The Effect of Human Bodies on Path Loss Model in an Indoor LOS Environment

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Abstract— **This paper deals with the effect of the presence of people sitting in an indoor Line-of-Sight (LOS) environment on a Ultra-Wideband (UWB) channel. To assess this, we selected four scenarios with no people, 5, 10, and 20 people in the room. We created two regions in the room, one near two side walls and the other in the center aisle. In each scenario, we measured the channel at 24 receiving points from a fixed transmitting point in the room. At each receiving point, the receiver was moved around to 9 local positions to obtain a local average. In this paper, the considered UWB channel parameters are a frequency-independent pathloss model and a frequency-dependent pathloss model. We find that the pathloss exponent for the region of the center aisle decreases as more people are in the room, while the pathloss exponent for the region near the side walls increases when there are more people in the room. We also study the effect of the frequency on the pathloss characteristic. The results suggest that the effect of the presence of people on UWB channels should be considered when assessing the performance of UWB systems.**

Keywords-Path loss model; Human Bodies; UWB; Indoor; LOS.

I. INTRODUCTION

UWB systems are commonly defined as systems that have either more than 20% relative bandwidth or more than 500MHz absolute bandwidth. It is well known for UWB systems to have many advantages, such as low complexity, a low cost, resistance to severe multipath fading, and the capability of a fine time resolution. There are numerous applications of UWB systems, such as personal area networks (PANs), sensor networks, geo-location sensors, and emergency communications. UWB systems using a relatively large bandwidth have to use low power so as not to cause interference in the neighboring communication systems. This feature makes UWB systems deployable in LOS and weak non-line-of-sight (NLOS) environments in which the signal undergoes less attenuation. A classroom is an example of a LOS environment, and furniture (e.g., desks and chairs) as well as the people in the classroom are factors that change the UWB channel. In previous work, there were three types of channel variation by people: 1) the depth and duration of shadow fading due to pedestrians moving in the vicinity of such links [1-3], 2) the effect of the presence of humans on wireless personal area networks (WPANs) in which one end of the link is located either close to or on a person [4-7], and 3) the effect of the presence of a human on wireless body area networks (WBANs) in which both ends of the link are located either close to or on a person [8-10]. The above-mentioned papers deal with channel variation by only a person. Another recent paper [11] assesses the channel variation depending on how many seats are occupied by passengers in airplane, but this environment, which commonly involves metal material, is different from an indoor environment in a building.

This paper addresses UWB channel variation depending on the presence of people sitting in an indoor LOS environment. From the measurement data, we obtain a frequency-independent pathloss model and a frequency-dependent pathloss model. The paper introduces a frequency-dependent pathloss model, which includes the effect of the frequency on the pathloss characteristic. This can be useful for multiband orthogonal frequency-division multiplexing (MB-OFDM), as it divides the entire frequency band into several sub-bands with a bandwidth of 528 MHz.

This paper is organized as follows: Section II presents the channel measurement system and the measurement scenario. In Section III, we describe the channel parameters, i.e., the frequency-independent pathloss and frequency-dependent pathloss. Finally, the paper is ended with a summary and conclusion in Section IV.

II. MEASUREMENT METHODOLOGY

A. Measurement System

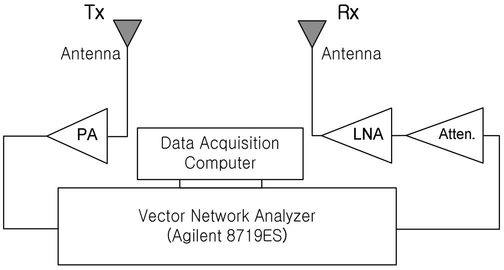


Figure 1. Block diagram of the measurement system.

In this paper, we measured the UWB channel using a frequency-domain channel sounding method for channel characterization with a vector network analyzer (VNA). The VNA (Agilent 8719ES [12]) transmits 801 discrete tones that are uniformly spaced from 3.1 to 4.7 GHz with a frequency interval of 2 MHz, requiring 400 ms for one sweep. This frequency interval allows us to measure a multipath with a maximum excess delay of 500 ns, and the bandwidth of 1.6 GHz gives a time resolution of less than 0.01 ns. The measurement system is described in Fig. 1. The same dipole antennas with a gain of 2 dBi are used on both the transmitting and receiving sides and are located on 1.5-m-high tripods. A power amplifier (PA) with a gain of 25 dB and a low-noise amplifier (LNA) with a gain of 27 dB are used on the transmitting and receiving sides, respectively. To eliminate the effect of the antennas, the PA, the LNA and the cables, all measured data are calibrated in an anechoic chamber.

