# *An Orthogonal Polarization based MIMO Transmission for Advanced 60GHz WLAN*


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***Abstract*—An orthogonal polarization based MIMO transmission scheme is proposed to achieve over 10Gbps transmission for advanced 60GHz WLAN. As the proposed MIMO transmission scheme uses V(Vertical)/H(Horizontal) polarization directional antennas, stable 2X2 MIMO transmission is enabled even in LOS (line-of-sight) environment. A ray-tracing method is employed for computer simulation to evaluate channel capacity and BER performance of the proposed scheme in indoor conference room environments. The simulation results confirm that the proposed orthogonal polarization based MIMO transmission scheme achieves higher channel capacity than the conventional MIMO transmission using the same polarization antenna. Furthermore, this paper shows that BER performance depends on the location of transmitter and receiver as well as the beam-width of the directional antenna. BER performance is significantly degraded when the antenna height of the transmitter is the same as that of the receiver. On the other hand, better BER performance can be achieved when the antenna height difference is large.**



***Keywords-Orthogonal polarization; 60GH; MIMO; Ray Tracing***


## I. INTRODUCTION

Recently, WPAN (Wireless Personal Area Network) and WLAN (Wireless Local Area Network) using 60GHz band have been drawing a great deal of attentions as a means for multi Gbps transmission for projection to high definition TV and rapid Sync&Go applications. One of the most realistic approaches for multi Gbps WPAN/WLAN is to use 60GHz band considering its global frequency allocation, where 7GHz bandwidth is available in USA, Europe, Korea and Japan. With the increasing demand for such short range multi Gbps wireless systems, IEEE802.15.3c was standardized for 60GHz WPAN[1] and IEEE802.11 TGad have been developing the standards for 60GHz WLAN [2].

Considering the increasing demand for higher bit rate, 60GHz WLAN will be required to support over 10Gbps transmission rate in near future. The channel spacing in draft IEEE802.11ad specification is 2.16 GHz. Therefore, it is not possible to double the bandwidth, i.e. from 2.16GHz to 4.32GHz, to achieve over 10Gbps transmission rate by SISO (Single Input Single Output), since only one channel will be available even in 60GHz band. Hence, MIMO (Multiple Input Multiple Output) will be necessary for advanced 60GHz WLAN and several papers discuss about the feasibility of MIMO transmission in 60GHz band [3]-[6].

In 60GHz WLAN, a high gain narrow beam directional antenna needs to be used at both transmitter (TX) and receiver (RX) for its link budget design due to the large free space loss in 60GHz band. As a result, the propagation situation becomes almost Line-of-Sight (LOS) rather than the multi-path propagation situation as seen in 2.4/5GHz WLAN where omni-directional antenna is used. If the conventional approach to use sufficiently spaced multiple directional antennas is employed for MIMO transmission in 60GHz WLAN, MIMO transmission performance heavily depends on the location of TX and RX. To solve this problem, this paper proposes orthogonal polarization based MIMO transmission to achieve over 10Gbps transmission for an advanced 60GHz WLAN.

As MIMO channel model in 60GHz band is not available as far as the authors know, we evaluate channel capacity and BER performance by computer simulation using a ray tracing method in an indoor conference room environment, which is defined in the IEEE802.11ad channel model document [7]. Channel capacity of the proposed orthogonal polarization based 2X2 MIMO transmission is compared with that of the conventional 2X2 MIMO transmission using the same polarization. The simulation results show that the orthogonal polarization based MIMO transmission achieves higher channel capacity than the conventional MIMO transmission. Furthermore, we evaluate BER performance of the proposed MIMO transmission using ZF (Zero Forcing) algorithm and reveal that BER performance heavily depends on the location of TX and RX as well as the beam-width of the directional antenna.

