MIMO Channel Capacities of Polarized / Spatial Multiplexing with Human Effect to a Mobile Terminal in Suburban Area

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1. Introduction

In recent years, next generation systems have been actively studied to realize high speed and high capacity mobile communication. MIMO (Multiple-Input Multiple-Output) systems with a multiple-antenna on a transmitter and receiver are expected to achieve multi-stream transmission at the same time and frequency by taking advantage of the multi-path environment. The evaluation of MIMO channel capacity of a MIMO antenna for mobile terminals (MTs) including human effects have progressed in the past several field experiments [1]. However, it is insufficient to compare the MIMO channel capacities of orthogonal polarized and spatial multiplexing under a real field environment.

This paper evaluates the MIMO channel capacities of the orthogonal polarized/spatial multiplexing with human effect to a MIMO antenna for MTs through the field experiments in suburban area.

2. Field Experiments

The field experiments were conducted around KDDI R&D Laboratories at Fujimino-shi, SAITAMA Japan. This area is a typical Japanese suburban area with many one- or two-storey houses made of wood and concrete. A transmitting 2-branch MIMO antenna for base station (BS) was installed on the rooftop of KDDI R&D Laboratories whose height is 18m. The system configuration is shown in Fig.1. The polarized MIMO antenna is a orthogonal dual-polarized MIMO antenna consisting of horizontal and vertical polarized (H-V pol.) antenna elements; meanwhile, the spatial MIMO (V-V pol.) antenna consists of two vertical polarized antennas separated by 5λ. A MIMO antenna and receiver for MT were loaded onto a measurement vehicle. The route taken by the measurement vehicle is shown in Fig.2. The route is almost straight street and the distance from the Tx MIMO antenna of BS is from 270 to 680 m. The system specifiations of the MIMO measurement system are summarized in Table 1.

Fig. 3 shows the configuration of the MIMO antenna for MTs [2]. Two pairs of IFA (Inverted F Antenna) elements for 2127.5MHz are installed orthogonally in the diagonal position of a small ground plane 115 x 45 mm. The length and diameter of the IFA are 38 mm and 1.6mm, respectively. The VSWR (Voltage Standing Wave Ratio) and mutual coupling of each elements are less than 1.5 and -10 dB in 2127.5 MHz, respectively.

In the field experiments, the measurements of the MIMO antenna for MT not only without but also with ULCP (Ultra Light Carbon Phantom), that is the lightweight electromagnetic-equivalent phantom [3], under a user using situation was carried out. The installation of the MIMO antenna to ULCP is shown in Figs. 4. The ULCP was placed in the passsenger seat of the measurement vehicle and held the MIMO antenna in the talk position at an angle of 55 degrees to the zenith direction. In the case of measuring the MIMO antenna without ULCP, it was installed in a mobile teminal holder consisting of wood and plastic with a foamed polystyrene spacer in order to maintain the same position and angle as the measurement with ULCP.

3. MIMO channel capacity

The measured data consists of 2x2 channel matrices of 512 subcarriers with respect to the 1.25 ms OFDM frame. The analysis of the channel matrices is based on the theoretical 2x2 MIMO channel capacity *C*, in the case that the signals are transmitted with even power from each branch and without channel state information at BS transmitter, given by

$$C = E\left[\log\left\{\det\left(\frac{\gamma}{2}\mathbf{H}^{\mathrm{H}}\mathbf{H}+\mathbf{I}\right)\right\}\right] = \left[\sum_{i=1}^{2}\log\left(\frac{\lambda_i\gamma}{2}+1\right)\right] = E\left[\log\left(\frac{\gamma}{1+\lambda_R}+1\right)+\log\left(\frac{\lambda_R\gamma}{1+\lambda_R}+1\right)\right], \quad (1)$$

where γ is the averaged SNR (Signal-to Noise Ratio) received at the 2-branch MIMO antenna of MT, and **H** and **I** are the 2x2 channel matrix normalized by the averaged signal power received at 2-branch MIMO antenna and unit matrix, respectively. $^{\mathrm{H}}$ is defined by complex conjugate transposition. λ_i is the eigenvalues of the matrix $\mathbf{H}^{\mathrm{H}}\mathbf{H}$, where λ_1 is larger than λ_2 and the average is one. Defining the *eigenvalue ratio* λ_R given by λ_1/λ_2, the 2x2 MIMO channel capacity is given as a function with two variables, the averaged SNR γ and eigenvalue ratio λ_R. Then, the eigenvalue ratio λ_R is corresponded to the ratio of the signal powers received multi-stream MIMO transmission. Thus, if the eigenvalue ratio decreased, namely both eigenvalues were almost equal values, the high MIMO channel capacity with multi-stream transmission would be achieved.

