Transmit Antenna Selection Methods For Mimo Systems
In Wireless Communications

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Abstract: Though MIMO systems improve performance of a wireless communication network by the usage of multiple antennas, demand of distinct set of RF chain (i.e., electronic components required for antenna transmission and reception, in wireless communication) for all the antennas leads to an increase in complexity and cost. Antenna selection technique of MIMO has proved to be a good means to solve this issue. Antenna Selection methods find optimal number of antennas required out of the total antennas present in the MIMO (Multiple Input Multiple Output) system. The selection of antenna can be performed at both ends of the communication network i.e., transmitter or receiver. In this paper, an overview of various Transmit Antenna Selection techniques for various MIMO systems is presented.

Keywords: BER, EGC, MRC, RF, SNR, SNIR

1. Introduction

Multiple Input Multiple Output systems enhance capacity & reduce Bit Error Rates (BERs) and outage probability of wireless networks and hence, have gained popularity [1]. MIMO systems achieve improvement in gain by using the technique of spatial multiplexing and diversity methods. Diversity gain is obtained by the usage of multiple antennas. However, the problem of mutual interference arising due to antennas transmitting simultaneously has to be tackled. Space -time codes can prove to be effective as diversity order is achieved which is given as a product of number of transmitter and receiver side antennas. Here, diversity order is given as the slope of the curve of the Bit Error Rate (BER) and Signal to Noise Ratio (SNR).

A MIMO technique, Spatial Multiplexing achieves improvement in system capacity which scales to the factor of min (Nt,Nr) by converting the serial data coming out from one antenna into multiple parallel streams of data from simultaneously transmitting antennas. An example of a system employing the Spatial Multiplexing technique of MIMO is the Bell Labs Space Time (BLAST) architecture.

Although MIMO systems prove to be advantageous by using various techniques such as Spatial Multiplexing, Diversity methods, etc., there is an increment in the size, cost and complexity of hardware. Antenna selection techniques in MIMO come as a rescue for exploiting the advantage of MIMO systems without the additional complexity [2]. The succeeding section provides a description of such techniques.

2. Formatting your Paper Antenna Selection Techniques to improve SNR and Diversity

Diversity implies the usage of multiple paths (separated in time, space, frequency, polarization etc) for the signal from transmitter to receiver side by employing more than one antenna. The concept of adding Diversity in antennas is that if different paths have statistically independent channel coefficients (hi(t) and noise ni(t)), fading of different paths will not be the same and hence, there is less probability that signal at receiver will be incorrectly detected. Antenna selection techniques are of two types, depending on which end of the communication network, multiple antennas are employed i.e., transmit antenna selection and receive antenna selection.

2.1. Receive Antenna Selection

At the receiver side, due to diversity in the number of receiving antennas, gain can be
achieved by combining the signal received at all the antennas of the receiving end (as shown in fig. 1) by using certain techniques which are given as follows [2]:

2.1.1. Selection Diversity:
The path with highest strength (i.e., having maximum SNR) is given to the detector to reconstruct the original signal. However, as there is only one set of RF chain, it is not feasible to find SNR of all the paths at the same time. A few methods can be used solve this problem depending on the different channel gain’s quasi-stationary. A training signal may be used in the preamble along with the data to be sent. Using this preamble, the receiver can easily find the channel with highest gain. However, it has been observed that using an envelope detector is an easier option as it efficiently selects the path having highest Signal to Noise and Interference Ratio (SNIR).

![Figure 1. Simplified block diagram of TAS based MIMO system](image)

If more than one RF chain (but < Nr) is available at the receiver, Generalized Selection Diversity can be employed. A few receive antennas may be selected for combining their signals. Another term for it may be hybrid selection or maximal ratio combining [4]. For combining the selected paths, either MRC or EGC can be used and are described as follows:

2.1.2. Equal gain combining (EGC):
The transmitted signal is decoded by making the phase of all the signals received from multiple receiver antennas to be same and combining them. EGC is easier to perform as compared to MRC but it is less efficient [4].

2.1.3. Maximum ratio combining (MRC):
This technique is similar to the EGC technique. In addition, each signal obtained from multiple antennas is amplified before getting co-phased and combined to increase the SNR. The objective is to choose one path out of Mr receive paths to optimize the received SNR [1].

2.1. Transmit Antenna Selection
TAS or Transmit Antenna Selection calls for a feedback link from the receiving end to the transmitting end. TAS can be of two types:

1. Single TAS
2. Multiple TAS

In single TAS, the antenna with highest receive SNR is selected. In multiple TAS, the task is to choose Lt RF chains out of Nt transmitting end antennas (where, Nt > Lt) when only a single antenna is present at the receiver end. In order to achieve this, the amplitude and phase of all the signals sent from the transmitting antennas should be adjusted so as to maximize the SNR of the received signal. So, Lt number of transmit antennas that give the highest channel gain, have to be chosen. This technique is also termed as hybrid maximal ratio transmission and over the selected antennas, is equivalent to the method of beamforming. For this, the transmitter has to be
provided feedback as it requires information about not only how many transmitter side antennas (Lt) are necessary but also about channel gains (which are complex in value).