## II. ORTHOGONAL POLARIZATION DASED MIMO TRANSMISSION FOR 60GHZ WLAN

The schematic diagram of the proposed orthogonal polarization based MIMO transmission is shown in Fig. 1, where V(Vertical)/H(Horizontal) polarization directional antennas are co-located at both TX and RX. Directional antenna at TX and RX is assumed to be properly directed to each other. As shown there, one data stream, $s_1(t)$ is transmitted using V polarization and the other data stream, $s_2(t)$ is transmitted using H polarization for 2X2 MIMO transmission. The received signal, $r_1(t)$ using V polarization antenna and the other received signal, $r_2(t)$ using H polarization antenna are given by


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$$\begin{pmatrix} r_1(t) \\ r_2(t) \end{pmatrix} = \begin{pmatrix} h_{11} & h_{21} \\ h_{12} & h_{22} \end{pmatrix} \begin{pmatrix} s_1(t) \\ s_2(t) \end{pmatrix} + \begin{pmatrix} n_1(t) \\ n_2(t) \end{pmatrix}, \qquad (1)$$

where $h_{ij}$ (i,j=1,2) is the channel gain, and $n_1(t)$ and $n_2(t)$ are Gaussian noise with the same power. Note that $h_{12}$ and $h_{21}$ means the cross polarization coupling, i.e. H to V and V to H.

Then, the transmitted signal, $s_1(t)$ and $s_2(t)$ are estimated at RX using ZF (Zero Forcing) or MMSE (Minimum Mean Square Error) algorithm. Thus, $h_{12}$ and $h_{21}$ do not need to be zero. As the V/H polarizations are orthogonal each other for LOS path, stable spatial multiplexing by MIMO is expected even in the LOS propagation environments in 60GHz WLAN.

## III. Performance Evaluation Using a Ray Tracing Method

Channel capacity and BER performance of the proposed orthogonal polarization based MIMO transmission are evaluated by computer simulation using a ray tracing method. In addition, the channel capacity of the conventional 2X2 MIMO transmission using the same V(Vertical) polarization is evaluated using the ray tracing method and compared with that of the proposed MIMO transmission scheme.

The conference room environment used for computer simulation is shown in Fig. 2, where the first order reflected waves from the table, four walls and the ceiling are considered. We assume that TX and RX antennas are properly directed to each other for LOS path. As the higher order reflected waves have much smaller received power than the first order reflected waves, only first order reflected waves are taken into account. Supposing that the transmitted signals are $s_1(t)exp(j\omega t)$ at TX1 and $s_2(t)exp(j\omega t)$ at TX2, where $\omega$ is the carrier angular frequency, the received signal, $r_1(t)$ and $r_2(t)$ are given by:

$$r_1(t) = \left( \sum_{k=1}^{7} A_{k11} s_1(t-\tau_k)\exp(-j\omega\tau_k) + \sum_{k=1}^{7} A_{k12} s_2(t-\tau_k)\exp(-j\omega\tau_k) \right)\exp(j\omega t)$$

$$r_2(t) = \left( \sum_{k=1}^{7} A_{k21} s_1(t-\tau_k)\exp(-j\omega\tau_k) + \sum_{k=1}^{7} A_{k22} s_2(t-\tau_k)\exp(-j\omega\tau_k) \right)\exp(j\omega t) \qquad (2)$$

where k is the path number and $\tau_k$ is the delay time of the kth path. Note that $\tau_0$ for the LOS path is 0. $A_{kij}$ is the path loss of the kth path for the signal $s_j(t)$ at TX $j$ to the signal $r_i(t)$ at RX $i$ $(i,j=1,2)$. $A_{kij}$ is obtained by calculating the antenna gain for each polarization, reflection co-efficient and free space loss of the kth path, considering the four polarization combinations, i.e. V to V, V to H, H to V, H to H. Note that $\tau_k$ is the identical for each polarization combination in the proposed scheme since V/H orthogonal polarization antenna is assumed to be co-located at both the TX and the RX.

As the channel capacity and BER performance depends on the location of TX and RX as well as the antenna height, we assume three cases as shown in Fig. 3. CASE1 assumes Laptop PC usage model, CASE2 assumes inter-Desktop PC link application, and CASE3 assumes the video conference using AP (Access Point) on the ceiling.

Major simulation parameters are summarized in Table 1, where the clock rate is 1.76GHz, according to the draft IEEE802.11ad specifications [2]. We assume that -3dB beam-width ($\theta_{3dB}$) of the directional antenna is 15, 30 and 60 degree using the antenna pattern model in the channel model document of IEEE802.11ad TG [7]. For BER performance evaluation, QPSK without FEC is employed. Relative complex dielectric constant is selected according to the materials used in the ceiling, walls and the table [9].

