사무실 환경에서 초광대역 채널의 통계학적 특성모델

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Statistical Characterization of UWB channel in Office Environments

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Abstract

In this paper, we present the statistical characterization of ultra wideband (UWB) channel of office environments in frequency domain. The 23,000 channel transfer functions of 46 transmitter-receiver location pairs are obtained using the measurement system based on frequency sweep technique. From the measured data, path loss exponent variation to the sub-frequency band is firstly reported. Then, distributions of received signals are analyzed considering the propagation environments and existence of line-of-sight (LOS). Finally, the statistical properties of received signal powers of frequency tones are reported. For LOS cases, as the separation between transmitter and receiver increases, the standard deviation of signal powers of the received frequency tones increases and probability, the received signal powers are located within specific range from the received power mean values, decreases.

1. Introduction

For prospective high data rate and short range communication system, the ultra wideband (UWB) technique has attracted increasing interest in recent years. Especially, after Federal Communication Commission (FCC) approved the regulation for UWB transmission, discussions about the commercial UWB systems have been very active [1]. In order to develop the efficient UWB system and to predict its effects on other communication systems, it is required to understand the accurate UWB communication channel properties at first. The literature has reported the experimental campaign and results about UWB channel models including suggested standard model [2] ~ [7]. However, the channel characterization works in frequency domain are insufficient even though the wide frequency band is the most distinguishable feature of UWB signal and some researches were dealt with in [8][9]. So, we studied the UWB channel in office environments based on the measurement results obtained from the frequency sweep measurement system. The office is selected as measurement environment because it is the environment where huge data are transferred frequently and many devices coexist.

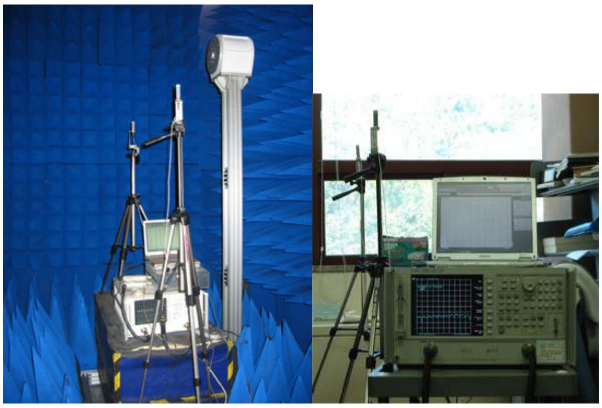
In this work, we investigated the statistical characteristics of UWB signal in frequency domain. At first, the path loss exponent variation to the frequency is analyzed. Path loss exponent is the essential parameter of log distance path loss law which is the most widely used path behavior describing formula. The parameters are analyzed according to the receiver conditions and smaller frequency band with 500MHz bandwidth. Then, distribution of received signal power of each receiver condition is reported. Finally, we investigate the standard deviation of received signal power and existence probabilities of the received signal power within specific range from the received power mean values.

The rest of the paper is organized as follows: Section 2 describes the channel measurement system and scenario. Section 3 gives the measured results and analysis. Finally, the conclusion is described in section 4.

2. Measurement Campaign

A. Measurement system

Among UWB channel measurement techniques, we selected the frequency domain channel sounding system for measurements [10]. In this measurement technique, wide frequency bands are swept using a set of narrow-band signals and channel frequency responses are recorded using a vector network analyzer (VNA). The constructed measurement system is pictured in Figure1. A VNA transmits 801 continuous frequency tones uniformly distributed from 5GHz ~ 6.6GHz with the frequency separation of 2MHz. This frequency interval allows us to capture multi-paths with the maximum excess delay of 500 nano-seconds and the bandwidth of 1.6GHz gives the time resolution of 0.625 nano-seconds. The transmitting and receiving antennas are omni-directional with 2.1dBi gain and mounted on the 1.6m tripods. The sample of measured channel transfer function is illustrated in Figure 2.



a) b)

Figure 1. Measurement system in a) anechoic chamber and b) measurement environment

