Combination effect of circular and linear polarizations for a 2x2 MIMO-OFDM system

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1. INTRODUCTION

Various Multiple-Input Multiple-Output (MIMO) systems have been studied and developed with the aim of achieving high-speed data transmission for future Nomadic-Wireless-Access (NWA) systems such as Wireless Local Area Network Systems (WLANS). The MIMO-Orthogonal Frequency Division Multiplexing (OFDM) technique has also been studied as a candidate that can achieve high transmission speeds, e.g., [1]. Furthermore, achieving high performance requires an adequate design involving multiple transmit and multiple receive arrays in order to yield the maximum effect. There have been numerous studies, for example [2], on MIMO array design in terms of polarization to achieve identical fading among more than two branches, and it is well known that using orthogonal polarized (vertical and horizontal polarization (hereafter V-pol. and H-pol., respectively)) antenna has exhibited good performance in a MIMO channel. However, in a MIMO system that uses an array comprising more than three branches, it is inevitable that the same polarization will be used in other branches. Using a circular polarized antenna array comprising V-pol. and H-pol. antennas is method that can achieve identical fading among more than three branches. Therefore, this paper presents simulation and experimental evaluation results of a circular polarized antenna array that is applied to the MIMO system in an indoor environment. A ray-trace simulation is used for the theoretical analysis. Measurements are carried out using a newly developed 2x2 MIMO-OFDM channel measurement system. The analysis results in terms of OFDM sub-carriers are also presented.

2. SIMULATION OF 2X2 MIMO-OFDM CHANNELS FOR EVALUATING COMBINED EFFECT OF CIRCULAR AND LINEAR POLARIZATIONS

2.1 Simulation Parameters

A ray-trace simulation using a geometrical optical character was performed [3]. The size and range parameters of the simulation are shown in Fig. 1. The transmission and received antenna height are 1.8 m from the floor and the frequency is 5.2 GHz. The walls are constructed of concrete, which has the electric conductivity of 7.0-j0.85 [4]. The number of sidewall reflections is ten, and the number of ceiling and floor reflections is two. The ray-trace method takes into consideration only specular reflection waves, and disregards scattering waves. Therefore, the ability to maintain polarization is very high and polarization rotation only rarely occurs. In this simulation, the received cross-polarization level is calculated by setting the antenna's own cross polarization discrimination (XPD) to 20 dB and the antenna's own phase characteristics are ignored. The following types of antenna arrays are used the in the simulation: four V-pol. antennas, *VV-VV*; a combination of V-pol. and H-pol. antennas, *VH-VH*; a combination of right-handed and left-handed circular polarized antennas, C_rC_l-C_rC_l; four right-handed circular polarized antennas, C_rC_r-C_rC_r; and a combination of V-pol. antennas and right-handed polarized antennas, VC_r-VC_r.

2.2 2x2 MIMO Channel Capacities

The capacity computed by the formula below is a theoretical marginal value given by MIMO. For n_t transmit antennas with equal transmit power and n_r receiving antennas, the generalized formula for the capacity, C_{MIMO}, can be derived as

$$C_{MIMO} = \log_2 \left| \det \left\{ I + H * H' / (\sigma^2 n_t) \right\} \right| \qquad (1)$$

where I is a identity matrix, H is an n_r x n_t matrix, H' is its transposed conjugate, and σ^2 is the noise

power. Here, the transmission power is set to 0 dB, and capacity is calculated by setting the noise power to -80 dB. Fig. 2 shows the capacity computed based on the simulation. In the simulation, when a combination circular polarized antenna array is used, a high capacity is achieved. Therefore, we conclude that a circular polarized antenna is suited for use in 2x2 MIMO transmissions.

2.3 Space Division Multiplexing (SDM) vs. Space Time Code (STC)

SDM and STC are examined as a leading method for MIMO transmission. When performing 2x2 MIMO transmissions, the system design should be able to discern which is more suitable, STC or SDM. The Demmel condition number of an instantaneous MIMO channel can be used to evaluate the applicability of SDM [5].

2.3.1 Demmel condition number

The Demmel condition number of the instantaneous channel matrix was proposed as a parameter to characterize the suitability of a given instantaneous MIMO channel matrix for SDM compared to using STC. When the overall data rate is fixed whenever using SDM or STC, SDM is preferred when Eq. (2) is realized.

$$C_D \leq d_{min,SDM} / d_{min,STC} \quad (2)$$

where C_D is the Demmel condition number. The Demmel condition number is defined as

$$C_D = |H|_F \cdot |H^{-1}| \quad (3)$$

where $|H|_F$ and $|H^{-1}|$ are the Frobenius norm and 2-norm of the instantaneous inverse channel matrix, H. Terms $d_{min,SDM}$ and $d_{min,STC}$ are the square-root minimum Euclidean distance of the SDM and STC constellations, respectively. The formula of the $2^R QAM$ minimum Euclidean distance, $d^2_{min, R}$, is

$$d^2_{min,R} = 12/(2^R-1) \quad (4)$$

For example, the cases for *QPSK* and *16QAM* are $d^2_{min,2} = 4$ and $d^2_{min,4} = 4/5$, respectively. So, this can be used to calculate the threshold value as *2.2362*.

