radio channel, due to the fact that reflections and scattering occur at seemingly random locations, and the resulting multipath channel response appears random, as well. Since time dispersion is dependent on the geometric relationships between the transmitter, receiver and the surrounding physical environment, rms delay spread, calculated for diverse apartments with different dimensions, is very important for the performance evaluation of WLANs at home environments. The rms delay spread can be calculated from the channel PDP as follow [4]

$$\sigma_\tau = \sqrt{\overline{\tau^2} - (\bar{\tau}^2)} \tag{2}$$

where $\bar{\tau} = \sum_k \beta_k^2 \tau_k / \sum_k \beta_k^2$ and $\overline{\tau^2} = \sum_k \beta_k^2 \tau_k^2 / \sum_k \beta_k^2$, β_k is the amplitude of kth multipath arriving at τ_k .

Mean excess delay spread, $\bar{\tau}$, is the first central moment of the PDP and indicates the average excess delay offered by the channel. RMS delay spread measures the spread of power about the value of $\bar{\tau}$. The mean of the cumulative distribution function (CDF) of rms delay spread can be used as a measure for the frequency-selectivity of the channel, and the standard deviation of the CDF can be used as a measure for its time-variant behaviour.

4. Measurements Results

A. Log-Distance Model

In path loss analysis, measurement results are fitted to an exponential decay model on the basis of least mean square error. Fig.1 shows the scatter plot of path loss for all LOS data measured in the three apartments, including data taken in corridors. The path loss for LOS condition can be modeled by the following distance power decay law

$$PL(d) = -6.06 + 10 \times 1.61 \times \log(d/1m) \tag{3}$$

where *PL*, in dB, is the mean path loss respective to the reference distance, which is 1 meter in our model, *d* is the transmitter-receiver distance in the intervals [1-12] m. Due to shadowing effects, statistical deviation of the total receiver power from the deterministic values in (7) occurs, modeled by a zero mean Gaussian variable having standard deviations of $\sigma = 1.22$ dB.

Fig.2 presents the comparison of path loss in each individual apartment and corridors based on the obtained fitted functions characterized by the parameters given in Table I. Corridor results are based on the data taken in all corridors of the three apartments. The results reveal that the exponential constants for all LOS scenarios in the three apartments are less than 2. The averaged exponent for all LOS cases is 1.61. The smallest value ($n=1.44$) is observed in apartment C, which has the smallest size. Note that for all three apartments the hallway effect is not very significant. The average value of *n*, regarding corridor data, is recorded at 1.59. As shown in Fig.2, the LOS *PL* in all three apartments is almost the same.

Fig.3 presents the scatter plot of path loss for all NLOS data acquired from the three apartments, and Fig.4 depicts the comparison of the path loss in individual apartments for NLOS cases. By fitting measured data, we can obtain the exponential constant of the best-fitted model. The fitted parameters for NLOS scenarios are included in Table I. The path loss for NLOS condition in all three apartments can be represented by the following distance power decay law

$$PL(d) = -0.59 + 10 \times 3.92 \times \log(d/1m) \tag{4}$$

where the transmitter-receiver distance, *d,* is in the intervals [3.5-14] m. The standard deviation of shadowing statistical deviation is recorded at 6.85 dB, when this model is applied.

As it can be seen from Table I, the fitted *n* always appears to be larger than 2, both for the overall NLOS path loss (for which n=3.92), as well as for the NLOS path loss in individual apartments. Moreover, it is found that the exponential constant increases with the size of the apartment. This means faster decay rates are observed in larger apartments, because of the existence of more walls. Note that, for each individual apartment, the fitted model has its own effective range of the transmitter-receiver distance, *d*. Comparing the parameters of standard deviation for LOS and NLOS channels in Table I, it is found that the fitted model for LOS scenarios, which has a standard deviation of 1.22 dB, is more precise than that for NLOS scenarios.

B. Time Dispersion

The temporal statistical parameters, examined in our measurements, are mean excess delay ($\bar{\tau}$) and rms delay spread (σ_τ). These parameters, calculated from PDP for both LOS and NLOS channels, are tabulated in Tables II and III respectively. For all calculations, a noise floor of –40 dB from the strongest component has been presumed. The cumulative distribution functions of rms delay spreads are plotted in Fig.5 for LOS scenarios and in Fig.6 for NLOS cases. In Tables II and III, the calculated standard deviation of σ_τ for each scenario is also included.

For LOS channels, the rms delay spreads in the apartments are similar. The rms delay spread in apartment A is only about 1-2 ns larger than that of apartments B and C. The standard deviation of rms delay spread is in the range of 1.4 to 3.2 ns. The mean excess delays do not differentiate too much in the three apartments. As regards the corridor results, a great number of strong reflections take place there, resulting in a relatively larger rms delay spread and the largest mean excess delay of 39.66 ns. On the other hand, for NLOS channels, big difference of about 11 ns is found between the values of rms delay spread in apartment A and that of apartments B and C. The standard deviation of rms delay spread increases with the size of the apartment. The average standard deviation for NLOS scenarios is 9.26 ns, which is larger than that of LOS scenario (2.76 ns). Both mean excess delay spread and mean rms delay spread for NLOS scenarios are larger than the respective values of LOS scenarios in each apartment.

4. Conclusions

This paper presents the experimental results of channel measurements at the 5 GHz band in high-rise apartments. Path loss varies in different apartments with different size, due to the complex structure of home environments, which differ from typical office environments. The calculated rms delay spreads have a close relationship with the size of apartments. Our experimental results are useful for the coverage prediction and interference reduction in the deployment of WLANs at home environments.

References

[1] L. M. Correia, *Wireless Flexible Personalised Communications: COST 259: European Co-operation in Mobile Radio Research*: John Wiley &Sons, 2001.

[2] J. Kivinen, X. Zhao, and P. Vainikainen, "Empirical Characterization of Wideband Indoor Radio Channel at 5.3 GHz," *IEEE Trans.on AP*, vol. 49, pp. 1192 -1203, Aug, 2001.

[3] H. Hashemi, M. McGuire, T. Vlasschaert, D. Tholl, "Measurements and Modeling of Temporal Variations of the Indoor Radio Propagation Channel," *IEEE Trans. on VT,* vol. 43, pp. 733 –737, Aug. 1994.

[4] T. S. Rappaport, *Wireless Communications: Principles and Practice*, Second ed: Prentice-Hall, Inc., 2002.

TABLE I. PATH LOSS PARAMETERS

	All		Corridor		A		B		C	
	n	**std**	**n**	**std**	**n**	**std**	**n**	**std**	**n**	**std**
LOS	1.61	1.22	1.59	2.74	1.63	1.34	1.74	0.79	1.44	1.25
NLOS	3.92	6.85			7.03	3.93	6.66	5.57	5.46	6.85

TABLE II. TEMPORAL PARAMETRS FOR LOS SCENARIOS

LOS	**ALL**	**A**	**B**	**C**	**Corridor**
mean rms DS [ns]	10.99	11.99	9.91	10.23	10.44
Std [ns]	2.76	3.20	1.41	2.39	2.96
mean excess delay [ns]	32.76	35.21	30.21	30.07	39.66

TABLE III. TEMPORAL PARAMETRS FOR NLOS SCENARIOS

NLOS	ALL	A	B	C
mean rms DS [ns]	20.05	26.95	15.40	15.23
Std [ns]	9.26	10.09	5.52	1.65
mean excess delay [ns]	47.68	50.11	46.24	45.80

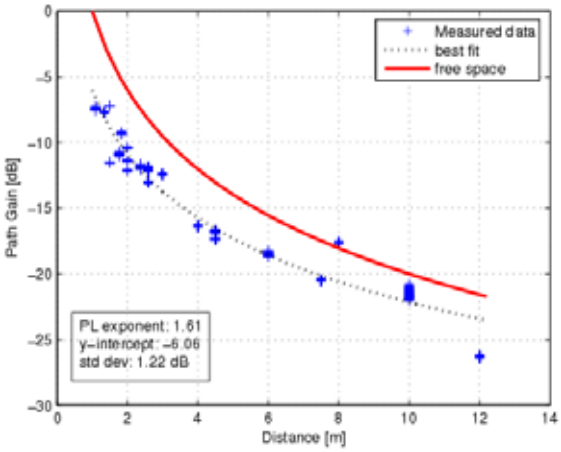

Fig.1. Scatter plot of path loss for all LOS scenarios.