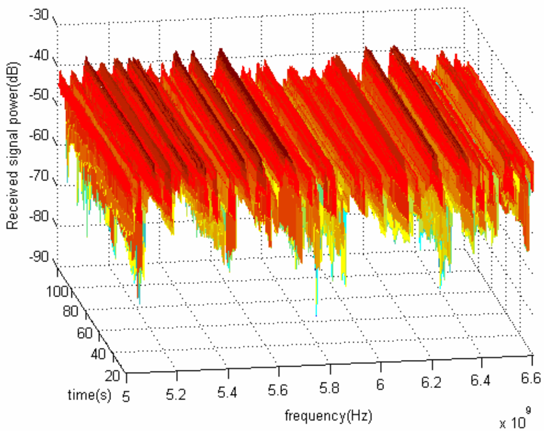


Figure 2. Measured channel transfer function at a LOS receiver position over 100 seconds

B. Measurement Scenario

We carried out the measurements at three office environments of SNU, Korea. The locations of transmitting and receiving antennas are illustrated in Figure 3 with the floor and wall-type description of environments. The Office 1 is located on the 5th floor of ferroconcrete building, Office 2 is located on the 2nd floor and Office 3 is on the 4th floor of the other ferroconcrete building. In Office 1 and 2, there is a metal wall at the center dividing the office into two small laboratories while the last environment consists of small offices and corridor. During measurements, all doors are kept opened and pedestrians are restricted. Out of 46 receiver positions, 21 positions have line-of-sight (LOS) path from transmitter to receiver and 25 positions do not. The each receiver position had 5 spatial positions for sector average and 100 frequency responses were collected in each spatial position (500 responses in single receiver positions). The time interval between conjunctive responses is one second which is much larger than the general maximum excess delay in indoor environments [11].

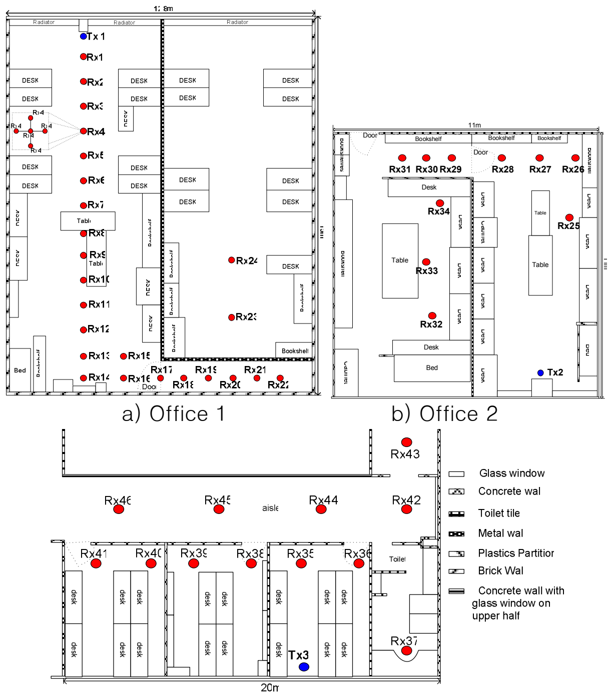


Figure 3. Ground plans and wall types of three offices where measurements performed

3. Measurement Results and Analysis

A. Path loss exponent variation

Generally used log-distance path loss formula is given in Eq. 1 where $PL(d_0)$ means path loss at the reference distance $d_0(=1\text{m})$, d is separation of the transmitter-receiver, n is the path loss exponent and X_σ is the standard deviation of shadowing factor [9].

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

From the measured data, the optimized parameters are obtained in Table 1 using minimum mean square error algorithm. In general, path loss exponent is 2 in free space and smaller than 2 when the waveguide effect works on for indoor LOS environments [12]. For LOS positions of Office 1 and Office 2, the path loss exponent values are much smaller than 2 because a metal wall dividing offices made the waveguide effect. Especially, in Office 2, as the upraised desks, bookshelves and metal blinds of glass window enhanced the waveguide effect, the path loss exponent value is very small. And the standard deviation of shadowing factor is about 1 dB in LOS cases and it is increased to the 2.5 ~ 4dB in NLOS cases [9].

However, as indicated in FCC regulation, UWB system could use only 500MHz bandwidth of the assigned frequency band and widely suggested UWB system, multi-band orthogonal frequency division multiplexing scheme, is based on this UWB property [14]. According to this scheme, UWB system is operated with divided frequency band of 500MHz bandwidth.

