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Spatial Modulation With Multiple Active Transmit Antennas

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Abstract—This paper introduces Generalized spatial modulation with multiple active transmit antennas. This is a novel high rate low complexity MIMO transmission scheme. This will use multiple antennas to convey information, the extra information will encode in the physical location of transmitting antenna. So it can increase the transmission rate without using additional bandwidth. This system can achieve high diversity, high transmission rate and multiplexing gain. This system activates only a minimum number of antennas for transmission compared to MIMO, which helps to decrease the power consumption. Hence MA-SM make the communication system both energy efficient and spectral efficient. The minimum number of active antennas also reduces inter channel interference and inter antenna interference.

Keywords— Multiple active spatial modulation (MA-SM), Generalized Spatial Modulation (GSM), Spatial Modulation(SM), Inter Channel Interference (ICI) component

I. INTRODUCTION

The new system multiple active antenna spatial modulation (MA-SM) is a modification of MIMO technique. It is a novel high-rate, low complexity MIMO transmission scheme. The four communication models includes Single input single output (SISO), Multiple input single output (MISO), Single input multiple output (SIMO) and Multiple input multiple output (MIMO). MIMO system was introduced to overcome the drawbacks of three other previous techniques like SISO, MISO, and SIMO. MIMO has many advantages including spatial diversity; multiplexing and can improve reliability of communication by using multiple numbers of antennas. Data rate will linearly increase with the number of available transmitting antennas. But the increase of number of transmitting antennas beyond limit is not favorable. MIMO has got some limitation in terms of increasing the number of transmitting antennas. As the data transmits by multiple numbers of antennas it will create interference. So some powerful receivers are required to decode the streams of transmitted data, and also there should be a powerful synchronization between the antennas. The complexity of receiver should increase to get better performance. One of the main another issue in MIMO is increased power consumption. To get increased rate multiple antennas are required. Each antenna has RF chain. In a communication system power dissipation is mainly of two types, static power dissipation and dynamic power dissipation. Dynamic power dissipation is the power dissipation occurs during data transmission while static power is the power required to feed into RF chain to maintain the system in operating region. Static power loss occurs mostly in power amplifiers. In a communication system there will be RF chain associated with every antenna. Each RF chain has power amplifier. So as the number of antennas increases number of RF chain will increase, the number of power amplifier increase, hence the power dissipation. So in a MIMO system if the number of transmitting antenna increased for increasing data rate, the power required will be more. There should be a tradeoff between energy efficiency and spectral efficiency. So a new system is required which is efficient in terms of both energy and data rate. This requirement resulted in a new scheme of MIMO which is called spatial modulation. Then more efficient spatial modulation techniques like generalized spatial modulation and multiple active antenna spatial modulation introduced, which are modifications of spatial modulation.

The basic idea of spatial modulation is to map a block of information bits into two units, (1) the signal that was chosen from constellation diagram (2) Unique transmit antenna number or position that selected from a set of transmit antennas. The use of the transmit antenna number as an information-bearing unit increases the overall spectral efficiency. Spectral efficiency will increased by the base-two logarithm of the number of transmit antennas. In a group of antennas only one antenna transmits at a time in case of spatial modulation. Generalized spatial modulation is actually a modification of spatial modulation. GSM has multiple numbers of antennas which will transmit the same symbol. Since multiple antennas are transmitting at a time, antenna combination can be used to map information instead of a single antenna number that helps to achieve same data transmission rate with less number of antennas. GSM modified again to increase the data transmission rate which is called multiple active transmit antenna spatial modulation (MA-SM), in which different antennas will transmit different symbols so that data rate can be increased again.

II. SPATIAL MODULATION

The need for high data rate and high power efficiency are the key elements that drive research in future wireless communication systems. One approach to achieve this requirement is spatial modulation.

In Spatial Modulation, the basic principle is modulating the symbol with not only phase or amplitude of the carrier but also with selection of the antenna for transmission of the carrier. The location of the activated antenna in spatial domain is used as an information source for transmission of the data and thus spectral efficiency is increased. In spatial modulation there will be a group of antennas, where one antenna will active at each time instant and that antenna transmits a given data symbol (*constellation symbol*). SM exploits spatial position (index) of the active antenna as an additional dimension for data transmission (*spatial symbol*) [11]. Both the *constellation symbol* and the *spatial symbol* depend on the incoming data bits. Each unique antenna position can denote by using specific binary data. According to the incoming information active antenna will be selected and that will transmit the remaining information bits. This will helps to improve the data rate without increasing the bandwidth [2,3].

