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Spatial Modulation - A High Efficient Technique for MIMO Communication

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Abstract: *Spatial Modulation (SM) technique is used to enhance the capacity of MIMO systems by exploiting the index of transmit antenna, as additional means of data transmission. In any given symbol interval, SM selected only one antenna from multiple available antennas for transmission. The transmitted information bits are divided into two parts. The first part is mapped to a symbol chosen from the signaling constellation, where depending on modulation scheme the number of bits per symbol varies. The second part determines the antenna index to be selected from a set of antennas available for data transmission. This would increase the spectral efficiency and decrease the complexity at the receiver. At the receiver, an optimal detector is employed to estimate the transmitted symbols as well as the index of the active transmit antennas. The rate of data transmission can much more increased by mapping into subsets of antennas in MIMO. The paper describes some of the recent works related to SM-MIMO.*
Keywords- *CSI, GSM, ICI, MIMO, OFDM, QPSK, SM*

I. Introduction

Multiple-Input Multiple-Output (MIMO) technology is a wireless technology that uses multiple transmitters and receivers to transfer more data at the same time to achieve higher data rate and retrieve data efficiently with minimum possible error. For this purpose there have been proposed a number of MIMO system models. The main problem in MIMO systems is the increase in complexity of receiver as number of antenna increases. This complexity have been reduced to a large extend by introducing various receiver models but with corresponding loss in its efficiency in reducing the error rate. Another major problem with MIMO system is the Inter Channel Interference (ICI) due to simultaneous transfer of data from multiple antennas.

Spatial Modulation (SM) is a new technique in MIMO communication system where only one antenna at a time is active while transmitting. This reduces the Interference occurred in MIMO when a number of antennas transmitted simultaneously. This also reduces the complexity of receiver. In SM a block of information stream is mapped into constellation points in signal domain and in spatial domain [1]. The spatial domain mapping is done based on the information bits and this helps in gain of data rate when only one antenna is active at an instant.

Compared to the conventional MIMO system, SM using only one active antenna at a time to avoid ICI [1] [2] [3]. Complexity of receiver is far reduced in SM-MIMO by using only one active antenna at a time and the complex receiver design for overcoming the ICI problems is not required. The data rate is increased in SM due to the mapping of data into spatial domain and thus helps in increase in spectral efficiency [1]. The circuit complexity is reduced at transmitter because only one radio frequency chain is needed for transmission at an instant. The main power consumption in base station is at the power amplifier section at the transmitter which increases with number of RF chains [4]. Thus in SM-MIMO systems this power consumption is reduced to a great extent. SM can help in designing efficient unbalanced MIMO channels where the number of receiver antenna is less than number of Transmitting antennas used [5].

The rest of the paper is organized as follows. Detailed working of Conventional SM-MIMO in Section II. Problems of SM-MIMO are discussed in section III. Overview of existing techniques is discussed in section IV. SM-MIMO can be much more extended in MIMO systems to attain higher data rates by new novel idea discussed in section V. Section VI concludes this paper.

II. Basic SM-MIMO system model

System model of SM-MIMO is shown in Figure.1. We consider N_T Transmit antennas and N_R receive antennas. Let M be the size of Signal Constellations. In SM-MIMO only one antenna is active at a time. The length n of information block:

$$n = \log_2 N_T + \log_2 M \qquad (1)$$

These information bits with length n are divided into:

i. $\log_2 N_T$ bits for mapping into set of antenna combinations, and

ii. $\log_2 M$ bits for mapping into signal constellations.

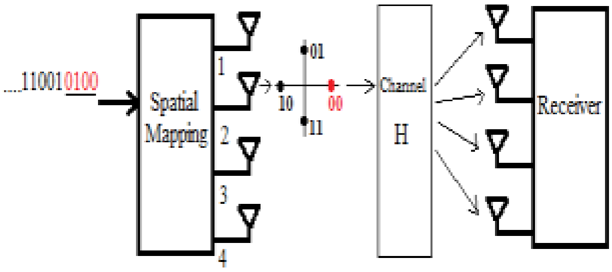

Figure 1: Conventional SM MIMO [11]

As shown in Fig.1, a stream of information data is selected as blocks containing two fields. Here first selected the block 0100 from the information stream in which first two bits 01 maps to antenna through which the data is sent. Since the system shown is of 4x4 MIMO, the number of bits to map spatial constellation will be $\log_2 4$=2bits. The remaining bits of 0100 is mapped into signal constellation, here it is shown with QPSK signalling. The mapping is well described in the Table.1.

