Antenna Selection for Full-Duplex MIMO Systems

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Abstract: In this paper, we investigate an antenna selection (AS) method for full-duplex multiple-input multiple-output systems, in which antennas at each node can be selected to either transmit or receive. In this configuration, we analyze the average sum rate of the optimal AS scheme which finds the best antenna set solution by examining all the possible candidates. The result provides insight on which transmit and receive antenna configuration improves the average sum rate performance of the AS scheme. From simulation results, we verify that our analysis matches the numerical results, and a sub-optimal AS scheme which chooses an antenna set maximizing the sum rate under the derived antenna configuration provides a near-optimal performance.

Keywords—**full-duplex, antenna selection**

1. Introduction

Full-duplex (FD) communication systems have attracted much attention because they can provide better spectral efficiency than conventional half-duplex systems. Since the FD protocol performs transmission and reception on the same frequency band at the same time, the performance may be degraded by self-interference (SI) generated from each nodes own transmit antennas. Several recent studies described SI cancellation techniques and demonstrated the feasibility of FD systems experimentally [1].

In the meantime, multiple-input multiple output (MIMO) wireless systems have been widely studied to increase spectral efficiency [2][3]. Among several schemes for MIMO systems, antenna selection (AS) methods have been considered promising for improving system performance. Many studies have reported adoption of the AS method in FD systems [4]. [4] provided AS schemes which select a single transmit and a single receive antenna for FD systems with two antennas at each node. However, the schemes in [4] was limited to single-stream transmission environments, so it is not easy to apply to general multiple-stream cases.

In this paper, we investigate an AS method for FD MIMO systems in which each node has multiple transmit and receive antennas. Unlike the works in [4], this paper considers a general multiple-stream transmission scenario. We analyze the average sum rate of the optimal AS scheme which selects the best antenna set by conducting an exhaustive search. The result provides insight on which transmit and receive antenna configuration maximizes the average sum rate performance. Simulation results confirm that our derived analysis matches the numerical simulations well, and a sub-optimal AS scheme which chooses an atenna set maximizing the sum rate under the derived antenna configuration provides a near-optimal performance.

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2. System Model

We consider bidirectional FD MIMO systems in which two FD nodes transmit and receive signals on the same frequency band at the same time. It is assumed that each antenna can be set to either transmit or receive. Let us define the numbers of transmit and receive antennas at node $i (i = 1, 2)$ are represented by $N_{t,i}$ and $N_{r,i}$, respectively, with $N_{t,i} + N_{r,i} = N_i$, where N_i represents the total number of antennas at node i. Further, we use the notation $\mathcal{S}$ to indicate a certain antenna set selection candidate and denote $\mathcal{A}$ to represent the set of all possible antenna set candidates $\mathcal{S}$. The channel from node $\bar{i}$ to node i for a given $\mathcal{S}$ is modeled as $\mathbf{H}_{i\bar{i}}(\mathcal{S})$ with $\bar{1} = 2$ and $\bar{2} = 1$, and the SI channel at node i is denoted by $\mathbf{H}_{ii}(\mathcal{S})$.

Then, the received signal at node i is given by

$$\mathbf{y}_i(\mathcal{S}) = \sqrt{P_{\bar{i}}}\mathbf{H}_{i\bar{i}}(\mathcal{S})\mathbf{x}_{\bar{i}}(\mathcal{S}) + \sqrt{P_i}\mathbf{H}_{ii}(\mathcal{S})\mathbf{x}_i(\mathcal{S}) + \mathbf{n}_i(\mathcal{S}),$$

where $\mathbf{x}_i(\mathcal{S})$ defines the transmitted signal for a given $\mathcal{S}$ with $\mathbb{E}\{\mathbf{x}_i(\mathcal{S})\mathbf{x}_i(\mathcal{S})^H\} = 1/N_{t,i}\mathbf{I}_{N_{t,i}}$. Further, $\mathbf{n}_i(\mathcal{S})$ denotes the additive white Gaussian noise with $\mathbb{E}\{\mathbf{n}_i(\mathcal{S})\mathbf{n}_i(\mathcal{S})^H\} = \sigma_n^2\mathbf{I}_{N_{r,i}}$, and P_i stands for the transmit power. Then, the achievable rate at node i for a given $\mathcal{S}$ can be written as

$$\begin{aligned} R_i(\mathcal{S}) = \log_2 |\mathbf{I}_{N_{r,i}} &+ \gamma_{\bar{i}}\mathbf{H}_{i\bar{i}}(\mathcal{S})\mathbf{H}_{i\bar{i}}(\mathcal{S})^H \\ &\times \left(\sigma_n^2\mathbf{I}_{N_{r,i}} + \gamma_i\mathbf{H}_{ii}(\mathcal{S})\mathbf{H}_{ii}(\mathcal{S})^H\right)^{-1}|, \end{aligned}$$

where $\gamma_i \triangleq P_i/N_{t,i}$.

