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BER Performance of Adaptive Spatial Modulation

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Abstract— *Adaptive spatial modulation(ASM) is a recently developed communication system that generalizes both Spatial Modulation(SM) and Transmit Antenna Selection(TAS). Data stream is divided in signal carried information and spatial carried information. Using Huffman coding transmitter can adjust activation probability of transmit antenna according to receiver side feedback. Huffman coding helps to assign binary data antenna index. Antenna information bits are mapped to corresponding transmit antenna according to constructed code. Activation probability is derived by optimizing capacity which helps to select transmit antenna. Bit error rate is calculated to compare performance of ASM and SM. ASM minimizes bit error and there by producing improvement in performance.*
Index Terms—*ASM, SM, TAS*

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I. Introduction

Spatial modulation is a recently developed technique which offers less complexity(due to utilizing single RF frond end) and interference when compared with Multiple Input Multiple Output(MIMO) communication system. Also spatial modulation offers better data rate when compared with MIMO system. The main objective of spatial modulation is to split data or information into two units, one unit is for spatial indexing or antenna index and the other one is for signal constellation. There will be a total of $n = \log_2 N_T + \log_2 M$ blocks of information if number of antenna transmitted is Nt and receiver antenna number is Nr. M is the size of constellation. The channel qualities of possible links between transmitter and receiver are different. Information sending via a weak link is worst than sending a signal over strong link. These effects the performance of spatial modulation.

Spatial modulation intended to maximize antenna information (spatial information). Sending a signal through weak link also affect the mutual information and this tends the communication system to depend on favorable conditions. Another limitation of spatial modulation is only one antenna is active at a time.

Transmit Antenna Selection(TAS) is a transmission scheme, where antenna having strongest link is selected for transmission. Transmit antenna selection, requires a feedback path from the receiver to the transmitter for inter channel information to be known. The capacity of a wireless channel with transmit-side channel state information (CSI) is generally higher than without it. In other words, there is some excess capacity generated by the transmitter knowledge of the channel. When the transmitter is fully aware of the channel coefficients, the maximum capacity available in the channel will be attained. Transmit antenna selection is very similar to receive antenna selection, the antenna is selected that provides the highest equivalent receive SNR. Different from spatial modulation, the information is fully carried by signal symbol and no information is conveyed spatially. Antenna selection mainly relays on the feedback path from the receiver in order to choose the specific antenna, along with that transmit diversity can be obtained. Limitations in design flexibility restricts the enhancement in system performance.

Performance of spatial modulation depends on channel qualities of each link. On the other hand, antenna selection depends only on the strongest link and it is not affected by weak link. SM aims to maximize the spatial information but signal information is not fully optimized which limits system performance. Transmit antenna selection intended to maximize the signal information and no spatial information is conveyed . So the main objective is to design flexible communication system that unifies SM and antenna selection. Huffman mapping helps to adjust activation probability of each transmit antenna with the use of feedback path from the receiver section. Channel capacity can be optimized for good approximation. BER performance of adaptive spatial modulation is compared with conventional spatial modulation. ASM offers better system performance and error rate is reduced.

II. Adaptive Spatial Modulation

Adaptive SM (ASM) scheme is proposed to improve the bit error ratio (BER) performance of conventional spatial modulation system.

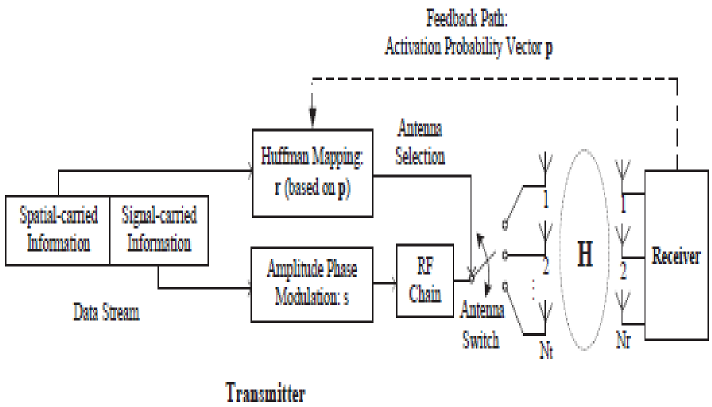

Fig. 1: Structure of adaptive spatial modulation using huffman coding [1]

