ANTENNA SELECTION USING HUFFMAN CODING FOR MIMO WIRELESS NETWORKS

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Abstract

In MIMO systems, the transmit and receive antennas can both be used for diversity gain. Multiplexing exploits the structure of the channel gain matrix to obtain independent signaling paths that can be used to send independent data. Multiple antennas on the transmitter side can be selectively used based on the channel state information to improve the capacity of the system. Spatial modulation does not need channel state information but its performance deteriorates rapidly during unfavorable channel conditions. Therefore an adaptive scheme that uses uniquely decodable Huffman codes for antenna selection is implemented in this paper. Performance of this scheme is compared with that of conventional spatial modulation and for different channel state information feedback values. Experimental results show remarkable improvement in channel capacity with probabilistic selection of transmitter antennas.

Keywords: Spatial modulation, Huffman coding, MIMO, Gaussian distribution, CSI

1 Introduction

Wireless communication is the fastest going area of the communication industry. Cellular phone using cellular wireless system is rapidly supplementing wire line systems. Therefore, explosive growth of wireless systems has paved the way for intensive research in the field of wireless communication. One such sub field is work on reliable communication through the hostile wireless communication channel over which Information undergoes multipath fading. The channel suffers from fading introducing a certain amount of randomness- randomness in users' wireless technology, randomness in users' geographical location, randomness in route failure because of the physical characteristics of the channel and multi path interferences, resulting in a decrease in the channel capacity. These have time scale variation affecting the reliability of communication system. [1, 2] These can be termed as non-ergodic losses and diversity is one method to combat these problems. In this information is conveyed through multiple independent instantiations. Diversity can be obtained in terms of usage of multiple antennas, multiple users and multiple routes. Multiple antenna spatial diversity (space-time) communication not only provides robustness but also improves reliable data rates. This has paved way for research on MIMO systems-usage of multiple antennas at the transmitter and receiver locations. MIMO is a well-known tool for increasing capacity as well as reliability. The capacity of this MIMO system strongly depends on the power imbalance between the multiple antennas. In this paper, Huffman code mapping is done to select the transmitting antennas over which signals are transmitted, maximizing channel capacity.

The rest of the paper is organized as follows: Section 2 gives details of diversity techniques and MIMO systems; Section 3 deals with antenna selection followed by Huffman coding scheme in section 4.Section 5 gives the experimental results followed by conclusion in section 6.

2 MIMO Systems

Rayleigh fading and log-normal shadowing exact a large power penalty on the performance of modulation over wireless channels. [3, 4] One of the best techniques to mitigate the effects of fading is diversity combining of independently fading signal paths. Diversity combining exploits the fact that independent signal paths have low probability of experiencing deep fades simultaneously. There are ways of achieving independent fading paths in a wireless system. One method is to use multiple transmit or receive antenna, also called an antenna array, where the elements of the array are separated in distance. Systems with multiple antennas at the transmitter and receiver are commonly referred to as multiple-input multiple-output (MIMO) systems. This type of diversity is referred to as *space diversity*. With receiver space diversity, independent fading paths are realized without an increase in transmit signal power or bandwidth. Coherent combining of diversity signals increases the signal-to-noise power ratio at the receiver over the SNR that would be obtained with just a single receive antenna. This SNR increases, called array gain, can also be obtained with transmitter space diversity by appropriately weighing the antenna transmit powers relative to the channel gains [5].

The multiple antennas can be used to increase data rates through multiplexing or to improve performance through diversity. In MIMO systems, the transmit and receive antennas can both be used for diversity gain. Multiplexing exploits the structure of the channel gain matrix to obtain independent signaling paths that can be used to send independent data. The initial work on MIMO was given by Telatar [6] predicting remarkable spectral efficiencies for wireless systems with multiple transmit and receive antennas. The spectral efficiency gains require accurate knowledge of the channel at the receiver - and sometimes at the transmitter as well. In addition to spectral efficiency gains, ISI and interference from other users can be reduced using smart antenna techniques. The cost of the performance enhancements obtained through MIMO techniques is the added cost of deploying multiple antennas, the space and circuit power requirements of these extra antennas and the added complexity required for multidimensional signal processing. [7]

A second method of achieving diversity is by using either two transmit antennas or two receive antennas with different polarization. Directional antennas provide angle (or directional) diversity by restricting the receive antenna beam width to a given angle. In the extreme, if the angle is very small then at most one of the multipath rays will fall within the receive beam width, so there is no multipath fading from multiple ways. [8,9,10] However, this diversity technique required either a sufficient number of directional antennas to span all possible directions of arrival of or a single antenna whose directivity can be steered to the arrival angle of one of the multipath components (preferably the strongest one). Note also that with this technique the SNR may decrease owing to the loss of multipath components that fall outside the receive antenna beam width – unless the directional gain of the antenna is sufficiently large to compensate for this lost power.

