Effectiveness of Short Range MIMO Transmission

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Introduction

Short range communication is key emerging field in wireless communication; examples include RF-ID, UWB (Ultra Wide Band), millimeter-wave high-speed communication, and so on. Recently, multiple-input-multiple-output (MIMO) technologies have been much attracted attention [1], because these can improve a frequency utilization with a limited frequency band. We proposed a short range transmission that utilizes MIMO techniques [2]. The channel capacity with an optimal element spacing exceeds the Ergodic capacity of the i.i.d. channel since the short range MIMO (SR-MIMO) scheme is very similar to parallel data transmission [2].

In this paper, the effectiveness of SR-MIMO transmission is evaluated. First, we describe the feature and concept of SR-MIMO. Next, we evaluate the channel capacity by using actual transmission methods which are generally used in MIMO systems. The channel capacity obtained through Zero Forcing (ZF) algorithm is almost same as that using Eignemode beamforming (EM-BF) when considering the optimum element spacing [2]. Then, we introduce the use of dual-polarized antenna, because dual-polarized MIMO configuration can not only reduce the antenna size but also improve the channel capacity compared to vertically-polarized MIMO configuration. The effectiveness of dual-polarized SR-MIMO transmission is finally evaluated using a 8×8 MIMO-OFDM testbed.

System model

Fig. 1 shows the comparison between basic concepts of general MIMO and SR-MIMO. General MIMO transmission shown in Fig. 1(a) can transmit multiple signal streams by utilizing the multipath-rich environment. Fig. 1(b) denotes the basic concept of SR-MIMO discussed in this paper. To achieve full-rank MIMO transmission, SR-MIMO utilizes the length differences among each path between transmitting (Tx) elements and receiving (Rx) elements. The signal streams are transmitted almost directly between opposing transmitting and receiving elements and the transmission lines are formed in parallel when the transmitting and receiving antenna arrays are in very close proximity. Though the transmission is not completely parallel because the signals reach elements other than the directly facing element, low spatial correlation can be achieved between adjacent elements because the signals that reach those elements have different phases and amplitudes depending on the path length differences. Hence, high channel capacity can be expected even if there are no multi-path waves.

In this paper, we assume that two facing identical array antennas, each of which is

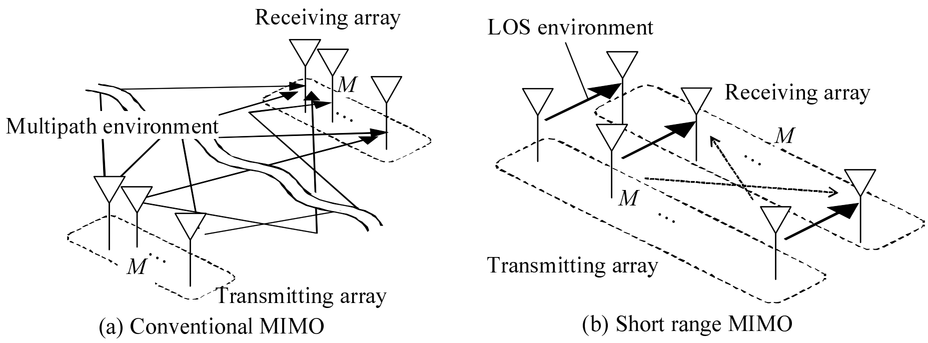

Figure 1: Conceptual diagram of short range MIMO.

a squarely arranged dipole array, are placed in parallel. The number of elements are given as $M_T = M_R = M$, the vertical and horizontal spacing of the antenna element are given equally as d; the array antennas are separated by D. Free space is defined between the array antennas in the simulation and experiment.

Complex signal processing such as singular value decomposition plus channel feed back or signal decoding such as MLD is required, in order to obtain the maximum channel capacity in the MIMO transmission. In this paper, the channel capacity and transmission rate are investigated when using actual transmission schemes in MIMO systems. We focus on EM-BF and ZF. The EM-BF can obtain the maximum channel capacity in the MIMO transmision. The ZF algorithm is well known as a simple decoding algorithm in MIMO transmission [1].