Consider a communication system with Nt transmit antennas and Nr receive antennas as shown in Figure. At transmitter side, a single RF chain is connected with Nt transmit antennas through an antenna switch and thereby reducing complexity. At receiver side, each receive antenna has its corresponding RF chain. The received signals can be represented as

$$y=Hx+n$$

Where H is the channel matrix, and n is the additive white Gaussian noise. The transmitted signal x can be written as

$$x = (0 \quad 0 \,. \quad .... \quad 0 \qquad s \quad .... \quad 0 \qquad 0)^T$$

Where s is the transmitted signal. At a time only one antenna is transmitting signal while other antennas are transmitting zero power. i.e

$$x = r.s$$

Where r is symbol which is chosen from finite set or code book which is given by

$$C = e1, e2, ...eN\ t$$

and e_i is a vector with the i th element being 1 and all other elements 0. That is, when e_i is chosen, it means the ith transmit antenna is activated to transmit the signal s, and all other transmit antennas are deactivated. In block diagram, the data stream is split into two independent streams, that is one is for signal carried information and other is for antenna information or spatial information. Signal information is conveyed via the signal s, and antenna information is mapped to the spatial symbol r (antenna index). In each time slot, the signal s is conveyed by the active transmit antenna that is selected according to the antenna information.

Prob(r = ei) = pi; i = 1, 2, ..., N t

The probability of selecting the ith transmit antenna is

represented as p(r=ei), where pi satisfies N t, i=1 pi = 1.

In conventional spatial modulation, the probability vectorp = [p1, p2, ..., p_{Nt}] is 1/Nt. That is, In spatial modulation all transmit antennas have the equal probability to be activated, regardless of the channel quality. Probability of antenna having strongest link is same as probability of antenna having weak link. In this case, up to log2 {Nt} bits extra information can be conveyed by antenna index [6], [7]. In transmit antenna selection [13], the probability vector p is

pj = 1; j = argmax {hi} ; pi = 0; i = j

Above equation represents equation for calculating the probability of transmit antenna. Only the strongest transmit antenna j is selected to convey the signal information and no spatial information is conveyed via antenna index. Spatial modulation and transmit antenna selection are two special transmission schemes for single RF chain MIMO. Spatial modulation aims to maximize the antenna information, but its signal information is not optimized. Transmit antenna selection intends to maximize the signal information, but no spatial information is conveyed via antenna index. Neither of them is necessarily optimal in terms of capacity. ASM intended to unify both SM and TAS so that both antenna information and spatial information can be optimized. Bit error rate is analyzed in order to check error rate performance and compare it with conventional spatial modulation.

Main idea of Huffman coding for adaptive spatial modulation is to assign binary codes to spatial information that is the antenna index that take into account the frequency of occurrence of each symbol. The antenna information bits are mapped to its corresponding transmit antenna according to the constructed Huffman code. The longer code word means its corresponding antenna has less chance to be activated. In addition, no code word in the generated code book should be a prefix of any other code word. In SM, only one antenna is active at a time. This limits the performance. Transmitting through more than one antenna can improve the efficiency of the system. This can be achieved by grouping the transmit antenna.

Bit Sequence	Spatial Symbol	Probability%
01	Tx1	25
10	Tx2	25
110	Tx3	12.5
1111	Tx4	6.25

TABLE I: Huffman Mapping for p =[1/4; 1/4;; 1/8; 1/16]

Example 1: When the probability vector p =[1/4; 1/4; 1/8; 1/16] the corresponding Huffman mapping is shown in Table I. The incoming antenna information bits are sequentially detected and then mapped into different transmit antenna indices. If the first bit 0 is detected, then antenna Tx1 is selected. Otherwise, the first bit is 1, go to detect the second bit. If the second bit 0 is detected, then antenna Tx2 is selected. Otherwise, the second bit is 1, go to detect the third bit. If the third bit 0 is detected, then antenna Tx3 is selected. Otherwise, the third bit 1 is detected, then antenna Tx4 is selected. On the average, the activation probabilities of antennas Tx1, Tx2, Tx3, and Tx4 are 25, 25, 12.5 and 12.5 percent , respectively. Hence, the transmitted antenna information is up to 1:625 bits.
The objective of adaptive spatial modulation is to find probability that optimizes the system performance. The design problem can be generalized as follows:

p1=max/minf(p)

Where f(p) is performance metric it can be capacity or SER.

