A Study on the Dual-mode Antenna Selection for Spatial Multiplexing Systems with Linear Receivers

Woong-Bi Lee, *Heung-No Lee[1)]

School of Information and Communications

Gwangju Institute of Science and Technology

wblee@gist.ac.kr, *heungno@gist.ac.kr,

선형 수신기를 이용한 Spatial Multiplexing 시스템의 듀얼모드 안테나 선택에 관한 연구

이웅비, *이흥노

광주과학기술원 정보통신공학부

Abstract

Spatial multiplexing with linear receivers is simple technique that increases capacity of multiple-input multiple-output(MIMO) communication system by transmitting different data through different antennas. However, spatial multiplexing systems cannot achieve additional diversity gain because mulitplexing gain and diversity gain are tradeoff. In this paper, it is shown that choosing either spatial multiplexing with all transmit antennas or single best antenna provides both diversity gain and multiplexing gain.

1. Introduction

In multiple-input multiple-output(MIMO) wireless communication, spatial multiplexing is widely used to increase capacity by dividing incoming data into multiple substreams and allocating each substream to a different transmit antenna[1]. However, in Rayleigh fading channels, spatial mulitplexing with low-complexity linear receivers suffers lack of diversity gains. Therefore, using only spatial multiplexing is not efficient under fading channels. In such case, given perfect channel state information from receivers, selecting an optimal subset of all antennas has been studied[2]. In prior work, it is proved that optimal antenna selection with fixed data rate and fixed number of selecting antennas, provides selection diversity to the system[3], [4].

This paper shows that selecting either spatial multiplexing with all the transmit antennas or selection diversity with single best transmit antenna improves not only the multiplexing gain but also the diversity gain.

2. System Model

2.1 System model of Spatial multiplexing

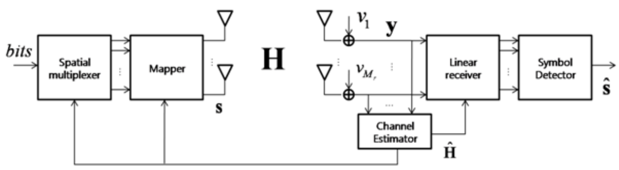

Fig 1. Overall system model of an antenna selection system for spatial multiplexing with linear receiver

Spatial multiplexing system of MIMO communication with M_t-transmit antennas and M_r-receive antennas is shown in Fig. 1.

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The system is composed of a spatial mulitplexer, bits-to-symbol mapper, propagation channel, channel estimator, linear receiver, and symbol detector. Feedback channel exists in order to send information of the number of selecting antennas and optimal subset matrix($\mathbf{W}_{M,p}$). Received signal vector is

$$\mathbf{y}_k = \sqrt{E_S}\mathbf{H}\mathbf{W}_{M,p}\mathbf{s}_k + \mathbf{v}_k \tag{1}$$

at symbol period k, where transmitted symbol vector $\mathbf{s}_k = [s_{k,1}, s_{k,2}, \cdots, s_{k,M}]^T$, channel matrix $\mathbf{H}$, complex Gaussian noise $\mathbf{v}_k$ and average transmit energy E_s. At the receiver, received vector $\mathbf{y}_k$ is multiplied by the linear equalizer matrix $G = (\mathbf{H}\mathbf{W}_{M,p})^{\dagger}$. Fixed data rate(R), flat-fading channel, zero-delay and zero-error feedback link, and perfect channel knowledge are assumed.

2.2 Performance analysis

Selection is defined with respect to error probability at the receiver.

A. Performance With Spatial Multiplexing

Vector symbol error rate(VSER) using nearest neighbor upper bounds (NNUBs) on spatial multiplexing is

$$P_e^{(m)}(H) \le 1 - \left(1 - N_e(M_t, R) \times Q\left(\sqrt{\min_{1\le k\le M_t} SNR_k(M_t, 1)\frac{d_{\min}^2(M,R)}{2}}\right)\right)^{M_t} \tag{2}$$

where $N_e(M,R)$ is average number of nearest neighbors of constellation and

$$SNR_k^{(ZF)} = \frac{E_s}{N_o}\frac{1}{[H^H H]_{kk}^{-1}} \tag{3}$$

B. selection diversity

VSER using NNUBs on selection diversity is

$$\begin{aligned} P_e^{(s)}(\mathbf{H}) &\le N_e(1,R)\min_{1\le p\le M_t} Q\left(\sqrt{SNR_1(1,p)\frac{d_{\min}^2(1,R)}{2}}\right) \\ &= N_e(1,R)Q\left(\sqrt{\max_{1\le p\le M_t}\frac{E_S}{N_0}\|\mathbf{h}_p\|^2\frac{d_{\min}^2(1,R)}{2}}\right) \end{aligned} \tag{4}$$

where $\mathbf{h}_p$ is p-th column of $\mathbf{H}$.