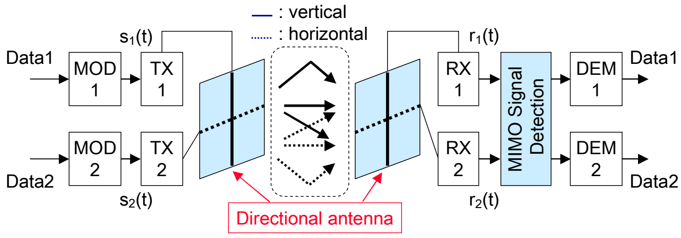



Fig.1. Schematic diagram of the proposed orthogonal polarization based MIMO transmission.

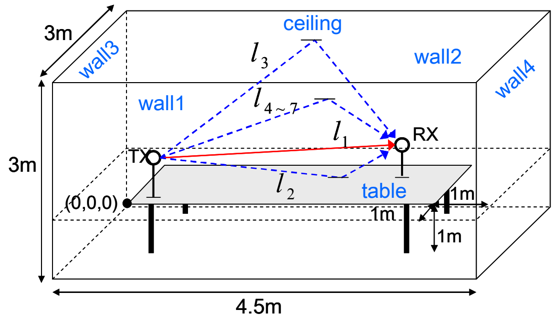



Fig.2. Indoor conference room environment.

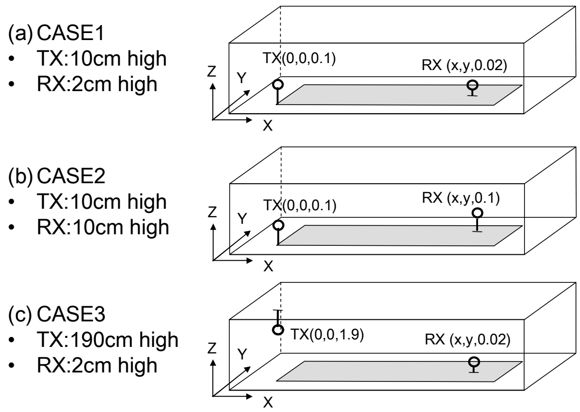



Fig.3. Location of the transmitter and the receiver.

TABLE I. Major Simulation Parameters.

| | |
|---|---|
| Frequency | 60GHz |
| Clock rate | 1.76GHz |
| Modulation scheme | QPSK without FEC |
| Antenna -3dB beam-width | 60, 30 and 15 degree |
| Antenna pattern | According to IEEE802.11-09/334r8 channel model document |
| Relative complex dielectric constant for reflection co-efficient calculation | Ceiling: 1.59-j0.01<br>Walls: 6.50-j0.43<br>Table: 3.91-j0.33 |

## IV. CHANEL CAPACITY EVALUATION

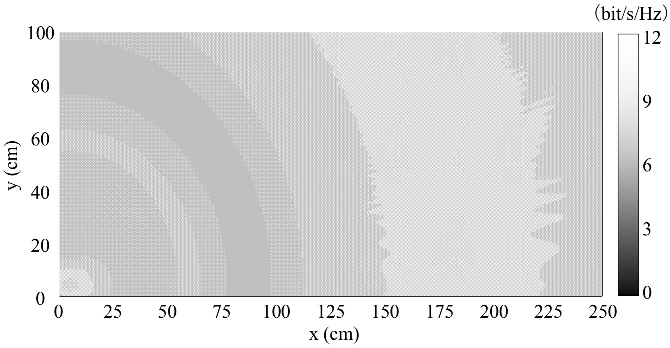
Channel capacity of the orthogonal polarization based MIMO transmission is evaluated by computer simulation using a ray-tracing method and compared with that of the conventional MIMO transmission using the same V polarization for both channels. In the conventional MIMO transmission, the antenna spacing is set as 2cm, which is 4λ when the carrier frequency is 60GHz, at both TX and RX.

Channel capacity according to the received position on the table in the case of CASE1 is shown in Fig. 4, where (x,y) indicates the position of RX. The position of TX is fixed as shown in Fig. 3. It is assumed that SNR for LOS path is 20dB at any RX positions and $\theta_{3dB}$ of TX and RX antenna is 30 degree. Evaluated channel capacity of the conventional MIMO transmission is shown in (a) and that of the proposed orthogonal polarization based MIMO transmission is shown in (b). Light and shade of the color indicates the channel capacity in bit/s/Hz according to the receiving position of RX. As shown there, the proposed orthogonal polarization based MIMO transmission can achieve higher, i.e. lighter in color in Fig. 4, channel capacity in most RX locations.

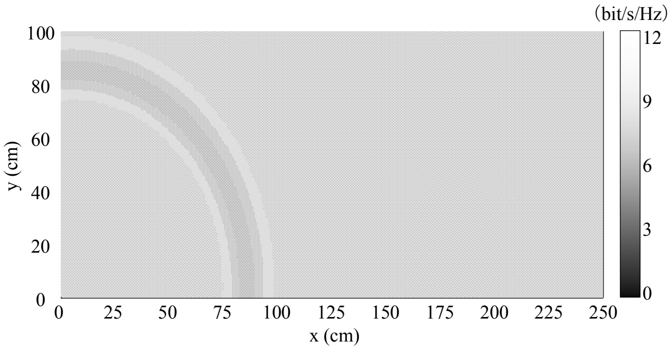
Fig. 5 shows the cumulative probability of the channel capacity in CASE1 and CASE2, assuming RX is located at random on the table. In CASE1, the antenna height at TX is 10cm and that at RX is 2cm. In CASE2, the antenna height at both TX and RX is 10cm. VH MIMO denotes the proposed orthogonal polarization MIMO transmission and VV MIMO denotes the conventional MIMO transmission using the same V polarization. As shown in Fig. 5, 10% channel capacity of VH MIMO is 3 bit/s/Hz higher than that of VV MIMO in both CASE1 and CASE 2 for $\theta_{3dB}$=15, 30 and 60 degree. However, in CASE1, 1% channel capacity of VH MIMO decreases as $\theta_{3dB}$ of the directional antenna increases. Thus, although 1% channel capacity of VH MIMO is higher than that of VV MIMO when $\theta_{3dB}$=30 and 15 degree, it is almost the same as that of VV MIMO for $\theta_{3dB}$=60 degree. In CASE2, 10% channel capacity of VH MIMO is still 2 to 2.5 bit/s/Hz higher than that of VV MIMO for any $\theta_{3dB}$ though it is slightly less than CASE1, and it decreases as $\theta_{3dB}$ increases. In the case of $\theta_{3dB}$=60 degree, VH MIMO does not achieve higher channel capacity than VV MIMO. In conclusion, the simulation results confirm that the proposed orthogonal polarization based MIMO transmission achieves higher channel capacity than the conventional MIMO transmission using the same V polarization antennas in most cases.

## V. BER PERFORMANCE EVALUATION

BER performance of the proposed orthogonal polarization based MIMO transmission is evaluated using the ray-tracing method. As the ray-tracing method is a deterministic way for propagation channel simulation, BER performance of MIMO transmission at 25 receiving points is evaluated and averaged. In the BER performance simulation, we assume V/H polarization plane at TX is matched to that at RX, regarding the LOS component. In addition, ZF (Zero Forcing) algorithm is used for MIMO signal detection since ZF is simpler for hardware implementation than MMSE (Minimum Means Square Error) and MLD (Maximum Likelihood Detection).

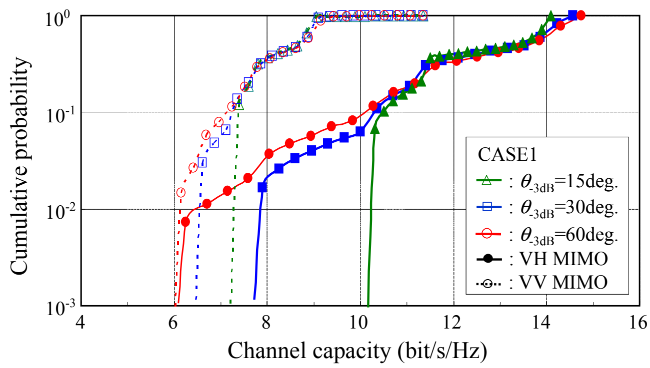


(a) Conventional MIMO transmission using V polarization waves

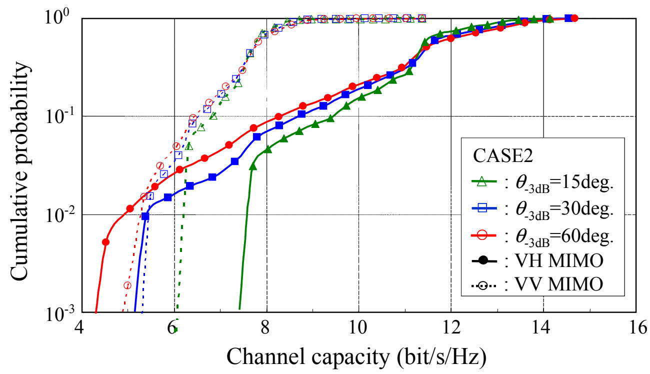


(b) Proposed MIMO transmission using orthogonal V/H polarization waves

Fig.4. Channel capacity according to the received position on the table in CASE1. SNR for LOS path=20dB and $\theta_{3dB}$=30 degree at TX and RX.



(a) CASE1

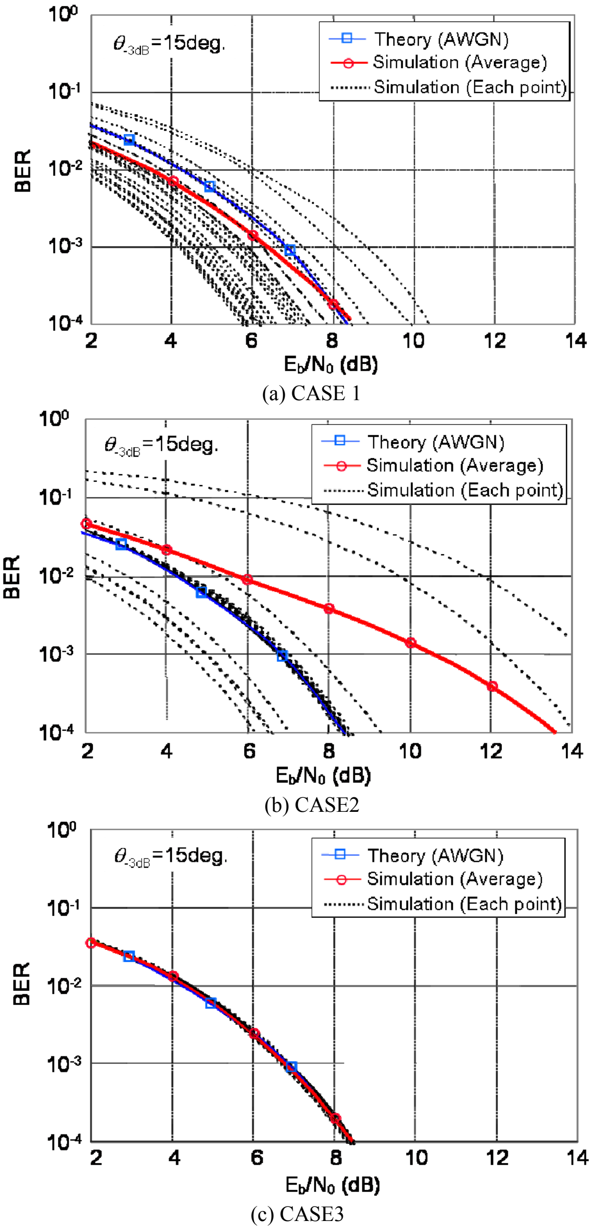


(b) CASE2

Fig.5. Cumulative probability of channel capacity in CASE1 and CASE2. SNR for LOS path=20dB and $\theta_{3dB}$=15, 30 and 60 degree at TX and RX.