Initially until mid-1990s, focus was on receiver diversity where multiple copies of transmitted signal were obtained using many receiving antenna ($\mathbf{N_t} = 1, \mathbf{N_r} = \mathbf{N}$).Use of multiple transmit antennas was restricted to sending the signal over each antenna- a form of repetition coding. This led to increase in the capacity of channels first introduced by Shannon in 1948, where he showed that on noisy channels one can transmit information at positive rate with error probability going to zero asymptotically in the coding block size. For a noisy channel at time k for the input $\{ X_k \}$ there is the output $[Y_k]$, the capacity is given in terms of the mutual information between the channel input vector **x** and the output vector **y** as

$$C = \max I(\mathbf{X};\mathbf{Y}) = \max[H(\mathbf{Y}) - H(\mathbf{Y}|\mathbf{X})] \qquad (1)$$

H ($\mathbf{Y}|\mathbf{X}$) = H ($\mathbf{n}$), is the entropy in the noise. Since this noise **n** has fixed entropy independent of the channel input, maximizing mutual information is equivalent to maximizing the entropy in **y**. The MIMO capacity is achieved by maximizing the mutual information satisfying the power constraint [11]. MIMO though has many advantages, also has several limitations of increasing cost of radio frequency system. This disadvantage can be overcome by using single RF frontend and employing transmitter antenna selection or spatial modulation. Multiple antennas on the transmitter side can be selectively used based on the channel state information to improve the capacity of the system. Spatial modulation does not need channel state information but its performance deteriorates rapidly during unfavorable channel conditions.

Therefore an adaptive scheme incorporating the features of the two schemes is thought of,[12,13,14].

3 Antenna Switching

Consider a MIMO system with Nt transmitting antennas and Nr receiving antennas arranged as shown in figure 1.On the transmitter side there is a single RF chain system with Nt antennas connected through antenna switch. However on the receiver side, every receiving antenna has a RF chain [15].

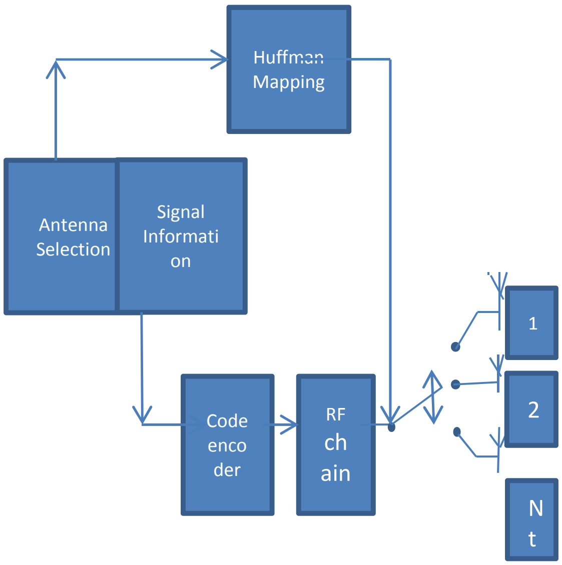

Figure 1: RF chain model with Huffman Coding

The received signals can be expressed as

$$y = \sqrt{\gamma}\, Hx + n \qquad (2)$$

Where H= [$h_1, h_2, h_3 \ldots\ldots\ldots h_{Nt}$] denotes flat fading MIMO channel, 'n' is the additive white Gaussian noise, γ is the SNR and the transmitted signal X is

$$X = r.s \qquad (3)$$

Where s is the signal having Gaussian distribution and r is the antenna selection vector chosen from a set

$$C_r=\{e_1,e2\ldots\ldots e_{Nt}\} \qquad (4)$$

By having e_i=1, the i^{th} antenna is activated to transmit the signal s and the antenna information is mapped to the antenna index. Probability of selecting the i^{th} antenna is

$$P(r=e_i) = p_i \qquad i=1,2 \ldots Nt \qquad (5)$$

Where $\sum_{i=1}^{N_t} p_i = 1$.

4 BINARY HUFFMAN CODING

Given a source sequence X^t ={X (1)…X(T)} for a given alphabet X,it is mapped to a set of binary sequences called Huffman codes. Index set being binary, based on probability of occurrence of sampling, mapping is done. Frequently occurring is given a longer code length and rarely occurring given shorter code lengths-codes being uniquely decodable by the receiver. Therefore this concept can conveniently because be used to select all or few among the transmitting antennas based on the feedback of channel state and offered capacity .The feedback about the overall SNR is provided by the multiple receiver system. Selection of a transmitter antenna based on a code sequence for maximum channel capacity dependent on feedback from receiver is illustrated for Nt=4 and Nt=8.

Example 1: For Nt=4, considering probability vector **p**= [1/2,1/4,1/8,1/8], the Huffman mapping is as shown in Table 1. The incoming antenna information bits are sequentially detected and mapped to different antenna indices. If the sequence is 110, the Tx-3 is selected for transmitting the signal. