Experimental Evaluation of Inter-Array Decoupling Technique Suitable for MIMO Full-Duplex System

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Abstract **– In this paper, we discuss the inter-array decoupling technique suitable for MIMO full-duplex, which uses a combination of the end-fire antenna arrangement and eigen-beamforming. An experimental evaluation clarifies that the end-fire antenna arrangement contributes to the reduction of the inter-array coupling by 18.7 dB compared with the facing antenna arrangement, and that the small antenna aperture of the array brings the significant interference reduction by the beamforming.**

Index Terms **— MIMO, full duplex, inter-array coupling, interference reduction, end-fire arrangement.**

1. Introduction

An upcoming 5-th generation (5G) wireless system demands the evolution in a significant increase of capacity as well as the kinds of devices[1]. Some recent works try to reuse spectrum resources by spatial approaches[2][3]. The authors have investigated the multiple-input multiple-output (MIMO) full-duplex communication systems as one of the key technologies of the spectrum efficiency enhancement[4]. MIMO has the capability to deal with lots of traffic and devices with high spectrum efficiency; however, a *self-interference* problem avoids us from realization of the full duplex communication, which will offer further high spectrum efficiency. The self-interference in MIMO full-duplex system is caused by the inter-array coupling between the transmitter and receiver since the transmitting and receiving arrays would be arranged at the close locations.

The authors have proposed the simple solution for mitigating the inter-array coupling, where all antenna elements of the transmitting and receiving arrays are arranged in line (end-fire antenna arrangement) and a null is formed using the orthogonal weights (eigen-beamforming), and the simulation revealed that proposed system is expected to reduce the interference by over 100 dB.

In this paper, we demonstrate some experimental results of the proposed system, which is compared to a system with the different antenna arrangement. To discuss the physical mechanism of the proposed method, the eigenvalues of the self-interference channel are presented, and the radiation patterns with of the decoupled modes are shown.

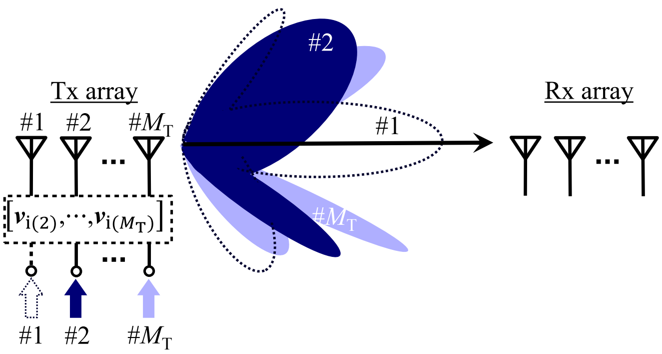


Fig. 1. Conceptual sketch of the proposed self-interference reduction technique: weighted Tx array nulls a direction to Rx array with a cost of one MIMO stream.

2. Inter-Array Decoupling Technique Suitable for MIMO Full-Duplex

Fig. 1 shows a conceptual sketch of the proposed inter-array decoupling technique, where a transmitting (Tx) array consisting of M_T elements is weighted to form a null to the receiving (Rx) array direction. Assume the Tx and Rx array to be in a same base station and use same frequency bands. The terminal saves a half of spectrum resources by full duplex communication, however, *loud* signals from the Tx hide *whispering* signals from other terminals (self-interference). This interference is hard to be suppressed in a usual MIMO system due to its multi-stream signals.

Our key idea to reduce the interference has the following two steps:

(i) degenerating coupling modes between Tx and Rx,
(ii) cutting the dominant coupling mode.

The eigen-beamforming can realize (ii), to be more specific, orthogonal transmitting weights ($\boldsymbol{v}_{i(1)},\ldots,\boldsymbol{v}_{i(M_T)}$) are given by a singular value decomposition (SVD) of a channel matrix between Tx and Rx, where $\boldsymbol{v}_{i(1)}$ means a weight vector corresponding to the dominant coupling mode. Then, the MIMO transmission with $\boldsymbol{v}_{i(2)},\ldots,\boldsymbol{v}_{i(M_T)}$ does not couple to the receiving array, and this can be realized with a cost of one MIMO stream mode.

We have already found the end-fire antenna arrangement suitable for (i) by the calculation. When the Tx and Rx linear array antennas are arranged with the same element spacing in line, ideally, the unique channel matrix with only one eigenvalue is realized.