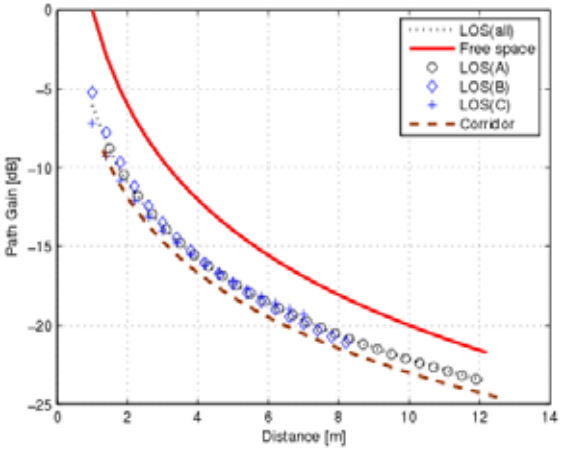

Fig.2. Comparison of LOS path loss in apartments A, B and C.

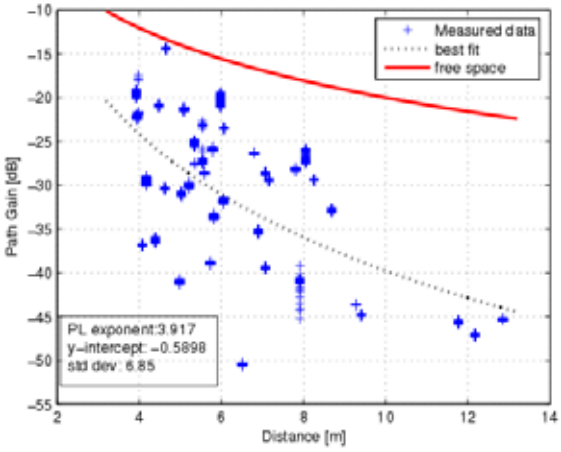

Fig.3. Scatter plot of path loss for all NLOS scenarios.

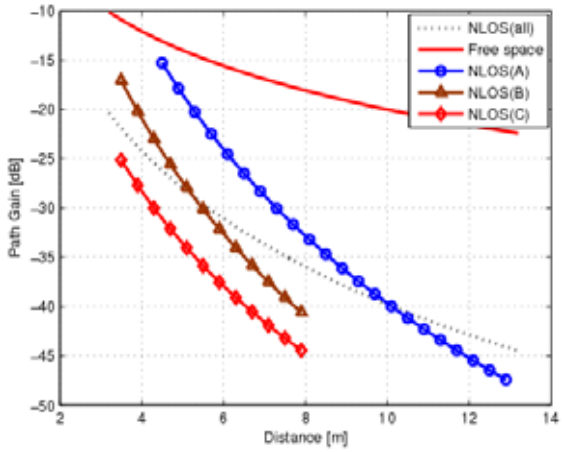

Fig.4. Comparison of NLOS path loss in apartments A, B and C.

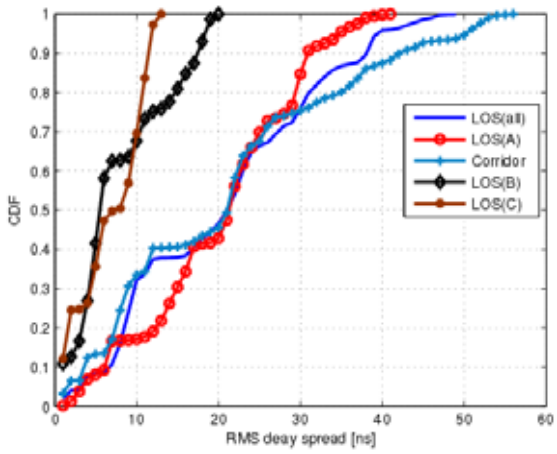

Fig.5. CDF of rms delay spread of LOS channels.

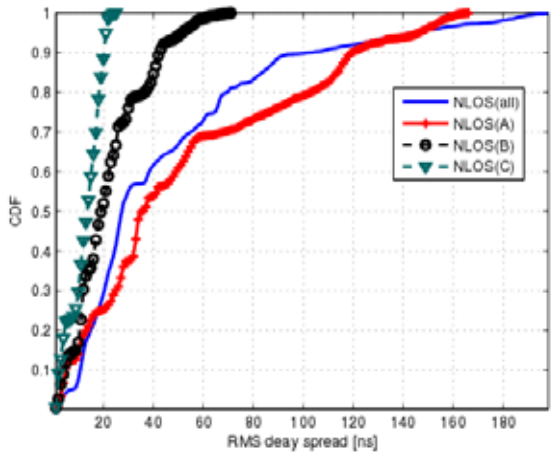

Fig.6. CDF of rms delay spread of NLOS channels.