Table.1: Mapping Table for SM with 4 Transmit Antenna and QPSK signalling

N_T=4 , N_R=4 , M=4		
Input Stream	**Antenna Number**	**Symbol Transmitted**
0000	1	+1
0001	1	+j
0010	1	-1
0011	1	-j
0100	2	+1
0101	2	+j
0110	2	-1
0111	2	-j
1000	3	+1
1001	3	+j
1010	3	-1
1011	3	-j
1100	4	+1
1101	4	+j
1110	4	-1
1111	4	-j

In SM with OFDM the binary streams is mapped into a matrix of dimension $N_T$xn where n is the number of OFDM subcarriers [1]. Let the matrix be denoted as $S(k)=[s_1(k)\ s_2(k)\ s_3(k)\ldots\ s_{NT}(k)]^T$. since only one antenna is active at a time, S(k) will have only one nonzero element in each column at the position of mapped antenna. The transmitted vector from each antenna is transmitted over the MIMO channel and is added with Additive white Gaussian Noise (AWGN) n(k). The received matrix will be Y(k)=H(k)*S(k)+n(k), where H(k) is the CSI and * denotes the convolution. The received signal Y(k) contains both antenna constellation point and signal constellation point and are retrieved back by various receiver algorithms. In MRRC algorithm, the received column vector is multiplied with the Hermitian conjugate of CSI, which is assumed to be known by the receiver. i.e.

$$g(k)=H^H(k)y(k) \quad (2)$$

In ideal case, the estimated g(k) will be same as s(k). Thus the antenna number P of the transmitted antenna is given by the index of g(k) in matrix whose absolute value is maximum in presence of AWGN, as:

$$P=\text{argmax}(|g_i(k)|) \quad \forall\ I \quad (3)$$

Antenna number is then used for attaining the symbol at that instant by:

$$\tilde{s}(k) = Q(g_{i=P}(k)) \quad (4)$$

Where Q(.) denotes the constellation quantization function and $\tilde{s}(k)$ is the estimated symbol. These two results are then used to decode the transmitted data.

III. Problems of SM-MIMO systems

- As only one antenna is active at a time, the spectral efficiency of SM is reduced as the number of transmitting antenna is increased [5].
- Data rate can be increased only in logarithmic scale, rather than linear, in SM-MIMO [2]. This limits SM to attain high spectral efficiency as number of antenna increase beyond a limit.
- Accurate knowledge of CSI is required at receiver to retrieve the message transmitted. Estimation of CSI may require complex constraints in SM-MIMO because the N_TN_R impulse responses may need to be estimated every time.
- Design problems of SM-MIMO in frequency selective fading channels still exist. Frequency selective fading cannot be avoided in 5G networks due to the high transmission rate [5].

3.1. Spectral efficiency

Thus compared to MIMO systems, SM-MIMO attains less spectral efficiency as the number antenna increases. This is because of the fact that as antenna number increases logarithmically in SM-MIMO. Better spectral performance of SM-MIMO is essential as number of transmitting antennas increases. This can be achieved by modifying the SM conventional model for complete use of spectrum available. One of the possible methods is by activating more than one antenna at a time. But though by increasing the number of antennas active at a time is increased, the efficiency is seen to be saturated as the number of antennas at the transmitting end of the MIMO system increases, similar to that of one active antenna at a time. But still the increase in efficiency is better than that of one active antenna.