2.3 Transmit/Receive Antenna Selection

In transmit/receive antenna selection, there are multiple antennas at both the transmitter side (i.e., Nt antennas, having Lt RF chains) as well as at the receiver side (i.e., Nr antennas, having Lr RF chains). Thus, Lt number of parallel data streams are feasible. Here, space time block code maybe used for providing diversity. Let the overall Nt x Nr channel matrix be denoted by H and the corresponding Lt x Lr channel matrix of selected antennas is represented by D~. The orthogonal space time block codes employ a simple detector that causes the channel to behave like a SISO (Single Input, Single Output) link with equivalent channel gain (where, d~ij are the elements of the channel matrix D~). The Signal to Noise Ratio is in proportion to Frobenius norm which is calculated of the chosen matrix formed by channel i.e., \[\|\tilde{D}\|^2 = \sum_{i,j} |d_{ij}|^2\] [2]. Hence, combined transmitter and receiver antenna selection techniques aim at choosing a smaller set (which will maximise the square of magnitude of channel gain) out of the rows and columns of the D matrix. Exhaustive search is the only known solution for this kind of antenna selection technique as it is a complex task.

3. Transmit Antenna Selection (TAS) Techniques

It constitutes a closed-loop MIMO technique in which total number of antennas actually working at the same time (from a larger set of multiple antennas present at the transmitter side) in a MIMO system is reduced by finding optimal subset required. It offers a lot of advantages such as:

- Single RF chain for multiple antennas implies simpler hardware, less cost and smaller size of equipment.
- No inter antenna interference leads to easy detection at the receiver.
- Diversity gain remains same [6].
- No need of complete CSI to be fed-back to the receiver as only information regarding the best link i.e., the selected index has to be sent. Hence, easy establishment of lower rate feedback link is possible.

If CSI (Channel State Information) is known at sending end, adaptation becomes easier at the transmitting end [6], [7], [8]. So, a number of researchers have used Transmit Antenna Selection schemes for performance enhancement of their MIMO systems:

In [6], the authors have used MRC at the receiving end of a MIMO system using TAS for which outage performance is presented. Also, in [10], for the MIMO system using TAS technique and employing space-time code, outage probability is described. There is improvement in diversity gain when CSI is perfectly known at transmitter side, as described in [9] and [10]. On the other hand, imperfect CSI not only affects the antenna selection procedure but also the decoding procedure. The authors have shown in [11] that in a single TAS system, the diversity order is dependent on the ordinal number of the antenna that is selected. Thus, it has been proved in literature that performance and diversity order of the MIMO system is severely affected if there is wrong selection of antenna. Also, errors that occur during estimation of channel state at the transmitter side cause degradation on performance, as discussed in [12] to [16]. In [12], degradation in capacity due to imperfect CSI in a Hybrid Selection MRC scheme, has been depicted using simulation results. In [13], loss in SNR due to error in CSI estimation in a Generalized Selection Combining system is compared (in terms of error probability) with that of the perfect CSI estimation case. In [14], error in CSI estimation in an OFDM-MIMO system using Antenna Selection is depicted. In [15], the Symbol Error Rate of AS subsystem is discussed if channel estimation errors are present. For a joint transmit and receive AS technique employing Space Time coding, the outcome of errors in CSI estimation is
studied [16]. In [12] to [16], it has been described that though errors that occur during channel estimation cause a loss in the SNR, the diversity gain remains intact.

In recent times, the methods of data driven techniques such as Machine Learning etc. have been applied to the TAS systems as compared to the conventionally used optimization driven methods [17]. In [18], the usage of various pattern recognition methods such as k-NN & SVM algorithm in AS has been described. Though these newer techniques provide improvement in performance by reducing the BER, there is increase in complexity. In [19], authors have given a novel deep learning based AS technique for MIMO system that shows improvement in results. In [20], a new AS algorithm based on K- means clustering is proposed.

