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Antenna Selection with Spatial Multiplexing MIMO Systems

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Abstract-Future cellular systems will employ spatial multiplexing with multiple antennas at both transmitter and Receiver to take advantage of large capacity gains. In such systems it will be desirable to select a subset of available transmit antennas for link initialization, maintenance or handoff. This is possible with one of the most promising technology for future generation wireless communication called as Multiple-Input Multiple-Output (MIMO). MIMO architecture allows getting the diversity benefit or increased data rate. The work in the report will be aimed at evaluating performance of MIMO system targeted for improving data rate or capacity. Spatial multiplexing emerged from the fact that in a rich scattering environment it is possible for the receiver to descramble signals that are transmitted simultaneously from the multiple Antennas, thus one is able to send parallel independent data streams and achieve overall capacity.

Keywords*: - MIMO, Spatial multiplexing*

I. INTRODUCTION

Multiple-input–multiple-output (MIMO) wireless systems are those that have multiple antenna elements at both the transmitter and receiver [1]. They were first investigated by computer simulations in the 1980s [2], and later papers explored them analytically [3], [4]. Since that time, interest in MIMO systems has exploded. They are now being used for third-generation cellular systems (WCDMA) and are discussed for future high-performance modes of the highly successful IEEE 802.11 standard for wireless local area networks. MIMO-related topics also occupy a considerable part of today's academic communications research.

The multiple antennas in MIMO systems can be exploited in two different ways. One is the creation of a highly effective antenna diversity system; the other is the use of the multiple antennas for the transmission of several parallel data streams to increase the capacity of the system. Antenna diversity is used in wireless systems to combat the effects of fading. If multiple, independent copies of the same signal are available; we can combine them into a *total signal* with high quality—even if *some* of the copies exhibit low quality. Antenna diversity at the receiver is well known and has been studied for more than 50 years. The different signal copies are linearly combined, i.e., weighted and added. The resulting signal at the combined output can then be demodulated and decoded in the usual way. The optimum weights for this combining are matched to the wireless channel [maximum ratio combining (MRC)]. If we have N receive antenna elements, the diversity order, which describes the effectiveness of diversity in avoiding deep fades, is N; in other words, the diversity order is related to the slope of the signal-to-noise ratio (SNR) distribution at the combined output. The multiple antennas also increase the *average* SNR seen at the combined output. The study of transmit diversity is much more recent, starting in the 1990s.

When the channel is known to the transmitter, we can again "match" the multiple transmitted signal copies to the channel, resulting in the same gains as for receiver diversity. If the channel is unknown at the transmitter, other strategies, like delay diversity or space-time-coding, have to be used. In that case, we can gain high diversity order, but not improvement of average SNR. The logical next step is the combination of transmit and receive diversity. It has been demonstrated that with Nttransmit and Nr receive antennas, a diversity order of NtNrcan be achieved [5]. A MIMO system can thus be used for a high-quality transmission of a single data stream even in challenging environments

An alternative way of exploiting the multiple antenna elements is the so-called "spatial multiplexing" [6] or "BLAST" [7] approach. The principle of this approach is sketched in Figure 1. Different data streams are transmitted (in parallel) from the different transmit antennas. The multiple receive antenna elements are used for separating the different data streams at the receiver. We have Nr combinations of the Nttransmit signals. If the channel is well-behaved, so that the Nr received signals represent linearly independent combinations, we can recover the transmit signals as long as Nt≤ Nr. The advantage of this method is that the data rate can be increased by a factor Ntwithout requiring more spectrum! In this article, we will mostly discuss the information-theoretic capacity, i.e., the data rate that can be transmitted over a channel without errors if ideal coding is used. Practical schemes, like layered space-time (ST) receiver structures [8]–[10] combined with

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space-time codes [11] allow us to approach these capacity limits.

1. MIMO System Model

With the integration of Internet and multimedia applications in next generation wireless communications, the demand for wide-band high data rate communication services is growing. As the available radio spectrum is limited, higher data rates can be achieved only by designing more efficient signaling techniques. Such large gains in capacity of communication over wireless channels are feasible in Multiple-input multiple-output (MIMO) systems.The MIMO Channel is constructed with multiple element array antennas at both ends of the wireless link.