3. Performance Analysis

In this section, we analyze the average sum rate of the optimal AS scheme $\bar{R}_{opt} \triangleq \mathbb{E}\left[\mathbb{R}(\mathcal{S}^*)\right]$, where $R(\mathcal{S}) = R_1(\mathcal{S}) + R_2(\mathcal{S})$ and $\mathcal{S}^* = \arg\max_{\mathcal{S}\in\mathcal{A}} R(\mathcal{S})$. Let us define $\mathcal{S}_j \in \mathcal{A}$ as the j-th element of $\mathcal{A}$ for $j = 1, \cdots, \hat{N}_c$, where $\hat{N}_c = (2^{N_1} - 2)(2^{N_2} - 2)$ is the number of all the possible antenna set candidates. Then, the average sum rate of the optimal AS scheme can be expressed as

$$\begin{aligned} \bar{R}_{opt} &= \mathbb{E}\left[\max_{j=1,\cdots,\hat{N}_c} R(\mathcal{S}_j)\right] \approx \mathbb{E}\left[\log_2 \sum_{j=1}^{\hat{N}_c} 2^{R(\mathcal{S}_j)}\right] \quad (1) \\ &= \mathbb{E}\left[\log_2 \sum_{j=1}^{\hat{N}_c}\prod_{i=1}^{2} D_i(\mathcal{S}_j)\right], \quad (2) \end{aligned}$$

where (1) comes from the max-log approximation, which is tight in the high signal-to-noise ratio (SNR) regime, and $D_i(\mathcal{S}_j) \triangleq |\mathbf{I}_{N_{r,i}} + \gamma_{\bar{i}}\mathbf{H}_{i\bar{i}}(\mathcal{S}_j)\mathbf{H}_{i\bar{i}}(\mathcal{S}_j)^H(\sigma_n^2\mathbf{I}_{N_{r,i}} + \gamma_i\mathbf{H}_{ii}(\mathcal{S}_j)\mathbf{H}_{ii}(\mathcal{S}_j)^H)^{-1}|$.

Since (2) still has a complicated form, it is difficult to obtain any insight on the optimal AS scheme. Thus, by applying the relation between the arithmetic and geometric means to (2), we further derive (2) as

$$\begin{aligned} \bar{R}_{opt} &\approx \log_2 \hat{N}_c + \mathbb{E}\left[\frac{1}{\hat{N}_c}\sum_{j=1}^{\hat{N}_c}\log_2\prod_{i=1}^{2}D_i(\mathcal{S}_j)\right] \\ &= \log_2 \hat{N}_c + \mathbb{E}\left[\frac{1}{\hat{N}_c}\sum_{j=1}^{\hat{N}_c}\{R_1(\mathcal{S}_j)+R_2(\mathcal{S}_j)\}\right] \\ &= \log_2 \hat{N}_c + \bar{R}_{conv}, \end{aligned} \tag{3}$$

where $\bar{R}_{conv} \triangleq \mathbb{E}\left[\frac{1}{\hat{N}_c}\sum_{j=1}^{\hat{N}_c}R(\mathcal{S}_j)\right]$ represents the average sum rate of conventional FD systems that select an antenna set randomly over $\hat{N}_c$ candidates. From (3), we conclude that the optimal AS scheme provides an average sum rate performance gain of $\log_2 \hat{N}_c$ compared to conventional FD systems. Note that this average sum rate gain is independent of the SI power and increases as the number of antennas N_i grows.

When the number of transmit and receive antennas is given, i.e., $N_{t,i}$ and $N_{r,i}$ for $i = 1, 2$ are fixed, we can rewrite (3) as

$$\begin{aligned} &\bar{R}_{opt}(N_{t,i}, N_{r,i}) \\ &\qquad \approx \log_2 N_c(N_{t,i}, N_{r,i}) + \bar{R}_{conv}(N_{t,i}, N_{r,i}), \end{aligned} \tag{4}$$

where $\bar{R}_{opt}(N_{t,i}, N_{r,i})$ and $\bar{R}_{conv}(N_{t,i}, N_{r,i})$ denote the average sum rate of FD systems with the optimal AS scheme and conventional FD systems for a given $N_{t,i}$ and $N_{r,i}$, respectively, and $N_c(N_{t,i}, N_{r,i}) = \binom{N_{t,1}+N_{r,1}}{N_{t,1}}\binom{N_{t,2}+N_{r,2}}{N_{t,2}}$ indicates the number of antenna set candidates.