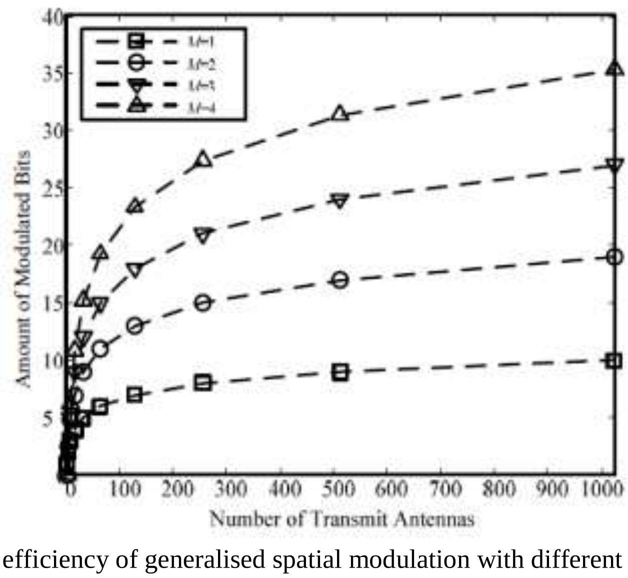

Figure 2: The modulation efficiency of generalised spatial modulation with different amount of active antennas [5]

Fig.2 shows the modulation efficiency of generalized spatial modulation with different amount of active antennas. Here the SM-MIMO with single active antenna, the amount of modulated information bits is limited even with the increase of transmit antennas. On the contrary, GSM is more efficient with the increase of the activated transmit antennas.

3.2. Receiver Complexity

The number of complex operations used at receiver is known as the receiver complexity. The complexity mainly includes addition and multiplication of complex numbers. The reduction in receiver complexity is significant for the system consists of large number of transmit and receive antennas, where as it is inferior for small numbers [1].

Fig.3 shows the receiver complexity comparison for 6-b/s/Hz transmission that uses different algorithm. SM and Alamouti algorithm have comparable receiver complexity. Main advantage of SM is the ability to work with any system configuration, even there are more transmit antennas than receive antennas [1]. Maximum likelihood (ML) algorithm has better performance than maximum receiving ratio combining (MRRC) in SM but the computational complexity of ML is larger than MRRC in SM [6].

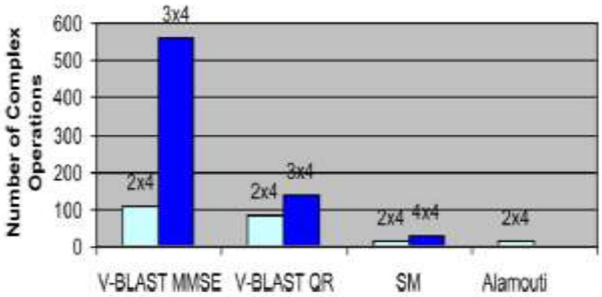

Figure 3: Receiver complexity comparison for the 6-b/s/Hz transmission that uses MMSE V-BLAST, V-BLAST-based QR decomposition, MRRC SM, and the ML Alamouti algorithm [1]

IV. BER performance of existing techniques

In spatial modulation the information bits to be transmitted are divided into two parts. The first part determines the symbol chosen from the signaling constellation. The second part determines the active antenna index from a set of antennas available for data transmission.

Generalized spatial modulation (GSM) is a new technique to utilize more number of transmits antennas and has been developed to improve the modulation efficiency. In GSM more than one antenna is active at a particular time for the data transmission. Increase in number of active antenna will increase the detection complexity at the receiver [5]. Similar SM, the transmission bits in GSM are mapped to a constellation symbol and a spatial symbol. The spatial symbol is the combination of transmit antennas activated at each instant. Overall spectral efficiency is increased by base-two logarithm of number of active antenna combination. In GSM, the number of transmit antennas required to attain a certain spectral efficiency is reduced by more than half as compared to SM [9]. Fig.4 shows the bit error rate (BER) performance of GSM for various number of transmit antennas (N_t) and active antennas (N_u). The system with 4 transmits antennas results worse performance. Performance of the system does not improve with increasing the number of transmit antennas. Therefore there might not be a solution for choosing better performance system [9].