A. Capacity Based Transmission Mode Selection

When the signal follows complex Gaussian distribution, objective is to choose transmission mode that leads to maximum capacity.

P2=max/minC(p)

When ith antenna is chosen for transmission that is r = e_i and received signal,

$yj_{r=ei}$ = shi + n

and yjr = ei follows multivariate normal distribution . For simplicity of expression, we use fi(y) to denote f(yjr = ei) . Through summation over all the possible ri, the PDF of y can be derived in terms of probability It is noted that y can be modeled as a Gaussian mixture with Nt components. The capacity is represented in terms of mutual information as:

C = I(x; y) = H(y) H(yjx)

= I(s; yjr) + I(r; y)

Where I(s; yjr) is signal information and I(r; y) is antenna information and D(f_j(y)kf(y)) is the Kullback Leibler divergence[1] between the Gaussian model j with the PDF fj(y) and the Gaussian mixture with the PDF f(y)is calculated

Although it does not have a closed-form expression, through bounding. D(f_j(y))jjf(y)), helps to derive the upper and lower bound of the capacity C bounds. That is some Propositions are stated in-order to derive the capacity bounds so that it is possible to get the closed form of capacity[1]. The channel capacity C of the proposed adaptive spatial modulation is upper bounded by C+ and is lower bounded by C- which is represented by some equation. Using these closed form expression, capacity bounds are plotted. Numerical results shows that by maximizing capacity bounds system performance can be improved. Using this maximum capacity optimum activation probability is derived, which in turn helps to select transmit antenna. Assume if input signal is a discrete QAM signal, a mapping scheme is proposed to minimize the error rate. In the receiver end, Maximum Likelihood Detector(MLD) is used for optimum detection, which minimizes error rate. MLD searches the symbol from the code book in order to minimize Euclidean distance.

B. BER Performance **Comparison**

Figure 2 shows the capacity performance comparison of adaptive spatial modulation over i.i.d Rayleigh fading channel realization with N_t = 4 transmit antennas. When N_r = 1, transmit antenna selection has the same performance as the adaptive transmission. This is because in each channel realization only the strongest transmit antenna is activated to transmit information, which verifies the conclusion in Theorem 1[1].