III. GENERALISED SPATIAL MODULATION

Generalised spatial modulation is a modification of spatial modulation technique. In spatial modulation only one antenna will active at a time. So Generalised spatial modulation (GSM) is proposed, to overcome the limitation in the number of transmit antennas in SM [5,6]. In GSM the same symbol is transmitted simultaneously from more than one transmit antenna. Transmitting the same data symbol from the active antennas retains the key advantages of SM like low computational complexity, which is equal to the complexity of single input Multiple output (SIMO) systems, and with less number of antennas in the antenna array same efficiency as that of spatial modulation can be achieved.

In GSM multiple antennas are active at a time. So for each antenna combination there should be a unique binary representation. The number of bits that can be used for antenna position representation will be more in GSM. This is because the possible antenna combinations will be always more than the number of antennas in an array. Instead of a single antenna, if combinations of antennas are used the number of bits for antenna index representation can be increased; this will help to improve the total data rate with minimum number of antennas.

IV. MULTIPLE ACTIVE ANTENNA SPATIAL MODULATION

Multiple active antenna spatial modulation (MA-SM) is a modification of GSM. In GSM multiple antennas will active at a time and all antennas transmit the same symbols while in MA-SM multiple active antennas will transmit multiple symbols. By allowing multiple transmitting antennas in the SM system to transmit different symbols at the same time instant, MA-SM takes advantages of the low complexity of SM and high multiplexing gain. In the MA-SM system, the transmitted symbols are mapped into a high dimensional constellation space including the spatial dimension. The general principles for designing the efficient MA-SM for arbitrary number of transmit antennas and modulation scheme is presented. At the receiver side receiver should detect the transmitted antenna after that receiver will decode the transmitted signal. Detection of transmitted antenna is essential since a part of data transmitted as antenna index.

In order to achieve high transmit rate, GSM requires a large number of transmit antennas that increases the complexity of the system exponentially. For GSM receiver complexity will be high for high data rate. In order to explore the multiplexing gain of system with low computational complexity, a novel multiple active-spatial modulation (MA-SM) scheme and a decoder with low complexity are proposed .In MA-SM scheme several transmit antennas carrying different information symbols are active during each time slot. Information bits in MA-SM are mapped into both spatial dimension and traditional complex dimension. So that using same bandwidth more spectral efficiency and energy efficiency can be attained. At the receiver zero forcing equalization can be used to detect the antenna set, and maximal ratio combining for signal detection. In GSM all active antenna transmit the same symbol while in MA-SM different antennas which are active at a time will transmit different information, also some information will encode as index of antenna combination. So the data rate of MA-SM will be more than GSM. This will help to achieve a system which is both spectrum efficient and energy efficient.

Example: Consider 4 alphabets A B C D which are the data that need to be transmitted. Assume a signal space, and link this symbols into a constellation diagram. Now there are four different signals and four different constellation points. Assume multiple antennas at the transmitter. These antennas have unique positions on antenna array. This fact can exploit in defining the location as a spatial constellation point. Now the system has signal constellation points and spatial constellation points.

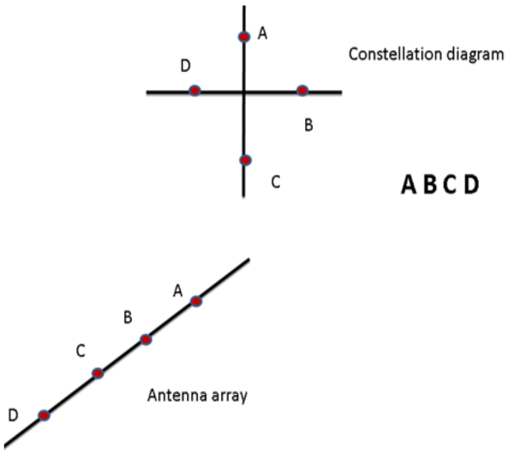

Figure 1. Mapping of symbols into constellation points and unique antenna positions

Assume two antennas are active at a time, and each antenna will transmit a single alphabet. **BAAB** are the data bits to be transmitted. Assume the first two bits will select the antenna and the remaining bits will be transmitted by them. So first and second antennas will be selected which correspond to symbol A and B respectively. Then first antenna will transmit symbol B and second will transmit symbol A as shown in figure 2. Here explicitly only two symbols are transmitting while implicitly four symbols are transmitting, so this is how a MA-SM system improves the system capacity without increasing the available resources.

