MIMO capacity in cellular systems

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Abstract: In this paper, we examine the performance of conventional MIMO schemes in cellular systems in terms of average capacity. We find that the performance behavior of using larger number of transmit antennas in cellular system can be different from that in an isolated system. And we propose the Number-of-Trasnmit-Antenna Selection scheme for MIMO cellular systems.

I. INTRODUCTION

The use of multiple-input multiple-output (MIMO) technologies which employ multiple antennas at transmitter and receiver has great potential for wireless links, in particular when the channels between antennas are uncorrelated [1]. MIMO systems provide high data rate by simultaneously transmitting multiple data streams, and reliable communications by exploiting spatial dimension made by MIMO channels.

In an isolated link where there is no co-channel interference, the use of larger number of transmit antenna always results in performance enhancement in terms of average capacity, i.e., average mutual information [1]. However, in cellular systems where there is co-channel interference induced from neighboring cells due to frequency reuse, the performance behavior of using larger number of transmit antenna can be different from that in an isolated link. In cellular systems, although the use of more transmit antennas provides larger capacity on the desired link, it may make fierce interference to the neighboring cells, which may result in degradation of total system capacity [2], [3].

In this paper, we consider MIMO cellular system where the universal frequency reuse policy (reuse factor = 1) and the power control are employed. First we examine the performance of conventional MIMO schemes in terms of average capacity and discuss the simulation results. Then we propose the Number-of-Trasnmit-Antenna Selection (NTAS) scheme which provide better performance enhancement in terms of average capacity, i.e., average mutual information [1]. However, in cellular systems where there is co-channel interference induced from neighboring cells due to frequency reuse, the performance behavior of using larger number of transmit antenna can be different from that in an isolated link. In cellular systems, although the use of more transmit antennas provides larger capacity on the desired link, it may make fierce interference to the neighboring cells, which may result in degradation of total system capacity [2], [3].

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This paper is organized as follows. Section II presents the system and channel model. Section III examines the performance of conventional MIMO schemes and presents proposed scheme. Conclusions are drawn in Section IV.

II. SYSTEM MODEL

We consider the downlink of MIMO cellular system with \( N_t \) transmit antennas and \( N_r \) receive antennas, where the universal frequency reuse policy is used, i.e., all cells use the same frequency band. We consider 1-tier hexagon cellular structure, as depicted in Fig. 1.

We assume frequency flat fading channel in which the transmit signals experience path loss, lognormal shadow fading, and Rayleigh fading. The channel matrix between the base station of cell \( m \) and the user of cell \( n \) may be expressed as

\[
\mathbf{H}_{m,n} = \sqrt{d_{mn}^{-\alpha}} \cdot 10^{\frac{s_{mn}}{10}} \mathbf{G}_{m,n}
\]

where \( d_{mn} \) is the distance between the base station of cell \( m \) and the user of cell \( n \), \( \alpha \) is the path loss exponent, and \( s_{mn} \) is a Gaussian random variable with zero mean and variance of \( \sigma^2 \) which is related to shadow fading. \( \mathbf{G}_{m,n} \) denotes \( N_t \times N_r \) channel matrix of i.i.d circularly symmetric complex Gaussian random variables with zero mean and unit variance which is related to Rayleigh fading.

We assume that each base station serves only one user at one time and users are uniformly distributed in cell region. In this environments, a user located in the cell’s boundaries experiences poor link condition for communications because there are severe interferences from neighboring cells. To deal with this problem, our cellular system employs the power control which guarantees that all users get the same average SNR independent of their distances from the base station. Then the total transmitted power at the base station of cell \( m \) may be expressed as

\[
P_m = P_0 / \sqrt{\sum_{n=1}^{N_r} d_{mn}^{-\alpha} 10^{\frac{s_{mn}}{10}}}
\]

where \( P_0 \) denotes required transmit power to achieve target received SNR in channel where there is no path loss and lognormal shadow fading.