BER performance according to the locations of RX in CASE1, 2 and 3 is shown in Fig. 6 when $\theta_{3dB}$=15 degree. In each figure, the dotted curve shows BER performance at 25 receiving points and the solid curve shows averaged BER performance. As seen in Fig. 6(a) for CASE1, the required $E_b/N_o$ varies in the range from -1.5dB to +1dB mainly due to the reflected signal from the table with very short delay time. If in-phase reflected wave is added to the LOS component, required $E_b/N_o$ at BER=$10^{-4}$ can be smaller than the theoretical required $E_b/N_o$, i.e. 8.4dB. If the reverse-phase reflected wave is added, BER performance is degraded due to the fading. As a result, the averaged BER performance is almost the same as theory, i.e. AWGN (Additive White Gaussian Noise) environment, in CASE1. On the other hand, in CASE2, BER performance is significantly degraded at a few receiving points mainly due to the reflected wave from the table, thus averaged BER performance is also significantly degraded as shown in Fig. 6(b). In CASE3, no BER performance degradation is observed at 25 receiving points, thus the averaged BER performance is almost the same as theory.

Fig. 7 shows averaged BER performance according to the -3dB beam-width, i.e. $\theta_{3dB}$=15, 30 and 60 degree in CASE1, CASE2 and CASE3. As seen there, almost the same BER performance as theory is achieved in CASE 1 when $\theta_{3dB}$=15, and 30 degree. However, in the case of $\theta_{3dB}$=60 degree, BER performance is significantly degraded. In CASE2, BER performance is significantly degraded not only when $\theta_{3dB}$=30 and 60 degree but also when $\theta_{3dB}$=15 degree. However, In CASE3, no BER performance degradation is seen for $\theta_{3dB}$=15,

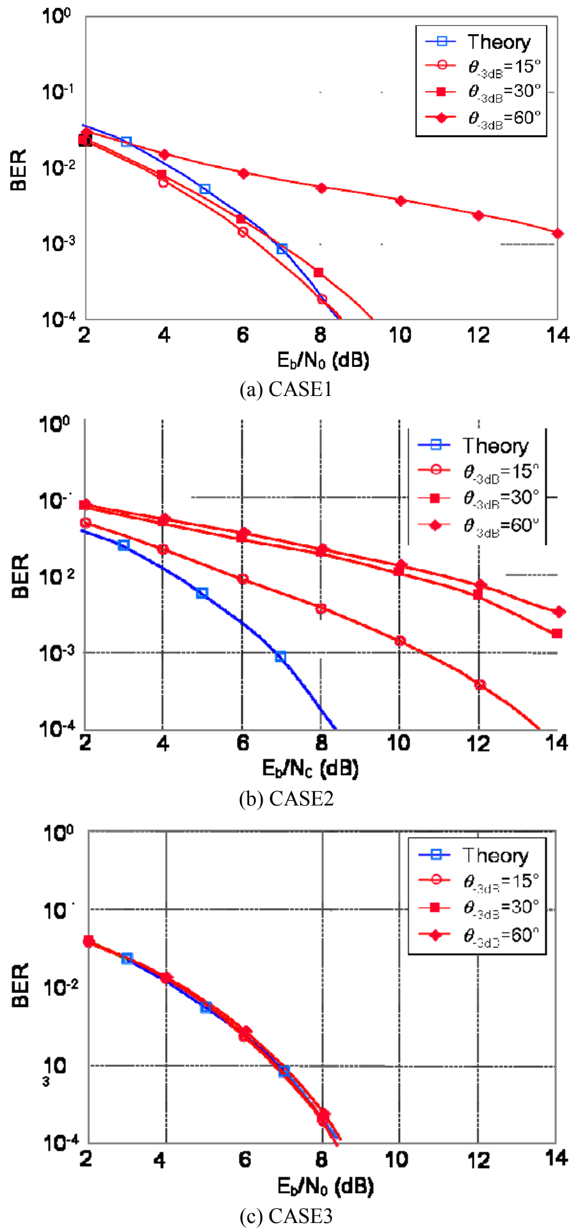


(a) CASE 1

(b) CASE2

(c) CASE3

Fig.6. BER performance according to the location of RX when $\theta_{3dB}$=15, 30 and 60 degree.



(a) CASE1

(b) CASE2

(c) CASE3

Fig.7. Averaged BER performance according to $\theta_{-3dB}$=15, 30 and 60 degree in each CASE.

30 and 60 degree. Thus, we can draw the following conclusions from the above-mentioned simulation results:

(1) BER performance is affected by the location as well as the antenna height of TX and RX. The larger antenna height difference between TX and RX, the better BER performance. The worst BER performance degradation when the antenna height at TX and RX is the same.
(2) The narrower -3dB beam-width, the better BER performance.