2.3.2 Narrowband characteristics of Demmel condition number

The cumulative probability of the Demmel condition number calculated from the simulation results is shown in Fig. 3. Designations (1) to (5) represent *VV-VV*, *VH-VH*, C_rC_l-C_rC_l, C_rC_r-C_rC_r, and VC_r-VC_r respectively. When comparing SDM (*QPSK*) and STC (*16QAM*), the rates where SDM (*QPSK*) is superior are 5.2%, 76.4%, 74.1%, 3.1%, and 10.6%. Based on these results, C_rC_l-C_rC_l exhibits superior characteristics to *VV-VV* and nearly equivalent characteristics to *VH-VH*.

3. MEASUREMENT OF 2X2 MIMO-OFDM CHANNELS TO EVALUATE COMBINATION EFFECT OF CIRCULAR AND LINEAR POLARIZATIONS

3.1 Measurement Apparatus and Parameter

The OFDM signal is transmitted from a mobile station, which comprises two antennas with synchronized transmitters, mounted on a positioner to a base station, which comprises two antennas, mounted on top of a pole. Each transmitter continuously transmits different OFDM test signals using a coded OFDM technique [6]. At the receiver, the received signals are down-converted and sampled at 20 MHz. The transmitter and receiver are synchronized to the same 10-MHz reference signal via a wired connection. The parameters for the measuring equipment are given in Table 1.

Measurements of the instantaneous 2x2 MIMO channel matrix are performed. A photograph of the measurement environment is shown in Fig. 4. The size of the room is 17 m x 28 m x 6 m, and the heights of the transmission and reception antennas are 1.8 m from the floor. The transmitters on the positioner traveled at a constant speed of 15 cm/sec. Since the positioner moves along on a fixed rail, all data are acquired in the same course. The received data are acquired every 25.6μsec. The antenna separation at both the base station and mobile station is 1 λ (= 6 cm) in each case. Omni-directional antennas are used for all base station and mobile station antennas. In the horizontal plane, the antenna XPD values for the vertical, horizontal, and circular polarizations are approximately 20 dB, 20 dB, and 15 dB, respectively. In the vertical plane, the antenna XPD values for the vertical, horizontal, and circular polarizations are approximately 20 dB, 20 dB, and 5 dB, respectively. The antenna composition is the same as in the simulation.

3.2 2x2 MIMO Channel Capacity

Fig. 5 shows the capacity computed from the experiment. In the experiment, when using a

combined circular polarized antenna array, a low capacity achieved. We consider that this is the reason for the high antenna XPD of the circular polarized antenna in the simulation.

3.3 SDM vs. STC

3.3.1 Narrowband characteristics on Demmel condition number

The Demmel condition number can be used to calculate the experimental instantaneous MIMO channel matrix. The cumulative probability is shown in Fig. 6. Designations (1) to (5) represent *VV-VV*, *VH-VH*, C_rC_l-C_rC_l, C_rC_r-C_rC_r, and VC_r-VC_r respectively. When comparing SDM (*QPSK*) and STC (*16QAM*), the rates where SDM (*QPSK*) is superior are 19.3%, 38.9%, 23.8%, 19.0%, and 23.5%. These results exhibit the same tendency as that in the simulation. The C_rC_l-C_rC_l is improved 1.233 times compared to *VV-VV*, and *VH-VH* is improved 2.015 times compared to *VV-VV*. Although C_rC_l-C_rC_l and *VH-VH* are almost equivalent in the simulation, a difference is exhibited in the measurement results. This is because of polarization rotation due to reflection and scattering waves in an actual space and the antenna XPD.

3.3.2 Wideband characteristics of Demmel condition number

Here, sub-carrier number 1 to 49 except sub-carrier number 25 is evaluated. All the sub-carriers for the Demmel condition number are calculated from the instantaneous spectrum and number of sub-carriers which is less than the threshold value of SDM (*QPSK*) and STC (*16QAM*) is counted. The cumulative probability is plotted from the number of sub-carriers, which is less than the threshold value acquired for each instance (Fig.7). Designations (1) to (5) represent *VV-VV*, *VH-VH*, C_rC_l-C_rC_l, C_rC_r-C_rC_r, and VC_r-VC_r respectively. When the cumulative probability is normalized to the value of VV at 50%, *VH-VH* is 2.37, C_rC_l-C_rC_l is 1.25, C_rC_r-C_rC_r is 1.13, and VCr-VC_r is 1.25, respectively.