B. Measurement Scenario

To analyze the effect of the presence of people on a UWB channel, we use four scenarios: 1) a room with desks and chairs, 2) a room with desks, chairs and five people, 3) a room with desks, chairs and 10 people, 4) a room with desks, chairs and 20 people. We divide a room into two regions, the first near both side walls, Region A, and the second in the center aisle, Region B, as described in Fig. 2. In Fig. 2, 'Occupied' denotes people sit on the chair; otherwise this is 'Unoccupied' and the signs of the desk and chair is given. All scenarios are carried out in the same room of which the wall material is commonly concrete and where there are two large glass windows on one side wall. The locations of the transmitting and receiving antennas are identical in all scenarios, as illustrated in Fig. 2. At each of 24 locations in the room for each scenario, the channel responses are measured at nine local points arranged in a 3x3 square grid, as shown in Fig. 2 (a). 100 frequency responses were collected at each local position.

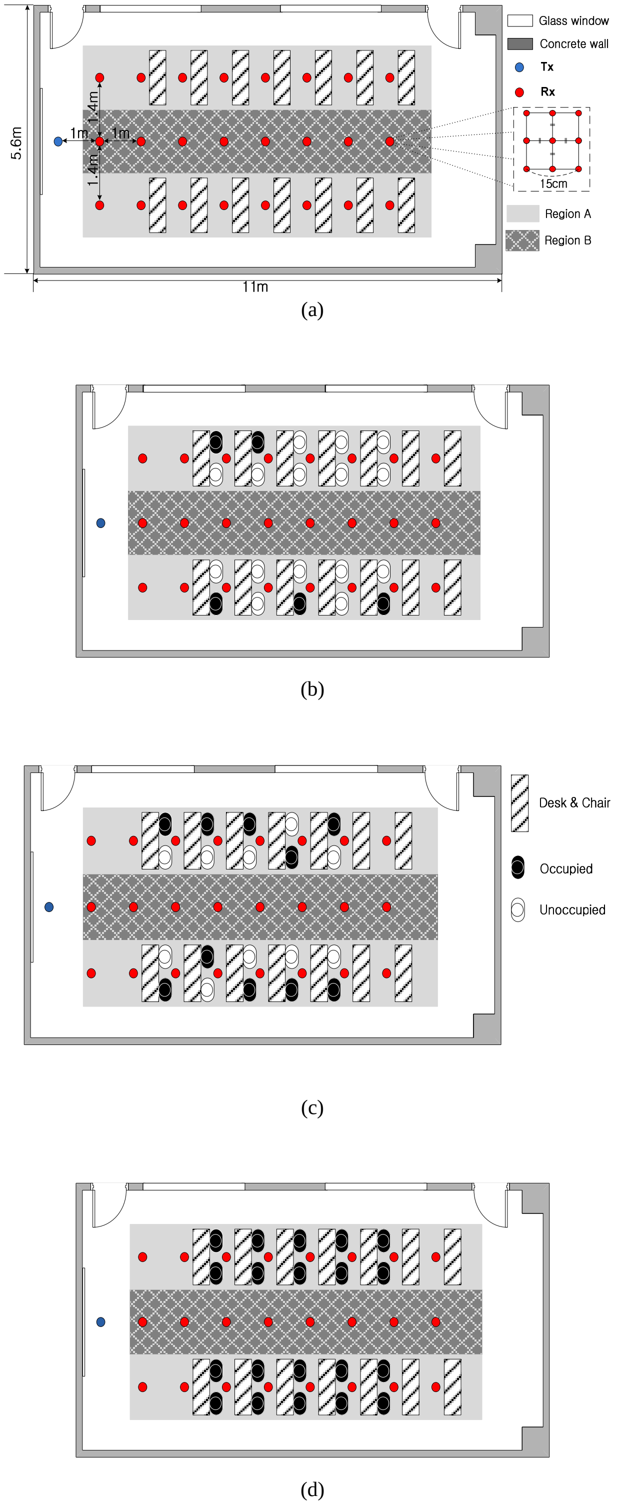
III. PATH LOSS MODEL

A. Frequency-independent Pathloss Model

In the conventional narrowband system, the pathloss model needs to calculate the link budget of the system and to minimize the interference in the neighboring systems. However, the UWB system is expected to require a pathloss model that accounts for the frequency component due to its much wider bandwidth than a conventional system, as discussed in Section III.B. First, in this section, we utilize the frequency-independent pathloss model using equation (1) to show the effect of the presence of people on the pathloss calculated with only the distance,