The received complex base band signal of cell \( m \) can be expressed as follows

\[
\mathbf{y}_m = \mathbf{H}_{m,n} \mathbf{x}_n + \sum_{r \neq m} \mathbf{H}_{r,n} \mathbf{x}_r + \mathbf{n}_m
\]

where \( \mathbf{x}_n \) is \( N_t \times 1 \) transmitted signal vector from the base station of cell \( m \), and \( \mathbf{n}_m \) is \( N_t \times 1 \) noise signal vector at the receiver. We assume \( \mathbb{E}[^{\dagger} \mathbf{x}_n \mathbf{x}_n] = \mathbf{R}_0 / N_t \) and \( \mathbb{E}[\mathbf{n}_m] = \sigma \mathbf{1}_{N_t} \). \( \mathbb{E}[\mathbf{a}] \) and \( \mathbf{a}^{\dagger} \) denote expectation and conjugation transpose of \( \mathbf{a} \) and identity matrix with \( N_t \) by \( N_t \), respectively. Then the downlink channel capacity of cell \( m \) can be expressed as

\[
C_m = \log_2 \det(\mathbf{I}_{N_t} + K_{m,n} \mathbf{K}_{N_t,N_t}^{-1})
\]

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where \( K_{D,m} \) and \( K_{S,m} \) denote the covariance matrix of desired signal and interference plus noise signal, respectively, and they can be expressed as

\[
K_{D,m} = \frac{1}{N_t} H_{D,m} H_{D,m}^\dagger, \quad (5)
\]

\[
K_{S,m} = \sum_{i=1}^{N_t} \frac{1}{N_r} H_{S,m,i} H_{S,m,i}^\dagger + \sigma_n^2 1_{N_r}. \quad (6)
\]

### III. MIMO PERFORMANCE OF CELLULAR SYSTEMS

#### A. Conventional schemes

We examine the capacity performance of conventional schemes in MIMO cellular environments with \( N_t = 2 \) and \( N_r = 4 \). Conventional schemes are listed as follows:

- 2Tx scheme: 2 transmit antennas are simultaneously used.
- 1Tx scheme: 1 randomly selected transmit antenna is used.
- TAS scheme: 1 transmit antenna which is selected on the criterion of providing larger capacity is used.

If we consider the performance of conventional schemes in an isolated link, 2Tx scheme will show better performance than 1Tx scheme since the use of larger number of transmit antenna gives larger capacity. However in cellular systems with multiple receive antennas, the performance behavior of using larger number of transmit antenna may be different from that in an isolated link due to co-channel interference. The co-channel interference generated from using larger number of transmit antenna makes co-channel interference handling at the receiver more difficult [4]. Therefore although the use of more transmit antennas provides larger capacity on the desired link, it decreases the capacity of neighboring cells, which may bring about the degradation of total system capacity.

Fig. 2 shows the average capacity of conventional schemes in cellular systems. We see from Fig. 2, that there is a cross point on the performance curves of 1Tx scheme and 2Tx scheme. Especially in the cell boundary region, 1Tx scheme offers larger capacity than 2Tx scheme since the use of 2 transmit antennas makes fierce co-channel interference to neighboring cells, which degrades total system performance. And we find that TAS scheme offers larger capacity than 2Tx scheme in all points because TAS scheme not only makes soft interference to neighboring cells but also achieves full transmit antenna diversity gain.

#### B. Proposed scheme

We propose the Number-of-Transmit-Antenna Selection (NTAS) scheme. In our scheme, we choose adaptively the number of transmit antenna used according to the transmit power. If the transmit power \( P_m \) is smaller than \( P_{\text{threshold}} \), 2 transmit antennas is used. In this case, the benefits of using 2 transmit antennas, e.g., multiplexing gain, can be achieved, while generating relatively soft co-channel interference to neighboring cells due to the small transmitted power. If \( P_m \) is larger then \( P_{\text{threshold}} \), 1 selected transmit antenna is used. In this case, full transmit antenna diversity gain is achieved as TAS scheme, while generating soft co-channel interference due to the use of 1 transmit antenna. Fig. 3 shows the performance of NTAS scheme in terms of average capacity. We see that NTAS scheme offers additional large capacity gain over TAS scheme especially in near region from the base station.

#### IV. CONCLUSION

We examine the performance of MIMO systems in cellular systems in terms of average capacity. We find that the use of larger number of transmit antenna doesn’t guarantee the best performance when in employing the multiple receive antennas in interference-limited environments such as cellular environments. And we propose the Number-of-Transmit-Antenna Selection (NTAS) scheme which considers the effects of using more transmit antennas on desired cell and on the neighboring cells. Our simulation results show that our proposed scheme offers larger capacity than the conventional MIMO schemes in cellular systems.

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**REFERENCE**