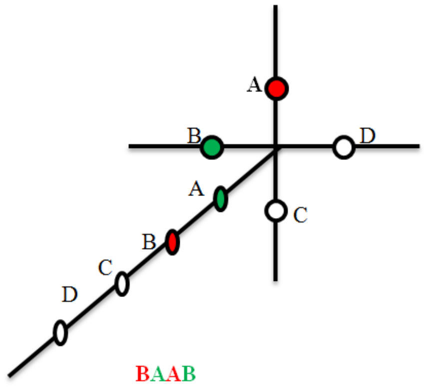

Figure 2. MA-SM example

The source information bits are transmitted from Nu of the transmit antennas after being mapped through an M order Quadrature Amplitude Modulation (M-QAM).
In practice, an MA-SM transmitter works as follows:

1) Every appropriate Nu antennas from Nt are selected as an antenna group,
 $2^\wedge \left\lfloor log_2 \binom{Nt}{Nu} \right\rfloor$ groups have to select.

2) Encode the antenna sets into bits sequence with length $\left\lfloor log_2 \binom{Nt}{Nu} \right\rfloor$.First $\left\lfloor log_2 \binom{Nt}{Nu} \right\rfloor$ bits will be used for antenna group selection and remaining $\log_2(M)$ symbols will map into signal constellation.

3) Give a rotation of θ_i angle for every symbols transmitting from i^{th} antenna. In the system, the information bits are conveyed by both the complex symbols and the indices of the active antennas from which those symbols are transmitted.

At the transmitter side, Nu antennas are chosen to carry different symbols during the transmission, which results in the increase of multiplexing gain. Theoretically, there is no limitation on Nu , which implies that Nu could be allowed to be any number not larger than Nt to benefit the available multiplexing gain. However, this will lead to the exponentially increasing complexity at the receiver side and the ICI and IAI would degrade the performance seriously. So Nu should be a trade-off between capacity and reliability performance. Select the active antenna groups such a way that interference can be minimized. Antennas are made to be far away from each other. The minimum distance could be maximised by proper selection of rotation angle. When a particular rotation is applied on the symbols from different antennas the distance between them will be increased compared to a system where no rotation is applied. Since there are multiple antennas being active simultaneously conveying different symbols, the number of antennas needed decreases prominently for a given size of constellation. For example 8 transmit antennas are needed in a GSM scheme and 64 antennas are needed in SM system while only 4 transmit antennas are essential in an MA-SM system for same data rate.

The optimal ML decoder, which detects the antenna set together with the symbols, increases exponentially in complexity for high order constellation since the exhaustive search space increases at the speed of $Nu * M^{Nu}$ as Nu grows. So an optimal detection method with low complexity can be used. It separates the antenna set detection from the traditional demodulator. Compared to the ML detection, the proposed detection algorithm reduces the computational complexity prominently. Received signal is the linear combination of the channel vector corresponding to the active antennas and transmitted symbols. So the received vectors lie in the subspace spanned by channel vectors. By finding the vertical distance of received vector to the subspace antenna set can be found. So Zero forcing detection can be used for antenna detection.

Maximum ratio combiner can be used for detection of symbol. This will give a linear low complexity detection scheme.

A. System Design and Optimization

- Transmitter

Step1:
The input serial data will be reshaped into a matrix having columns equal to
$\log_2$(M)*Nu+$\left\lfloor log_2 \binom{Nt}{Nu} \right\rfloor$ (1). Here M is the modulation order. Nu is number of active antennas, and Nt is the total transmitting antennas in the array. From $\binom{Nt}{Nu}$ total available antenna groups 2^$\left\lfloor log_2 \binom{Nt}{Nu} \right\rfloor$, antenna groups are selected, so in order to represent this much of antenna group $\left\lfloor log_2 \binom{Nt}{Nu} \right\rfloor$ bits are required. So the second term in equation represents the number of information bits that are going to transmit using the antenna index. In each group there will be Nu number of active antennas, and each antenna will transmit different information. For M-order QAM modulation each antenna can transmit $\log_2$(M) bits, so Nu antennas can transmit Nu*log2 (M) bits. It is shown in the first term of equation (1).
Step 2:
In order to minimize the interference the antenna group should select in such a way that the antennas in the group are maximum apart.
Step 3:
After antenna group selection apply modulation for the remaining bits.
Step 4:
Again to increase the minimum distance or minimizing the interference an angle of rotation θ can be applied to information from separate antennas. For each antenna a unique angle of rotation will be applied. Angle of rotation will be given by the below equation.

$$\Theta_i = \frac{2(i-1)\Pi}{Mn} \quad (2)$$

where M>4 and n= 2^$\left\lfloor log_2 \binom{Nt}{Nu} \right\rfloor$

Since the minimum distance between code words dominates the bit error probability, transmission scheme can be optimized by maximizing the minimum distance involved. Unlike the traditional complex space where Euclidean distance could be applied, the three dimensional space here contains a discrete dimension that confuses the definition of distance.

$$d(X,X') = min\left\{\sqrt{\delta + ||\quad X\theta i - \quad X'\theta i'||^2}\right. \quad (3)$$

$d(X,X')$ is the distance between the symbols. 'δ ' is the separation between antennas in an antenna group. θ_i is the angle of rotation applied. So here the minimum distance is a function of both antenna separation and angle of rotation, which is given by equation (3)
Step 5: Transmit the symbols using the antennas in the selected antenna group.