From eq. (1), MIMO channel capacity is a function with the averaged SNR and eigenvalues ratio. Thus, the following analyses were performed with regard to these. In the data analyses, the each analysis term was averaged in 1 second (800 frames). Then, the averaged data were merged with GPS data and averaged at 15-meter intervals with respect of the distance from the BS.

4. Analysis Results

The SNR distance performances of the MIMO antenna are shown in Fig.5. The horizontal axis is the distance from BS. The circle and square marks are the performances of the polarized MIMO (H-V pol.) and special MIMO (V-V pol.), respectively. Then, bold and blank marks are the performances without and with ULCP, respectively. The SNRs were decayed depending on the distance from BS, but there were several distances where SNR was singularly high. This is because the distances were those corresponding to the line-of-sight (LOS) environment and the others were non-LOS. In comparing the performances without and with ULCP, there was a difference about 4dB. This is because the ULCP was not only obstructed the receiving signal, but also caused the decrease of antenna efficiency due to mismatch of antenna impedance [2].

Figures 6 (a) and (b) show the eigenvalue ratio distance performances and cumulative distribution of eigenvalue ratio, respectively. The eigenvalue ratio of the polarized MIMO (H-V pol.) was almost the same value as 9dB, but those of the spatial MIMO (V-V pol.) were increased to more than 12dB at several distances. Notably, these distances corresponded to the distances where SNR was singularly high. That is, the LOS environment caused the increase of the eigenvalue ratio of the spatial MIMO transmission (V-V pol.); meanwhile, the polarized MIMO transmission (H-V pol.) provided the stable low eigenvalue ratio performance. In addition, the performance with ULCP was slightly better than that without UCLP. This is because the head and hand of ULCP generated non-LOS and improved the eigenvalue ratio.

Figures 7 (a) and (b) show the averaged SNR versus MIMO channel capacity performances of the MIMO antenna without and with ULCP, respectively. For comparison, the theoretical limit of 2x2 MIMO and that of SISO are shown in black solid and dashed lines, respectively. In addition, the curves of the polarized and spatial MIMO approximated by the eq.(1) with the eigenvalue ratio are also shown in solid and dashed lines, respectively. The eigenvalues ratio of the curves in the case without ULCP were 10.6 and 12.9 dB, those in the case with ULCP were 10.3 and 12.4 dB, respectively. The measured data fall below the approximated curves as the SNR increases, because the eigenvalue ratios were increased in the case of the LOS environment. The MIMO channel capacities of the polarized and spatial MIMO (H-V pol. and V-V pol.) were almost 1.6 and 1.5 times greater than those of SISO in the averaged SNR 20 dB, respectively. Thus, the performance of the polarized MIMO (H-V pol.) was improved more than that of the spatial MIMO (V-V pol.) due to the improvement of the eigenvalue ratio. Meanwhile, there is small difference in the performance between without and with ULCP.

Finally, MIMO channel capacity distance performances and cumulative distribution are shown in Figs. 8 (a) and (b), respectively. The distance performances almost corresponded to those of the averaged SNR rather than the eigenvalue ratio. Thus, while it is important to enhance averaged SNR versus MIMO channel capacity performances by improving the eigenvalue ratio, the improvement of the averaged SNR performances is more significant. The cumulative distributions confirmed that the MIMO channel capacities of the polarized MIMO (H-V pol.) were about 1.5 bit/s/Hz better than that of the spatial MIMO (V-V pol.) due to the improvement of the eigenvalue ratio. In addition, it is notable that the MIMO channel capacities with ULCP was degraded about 2 bit/s/Hz more than that without ULCP due to the degradation of the averaged SNR. Therefore, while the ULCP improved the eigenvalue ratio slightly, the degradation depending on the averaged SNR was dominant for the effective MIMO channel capacity.