Let us consider a single point-to-point MIMO system with arrays of $n_T$transmit and n_R receive antennas. We focus on a complex baseband linear system model described in discrete time. The system block diagram is shown in Fig. 1. The transmitted signals in each symbol period are represented by an $n_T\times 1$ column matrix **x**, where the *i*th component x_i, refers to the transmitted signal from antenna *i*.

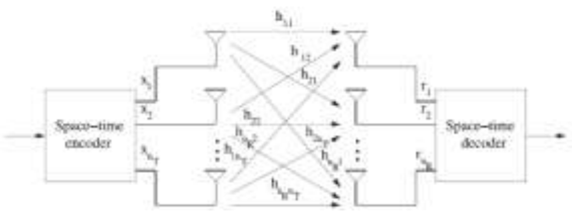

Fig 1. Block diagram of a MIMO System [12]

2. MIMO Channel Capacity

In this section, we study the capacity of a MIMO channel with n_R outputs. We assume that the receiver knows the realization of the channel that is it knows both **r** and **H**. For the transmitter, we study the case when the transmitter does not know the realization of the channel; however, it knows the distribution of **H**. This corresponds to an open-loop system. The channel path gains follow a Rayleigh fading channel model. The resulting capacity of the channel is a random variable because the capacity is a function of the channel matrix **H**. The distribution of the capacity is determined by the distribution of the channel matrix **H**. The total transmitted power is kept the same for different numbers of transmit antennas to make a fair comparison.

At each symbol period, transmitted signals, x_i,i= 1, 2, . . . , $n_T$are transmitted simultaneously from $n_T$transmit antennas. The received signal *r*, which is received at antenna n_R, is given by

$$\mathbf{r} = \mathbf{Hx} + \mathbf{n}$$

- The capacity of a MIMO channel is a function of the channel matrix **H**. Considering the random nature of the channel matrix **H**, the capacity of a MIMO channel subject to the input covariance matrix being an 2nd Rayleigh fading model can be considered as the following random variable [12]:

$$C = W \log_2 \det \left(\mathbf{I}_m + \frac{P}{n_T \sigma^2} \mathbf{Q} \right)$$

$$\mathbf{Q} = \begin{cases} \mathbf{H}\mathbf{H}^H, & n_R < n_T \\ \mathbf{H}^H\mathbf{H}, & n_R \geq n_T \end{cases}$$

- If the number of transmit and receive antennas are the same, the capacity increases at least linearly as a function of number of antennas.
- At high SNRs, a 3 dB increase in SNR results in min $\{n_T,n_R\}$ extra bits of capacity.
- The ergodic capacity of a MIMO channel, when the channel is isotropic, given any side information that exists at the transmitter, is [12]:

$$C = E\left\{ W \log_2 \det \left[\left(\mathbf{I}_r + \frac{P}{\sigma^2 n_T} \mathbf{Q} \right) \right] \right\}$$

- The ergodic capacity is for large n_T $\lim_{n_T \to \infty} C = W \log_2 \left(1 + \frac{P}{\sigma^2} \right)$.
- The outage capacity Cout is a value that is smaller than the random variable C (capacity), only with a probability Pout (outage probability):

$$P_{\text{out}} = P(C < C_{\text{out}}).$$

3. Spatial Multiplexing And Capacity

As mentioned earlier, in a wireless fading channel with sufficiently rich scattering, it is possible to achieve capacities with MIMO systems that were unthinkable even a decade ago. When the wireless channel has sufficient degrees of freedom, the data streams transmitted from multiple transmit antennas can be separated, thus leading to parallel data paths. The capacity of the radio channel under these conditions grows with min(n_T,n_R), that is, linearly with the number of antennas.