- The wireless channel as a modulation unit

The signal emitted by the active antennas then goes through a generic wireless channel. Owing to the different spatial positions occupied by the transmit antennas in the antenna array, the signal transmitted by each antenna will experience different propagation conditions due to the different interacting environmental objects along any transmit to receive wireless link. This represents the fundamental working principle of MA-SM The wireless channel plays the role of a "modulation unit", by introducing a distinct fingerprint that makes the signal emitted by distinct transmit antenna distinguishable at the receiver. If the transmit to receive wireless links are not sufficiently different, data communication might be impossible since the signals emitted by the transmit antenna will look approximately the same.

- Detection

In the MA-SM system, the receiver must find the antenna set and the information. The received signal ***y*** is the linear combination of the channel vector corresponding to the active antennas.The receiver signal information contains both symbol information and antenna index information. Along with the channel information, the active antenna information is also transmitted. The transmitted antenna set is first detected by the receiver. The Channel State Information (CSI) is considered to be known by the receiver. The Maximal Ratio Combining (MRC) can use to detect the signal from the diversity branches.

Step 1:
Antenna detection

- Find H^+, where $H^+ = (H^H \quad H)^{-1} H^H$ (4)
- Multiply the received signal (received signal=H*X) with matrix H^+, Select the row of the element which has maximum value after multiplication (Find max((H*X) H^+).
- Convert row number into binary which will give the antenna that used for transmission.

Step 2:
Based on the antenna used first apply the inverse of angle of rotation in the received signal. Then use maximum ratio combining technique.
Step 3:
Symbol detection
Maximal ratio combining for symbol detection Maximal-ratio combining (MRC) is a method of diversity combining in which: the signals from each channel are added together, the gain of each channel is made proportional to the rms signal level and inversely proportional to the mean square noise level in that channel.

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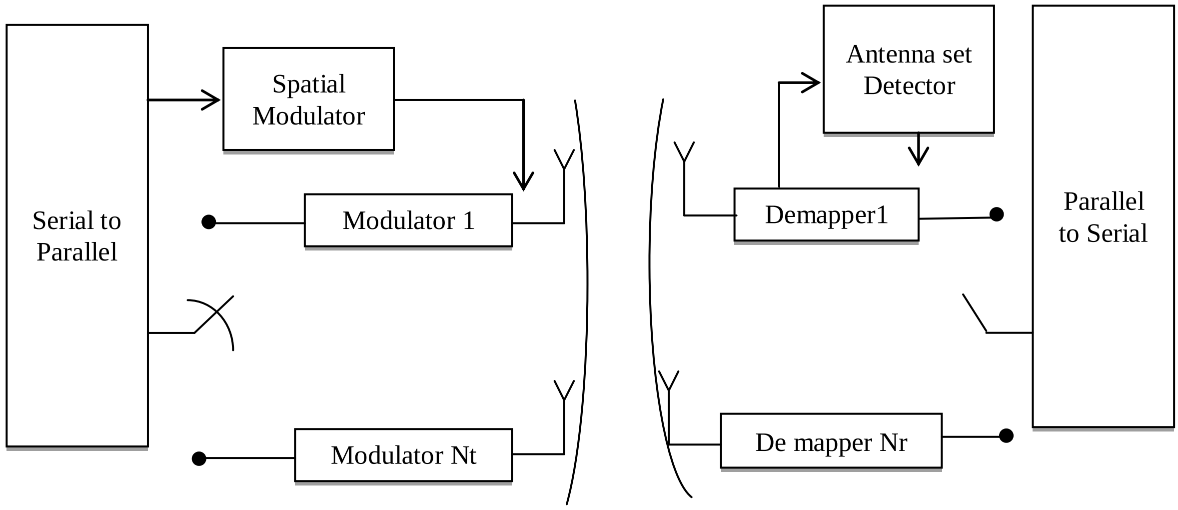

Figure 3. MA-SM system model

V. RESULTS

This section presents some simulation results for MA-SM system, made comparison with other MIMO systems such as Alamouti and V-BLAST. Another comparison made with SM. The bit error rate (BER) performance of these systems was evaluated as a function of the average SNR and in all cases the independence of channels is assumed to be known at the receiver.