$$PL_{dB}(d) = PL_{dB}(d_0) + 10n\log_{10}(d/d_0) + S \qquad (1)$$

where $PL_{dB}(d_0)$ is the pathloss at the reference distance d_0 (which is 1m in this paper), d is the separation between the transmitter and the receiver, n is the pathloss exponent, and S is related to the degree of large-scale fading with a zero-mean Gaussian distributed random variable (in dB) with a standard deviation of σ_S (also in decibels) [13]. $PL_{dB}(d_0)$, and σ_S in (1) are averaged over a 1.6 GHz bandwidth, and



(a)

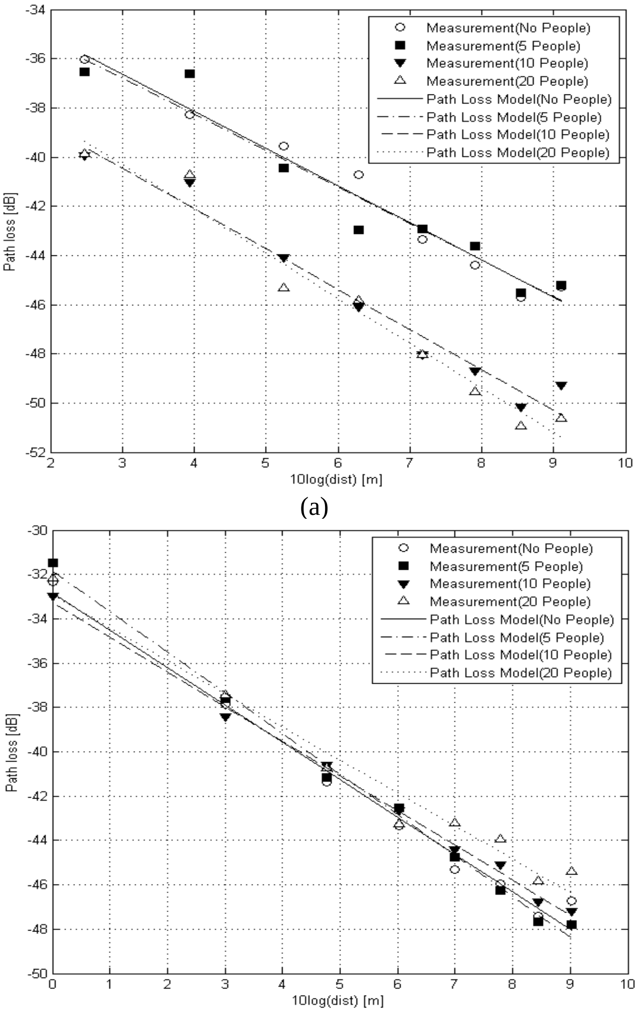
(b)

(c)

(d)

Figure 2. Floor plans and receiver locations in (a) a room with desks and chairs, (b) a room with desks, chairs and five people (c) a room with desks, chairs and 10 people, and (d) a room with desks, chairs and 20 people.

n is computed using the minimum mean square error algorithm. Fig. 3 shows the path loss and their linear regression model in Region A and Region B. The parameters of the regression model are summarized in Table I.



(a)

(b)

Figure 3. Path loss model of (a) Region A (Near wall) and (b) Region B (Center aisle)

Table I shows the variations of the pathloss exponent with the different scenarios in Region A and Region B. Before analyzing the effect of people on the pathloss exponent, for two regions with no people, Region A in which the desks and chairs are located, has a smaller pathloss exponent than Region B, which corresponds to the center aisle. This difference is due to the desks and chairs. For Region A, corresponding to the area near both of the side walls, the pathloss exponent increases when there are more people in the room. However, it decreases for Region B in the middle of the room. This difference is caused by the difference in the main propagation mechanism of the received signal: In Region A, as the number of people increases, the number of positions in which the direct path is blocked increases. In addition, some reflected paths through both side walls and the ceiling are affected by the existing people, and some diffraction paths exist around them [14]. In contrast, in Region B, the direct path is not affected by people because there are LOS paths in all positions, but some reflected paths are blocked or attenuated by people. This different propagation mechanism results in different tendencies of the pathloss exponent in Region A and Region B.