4. CONCLUSIONS

The effect of the combined use of circular and linear polarizations for a 2x2 MIMO-OFDM system was evaluated using a ray-trace simulation and indoor measurements. Various combinations of polarization were examined. The Demmel condition number of a 2x2 MIMO-OFDM channel was calculated in order to reveal the suitability of SDM in a MIMO channel for each combination of polarization. The simulation and measurement results indicated a similar tendency in regard to the Demmel condition number. In other words, the MIMO channel when using *VH-VH* is the most suitable for SDM compared to the other combinations of polarization. The antenna arrays including a circular polarized antenna such as C_rC_l-C_rC_l or VC_r-VC_r are more suitable for SDM than when using the *VV-VV* antenna. A similar suitability trend for SDM was observed for the wideband case. Therefore, it is possible to obtain identical fading by using circular polarized antennas with V-pol. and H-pol. antennas when the MIMO antenna array comprises more than three branches.

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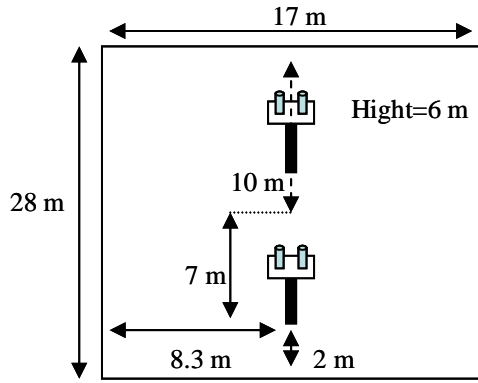
Figure 1. Experimental and simulation parameters

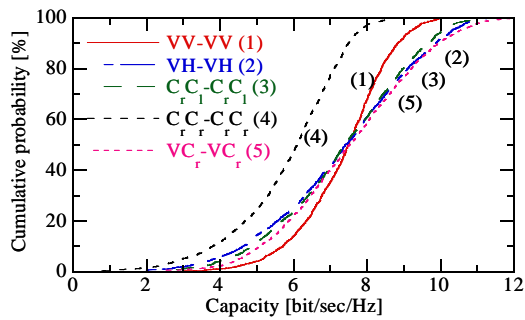Figure 4. Measurement environment
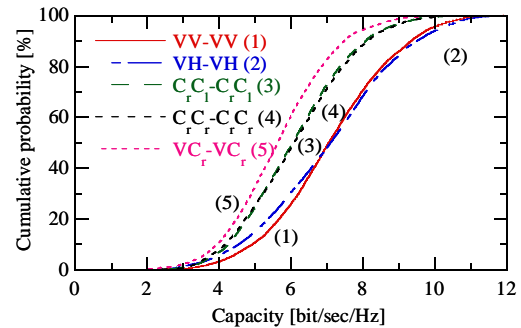

Figure 2. Channel capacity (Simulation)

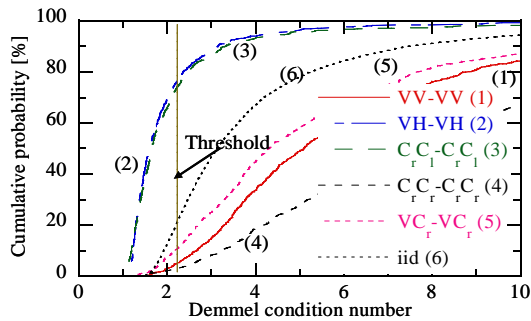Figure 5. Channel capacity (Experimental)

Figure 3. Demmel condition number (Simulation)

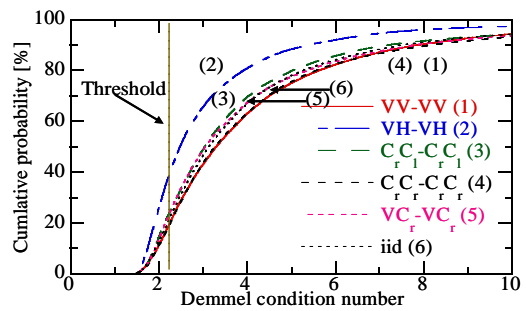Figure 6. Demmel condition number (Experimental)

Table 1. Measurement parameters

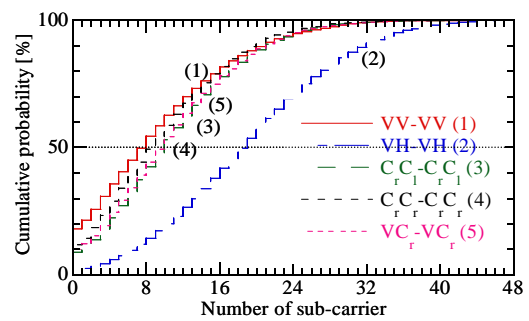| Center frequency	5.2 GHz (Bandwidth 7.5 MHz)
Transmit Antenna	V(XPD = 20 dB) H(XPD = 20 dB) C_r(XPD = 15 dB) C_l(XPD = 15 dB)
Receive Antenna	V(XPD = 20 dB) H(XPD = 20 dB) C_r(XPD = 15 dB) C_l(XPD = 15 dB)
Modulation	OFDM (Number of sub-carriers: 49)
Spectrum time resolution	25.6μs

Figure 7. Wideband experimental results