Ultra Wideband Propagation Characteristics in Office Environments

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Abstract: Ultra Wideband (UWB) is the promising candidate for short-range high-speed wireless communication system. But, the UWB propagation characteristics, the fundamental resource for overall system design, have not fully analyzed yet. In this work, we investigated the UWB indoor propagation characteristics in office environments. So, we constructed the UWB channel measurement system using the frequency sweep method to measure the frequency responses on the 5GHz ~ 6.6GHz band. The measurements were performed in the 2 different offices, 34 receiver positions (20 positions are line-of-sight and 14 positions are non line-of-sight). From these measurement results, firstly, we modeled the path loss behavior of UWB signal. The path loss exponent and variance of log-distance law are suggested. Not only in case of full band, but also in case of each sub-band path loss parameters are analyzed. Then, the distributions of received signal powers are compared with the Gaussian distribution according to the receiver condition. Finally, for 9 receiver positions located in the corridor, the propagation characteristic difference between the case when a door is closed and the case when a door is opened is reported. The additional path loss and loss due to the door material and frequency selective characteristics are primarily analyzed.

1. Introduction

As the next generation short-range high-data rate wireless communication system, the Ultra-WideBand (UWB) communication system is in the spotlight. Especially, after Federal Communication Commission (FCC) regulated the UWB transmission, discussions about the commercial usage of UWB systems have increased. For design the overall UWB system and predicted the effects of that to other communication systems, we have to make the UWB communication channel clear first of all. The literature reported the experimental campaign about the UWB channel model [1][2]. But, frequency domain attempts for the channel study are not sufficient although the wide frequency band is the most distinguishable feature of UWB signal [3].

In this work, we investigated the UWB channel in office environment in frequency domain. Using the frequency domain channel sounding system, we measured the channel complex frequency responses at the 2 different offices in Seoul, Korea. From the measurement results, we compared the path loss behavior of the measured UWB signal to the log-distance law. The path loss exponents and the shadowing factors are analyzed. Then, we analyzed the distributions of the received signals according to the receiver condition (line-of-sight or not). Finally, for non LOS positions, the frequency selectivity of UWB signal is analyzed.

2. Measurement system and Scenario

2.1 Measurement System

Among some UWB channel measurement techniques, used the frequency domain channel sounding system for measurents[4]. In this measurement technique, a wide frequency band is swept using a set of narrow-band signals, and channel frequency response is recorded using a vector network analyser (VNA). A VNA transmitted 801 continuous wave tones uniformly distributed from 5-6.6GHz, with a frequency separation of 2MHz. This frequency resolution allows us to capture multipaths with maximum excess delay of 500ns and the 1.6GHz wide bandwidth gives a time resolution of 625ps. The dyanamic range of measurement system is guaranteed as 110dB using power amplifier. The trranmitting and receiving antennas are omni-directional with 2.1dBi gain and mounted on the 1.5m tripode.

2.2 Measurement Scenario

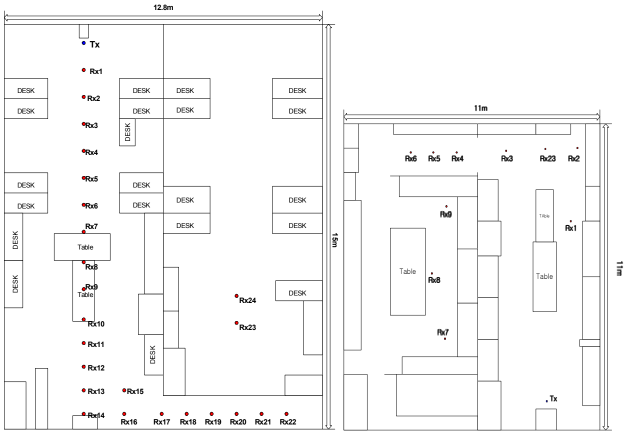

Figure 1. Measurement environments (2 offices at SNU)

Measurements were performed at two office buildings of Seoul National University, Korea. The positions of transmitting antenna and receiving antenna are repersented in Figure 1. illustrating the floor plan of the measurement environment. The left office (Office 1) is located on the 5th floor in bldg. 302. In this office, wall materials are gypsum while a wall behind transmitter is glass window. And the right one (Office 2) is loceted 2th floor in Institute of New media and communication. This office is surronded by two glass windows, one brick wall and center wall made of steel. In two offices, 34 receiver positions are selected, 20 positions are line-of-sight (LOS) and 14 ones are non-LOS (NLOS). In each receiver position, 250 channel frequency responses were collected. The interval between frequency responses is 1s which is much larger than the maximum excess delay.

3. Measurement results and analysis

3.1 Path loss behavior

Among propagation characteristics of wireless communication system, the path loss behavior is the very fundermental resource for calculating the service range and predicting the interference. Especially, as the UWB system is expected that it will be co-operated with many other communication systems, path loss behavior of UWB systems needs to be perceded. So, we arranged the LOS receiver positions of Office 1 with 1m separation and measured. The measurement results are compared with the log-distance path loss law in Figure 2. A general log-distance path loss formula is written in below where $PL(d_0)$ means path loss value at at the reference distance d_0(=1m), n is the path loss exponent and X_σ is the shadowing factor.

