MULTI-MODE ANTENNA SELECTION BASED ON SHANNON CAPACITY UNDER CORRELATED CHANNEL

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1. Introduction

MULTIPLE-INPUT multiple output (MIMO) antenna links are becoming increasingly important because of their potential for extremely high spectral efficiencies. However, a major limiting factor in the deployment of MIMO system is the cost of multiple analog chains. The core idea of antenna selection is to use a limited number of analog chains that are adaptively switched to a subset of the available antennas[1]. Previously, the researches on antenna selection have assumed that the channel is i. i. d. complex Gaussian, and in that case, the goal of the antenna selection is to decrease complexity, while keeping the performance loss as small as possible. However, in practice, moderately to severely ill-conditioned MIMO channels can arise for a number of reasons, including fading correlation and /or the presence of a Ricean component. Antenna correlation occurs due to a lack of a rich scattering environment or limited path angle spread. High correlation levels (>0.8) can also be obtained by design when building compact MIMO arrays with very small antenna spacing[2]. So it is meaningful to do some research on antenna selection under fading correlation.

Furthermore, the concept of adapting both the number of substream and the substream rate has been proposed in different contexts in [3],[4] and [5].Dynamically selecting the number of substreams and the optimal subset based on knowledge of the channel correlation matrices was investigated in [3] for various receivers to improve the performance of spatial multiplexing in correlated fading channels. Both the antennas used for transmission and the rate of constellation on each antenna is varied. In contrast, our algorithm is different because we adapt the number of substream and the antenna subset based on the instantaneous channel conditions as opposed to the correlation of the channel. According to the condition of channel, we can get the effective degree of freedom (EDOF), which can be used to determine the number of substream and according to the condition number of the channel matrix, we can determine the optimum antenna subset, and computation is simplified.

This paper is organized as follows. In Section 2, we use the "one-ring" model to model multipath propagation and fading correlation first presented by Jakes [6] and later used by Da-shan Shiu in [7] and we mainly discuss two special cases of the model. In Section 3, we introduce a multi-mode algorithm, which shows how to choose both the number of antennas selected for transmitting and the optimum subset. Simulation is shown in Section 4. We conclude in Section 5.

2. System model and scatter model

a. System Model

An n_T-input n_R-output multiple antenna system is referred to as an (n_T, n_R) MEA, the signal transmitted by the l th transmitting antenna element TA_l be denoted by $s^l(t)$, and the signal received by the m th receiving antenna element TR_m be denoted by $x^m(t)$. The impulse response connecting the input of the channel from TA_l to the output of the channel to TR_m is denoted by $h^{m,l}(t)$. The following vector notation describes the input output relation of the MEA system:

$$\mathbf{x}(\mathrm{t}) = \mathbf{H}(t) * \mathbf{s}(t) + \mathbf{n}(t) \tag{1}$$

Where $\mathbf{x}(t) = (x^1(t), x^2(t) \cdots x^M(t))'$, $\mathbf{s}(t) = (s^1(t), s^2(t) \cdots s^N(t))'$, $\mathbf{H}_{m,l}(t) = h^{m,l}(t)$ and $\mathbf{n}(t)$ is additive white Gaussian noise (AWGN), $*$ denotes convolution, x' and x^H denote the transpose and conjugate transpose of a vector x, respectively.

b. Abstract Scatterer Mode

Fig. 1 shows the "one-ring" model. This model will be employed to determine the spatial fading

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correlation of the channel H . The parameters in the model include the distance D between BS and SU, the radius R of the scatterer ring, the angle of arrival θ at the BS, and the geometrical arrangement of the antenna sets. As seen by a particular antenna element, the angles of incoming waves are confined within $[\theta-\Delta \ \theta+\Delta]$, Δ is angle spread.

