

Antenna Directivity Effect on the Delay Spread at Millimeter-Wave

Jong Ho Kim, Myoung-Won Jung, YoungKeun Yoon

Radio Technology Research Department, ETRI, Korea

jonghkim@etri.re.kr, mwjung@etri.re.kr, ykyoon@etri.re.kr

Abstract— Millimeter-wave band has been using for high-speed line of sight transmission in short range and there is no problem due to delay spread. But if it is used in indoor to connect an access point(AP) to terminals of WLAN, the delay spread made by multipath reflections limits the transmission speed. Typically, antenna beamwidth is the wider, delay spread is the bigger and it is also equally applicable at millimeter-wave band. Therefore, the delay spread characteristics according to antenna beamwidth is important to set a WLAN at millimeter-wave in indoor. To study the delay spread characteristics at millimeter-wave band, the propagation characteristics according to antenna beamwidth were measured in the empty office room with only an partition for non line of sight(NLOS). The simulation results compare with measured data to obtained the accuracy of simulation. Finally the statistical value of delay spread characteristics according to antenna beamwidth were obtained by simulation at indoor office line of sight(LOS).

Keywords— delay spread, mmW, NLOS, ray-tracing

I. INTRODUCTION

Corresponding to the requirement of new spectrum resources for the expansion of the existing services and incoming new services, the study of millimetre wave bands (30 to 300 GHz) has been improved [1]. At high frequency bands, above 60GHz band have been considered for providing the highest speed services[2][3]. But the transmission rate is limited by delay spread. This is more sensitive at millimeter-wave band because of high speed and very small wavelength[4].

Millimeter-wave band can not be used in outdoor and long distance because of severe rain attenuation and absorption by atmospheric oxygen. Instead, it has been proposed to use in indoor and short distance. On the other hand, the frequency resources at millimeter-wave band are plentiful, so it is suitable for a service which has wideband allowing high-speed multimedia data transmission without data compression. An example, HD-quality video transmission system using the 60 GHz band in indoor was starting to show in the markets.

Millimeter-wave band is widely used in conventional 1:1 communications, and an atmospheric attenuation or a pathloss is compensated by using a high-gain antenna with very narrow beamwidth. However in 1:m communications(between the APs and terminals of WLAN), the locations of the terminals

are not fixed. So AP's antenna has an omnidirectional pattern. In addition, terminal's antenna has wide beamwidth for easy to align with direction of AP and moving around in indoor. However, antenna beamwidth is the wider, delay spread is the bigger because the more multipath reflection waves are received[5]. Then the transmission rate is limited by delay spread. This is more sensitive at millimeter-wave band because of high speed and very small wavelength. Therefore, more accurate analyzing the propagation characteristics is needed to know how much difference the delay spread according to antenna beamwidth.

To study the delay spread characteristics at millimeter-wave band, we have simulated about 5 types of antenna beamwidth in an empty office room with only a partition by ray-tracing method. To verify a validity of ray-tracing method, we measured propagation characteristics in the office with NLOS and compared to simulated results. Finally we obtained the statistical value of delay spread characteristics according to antenna beamwidth by simulation at indoor office LOS.

II. PROPAGATION CHARACTERISTICS MEASUREMENTS AND SIMULATIONS AT 60 GHz BAND

The radio propagation measurements at 60 GHz was done in an empty office, the size is 13 x 8.6 x 3 m. The transmitter was composed of a signal generator, a power amplifier, and an omnidirectional antenna which was located on the corner of the room. The receiver was composed of a LNA, a spectrum analyzer, a laptop computer for data storage, and 4 kind of antennas, a directional antenna, 3 horn antennas each beamwidth 45°, 30°, 12°. The radio path was made NLOS installing a partition before the transmitter. The height of transmitter and receiver was 1.5 m equally, and the distance between them was from 1.8 m to 9.8 m. The receiver system was set on a 2m length of rail to move mechanically very precisely, 2 mm step, smaller than half wavelength. We was able to see a characteristics of the short term fading in this case.

Figure 1 shows a top view of measurement office room that is represented by x-y coordinate with 1m step. The center of the room is (0,0) and the transmitter is located at (-3.2, -5.5). Figure 2 is one of measurement photos, table 1 is

specifications of measurement, and figure 3 is a partition for NLOS.

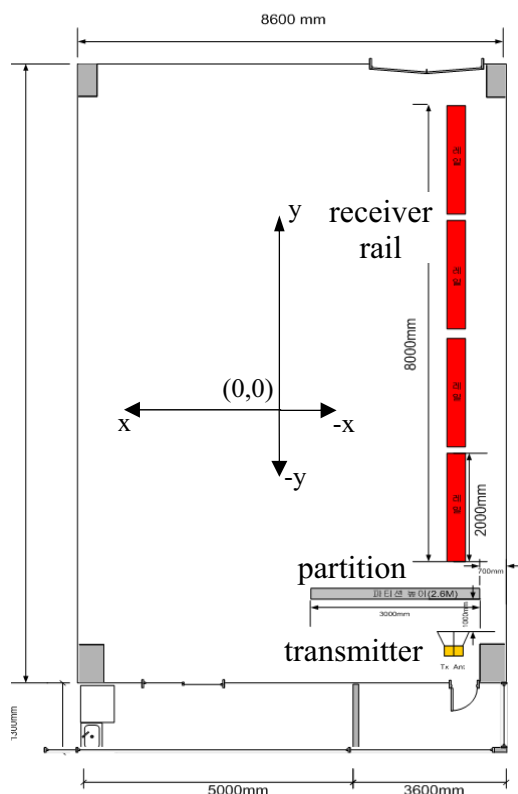


Figure 1. Top view of measurement environment



Figure 2. Measurement photo

TABLE 1. Measurement specifications

Tx antenna	Omnidirectional antenna
Rx antennas	4 types beamwidth : omni, 45°, 30°, 12°
Distance between Tx and RX	straight line, from 1.8 m to 9.8 m ($y = -3.7 \sim +4.3$)
Height of Tx and Rx	1.5 m
Measurement spacing	2 mm step
Empty room size	13 x 8.6 x 3 m



Figure 3. A partition for NLOS

A ray tube method of a ray-tracing was used for simulation in the same conditions of figure 1. To make the same conditions, it was considered windows, an iron gate, and four pillars located at the corners of the room. The tree of ray-tracing was considered three times reflections include a diffraction or four times reflections, and some transmission through obstacles.

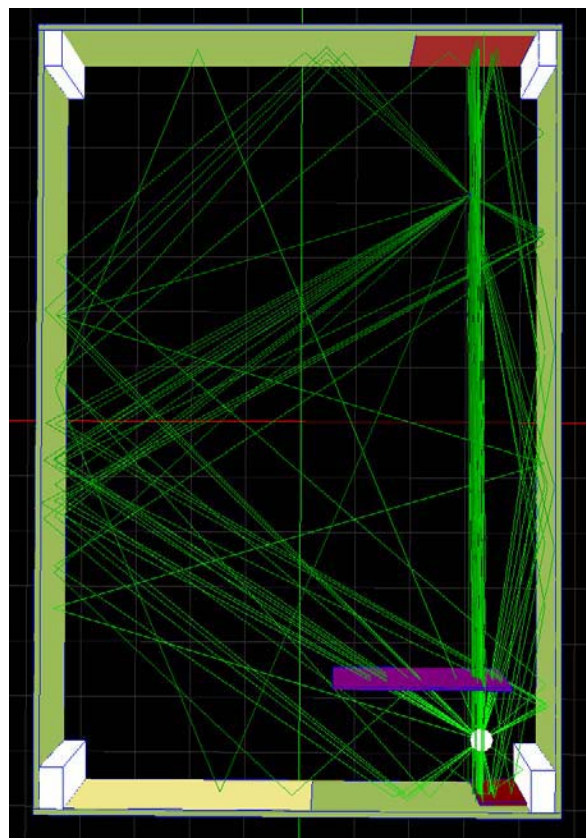


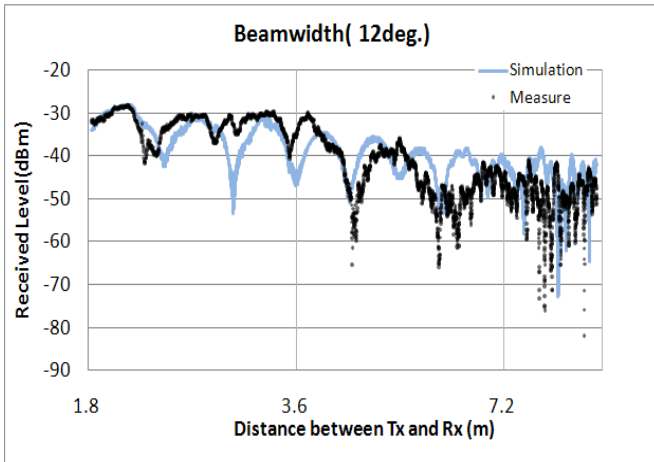
Figure 4. Simulation results of arbitrary receiving point : Ray paths

III. ANALYSIS OF MEASUREMENTS AND SIMULATIONS

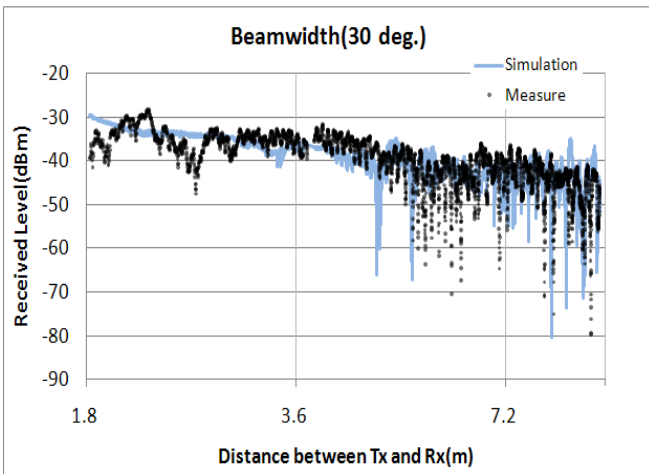
Figure 5 (a), (b), (c), (d) with the measured results and simulation results show the level of the received signals based on distance between transmitter and receiver. They almost agree with each other and the difference of them is represented by root mean square (rms) error of equation (1).

$$RMSE(s, m) = \sqrt{\frac{\sum_{i=1}^n (s_i - m_i)^2}{n}} \quad (1)$$

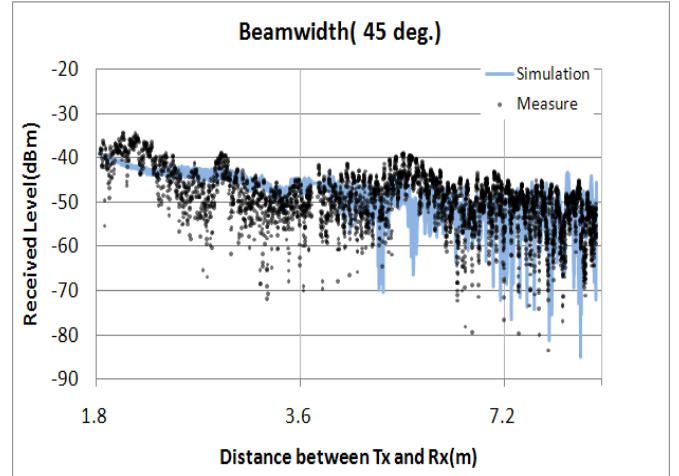
The receiving antenna of figure 5 (a) is 12 degrees beamwidth and it shows 6.8 dB of rms error. Figure 5 (b) shows 30 degrees beamwidth of the receiving antenna and 5.8 dB of rms error. Figure 5 (c) shows 45 degrees beamwidth of the receiving antenna and 6.9 dB of rms error. The omnidirectional receiving antenna of Figure 5 (d) is 7.3 dB of rms error. Overall, the rms error distributes between the 5.8 ~ 7.3 dB, and they are severe variation due to including the short term fading. If it were considered long term fading, the rms error is expected much reduced.



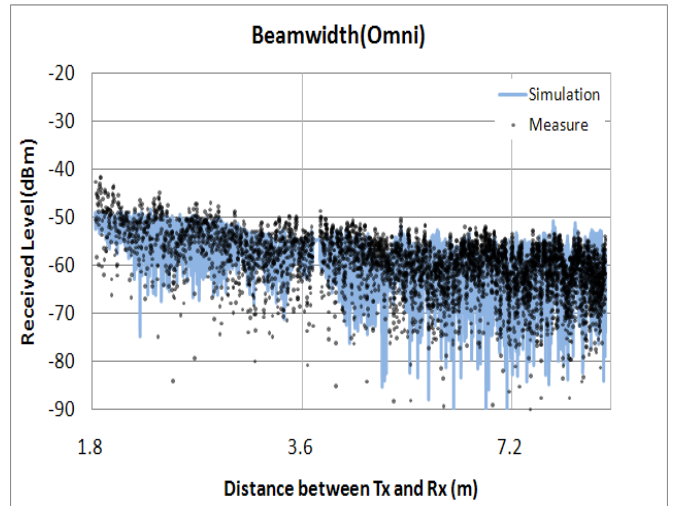
(a) beamwidth 12 deg., RMSE : 6.8dB



(b) beamwidth 30 deg., RMSE : 5.8dB



(c) beamwidth 45 deg., RMSE : 6.9dB



(d) omnidirectional antenna, RMSE : 7.3dB

Figure 5. Comparison of measurement and simulation results

Ray-tracing as one of the analytical method can make a much more accurate prediction of radio propagation characteristics than the other statistical prediction methods[6]. The statistical propagation model at millimeter-wave band can be obtained by analyzing the measured data in various conditions and environments. However, we can not get satisfactory results if the measurement is difficult or embarrassing. Therefore, the simulations have been conducted with various conditions instead of measuring at the real environments. After that, propagation model can be obtained by statistical parameters extracted from simulation results. The accuracy of the prediction results are obtained from comparing the actual measurement results with simulation results. The obtained rms errors are within about 6 ~ 7 dB in figure 5, this is a very accurate results because we have

considered the short term fading which has 20 ~ 30 dB of instantaneous fluctuation.

We can get channel impulse response $h(\tau)$ of equation (2) using a ray-tracing simulation.

$$h(\tau) = \sum_{i=0}^{I-1} p_i \exp(j\phi_i) \delta(\tau - \tau_i) \quad (2)$$

And the rms delay spread is

$$\tau_{rms} = \sqrt{\frac{\sum_{i=0}^{I-1} \tau_i^2 \cdot p_i^2}{\sum_{i=0}^{I-1} p_i^2} - \tau_n^2} \quad (3)$$

where

$$\tau_n = \frac{\sum_{i=0}^{I-1} \tau_i \cdot p_i^2}{\sum_{i=0}^{I-1} p_i^2} \quad (4)$$

We can get Figure 6 to figure 9 shows simulation results of the rms delay spread according to the variation of antenna beamwidth by ray-tracing method with figure 1's conditions.

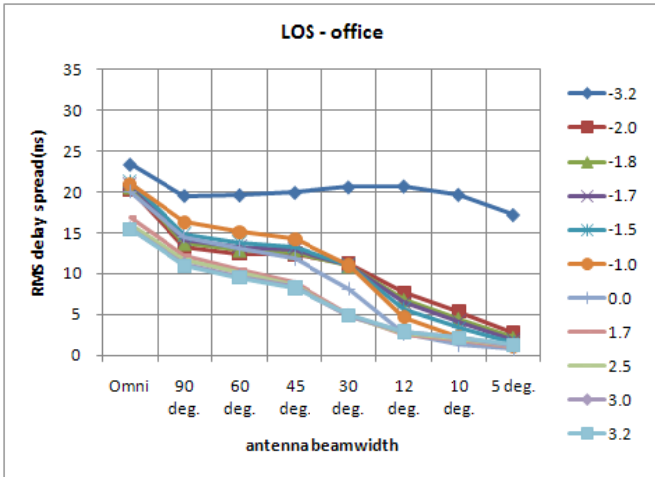


Figure 6. RMS delay spread according to beamwidth of antenna in LOS

Figure 6 shows that the narrower beamwidth of antenna was used in indoor, they have the smaller delay

spread (Because an antenna with narrow beamwidth can not receive many multipath reflection waves). It shows delay spread variation about 5 ~ 6 ns at each beamwidth according to x position except $x = -3.2$ that is the same with transmitter's position. The delay spread at this position has a different trend to any other positions at figure 7 also. The distance from transmitter is the farther, the delay spreads are the smaller.

There are severe variation of delay spread according to x position at figure 8 and 9 in NLOS. But they have a similar characteristic of delay spread according to antenna's beamwidth. In figure 8 and 9, the distributions of delay spread at a partition's location point ($x = -3.6 \sim -0.6$, $y = 4.47$, $z = 0 \sim 2.7$) have different type compare to that of other x positions.

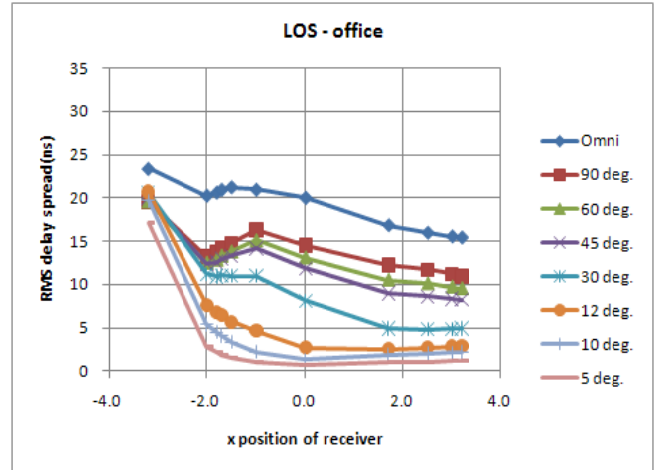


Figure 7. RMS delay spread according to x position of receiver in LOS

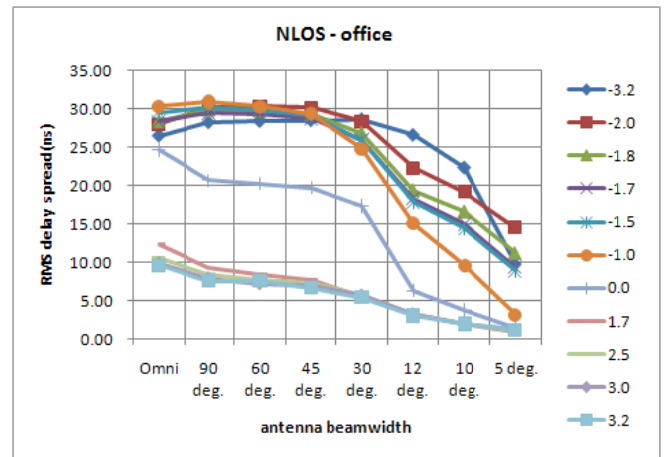


Figure 8. RMS delay spread according to beamwidth of antenna in NLOS

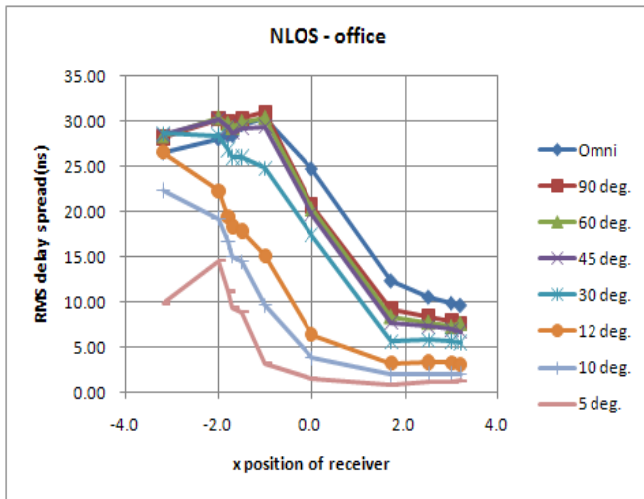


Figure 9. RMS delay spread according to x position of receiver in NLOS

IV. CONCLUSIONS

We have used the measurements and simulations to study the delay spread characteristics at millimeter-wave band. We measured propagation characteristics according to antenna beamwidth in the empty office room with only an partition for NLOS and obtained the accuracy of the simulation by ray-tracing method compare to the measurement results. Finally we obtained the statistical characteristics of delay spread according to antenna beamwidth using some simulations by ray-tracing method at indoor office LOS.

To generalize the statistical characteristics of delay spread at millimeter-wave band, we need more measurements and simulations in any other environments.

REFERENCES

- [1] S.K.Yong, C.Chong and S.S. Lee, "Generalization and parameterization for 802.15.3c channel model," IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs), IEEE 15-05-0261-00-003c, SAIT, 2005
- [2] N. Moriatis and P. Constantinou, "Indoor channel measurements and characterization at 60 GHz for wireless local area network applications," IEEE Trans. Antennas Propagat., vol. 52, no. 12, pp. 3180-3189, Dec 2004.
- [3] H. Xu, "Terrestrial Radio Wave Propagation at Millimeter-wave Frequencies", Ph. D. Dissertation, Virginia Polytechnic Institute and State University, Mat 2000.
- [4] T. Manabe, Y. Miura, and T. Ihara, "Effect of Antenna Directivity on Indoor Multipath Propagation Characteristics at 60GHz", IEEE Journal on Select. Areas in Comm., vol. 14, no. 3, Apr. 1996.
- [5] Recommendation ITU-R P.1238-5, "Propagation data and prediction methods for the planning of indoor radiocommunication systems and radio local area networks in the frequency range 900MHz to 100GHz," 2007
- [6] D. Dardari, L. Minelli, V. Tralli, and O. Andrisano, "Fast Ray-tracing Characterization of Indoor Propagation Channels at 60GHz", VTC'97, pp. 989-993, 1997.