5. Conclusion

This paper described the MIMO channel capacities of the orthogonal polarized/spatial multiplexing with human effect to a MIMO antenna for MTs through the field experiments in suburban area. From the analysis results confirm that the polarized MIMO (H-V pol.) was superior to the spatial MIMO (V-V pol.). Specifically the MIMO channel capacities of the polarized MIMO (H-V pol.) were almost 1.6 times greater than that of SISO while those of spatial MIMO (V-V pol.) were 1.5 times in the averaged SNR 20 dB. Especially if the propagation environment is LOS, the eigenvalue ratio of the polarized MIMO (H-V pol.) was improved 2dB more than that of the spatial MIMO (V-V pol.). In addition, the human effect degraded the averaged SNR more than 4dB and the MIMO channel capacity more than 2 bit/s/Hz. Therefore, the design and evaluation of MIMO antennas regarding the human effect to increase the antenna efficiency is important for the improvement of MIMO channel capacity.

References

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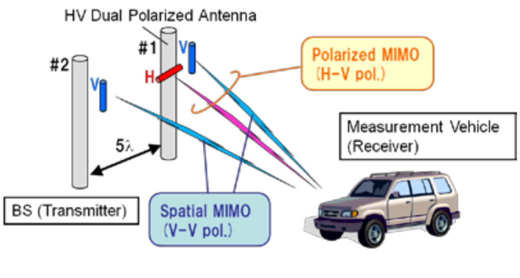


Figure 1: System configuration

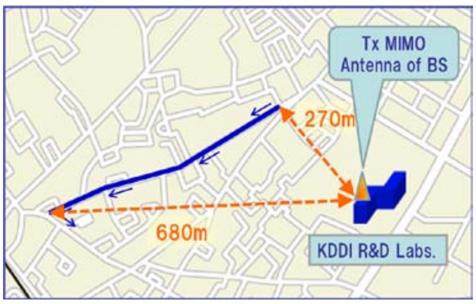


Figure 2: Measurement route.

Table 1: System specification

Carrier Frequency		2127.5 MHz
Transmit Power		1W per branch
Transmit Signal		
	Modulation	OFDM
	Subcarrier space	9.76kHz
	Number of carrier	512
	Guard interval length	25.6μs
	Symbol length	102.4μs
	Frame length	1.25ms
BS Transmit Antenna（H-V and V-V Pol. Sector）		
	Gain	17dBi
	Horizontal half- power beam width (HPBW)	80 deg
	Vertical HPBW	5 deg
	Distance between V pol. Antennas	5λ
	XPR (Cross polarization ratio)	20dB min. in HPBW

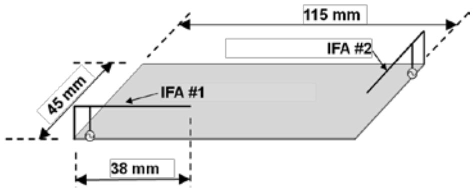
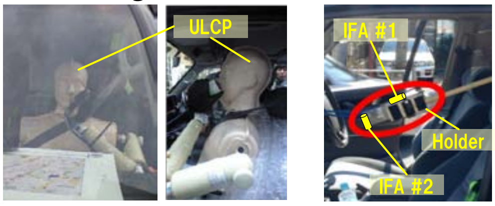


Figure 3: Configuration of MIMO antenna for MT.



Figures 4: Installation of MIMO antenna for MT.