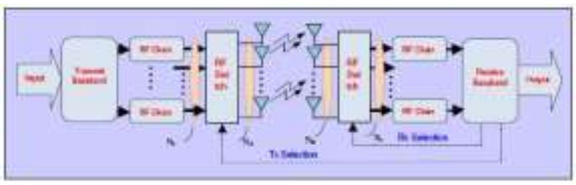

Fig 2 Antenna Selection in MIMO [1]

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From Fig. 2, a multiple-antenna system with n_T *transmits* and $n_R$receive antennas. The channel matrix H is an $n_T\times n_R$complex valued matrix. We assume a block fading model in which the channel statistics can be Rayleigh or Rician, and the system experiences additive Gaussian noise at the receive antennas.

The object is to select the best $L_r$out of $n_R$antennas at the receive side and the best L_tOutof $n_T$antennas at the transmit side so that theresulting system capacity is maximized. Assumingequal power transmission from antennas, thecapacity as a function of the channel matrix iswhere r is the receive SNR, H~ is the $L_r\times L_t$selected channel matrix, I is the $L_t \times L_t$identitymatrix, and $H^{\sim\dagger}$ is the Hermitian of $H^{\sim}$ .The ideal antenna selection technique chooses $H^{\sim}$ out of H such that the expression above is maximized.

Antenna Selection for MIMO

Regardless of the use as diversity or spatial multiplexing system, the main drawback of any MIMO system is the increased complexity, and, thus, cost. While additional antenna elements (patch or dipole antennas) are usually inexpensive, and the additional digital signal processing becomes ever cheaper, the RF elements are expensive and do not follow Moore's law. MIMO systems with Nt transmit and Nr receive antennas require Nt (Nr) complete RF chains at the transmitter, and the receiver, respectively, including low-noise amplifiers, down converters, and analog-to-digital converters.

4. Antenna Selection Criteria

Performance of spatial multiplexing with linear receivers depends on the induced by the particular subset of transmit antennas. One antenna subset selection criterion (SC) is obtained as follows. SC1-Maximum Post-Processing SNR: For every subset of transmit antennas compute and the corresponding. Choose the subset with the largest. Computation of the above requires first the equalizer. An alternative selection criterion, based on the channel, follows from (7). SC2-Maximum Minimum Singular Value: For every subset of transmit antennas compute corresponding to. Choose the subset with the largest. Finally, we provide the capacity-based selection criterion proposed in [5]. SC3-Maximum Capacity: For every subset of transmit antennas compute. Choose the subset with the largest. Note that SC3 is based on a general capacity formula and is not specialized to linear receivers.

Antenna Selection Algorithms

ALGORITHM I INCREMENTAL LOSS MINIMIZATION

Set $\underline{\boldsymbol{U}} = \boldsymbol{U}_{r1}$, where $r_1 = \arg\max_{1\le l\le M} \|U_l\|^2$.
for $n = 1$ to $(N-1)$
compute $\boldsymbol{B}_{\perp}(\underline{\boldsymbol{U}})$ a $N\times n$ orthogonal projector onto the row null-space of $\underline{\boldsymbol{U}}$;
update $\underline{\boldsymbol{U}} := [\underline{\boldsymbol{U}}^T, \boldsymbol{U}_{r_n}^T]^T$, where $r_n = \arg\max_{1\le l\le M} \|U_l \boldsymbol{B}_{\perp}(\underline{\boldsymbol{U}})\|$;
end

ALGORITHM II INCREMENTAL SELECTION

Set $\boldsymbol{A} := (E_s/N_0)\boldsymbol{I}_N$ and
$r_1 := \arg\max_{1\le l\le M} \|\boldsymbol{H}_l\|^2$.
for $n = 1$ to $(M'-1)$
update $\boldsymbol{A} := \boldsymbol{A} - \boldsymbol{A}\boldsymbol{H}_{r_n}^H (1 + \boldsymbol{H}_{r_n}\boldsymbol{A}\boldsymbol{H}_{r_n}^H)^{-1}\boldsymbol{H}_{r_n}\boldsymbol{A}$;
compute $r_{n+1} = \arg\max_{l\notin\{r_1,\ldots,r_n\}} \boldsymbol{H}_l\boldsymbol{A}\boldsymbol{H}_l^H$;
end