Channel capacity using actual transmission schemes

Fig. 2 shows the channel capacity versus array antenna spacing, d, with M=4. The antenna distance, D is set to be $1.6\lambda_0$ in Fig. 2. As can be seen in this figure, the highest channel capacity by the EM-BF is obtained regardless of d. This result confirms the optimal element spacing, d_{opt}, when considering the EM-BF and ZF. Moreover, the channel capacity by the ZF is almost same with that by the EM-BF with such an optimal element spacing with M=4. Moreover, the channel capacity of the the EM-BF or ZF with M=4 is the same with that on the upper bound. It is seen that the channel capacity without beamforming and/or interference cancellation is much smaller than that by EM-BF or ZF. Hence, a certain beamforming at the transmitter or inter-steam interference cancelation at the receiver is required even with the wide element spacing in the short range MIMO communication.

To clarify the mechanism of the short range MIMO communication, 1st to 4th eigenvalues versus the element spacing are plotted in Fig. 3. As can be seen in Fig. 3, all eigenvalues are almost identical when considering d_{opt} and these values are almost same with the SNR. This result indicates that identical modulation schemes can be adopted for all the data streams when using EM-BF using d_{opt}, because EM-BF can determine the modulation scheme level according to the size of the eigenvalue. The spatial correlations with d_{opt} ($d = 0.95\lambda_0$), $d = 0.5\lambda_0$ and $d = 5\lambda_0$ were 0.03, 0.86, 0.17, respectively. The channel capacity depends on both the SNR and spatial correlation. The channel capacity with the narrow element spacing is very small due to a very high spatial correlation even with a high SNR. On the other hand, the spatial correlation is well suppressed and the SNR is little lowered when d_{opt} is

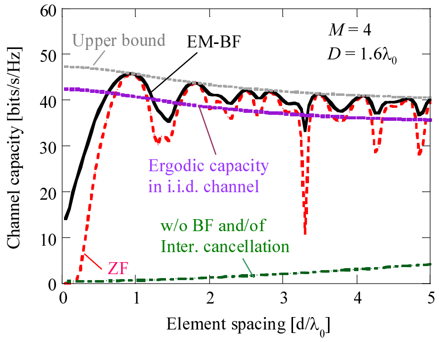

Figure 2: Channel capacity versus element spacing.

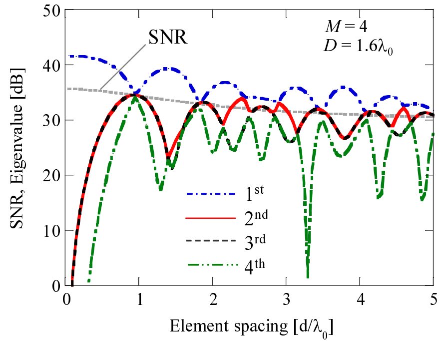

Figure 3: Eigenvalues and SNR versus element spacing.

adopted. By considering the wider element spacing, the spatial correlation can be suppressed but the SNR is also gradually decreased as shown in Fig. 3. Hence, the array using the wider element spacing yields lower channel capacity compared to that using d_{opt}.

Performance evaluation of dual polarized SR-MIMO

In this section, we demonstrate the effectiveness of using dual-polarized planar antennas as a means of miniaturizing SR-MIMO array antennas by measurements and analysis by using moment of method (MoM). Fig. 4 shows the measurement environment and MIMO testbed used in the experiment. 8×8 MIMO channel was measured. The center frequency was 4.85 GHz. Antennas with several element spacings, d, were used to verify the relationship between d_{opt} and the array distance, D. The values for d and D were set between 0.5∼1.5λ_0 and 1∼5λ_0, respectively. The gain of the micro strip antenna (MSA) elements was approximately 6∼7 dBi and fluctuated with the element spacing. The substrate thickness was 2.4 mm, and the relative permittivity was 2.2. In order to verify the effectiveness of SR-MIMO transmission, we used an actual signal specified in the IEEE802.11n/ac standards. Further details regarding this testbed are described in [3]. The EM-BF and ZF are adopted.