In order to do some further research on correlation, the covariance matrix of channel need to construct, $\mathrm{cov}(rec(H)) = E(vec(H)\cdot vec(H)^H)$, $rec(H)=(h_1^{'},h_2^{'}\cdots h_N^{'})$ and $h_1,h_2\cdots h_N$ are the column vectors of H . $E(H_{l,p}H_{m,q}^{'})$ denotes the covariance between $H_{l,p}$ and $H_{m,q}$, the formulation of $E(H_{l,p}H_{m,q}^{'})$ can be gotten through the model in figure 1.

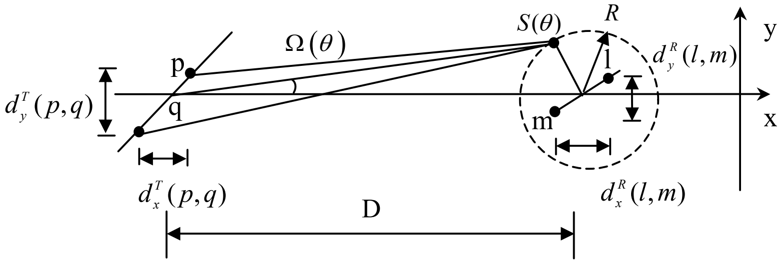

Fig. 1 Parameters used to derive the approximations for $E[H_{l,p}H_{m,q}^{*}]$ in the "one-ring" model

$$E[H_{l,p}H_{m,q}^{*}]=\frac{1}{2\pi}\int_{0}^{2\pi}\exp\{-j\frac{2\pi}{\lambda}[d_x^T(p,q)(1-\frac{\Delta^2}{4}+\frac{\Delta^2\cos 2\theta}{4}) \\ +\Delta d_y^T(p,q)\sin\theta+d_x^R(l,m)\sin\theta+d_y^R(l,m)\cos\theta]\}d\theta \tag{2}$$

Consider the special case where transmitter and receiver are linear array illustrated in Fig. 2.

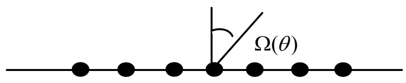

Figure 2. Linear array

The direction of signal transmitted is vertical to the array of transmitter, that is $\Omega(\theta)=0^\circ$, we call it configuration 1, if the array of receiver located in axis y, then

$$d_x^T(p,q)=0$$

$$d_x^R(l,m)=0$$

$$E[H_{l,p}H_{m,q}^{*}]=(1/2\pi)\int_0^{2\pi}\exp\{-j(2\pi/\lambda)[\Delta d_y^T(p,q)\sin\theta+d_y^R(l,m)\cos\theta]\}d\theta \tag{3}$$

The direction of signal transmitted is parallel to the array of transmitter, that is $\Omega(\theta)=90^\circ$, we call it configuration 2, if the array of receiver located in axis y, then

$$d_y^T(p,q)=0$$

$$d_x^R(l,m)=0 \tag{4}$$

$$E[H_{l,p}H_{m,q}^{*}]=(1/2\pi)\int_0^{2\pi}\exp\{-j(2\pi/\lambda)[d_x^T(p,q)(1-(\Delta^2/4)+(\Delta^2\cos 2\theta/4))+d_y^R(l,m)\cos\theta]\}d\theta$$

Let $\Psi=\mathrm{cov}(rec(H))$ and $\Psi=\Psi^{1/2}(\Psi^{1/2})^H$, then $vec(H_c)=\Psi^{1/2}vec(H_\omega)$, so we get the channel H_c .

3. The algorithm of antenna selection

(1) The determination of the number of substream

Let the singular value decomposition of the channel matrix H_c be $H_c=U_H D_H V_H^{\dagger}$ and the matrix U_H and V_H are the left singular matrix and right matrix, respectively. D_H is the diagonal matrix with the element ε_i .