4. TRANSMIT ANTENNA SELECTION IN SM-MIMO

SM or Spatial Modulation is a category of a MIMO system methodology for wireless communication that combines traditional modulation and SSK (Space Shift Keying) [21] to [26]. SM- MIMO systems prove to be advantageous as they can help in reducing the ICI (Inter Channel Interference) at the receiving side, synchronization problems at the transmitting side and improving the Energy Efficiency (EE). Even though there are so many advantages of SM- MIMO system, diversity gains can’t be attained at the transmitter side [27], [28]. Thus, certain other Open Loop and Closed Loop MIMO systems have to be combined with the Spatial Modulation system in order to make the overall MIMO system advantageous [29] to [32]. In [33], an open loop transmit antenna method using modulation diversity schemes is depicted. In [34], Spatial Modulation technique centred on space time codes used on multi strata has been shown. For closed-loop MIMO transmit schemes, an adaptive Spatial Modulation technique is presented in [29] and [30], in which TAS is used for improving the performance of the overall system. In [31], three different methods of performing TAS are presented that use SSK and use norm calculated on column vector (of matrix formed by channel between the transmitter and receiver). In [32], a new closed loop TAS scheme which uses feedback of information of the selected transmitting antennas is proposed. This is done so as to lift the restriction that the no. of antennas employed at the transmitting should be chosen in such a way that the integral number is a power of 2. A TAS MIMO scheme using antenna correlation (ACAS) is demonstrated in [35] that is shown to achieve good performance with reduced complexity of system. Similar to the TAS technique depicted in [31] that uses norm of vector, a TAS technique based on optimization of capacity (COAS) has been depicted in [34] and it proves to be a special case of the method given in [35]. Also, EDAS (i.e., TAS technique based on calculation of the Euclidean Distance) technique is gaining popularity as it uses SCI to maximize the instantaneous value of the Euclidean distance among all the Spatial Modulation received signals [37], [38], [39]. Though EDAS results in improvement of BER and transmit diversity gain, complexity increases of such a system [27] because of requirement of exhaustive search among all the Transmit Antenna subset candidate selection and that of the highly complex signal constellation of Spatial Modulation.

Various TAS techniques are proposed in [36], [41], [42] for reducing the computational complexity of EDAS- TAS MIMO system. As an example, in [36], such a low complexity technique is described that uses re-formulation of the Euclidean Distance matrix and uses classic QR Decomposition for the same. Similarly, an EDAS method using mirror symmetry is presented in [43] that is based on the mirror symmetry of symbols of MQAM such that there is further decrease the computation computation complexity proposed in [41] without causing any significant degradation in performance. Also, an EDAS technique based on Rotational Symmetry of signal constellation is proposed in [44] that significantly reduces the complexity. In [40], a new TAS scheme is proposed by using combination of optimization algorithm that works by employing the Greedy technique of Minimum Distance Ascent. Similarly, a TAS method based on Graph (GTAS) is presented to decrease the search complexity without degradation of performance [45].
5. TRANSMIT ANTENNA SELECTION TECHNIQUE IN LARGE SCALE SPATIAL MODULATION BASED MIMO SYSTEMS

Large scale MIMO systems aren’t practical as more transmit antennas lead to an increase in complexity. In [46], it has been depicted that though COAS technique gives a low complexity system, its performance can not be matched to that of an EDAS technique based system. Thus, COAS is not of much use in large scale SM MIMO systems. So, new schemes have to be developed to obtain an optimum fairness between the complexity and performance of the system. In the following section, these two conventionally used TAS schemes discussed.

5.1 ED (Euclidean distance )-Based TAS.

In an SM- MIMO system using Maximum Likelihood detection, receiver’s performance is dependent on Euclidean distance. The task of sub- optimal TAS technique is, thus, to find that subset of antennas for which Euclidean distance is minimized. It can be formulated in such a way that it searches for the most optimal no. of antennas that would have to work at the same time (out of all the antennas present at the transmitter) so that an optimal performance can be achieved in terms of BER. The problem arises when higher modulation schemes are used as exhaustive search is required in such cases which increase the computational complexity. Some ED based TAS algorithms have been proposed by a number of authors [47] to [49].

5.2 CO (Capacity Optimization)-Based TAS.

COAS technique is a very efficient technique which works on the principle that for antenna selection, only those antennas have to be chosen that give the maximum or optimal value of the Frobenius norm (taken on the column of the matrix representation of the channel, as shown in fig. 2) [45]. This technique is less complex as compared to EDAS, at the cost of performance loss.

6. TRANSMIT ANTENNA SELECTION IN OFDM- MIMO

Antenna selection is an important component of OFDM MIMO used in 4G systems as it helps in decreasing cost and complexity. Also, as compared to beamforming and precoding techniques, antenna selection requires lesser feedback information from receiver to transmitter [51]. Fig. 3 depicts the basic system model of Antenna Selection technique being used in an OFDM- MIMO system.
In OFDM systems, antenna selection techniques can be classified into two categories [53]:

- **Bulk Selection.** It constitutes the process of selecting the very same antennas in the case of all sub carriers present.
- **Per Subcarrier Selection.** In this, for different subcarriers, different antennae are chosen. Capacity and error reduction is observed by using this method (as compared to the bulk selection method) at the expense of increased Radio Frequency chains [54].
- **Combined selection method.** It combines the above two schemes [55].

In [19], antenna selection at transmitter side is applied for Interference Alignment in Multiple Input Multiple Output (MIMO) based OFDM (Orthogonal Frequency Division Multiplexing) systems by using both the Bulk Selection method and Per- Subcarrier Selection method.

### 7. CONCLUSIONS

In this paper, TAS techniques for various MIMO systems have been addressed. It can be concluded that TAS improves the MIMO system by decreasing the hardware, complexity and cost requirements and still achieving full diversity and capacity.

### References


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