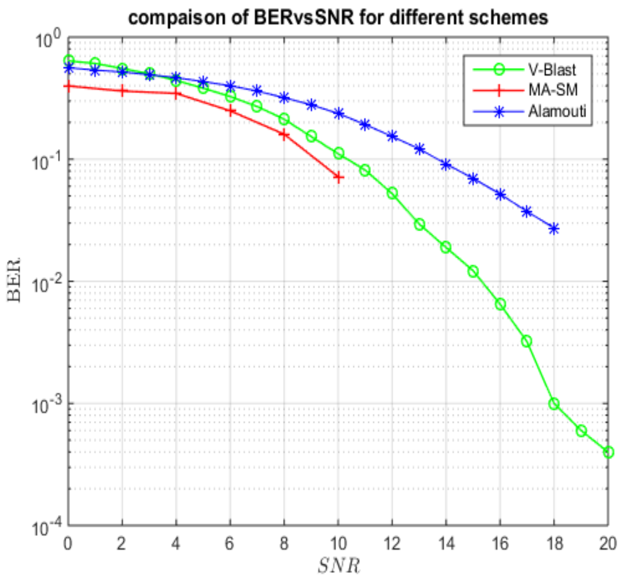

Figure 4. Comparison of MA-SM with V-BLAST and Alamouti.

Figure 4 represents comparison with some traditional MIMO schemes Alamouti and VBLAST. Here for Alamouti number of transmitting antenna Nt=2 and number of receiving antenna Nr=1, for V-BLAST Nt=Nr=2. For MA-SM Nt=4, Nu=2, Nr=2 and QPSK modulation. MA-SM provides better performance. The gap between V-BLAST and MA-SM is because interference is lesser for MA-SM than V-BLAST.

- Comparison of MA-SM and SM

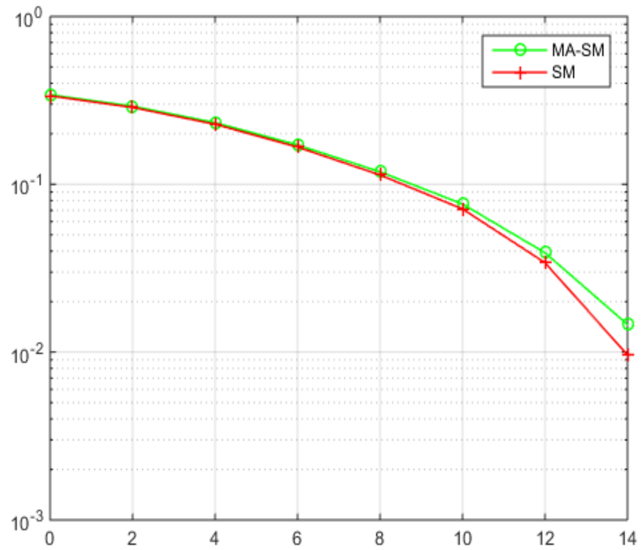

Figure 5. Comparison of MA-SM and SM

Here SM has one receiving antenna and '4' transmitting antennas, for MA-SM Nt=4, Nu=2 and Nr=2. In this case the data rate will be more for MA-SM. But the BER will be nearly same. SM will give slightly better performance than MA-SM, since ICI and IAI are not present in SM, but while considering both the data rate and BER MA-SM will be better.

VI. CONCLUSION

MA-SM is a novel high-rate, low complexity MIMO transmission scheme. It is an alternative to existing techniques, such as Alamouti, VBLAST etc. Spatial modulation system uses antenna index for data transmission. Hence the data transmission rate can be increased without using any additional resources. Spatial modulation system modified to generate generalized spatial modulation which has more capacity, MA-SM is the modified form of GSM. The proposed MA-SM scheme employs both conventional modulation techniques and antenna indices to convey information and exploit the transmit multiplexing potential of MIMO channels. It is more efficient than conventional wireless transmission techniques as well as SM and GSM in terms of energy and spectral capacity. Here a general technique has been proposed for the construction of the MA-SM which is optimized by maximizing the inter symbol distance using angle of rotation. The MA-SM system has an optimal decoder which will reduce the detection complexity. It has been shown via computer simulations that MA-SM offers significant improvements of system performance compared with VBLAST, Alamouti with an acceptable linear decoding complexity. It can be concluded that the MA-SM scheme can be useful for high-rate wireless communication systems. MA-SM can use in visible light communication or Li-Fi in future. Application of MA-SM in Li-Fi will be a revolution in wireless communication.

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