According to the capacity formulation $C=\log_2(\det(I+(\rho/N)H_cH_c^{\dagger}))=\sum_{k=1}^{n}\log_2(1+(\rho/N)\varepsilon_k^2)$

The overall transmit power constraint requires that $\sum_{k=1}^{n}\rho_k\le\rho$. If the transmitter can get the state of channel, water-pouring algorithm can be used to maximize the capacity, otherwise we have to allocate equal power to all subchannels, that is $\rho_k = \rho / n$. Through the deposition above, a MIMO channel is divided into n subchannels each with the complex gain ε_k^2 .

Through the analysis above, we know that though a MIMO channel can be divided into several subchannels, when the complex gains become small, due to such factors as angle spread and the distance between antenna elements, the complex gains are too small to transmit credibly. The effective degree of freedom (EDOF) is parameter that represents the number of subchannels actively participating in conveying information under a given set of operating conditions, so we can choose it as the number of antennas in the subset.

$$EDOF = \frac{d}{d\sigma} C(2^\sigma \rho)\Big|_{\sigma=0} = \frac{d(\sum_{k=1}^{n} \log_2(1 + 2^\sigma \rho_k \varepsilon_k^2))}{d\sigma}\Big|_{\sigma=0}$$
$$= \sum_{k=1}^{n} \frac{\ln 2 \rho_k \varepsilon_k^2 2^\sigma}{(\ln 2)(1 + 2^\sigma \rho_k \varepsilon_k^2}\Big|_{\sigma=0} = \sum_{k=1}^{n} \frac{\rho_k \varepsilon_k^2}{(1 + \rho_k \varepsilon_k^2}\Big|$$
$$= \sum_{k=1}^{n} \frac{\frac{\rho}{n}\varepsilon_k^2}{(1 + \frac{\rho}{n}\varepsilon_k^2)} = \sum_{k=1}^{n} \frac{\rho \varepsilon_k^2}{(n + \rho \varepsilon_k^2)} \tag{5}$$

Using formulation (2) and (5), we can get the relation between angle spread (the unit is degree) and EDOF for two kinds of configuration style , illustrated in Fig. 3.

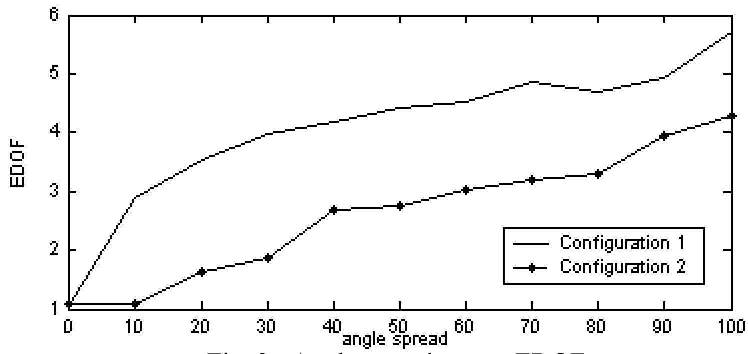

Fig. 3 Angle spread versus EDOF

(2) The determination of optimal subset for transmitting

Now we analyze the relation between complex gain and angle spread, when the angle spread becomes small, $\max\{\varepsilon_k^2\}$ becomes larger; the mean of $\varepsilon_k^2, k \geq 2$ become smaller; the difference between ε_k^2 and ε_{k+1}^2 gets larger. For a (N,M) matrix, its condition number can be defined as $cond(A) = \varepsilon_{\max} / \varepsilon_{\min}$ which is a positive number between 0 and 1. The matrix with smaller condition number is well behaved, while the matrix with larger condition number is ill behaved. For the matrix whose condition number is not infinite but nearly infinite has some row vectors or column vectors dependent on each other.

From the formulation of channel capacity, we can see that when the number of substream has been determined, complex gain ε_k^2 is the main factor affecting the capacity of channel. The smaller the difference between $\{\varepsilon_k^2 \quad k = 1 \cdots N_s\}$, the more balanced the subchannels are and the more credible the transmitting is. Because condition number of channel $cond(H) = \varepsilon_{\max}^2 / \varepsilon_{\min}^2$ reflects character above, so we can choose the subset that has smallest condition number among $C_N^{N_s}$ subsets.