3. Experimental Evaluation

(1) Measurement Conditions

In order to know an actual effect of the self-interference, we experimented on the proposed system with prototype antennas. Because the step (ii) can be imitated by the digital post-processing, the experiment focused on (i), which was evaluated by the measured interference channel and complex directivities. Fig.2 shows two antenna arrangements dealt with in this study. The element spacing and distance between Tx and Rx were assumed as $0.5\lambda_0$ and $10\lambda_0$ (λ_0: wavelength in a vacuum), respectively. The arrays consisted of four sleeve dipole antenna elements. We used a vector network analyzer (VNA), where the frequency was set to 2.47125 GHz.

(2) Experimental Results

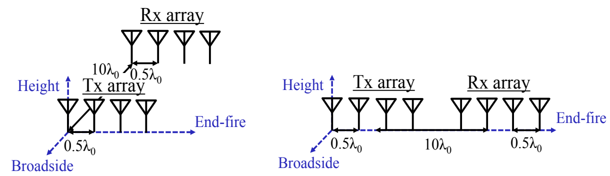
Here, the residual self-interference power after the step (ii) is defined as $P_i = (\lambda_2 + \lambda_3 + \lambda_4)/4$, where λ_k denotes the kth eigenvalue of the self-interference channel matrix. Table I shows eigenvalues of the self-interference channel matrix with P_i, given by the calculation and measurement using models in Fig. 2(a) and (b). According to the difference between λ_1 and $\lambda_2 \sim \lambda_4$, the end-fire antenna arrangement makes the coupling modes more degenerated than the facing antenna arrangement does. Owing to the end-fire antenna arrangement, the self-interference can be reduced by 18.7 dB from the facing antenna arrangement, where $P_\mathrm{i} = -65.9$ dB.

Fig. 3 and 4 show the horizontal radiation patterns with the weights from the models in Fig. 2 (a) and (b), where the facing and end-fire antenna arrangement null the broadside and end-fire direction, respectively. Both of the antenna arrangements form nulls to the Rx's direction by cutting the 1st mode, however, the facing antenna arrangement couples slightly because the antenna aperture of the Rx seen from the Tx is much larger than that of the end-fire antenna arrangement. Therefore the facing antenna arrangement cannot suppress the interference sufficiently with respect to the proposed scenario.

4. Conclusion

This paper has discussed the inter-array decoupling technique suitable for MIMO full-duplex, which uses a combination of the end-fire antenna arrangement and eigen-beamforming. An experimental evaluation clarified that the end-fire antenna arrangement contributes to the inter-array decoupling by 18.7 dB from the facing antenna arrangement, where the coupling between end-fire-arranged arrays can be weakened to $P_\mathrm{i} = -65.9$ dB. And the horizontal radiation patterns gave us an important idea, i.e. the small antenna aperture of the array brings the significant interference reduction by the beamforming.

Acknowledgment



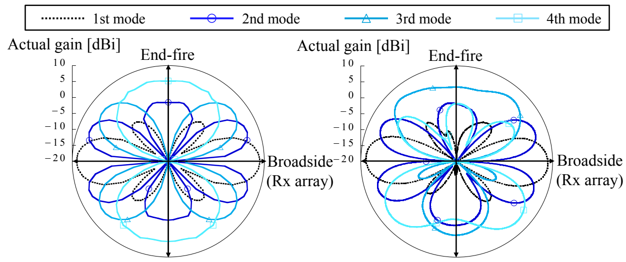
(a) Facing arrangement (b) End-fire arrangement

Fig. 2. Models of two antenna arrangements.

TABLE I

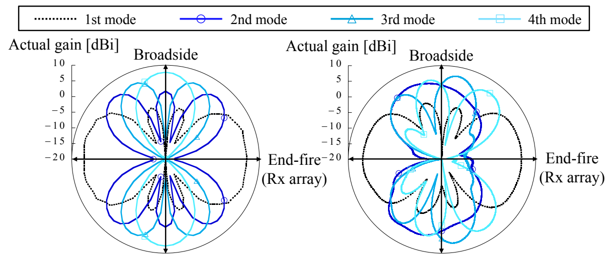
Eigenvalues of self-interference channel matrix

Eigenvalue(s) [dB]		λ_1	λ_2	λ_3	λ_4	P_i
(a)	Calc.	−24.8	−39.8	−64.4	−100.2	−45.8
	Meas.	−25.8	−41.2	−66.8	−72.5	−47.2
(b)	Calc.	−29.6	−76.1	−128.9	−156.1	−82.2
	Meas.	−33.0	−61.7	−64.6	−78.1	−65.9



(a) Calculation (b) Measurement

Fig. 3. Horizontal radiation patterns with weights to null *broadside* direction.



(a) Calculation (b) Measurement

Fig. 4. Horizontal radiation patterns with weights to null *end-fire* direction.

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