Practical Algorithms for Antenna Selection [7]

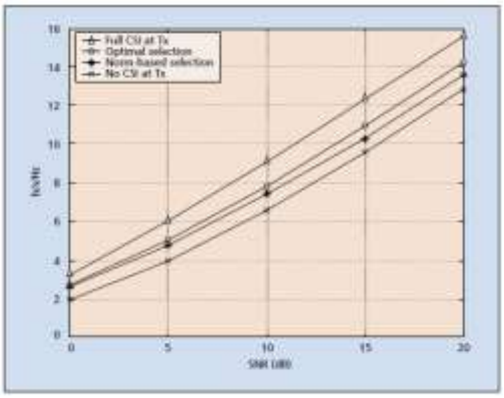
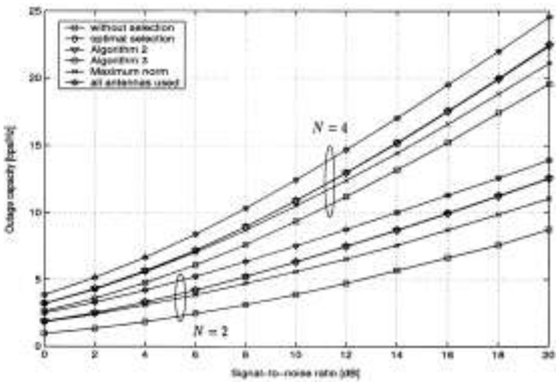


Fig 3. Capacity of Transmit antenna selection for n_T=8,

L_t=L_r=n_R=2. Optimal Selection and Successive selection curves are optimal. [1]



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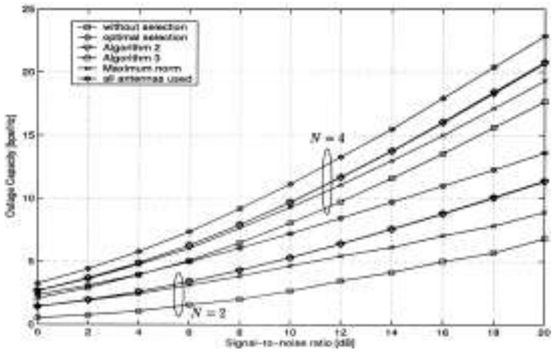

Fig. 4. Outage capacity of antenna selection versus SNR ($n_T E_S/N_0$), n_R = 6.(a) 10% outage rate. (b) 1% outage rate. [7]

From (Fig 4), it is noted that the proposed selection algorithms exhibit quasi-optimal performance, contrary to ad-hoc selection, which yields up to 20% capacity loss.

II. CONCLUSION

This article presents an overview of antenna selection in MIMO systems. Antenna selection can reduce hardware complexity and cost, achieve full diversity, and in the case of transmit antenna selection, gain rate (capacity). These objectives can be achieved at an affordable computational cost. There are two main approaches for antenna selection: norm-based selection and successive selection. The former approach is suitable when SNR is low, whereas the latter suits the high SNR regime. Both methods can be applied for either transmit or receive antenna selection. Antenna selection has certain inherent limitations. One of the most important limitations arises whenever the system bandwidth is larger than the coherence bandwidth of the channel (i.e., when the channel is frequency-selective).

The different response of the channel at different frequencies implies that at each band a different antenna selection is optimal. So whenever the channel is highly frequency-selective, with many uncorrelated frequency bands, antenna selection may not be feasible or useful. However, in moderately frequency-selective channels, antenna selection still provides significant gains.

Antenna selection also presents several practical issues we have overlooked in this introductory tutorial. For example, the RF switches available with current technologies are far from ideal, a fact that may offset some of the advantages of antenna selection. The most important shortcoming of the practical switches is their transfer attenuation, which must be compensated by more power from the output stage amplifier of the transmitter and by a more sensitive low noise amplifier at the receiver.

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