4. Simulation

The capacity of a MIMO system is a function of the channel matrix. Thus the capacity is a random variable with some distribution. In this section, All simulated points are obtained by averaging over 2000 channel realizations. Through our simulations, we assume that n_T=7 and n_R=7.

In the fist example, the style of configuration is configuration 1 and configuration 2 respectively and angel spread is 30° and 60° respectively. The relation between SNR (signal-to-noise ratio) and capacity of channel is illustrated in Fig. 4 and Fig. 5. Through the simulation above, we can see that when angle spread is 30°, no matter which kind of configuration is chosen, the capacity of using antenna selection is quite high compared with the case when no selection strategy is used; when angle spread is 60°, the system using antenna selection can still achieve lager capacity.

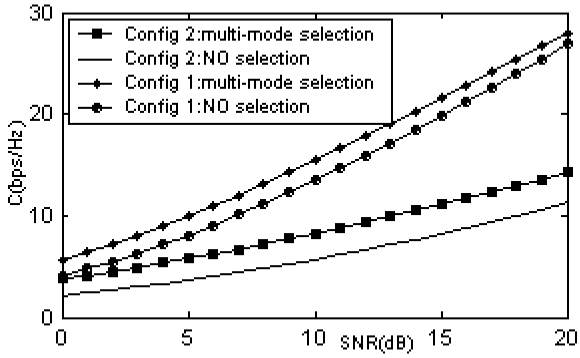

Fig.4 Capacity versus SNR. First example (Angle spread = 30°)

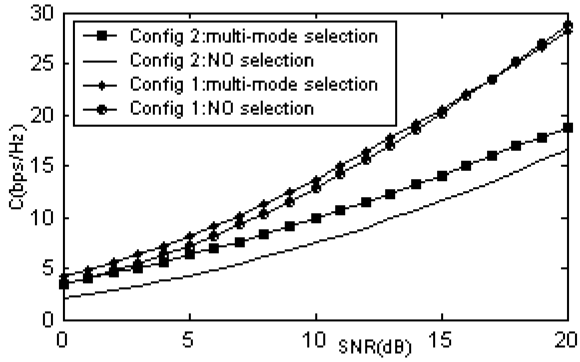

Fig.5 Capacity versus SNR. First example (Angle spread = 60°)

In the second example, the SNR is 18 dB, the relation between angle spread and capacity of channel is illustrate Fig. 6. We can see that the capacity of system using multi-mode selection is near to that of no selection strategy is used for different angle spread.

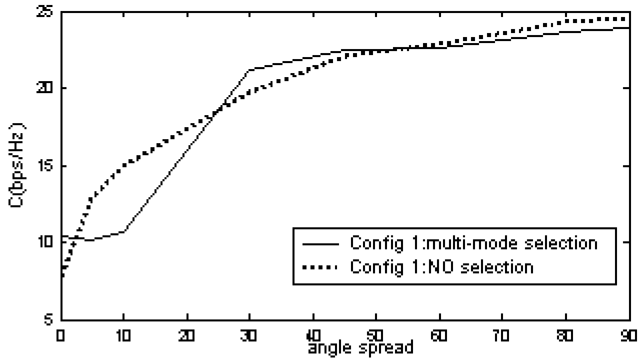

Fig. 6 Capacity versus Angle spread. Second example (SNR=18 dB)

5. Conclusion

In the paper, we mainly discuss two special cases of correlated channel and analyze the effect of angle spread on channel gain and EDOF under fading correlation. The multi-mode algorithm can determine the number of antennas selected dynamically according to the condition of channel, and then determine the optimum subset. The computation is simplified and simulation shows that the capacity loss through selection is very little.

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