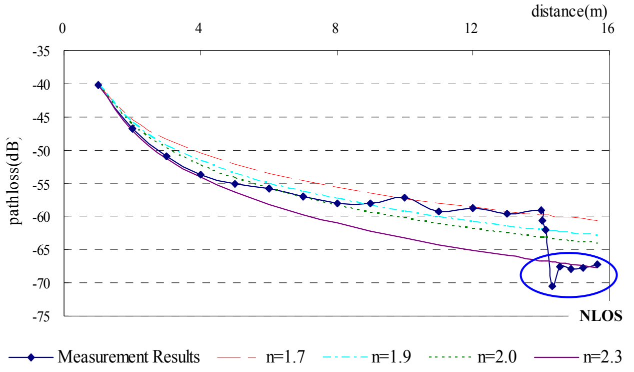

Figure 2. Comparison between measurement results and the log-distance path loss law with n=1.7 ~ 2.3

$$PL(d) = PL(d_0) + 10\, n \log(d / d_0) + X_\sigma (dB) \quad (1)$$

The meausrement results reveals that the log-distance path loss law with path loss exponent value between 1.7 and 2.3 could be used for predicting the UWB signal propagation. For NLOS positions, path loss exponent get bigger than 2.3. Through the MMSE algorithm, parameters of log-distance path loss law are calculated in the Table 1. As Office 2 is smaller than the Office 1, the signal in Office 2 is less attenuated than the one in Office 1.

Table 1. The measured path loss parameters according to the receiver condition

	$PL(d_0)$ [dB]	n	X_σ [dB]
LOS (Office 1)	-40.253	1.84	0.142
NLOS (Office 1)	-40.253	2.38	0.255
LOS (Office 2)	-28.979	1.64	0.131
NLOS (Office 2)	-28.979	2.11	0.184

3.2 Distribution of Received Signal

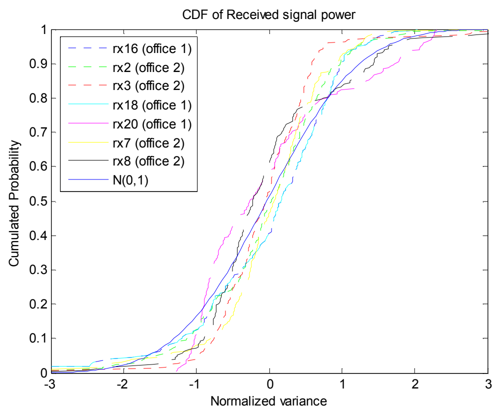

Figure 2. CDF of received signal power

To acquire the accurate path loss behavior of UWB signal, not only the average path loss but also the distribution has to be analyzed. Figure 2. illustrates the CDF of received signal power according to the receiver condition. In Figure 2, x-axis means the normalized variance and y-axis means the cumulated probability And dotted lines are distributions of LOS positions, dashed lines are of NLOS and the last one is of Gaussian distribution with zero-mean unit-variance. As a result, the received signal powers of LOS positions are gathered within one variance from the mean value. However, those of NLOS positions are much dispersed because the direct-path signal vanished due to the obstacles.

3.3 Frequency selectivity in NLOS positions

Table 2. Sub-band average of received signal power in NLOS receiver positions

Office1	Band1	Band2	Band3	Office2	Band1	Band2	Band3
Rx18	-24.10	-25.35	-28.12	Rx4	-13.14	-16.84	-9.09
Rx19	-21.97	-24.23	-24.46	Rx5	-12.98	-16.96	-10.17
Rx20	-21.85	-24.95	-24.68	Rx6	-13.64	-17.09	-9.79
Rx21	-21.40	-24.19	-25.08	Rx7	-11.49	-15.70	-8.76
Rx22	-20.84	-23.60	-24.82	Rx8	-11.82	-16.84	-9.09
				Rx9	-11.77	-16.24	-9.03

To find out the frequency selectivity of UWB signal, we divided the received signal of NLOS position into 3 sub-bands. (Band 1: 5.0GHz~5.6GHz, Band 2: 5.5GHz~6.1GHz, and Band 3: 6.0GHz ~ 6.6GHz) Table 2. shows the sub-band average of received signal power. In Office 1, as frequency gets higher, the signal attenuates more. But, in Office 2, signal of the highest frequency band is the strongest. It is because the material of wall located between transmitter and receiver is different from each other. On direct path, there is a wall made of gypsum in Office 1 while in Office 2, steel wall exists. This means that the received signal in NLOS position could be affected by the frequency selectivity due to the obstructing wall material.

4. Conclusion

UWB system is discussed as the next generation high speed short range wireless communication. For commercial use and solving the interference problem, propagation characteristics have to be made out. So, we investigated the channel characteristics of office environments using frequency domain channel sounding system. From the measurement results, we found that the UWB signal attenuates like the log-distance path loss law with path loss exponent which can be changed according to the receiver condition. And the received signals of LOS positions are normally distributed within one variance from the mean value while those of NLOS positions are much dispersed. Finally, the received signal in NLOS positions are divided into 3 sub-bands and analyzed. From sub-band analysis, we presumed that the different wall material could cause the imbalance between received signal powers of sub-bands.

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