Table 1. The empirical path loss parameters according to receiver condition

	$PL(d_0)$ [dB]	n	X_σ [dB]
LOS (Office 1)	-35.596	1.58	1.063
NLOS (Office 1)	-35.596	2.13	2.656
LOS (Office 2)	-37.913	1.32	1.101
NLOS (Office 2)	-37.913	2.10	4.546
NLOS (Office 3)	-43.786	2.85	4.441

n: path loss exponent

X_σ :the standard deviation of shadowing factor

Hence, we swept our measurement 1.6GHz bandwidth by sliding the 500MHz window with the discrete interval of 100MHz and analyzed the path loss exponent variation to the each 500MHz bandwidth window. The path loss exponent variation is illustrated in Figure 4 where x-axis means the center frequency of the smaller 500MHz band. From the results, we found out that the variation is related to the measurement environment not to the existence of LOS. In Office 1 and 3, path loss exponent increases as frequency band becomes higher while it has the convex shape in Office 2 while path loss exponent variation has the same tendency in LOS and NLOS cases in same office.

B. Distribution of received signal power

To understand the path loss properties of UWB signal properly, not only the average path loss characteristics but also the distribution of the received signal power has to be analyzed. Figure 5 illustrates the typical cumulative distribution functions (CDFs) of received signal of LOS and NLOS locations. The CDFs are based on the 500 frequency responses in each receiver location. In Figure 5, x-axis indicates the normalized received signal and y-axis means the cumulated probability. The CDF of LOS locations is similar to the Rician distribution with K=1 and those of NLOS locations are almost to the Rayleigh distribution.

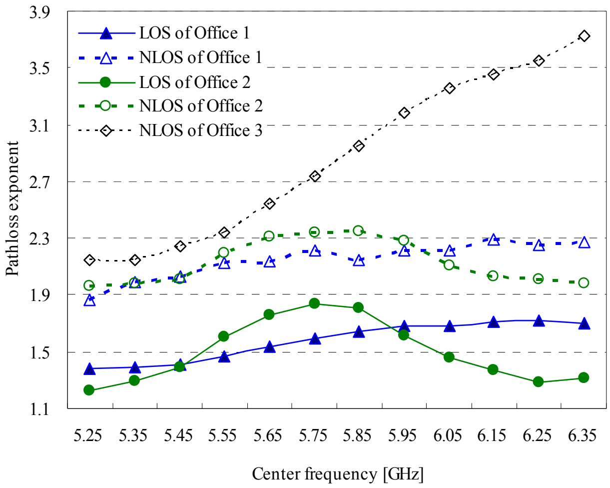


Figure 4. Path loss exponent (n) variation with respect to the center frequency of smaller frequency band in each propagation condition

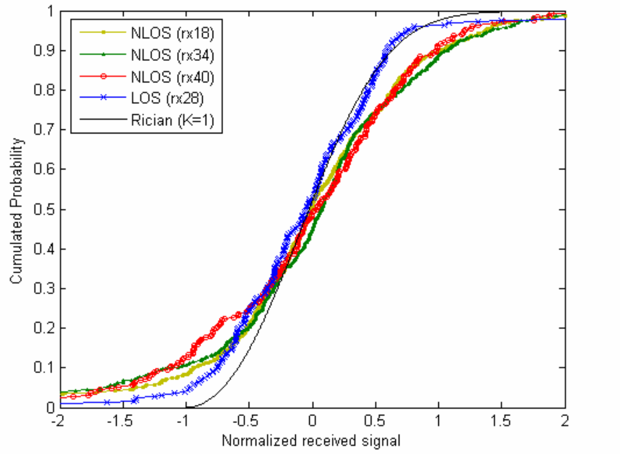


Figure 5. Comparison between received signal CDFs of LOS and NLOS locations

As the FCC regulates the transmission of UWB system, the low power transmit signal suffers the relatively bigger noise effect. As a result, CDFs of LOS locations are similar to the Rician distribution with low K value.

C. Statistical analysis of received frequency tones

In this section, we analyzed the statistical feature of received frequency tones. The STDEV of received signal power of frequency tones indicates the signal power difference of received frequency tones and probability is the systematic parameter which can be used for predicting the signal strength variation.

In LOS, the STDEV of received frequency tones increases as transmitter-receiver separation increases in near distance and saturates over the separation of 6m. This phenomenon is illustrated in Figure 6. This implies that the in near distance difference of received power to frequency is small and this value grows to the separation. But, over the certain distance (6m in this campaign), this parameter has the saturated value.

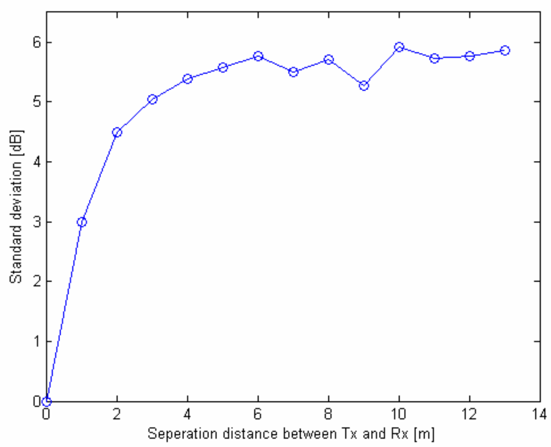


Figure 6. Standard deviation of received frequency tones to separation between transmitter and receiver in LOS condition

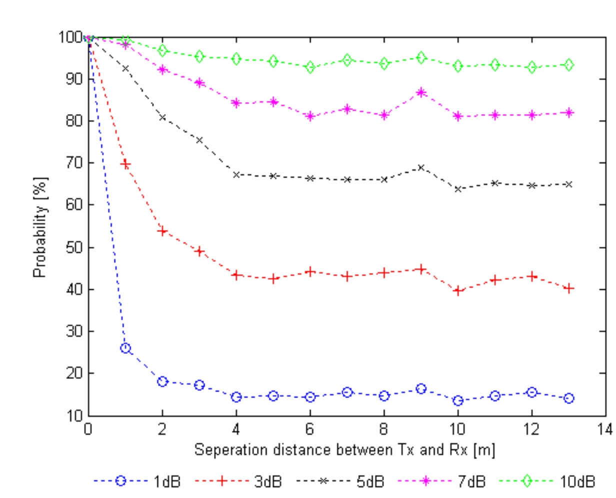


Figure 7. Probabilities of the power level of received signal tones is located in the specified range from the mean value in LOS of Office 1

The probabilities which the received powers of frequency tones are located within specific range from the mean value are drawn in Figure 7. The 1dB means the probability of the received powers of frequency tones are located within the range [(mean)-1,(mean)+1]. And 90% probability means the 90% among the total frequency tones (801 frequency tones * 500 snapshots) is being within the specific range. The probabilities get down as separation gets bigger and saturated as the STDEV. The saturated numerical values in LOS and NLOS locations are reported in Table. 2. As shown in Figure 6,7 and Table 2, the probabilities are in inverse proportion to the STDEV of received frequency tones.

Table 2. The saturated values of STDEV of received frequency tones and probabilities within the specific rage from the mean value

	STDEV	Pr_{1dB}	Pr_{3dB}	Pr_{5dB}	Pr_{7dB}	Pr_{10dB}
LOS	5.643	0.1529	0.4406	0.6692	0.8216	0.9294
NLOS	6.811	0.1205	0.3569	0.5602	0.7203	0.8730
$\frac{LOS}{NLOS}$	0.829	1.269	1.235	1.195	1.141	1.065

4. Conclusion

For efficient deployment of UWB communication system, the accurate channel has to be preceded. So, we analyzed the frequency dependent behavior of UWB channel in office environments. The measurement system uses the frequency sweep method for channel characterization. From the results measured at 3 offices, the path loss exponent is under 1.6 when the LOS path is guaranteed and is above 2 in NLOS case. And the path loss exponent of each smaller frequency band depends on the measurement environment not on the LOS condition. In distribution analysis we find that the measured signal levels of LOS sites follow the Rician fading and that of NLOS do Rayleigh. Finally, in LOS case, as separation between transmitter and receiver grows, the STDEV of received power of frequency tones increases and saturates to the similar value of NLOS. And, probabilities which received signal power located within specific range from the mean received power value are in inverse proportion to the STDEV..

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