TABLE I. EMPIRICAL PATHLOSS PARAMETERS

Scenario	n		PL(d0) [dB]		σ_S [dB	
	Region A (Near wall)	Region B (Center aisle)	Region A (Near wall)	Region B (Center aisle)	Region A (Near wall)	Region B (Center aisle)
no people	1.51	1.68	32.06	32.83	0.48	0.47
5 people	1.48	1.83	32.34	31.84	0.66	0.34
10 people	1.64	1.57	35.51	33.25	0.54	0.24
20 people	1.82	1.49	34.86	32.91	0.63	0.61

B. Frequency-dependent Pathloss Model

In the conventional narrowband system, it is sufficient to represent the pathloss model in formula (1) in section A, but the UWB system requires the pathloss model considering the frequency dependency due to its wide bandwidth. For this reason, the frequency-dependent pathloss property has been discussed in many studies [15-19]. In this paper, we analyze the frequency-dependent pathloss property through the frequency-dependent pathloss model as introduced by Jinwon Choi et al. [15]. The frequency-dependent pathloss is expressed using the following modified expression of (2)

$$PL_{dB}(d,f) = PL_{dB}(d_0) + 10n(f)\log_{10}(d/d_0) + S \quad (2)$$

where $n(f)$ is the frequency-dependent pathloss exponent. The other components are identical to those in (1).

For UWB systems in particular, the MB-OFDM scheme proposes that the assigned frequency bands should be divided into sub-bands having bandwidths of 528 MHz [20].

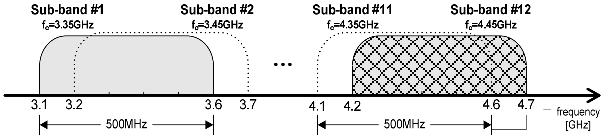
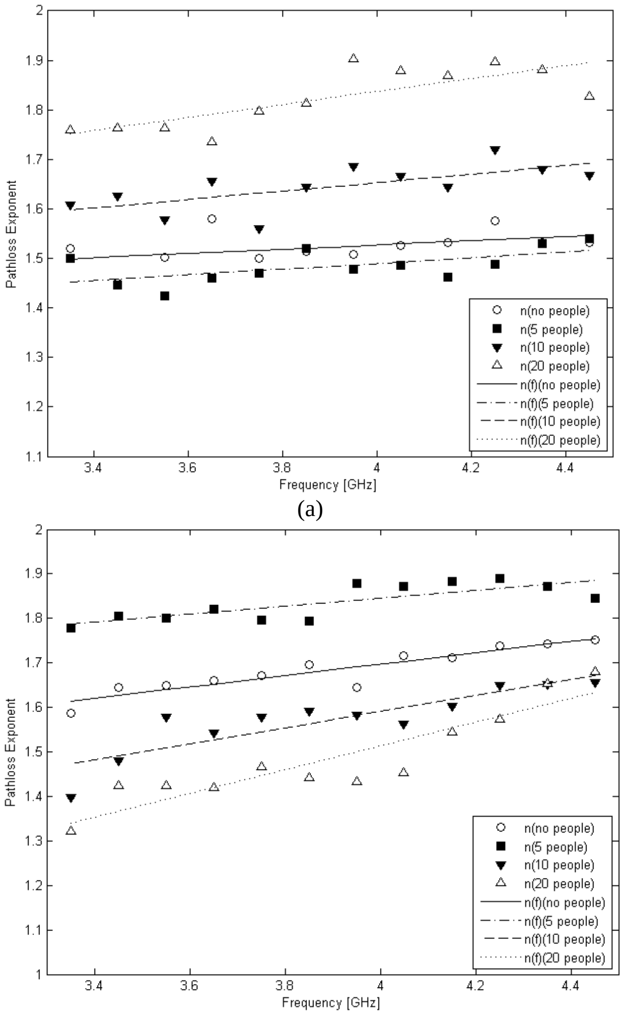


Figure 4. Twelve sub-bands with bandwidths of 500 MHz

To design an efficient MB-OFDM system, the effect of the frequency on UWB signals with different frequency bands should be characterized. For this, we obtained a practical pathloss exponent formula to express the loss as a function of the frequency. The pathloss exponent variation with the frequency is characterized by taking the average of the pathloss exponent over a 500-MHz overlapped window bandwidth whose center frequency is incremented from 3.35 to 4.45 GHz in steps of 100 MHz, as shown in Fig. 4. In this model, the pathloss exponent averaged over each sub-band is denoted as ns_k at the k th sub-band for k = 1, 2, . . . , 12. The variation of ns_k is expressed as a function of the center frequency of each sub-band.