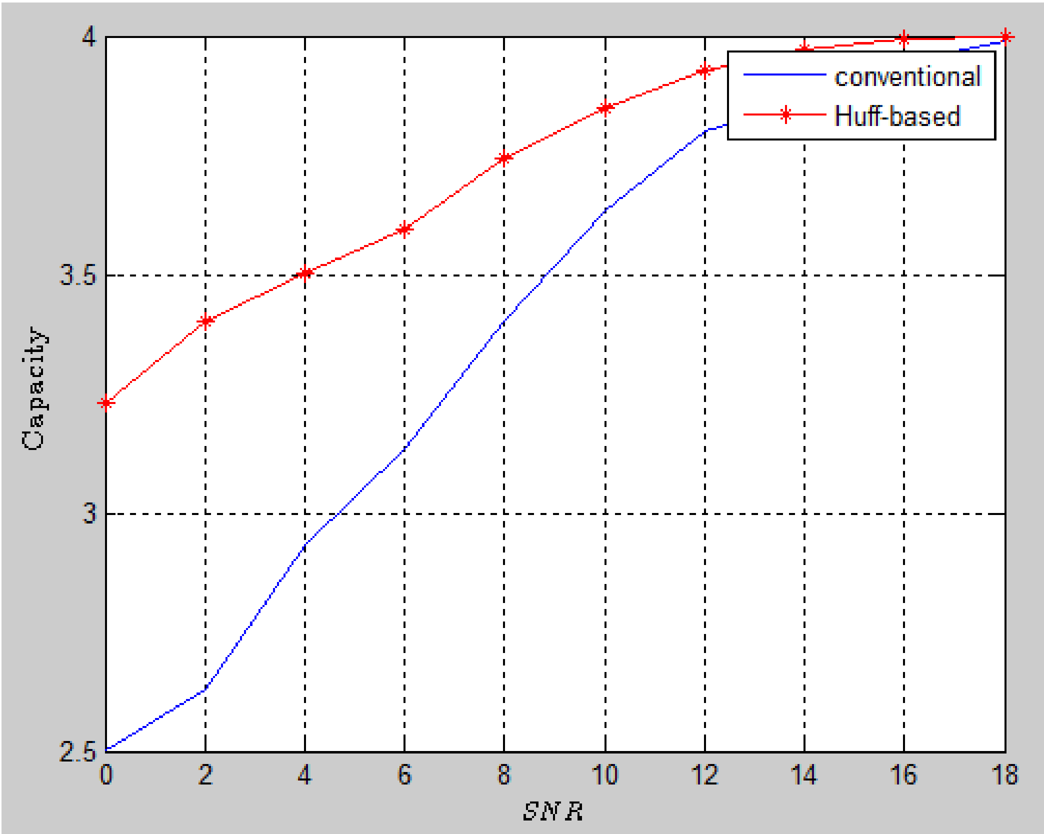

Figure 2: Capacity Comparison Over Rayleigh Fading Channel.

When N_r = 2, the performance of the adaptive spatial modulation is slightly better than the transmit antenna selection in low SNR . With the increase of SNR, the adaptive spatial modulation becomes significantly better than conventional spatial modulation and transmit antenna selection schemes. This result signifies the effectiveness of the adaptive spatial modulation and indicates that transmission schemes other than the conventional spatial modulation and the transmit antenna selection may be the optimal transmission strategy in general cases. However, when N_r increases, the performance enhancement of adaptive transmission over conventional spatial modulation becomes slight. It implies that conventional spatial modulation gradually becomes favorable with the increase of the receive antenna number N_r. Figure 2 shows capacity comparison of ASM with Conventional SM, it is seen that capacity performance is better for ASM.

Figure 3 shows BER comparison of adaptive SM and conventional SM. From the figure it is clear that ASM offers better performance, that is ASM minimizes BER and thereby improving system performance than spatial modulation and antenna selection. Data if transmitted through more than one antenna at same time slot helps to improve the capacity of the system. Such transmission in ASM offers better performance than transmitting data through one antenna at a time slot.

III. Conclusion

BER performance on adaptive spatial modulation proposes a system that minimizes the bir error rate of ASM. Proposed scheme unifies both spatial modulation and transmit antenna selection. Through variable length prefix codes, probability is assigned for each transmit antenna. Antenna selection helps to find out which link is strongest for transmission . Based on the probability of activation antenna is selected and BER is calculated.

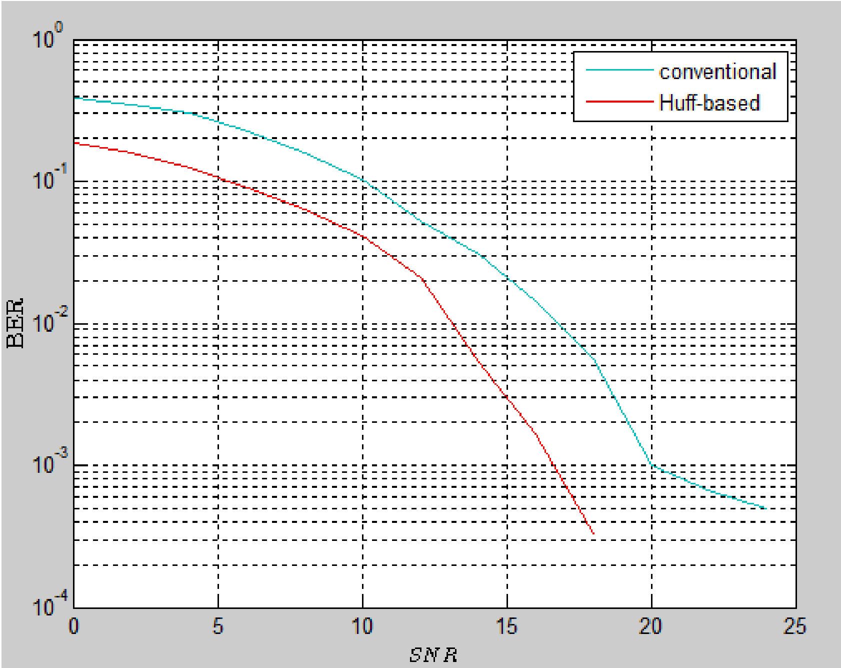

Figure 3: BER comparison

Highest probability or capacity is feedback to the transmitter. Spatial modulation assigns the spatial mapping and then according to antenna selection, transmit antenna adjust the activation probability. After comparing the bit error rate of conventional spatial modulation and ASM, ASM minimizes the bit error rate by maximizing the capacity.

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