Fig. 8 shows BER performance at point A, (x,y)=(1.674, 1.0) and point B, (x,y)=(0.844, 1.0) in CASE1 when $\theta_{3dB}$=15 degree. BER performance varies according to the location of RX. It also shows BER performance when the inclined angle of the V/H polarization plane at RX against TX is 15 and 45 degree. As shown in Fig. 8, BER performance is not degraded due to the inclination of the V/H polarization plane at RX, thanks to the function of MIMO signal detection using ZF. In the case of SISO transmission, the received signal power decreases when the polarization plane at RX is not matched to that at TX. This is an additional advantage of the proposed orthogonal polarization based MIMO transmission.

Fig. 9 shows the cumulative probability of the relative SNR of the received signals at V/H channels in CASE1 with $\theta_{3dB}$=15 degree when ZF is employed for MIMO signal detection. SNR of the LOS component is used as the reference, i.e. 0dB. As well-known, SNR is degraded if V/H channels are correlated. As shown in Fig. 9, 10% SNR of V polarization channel is about 3dB higher than that of H polarization channel. This difference is mainly caused by the difference of reflection co-efficient between V/H polarizations. As the link quality of V/H channels is not equal, the interleaving between V/H channels in combination with FEC or the adaptive modulation and coding for each polarization will be necessary to achieve better overall link quality.

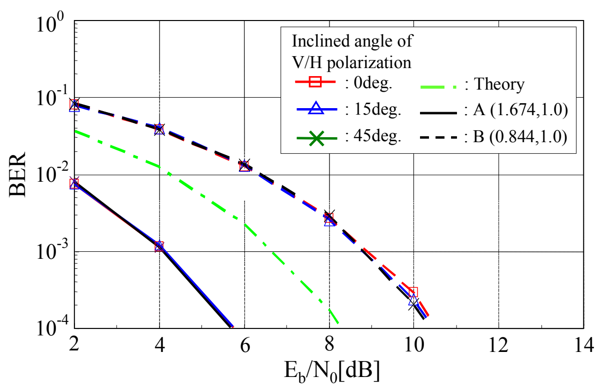



Fig.8. BER performance when V/H polarization at RX is inclined. $\theta_{3dB}$=15 degree in CASE1.

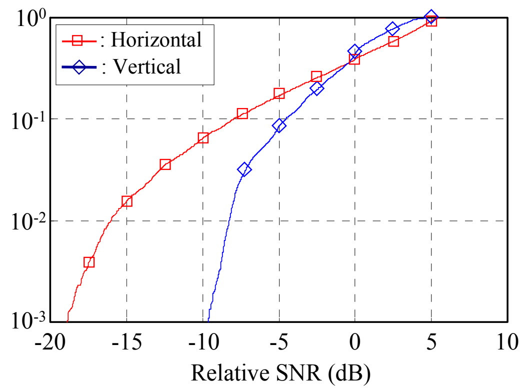



Fig.9. Cumulative probability of relative SNR in CASE1 with $\theta_{3dB}$=15degree.

## VI. Conclusions

This paper proposes an orthogonal polarization based MIMO transmission scheme to achieve over 10Gbps transmission for advanced 60GHz WLAN and describes the channel capacity and BER performance evaluation results in indoor conference room environments by computer simulation using the ray-tracing method. The simulation results confirm that the proposed V/H orthogonal polarization based MIMO transmission achieves higher channel capacity than the conventional MIMO transmission using the same V polarization antenna. This paper also shows that BER performance is affected by the location and the antenna height difference between TX and RX. When TX antenna height is the same as RX antenna height, BER performance is significantly degraded even if $\theta_{3dB}$ is as narrow as 15 degree. On the other hand, the larger antenna height difference between TX and RX, the better BER performance. Thus, no BER performance degradation is observed when the transmitter is located on the ceiling. Furthermore, the results show that better BER performance is achieved as $\theta_{3dB}$ of the directional antenna becomes narrower.

Future work includes BER performance evaluation using higher order modulation scheme such as 16QAM and 64QAM and FEC with V/H inter-channel interleaving.

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