(a)

(b)

Figure 5. ns_k and their linear regression models in (a) Region A (Near wall) and (b) Region B (Center aisle)

The measured ns_k ' values are illustrated in Fig. 5. In Region A near the side walls, ns_k ' values of the scenario with 5 people are similar to those of the scenario with no people, but ns_k increases in the scenarios with 10 and 20 people. This is because the blocked multipath increases as more people are in the region. In Region B which is the center aisle of the room, ns_k ' values of the scenario with 5 people are larger than those of the scenario with no people. This situation arises because the locations which are near to the transmitter have less blocked multipath by people, but the locations far from the transmitter have more blocked multipath. But ns_k ' values of the scenarios with 10 and 20 people are smaller than the other scenarios because the difference of the path loss with the distance. As shown in Fig. 5, ns_k increases with the center frequency of the sub-band and it can be regressed as a linear function. A linear regression model of the pathloss exponent with the frequency is obtained as follows:

TABLE II. LINEAR REGRESSION COEFFICIENTS OF (3)

Scenarios	Region A (Near wall)		Region B (Center aisle)	
	a	B	a	b
No people	0.04	1.36	0.13	1.19
5 people	0.06	1.26	0.09	1.48
10 people	0.09	1.31	0.18	0.87
20 people	0.13	1.31	0.27	0.45

$$ns(f_c) = a \times f_c + b \qquad (3)$$

where f_c is the center frequency of the sub-band (in gigahertz).

The statistical representatives of ns_k 'values and the linear regression coefficients a and b of (3) are shown in Table II. In both regions, the pathloss exponents increase as the frequency increases, but Region B shows faster growth of the pathloss exponents than Region A for the same scenario. These differences between Region A and Region B are the result of different main propagation mechanisms, of which the main difference is that the direct path is blocked by the people in Region A, whereas this is not the case in Region B. In addition, the slope of the pathloss exponents, a , increases as more people are in the room in the two regions. This means that the frequency response is affected by the presence of people in the room.

IV. CONCLUSION

To show how presence of people affects on a UWB channel in an indoor LOS environment, we selected four scenarios in the same room. The frequency-domain channel sounding method was used for channel characterization from 3.1 to 4.7 GHz. From the results, the presence of people causes channel variation. For the frequency-independent pathloss model, the pathloss exponent for the region of the center aisle decreases as more people are in the room, while the pathloss exponent for the region near both side walls increases as the number of people in the room increases. For the frequency-dependent pathloss model that is useful for the

MB-OFMD scheme in which the entire frequency band is divided into several sub-bands with a bandwidth of 528 MHz, the pathloss exponent increases as the frequency increases, but the region of the center aisle in the room experiences faster growth than the region near both side walls. In summary, this paper shows that the presence of people substantially affects radio-wave propagation in an indoor LOS environment and should be considered when characterizing the performance of UWB systems. This finding will be helpful to those who want to validate the results of software simulations of radio-wave propagation in an indoor LOS environment.

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REFERENCES

[1] R. Ganesh and K. Pahlavan, “Effects of traffic and local movements on multipath characteristics of an indoor radio channel,” Electron. Lett., vol. 26, no. 12, 7 Jun. 1990, pp. 810- 812.

[2] K. I. Ziri-Castro, W. G. Scanlon, and N. E. Evans, “Prediction of variation in MIMO channel capacity for the populated indoor environemnt using a radar cross-section-based pedestrian model,” IEEE Trans. Wireless Commun., vol. 4, no. 3, May 2005, pp. 1186–1194,

[3] K. I. Ziri-Castro, N. E. Evans, and W. G. Scanlon, “Propagation modeling and measurements in a populated indoor environment at 5.2 GHz,” in Proc. AusWireless 2006, 13-16 Mar. 2006, pp. 1-8.