Fig. 5 shows the measured frequency utilization obtained for dual-pol and V-pol. The transmit distance is $2\lambda_0$. First, we confirm that the measured frequency utilization well matches that obtained from the MoM. As shown in Fig. 5, the frequency utilization of transmission of ZF is much lower than that of EM-BF when considering V-pol. SR-MIMO. On the other hand, the frequency utilization of transmission of ZF is improved in dual-pol SR-MIMO and the difference between the EM-BF and ZF in dual-pol SR-MIMO is smaller than that in V-pol SR-MIMO, because the transmission rate is decreased by the ZF without transmit beamforming when the spatial correlation is high. Hence, dual-pol SR-MIMO is particularly useful when transmission beamforming is not performed.

Fig. 6 deceits measured frequency utilization versus transmission distance. The antenna size, $\sqrt{A}$ is 1.0λ_0 here. For example, when $D = 3\lambda_0$, performance improvements by applying dual-pol are 12.6 bit/s/Hz without beamforming and 5.0 bit/s/Hz with beamforming. Throughout the transmission distance, the improve-

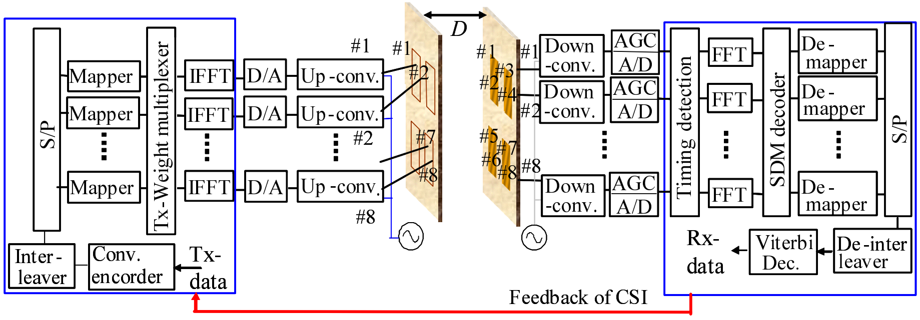

Figure 4: MIMO testbed and measurement scenario.

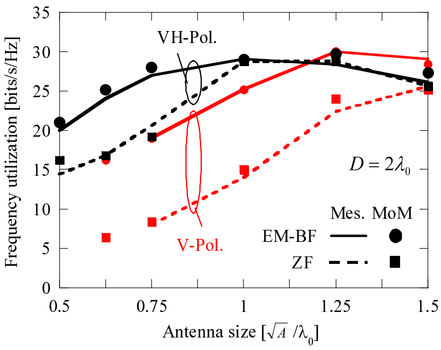

Figure 5: Frequency utilization versus element spacing.

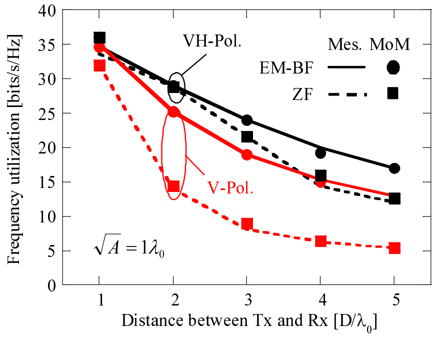

Figure 6: Frequency utilization versus transmit distance.

ment is larger without than with transmission beamforming. It is clear that the application of dual-pol on SR-MIMO is effective in improving frequency utilization performance.

Conclusion

In this paper, the effectiveness of SR-MIMO transmission was investigated by the capacity evaluation and measurement using signals on IEEE802.11n standard. When the optimal element spacing is obtained, the channel capacity when employing ZF is shown to be almost the same as that when using EM-BF. Moreover, we clarified the dual-polarized SR-MIMO can not only reduce the antenna size but also improve the frequency utilization compared to the vertically-polarized SR-MIMO. In particular, the effectiveness with the dual-polarized SR-MIMO was demonstrated when using the ZF.

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