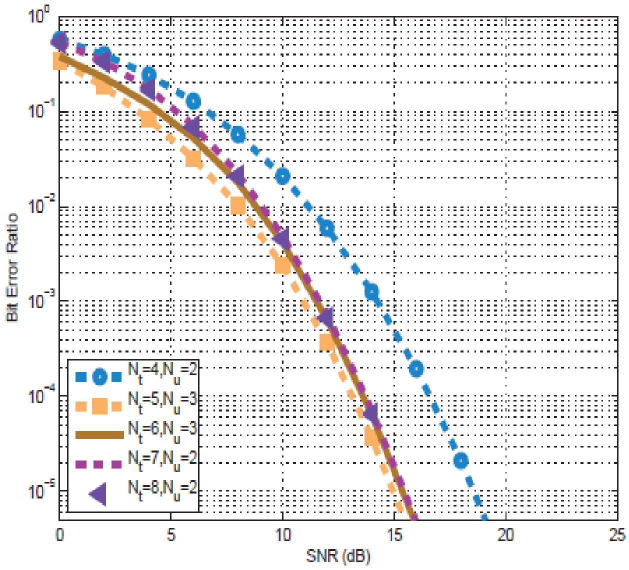

Figure 4: BER performance of GSM [9]

SM is combined with orthogonal frequency division multiplexing (OFDM) is called SM-OFDM. SM-OFDM is used to increase the spectral efficiency by mapping a block of information bits to single transmit antenna and an information symbol. Only one antenna is active for an entire OFDM symbol at any given subchannel and time instant. Depending on the sequence incoming bits, the active antenna might be different for each subchannel. Thus inter-channel interference (ICI) is avoided and high spectral efficiency is maintained [10]. Fig.5 and Fig.6 shows the BER performance of SM-OFDM with Alamouti-OFDM and V-BLAST-OFDM for 6 and 8-b/s/Hz transmissions respectively. All schemes show approximately similar performance at a low SNR (SNR < 10 dB) for both spectral efficiencies. For SM transmission, the 4×4 system with a 6-b/s/Hz transmission and the 8×4 system with an 8-b/s/Hz transmission start to show significantly better performance than V-BLAST at SNR > 10 dB, whereas the 2×4 system with a 6-b/s/Hz transmission and the 4×4 system with an 8-b/s/Hz transmission in both figures show better performance gains than V-BLAST at SNR > 20 dB. This is due to the use of a lower modulation order in the first set of systems as compared to the other set. The main reason behind the poor performance of Alamouti as compared to SM and V-BLAST is the use of a higher constellation size to achieve the same spectral efficiency as in SM and V-BLAST. Both figures explain the better performance of SM over V-BLAST and Alamouti scheme [1].

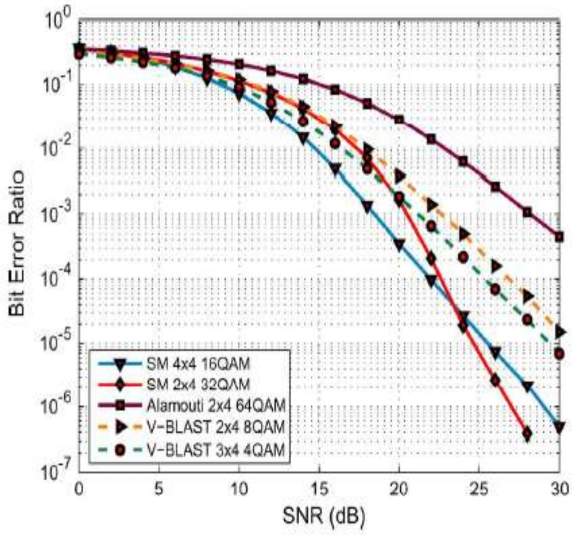

Figure 5: BER versus SNR for the case of a 6-b/s/Hz transmission [1]