From (4), we can see that the performance of the AS scheme can be improved by maximizing the number of antenna set candidates $N_c(N_{t,i}, N_{r,i})$. Utilizing Pascal's triangle, it can be shown that $N_{t,i}$ and $N_{r,i}$ maximizing $N_c(N_{t,i}, N_{r,i})$ under the antenna constraint $N_{t,i} + N_{r,i} = N_i$ $(i = 1, 2)$ are obtained as

$$\{N_{t,i}^*, N_{r,i}^*\} = \begin{cases} \left\{\frac{N_i}{2}, \frac{N_i}{2}\right\}, & \text{if} \quad N_i \text{ is even}, \\ \left\{\frac{N_i \pm 1}{2}, \frac{N_i \mp 1}{2}\right\}, & \text{if} \quad N_i \text{ is odd}. \end{cases} \tag{5}$$

It is interesting to note that if the number of transmit and receive antennas is set according to (5), we can not only improve the performance of FD systems compared to conventional FD systems, but also reduce the search size of the optimal AS scheme to $\binom{N_1}{\frac{N_1}{2}}\binom{N_2}{\frac{N_2}{2}}$ for even N_1 and N_2.

4. Simulation Results

In this section, numerical results are provided to evaluate the performance of AS scheme in FD MIMO systems. Now, we set $P_1 = P_2 = P$, $N_1 = N_2 = N$, and the SNR is defined as P/σ_n^2. We assume a spatially uncorrelated Rayleigh fading model for the channel matrices between two nodes $\mathbf{H}_{i\bar{i}}$ with zero mean and unit variance. Also, we consider the Rician fading environment for the SI channel such that the elements of the SI channel matrix $\mathbf{H}_{ii}$ are i.i.d. complex Gaussian random variables with mean $\sqrt{\sigma_{SI}^2 K/(1+K)}$ and variance $\sigma_{SI}^2/(1+K)$, where σ_{SI}^2 is the SI power and K equals the Rician factor, which is set to $\sigma_{SI}^2 = -20dB$ and $K = 1$ [5].

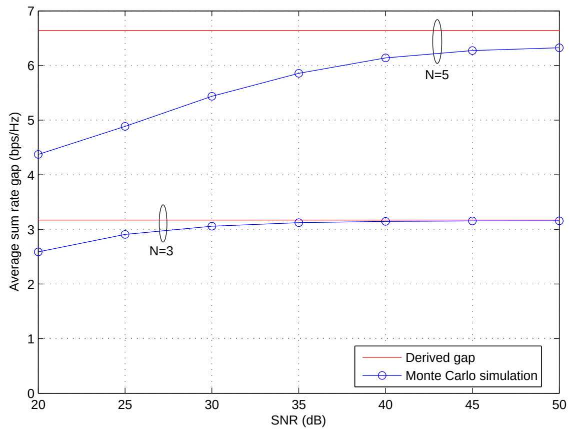

Figure 1. Performance gain of the optimal AS scheme over conventional FD systems.

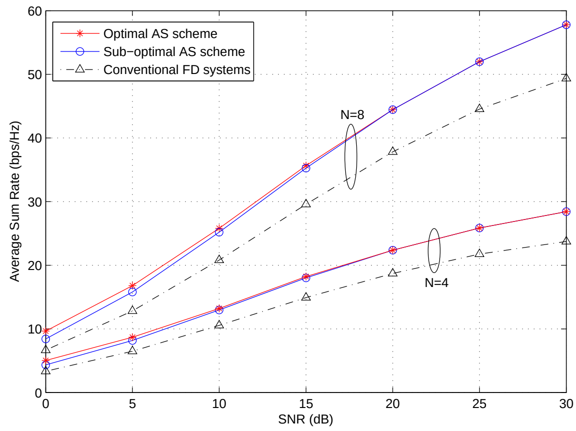

Figure 2. Average sum rate as a function of SNR.

Figure 1 depicts the average sum rate gap between the optimal AS scheme and conventional FD systems. The plot shows that our derived gap agrees well with the Monte Carlo simulations in the high SNR regime. Moreover, we can see that the gain grows as the number of antenna at each node increases.

Figure 2 shows the average sum rate performance of the optimal AS scheme and sub-optimal AS scheme which chooses an antenna set maximizing the sum rate under the antenna configuration (5). We observe that the sub-optimal AS scheme exhibits almost the same performance with reduced complexity compared to the optimal AS scheme and outperforms conventional FD systems for all simulated cases.

5. Conclusion

In this paper, we have investigated an AS method for FD MIMO systems. We have analyzed the performance of the optimal AS scheme. From this result, we have obtained insight on the antenna configuration. From the numerical simulations, we have confirmed that the analytical result agrees well with the simulation results and a sub-optimal scheme provides a near-optimal performance.

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