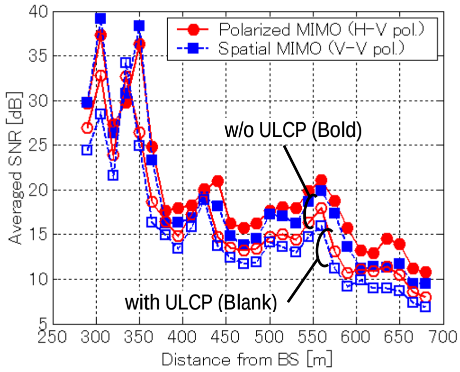
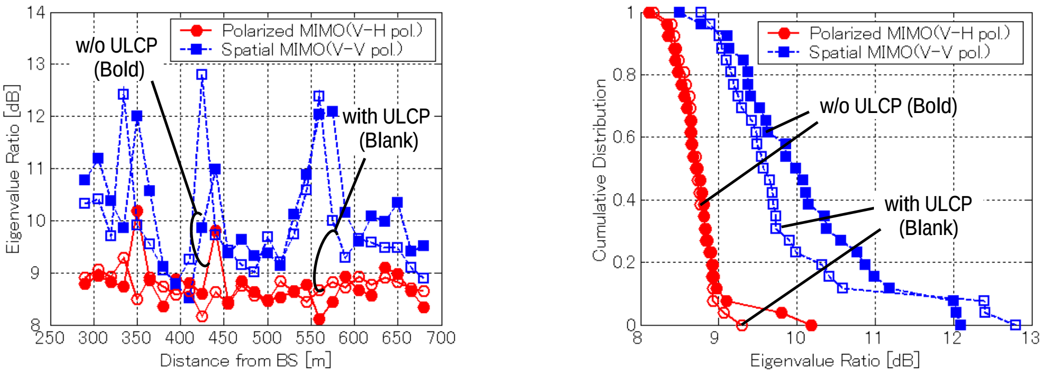


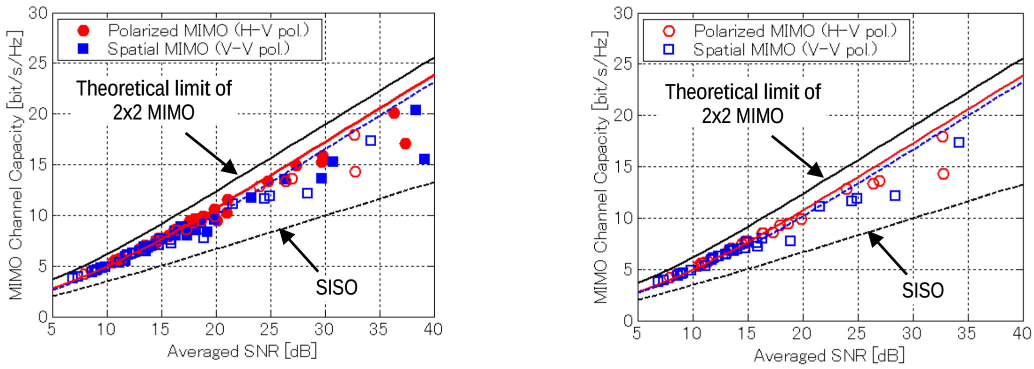
Figure 5: Averaged SNR distance performances.



(a) Distance performance

(b) Cumulative distribution

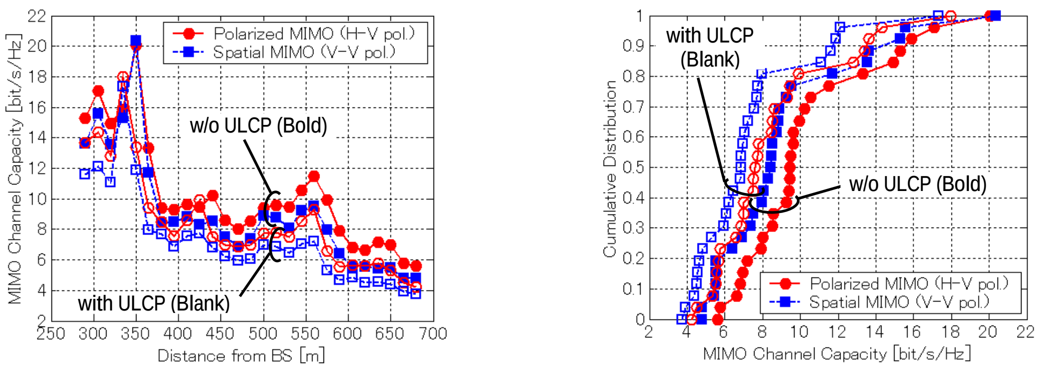
Figures 6: Eigenvalues ratio performances.



(a) w/o ULCP

(b) with ULCP

Figures 7: Averaged SNR versus MIMO channel capacity performances.



(a) Distance performance

(b) Cumulative Distribution

Figures 8: MIMO channel capacity performances.