3. Dual-mode antenna selection

From error probability point of view, dual-mode selection chooses either spatial mulitplexing with all transmit antennas or selection diversity with single best transmit antenna[5].

A. Vector symbol error rate-based selection

From (2) and (4), this selection criterion chooses spatial multiplexing when $P_e^{(m)} < P_e^{(s)}$ or selection diversity otherwise. This criterion comes from tight upper bound of VSER. However, its is difficult to implement due to complex Q-function.

B. Post-Processing SNR-based selection

By neglecting the nearest neighbor terms $N_e(1,R), N_e(M_t,R)$ in first criterion, we obtain second selection criterion. This selection criterion chooses spatial multiplexing when

$$d_{\min}^2(M_t,R)\min_{1\le k\le M_t} SNR_k(M_t,1) \ge d_{\min}^2(1,R)\max_{1\le p\le M_t} SNR_1(1,p) \tag{5}$$

otherwise chooses selection diversity.

C. Condition Number-based selection

During equalizing the channel effects at linear receiver, channel equalizer uses computation of $\mathbf{H}^H\mathbf{H}$. This term can be useful for determining selection. According to the Rayleigh-Ritz theorem[6], denominator term in (3) can be bounded as

$$\begin{aligned} \max_{1\le k\le M_t}\left[\mathbf{H}^H\mathbf{H}\right]_{kk}^{-1} &= \max_{1\le k\le M_t}\mathbf{e}_k^H\left[\mathbf{H}^H\mathbf{H}\right]_{kk}^{-1}\mathbf{e}_k \\ &\le \max_{1\le k\le M_t} x^H\left[\mathbf{H}^H\mathbf{H}\right]_{kk}^{-1}x \\ &= \lambda_{\max}\left(\left[\mathbf{H}^H\mathbf{H}\right]^{-1}\right) \\ &\le \lambda_{\min}^{-2}(\mathbf{H}) \end{aligned} \tag{6}$$

Using (6), minimum SNR of spatial multiplexing becomes

$$\min_{1\le k\le M_t} SNR_k^{(ZF)}(M_t,1) \ge \frac{E_S}{N_0}\lambda_{\min}^2(\mathbf{H}) \tag{7}$$

As a similar manner, selection diversity can be bounded.

$$\begin{aligned} \max_{1\le k\le M_t}\|\mathbf{h}_k\|^2 &= \max_{1\le k\le M_t}\mathbf{e}_k^H\left[\mathbf{H}^H\mathbf{H}\right]\mathbf{e}_k \\ &\le \max_{1\le k\le M_t}\mathbf{x}^H\left[\mathbf{H}^H\mathbf{H}\right]_{kk}^{-1}\mathbf{x} \\ &= \lambda_{\max}(\mathbf{H}) \end{aligned} \tag{8}$$

Maximum SNR of selection diversity is represented by

$$\max_{1\le p\le M_t} SNR_1^{(ZF)}(1,p) \le \frac{E_S}{N_0}\lambda_{\max}^2(\mathbf{H}) \tag{9}$$

Let $\kappa(H) = \frac{\lambda_{\max}(H)}{\lambda_{\min}(H)}$ be regular condition number of the channel $\mathbf{H}$. Using this condition number, third selection criterion can be defined as choosing spatial multiplexing when $\kappa(H) \le \frac{d_{\min}(M_t,R)}{d_{\min}(1,R)}$ or otherwise selection diversity. Since in the dual-mode system, the data rate R and M_t are fixed, the right term of this inequality becomes constant. Therefore in the third selection, the feedback channel can be implemented by only single bit channel.

4. Conclusion

Spatial mulitplexing systems with linear receivers guarantee large capacity but not diversity gain. However, using dual-mode antenna selection provides a much larger diversity gain than simple spatial multiplexing by switching spatial multiplexing and selection diversity. Moreover, dual-mode can be easily implemented with low complexity and limited feedback channel.

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