[4] S. L. Cotton and W. G. Scanlon, “Characterization and modeling of the indoor radio channel at 868 MHz for a mobile bodyworn wireless personal area network,” IEEE Antennas Wireless Propag. Lett., vol. 6, Dec. 2007, pp. 51-55.

[5] T. B. Welch et al., “The effects of the human body on UWB signal propagation in an indoor environment,” IEEE J. Sel. Areas commun., vol. 20, no. 9, Dec. 2002,pp. 1778-1782.

[6] A. Kara, “Human body shadowing variability in short range indoor radio links at 3-11 GHz,” Int. J. Elec., vol. 96, no.2, Feb. 2009, pp. 205-211.

[7] J. Karedal, A. J. Johansson, F. Tufvesson, and A. F. Molisch, “Shadowing effects in MIMO channels for personal area networks,” IEEE VTC 2006 Fall, 25-28 Sep. 2006, pp. 1-5.

[8] A. Fort, J. Ryckaert, C. Desset, P. De Donecker, P. Wambacq, and L. Van Biesen, “Ultra-wideband channel model for communication around the human body,” IEEE J. Sel. Areas Commun., vol. 24, no. 4, Apr. 2006, pp. 927-933.

[9] S. L. Cotton and W. G. Scanlon, “A statistical analysis of indoor multipath fading for a narrowband wireless body area network,” in Proc. IEEE PIMRC’06, Sep. 2006, pp. 1-5.

[10] A. Alomainy, Y. Hao, A. Owaldally, C. G. Parini, Y. I. Nechayev, C. C. Coonstantinou, and P. S. Hall, “Statistical analysis and performance evaluation for on-body radio propagation with microstrip patch antennas,” IEEE Trans. Antennas Propag., vol. 55, no. 1, Jan. 2007, pp. 245-248.

[11] Chiu S. and Michelson D.G., " Effect of Human Presence on UWB Radiowave Propagation within the Passenger Cabin of a Midsize Airliner," IEEE Trans. Antennas Propag., vol. 58, no. 3, 2010, pp. 917-926.

[12] 8719ES S-parameter Vector Network Analyzer, [Online]. Available: http://www.home.agilent.com/en/pd-1000002244%3Aepsg%3Apro-pn-8719ES/s-parameter-vector-network-analyzer-135-ghz?cc=CA&lc=eng, [retrieved: Jun., 2013]

[13] T.S. Rappaport, Wireless Communications: Principles and Practice, 2nd ed. Englewood Cliffs, NJ: Prentice-Hall, 2002.

[14] Zasowski T., Meyer G., Althaus F., and Wittneben, A.," UWB signal propagation at the human head," IEEE Trnas. Micro. Theory and Technol., vol.54, no. 4, 2006, pp. 1836-1845.

[15] Jinwon Choi, Noh-Gyoung Kang, Yu-Suk Sung, Jun-Sung Kang, and Seong-Cheol Kim, "Frequency-Dependent UWB channel characteristics in office environments," IEEE Trans. Veh. Tech., Vol. 58, Sept. 2009, pp. 3102-3111.

[16] A. F. Molisch, K. Balakrishnan, D. Cassioli, C.-C. Chong, S. Emami, A. Fort, J. Karedal, J. Kunisch, H. Schantz, U. Schuster, and K. Siwiak, “IEEE 802.15.4a channel model—Final report,” Tech. Rep. Doc. IEEE 802.15-04-0662-02-004a, 2005.

[17] C. C. Chong, Y. E. Kim, S. K. Yong, and S. S. Lee, “Statistical characterization of the UWB propagation channel in indoor residential environments,” Wireless Commun. Mobile Comput., vol. 5, no. 5, Aug. 2005, pp. 503–512.

[18] R. C. Qiu and I. T. Lu, “Wideband wireless multipath channel modeling with path frequency dependence,” in Proc. IEEE ICC, Dallas, TX, Jun. 1996, pp. 277–281.

[19] R. C. Qiu and I. T. Lu, “Multipath resolving with frequency dependence for broadband wireless channel modeling,” IEEE Trans. Veh. Technol., vol. 48, no. 1, Jan. 1999, pp. 273–285.

[20] MBOA, MultiBand OFDM Physical Layer Proposal for IEEE Task Group 3a, Sep. 2004. [Online]. Available: http://www.wimedia.org, [retrieved: Sept., 2010]