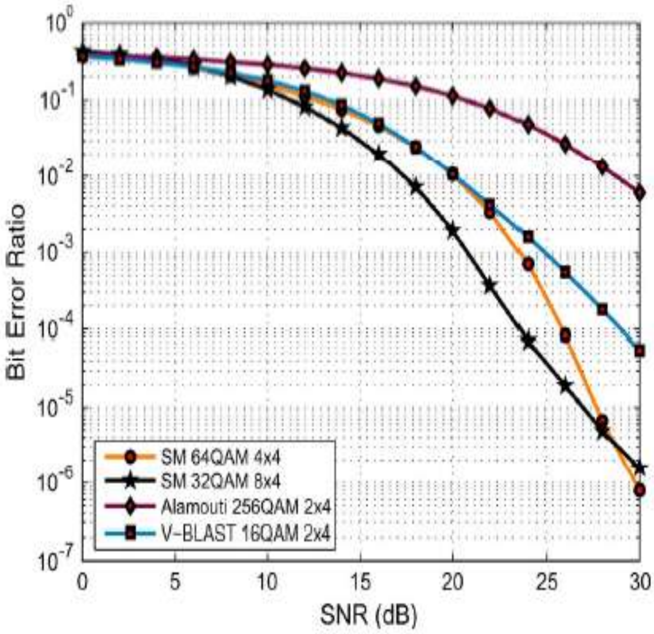

Figure 6: BER versus SNR for the case of an 8-b/s/Hz transmission [1]

V. Proposed technique

As in SM-MIMO, where a set of bits selects the antenna for transmission, here indexing is extended for two cases. One is for MIMO antenna subset selection and other for antenna selection. Thus the block of bit stream is mapped to 3 constellations, where antenna subset mapping in MIMO and antenna mapping of corresponding subset in MIMO is a part of mapping in Spatial constellation. Thus from a block of 6 bit, only two bits of data are transmitted by an antenna at time and the remaining 4 bits of data block are chosen by spatial constellation. Thus the data rate can be increasing to a much more level as compared to the conventional SM.

SM with transmit antenna subset mapping is as shown in Fig.7. Number of transmitting antenna N_T is 16 which is divided to 4 sets each having 4 antennas. Let N_S denote the number of antenna subsets. Then block of information bits will be of length $n = \log_2 N_S + \log_2 N_T + \log_2 M$ bits.

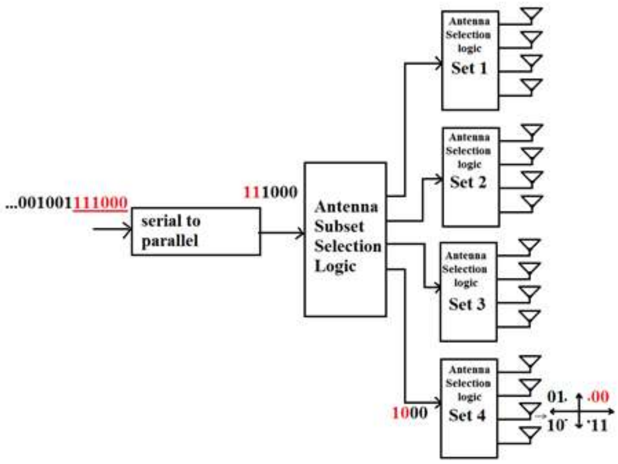

Figure 7: SM MIMO system with Antenna subset modulation [11]

Here the entire band provided to the station is divided equally to each antenna subset so as to simplify the process for identifying the antenna subset at the receiver. Antenna number is known by the same method as in conventional SM discussed earlier. Band division and its allocation to the subsets is direct application of FDMA technique. Each band can be efficiently used having OFDM at each Antenna subsets. Thereby a combination of FDMA and OFDM is used.

VI. Conclusion

This paper has summarized some of the recent works, some issues and proposed a new idea on SM-MIMO systems. SM-MIMO is one of the latest technologies where spatial points are taken along with symbol points as information and thus giving a much higher spectral efficiency. This SM-MIMO decreases the ICI and complexity of the receiver by activating only one antenna while transmitting. The data rate can much more increased by having antenna subset mapping in SM-MIMO. There are still a large number of issues to be overcome in SM-MIMO mainly the loss of modulation efficiency in higher order MIMO systems.

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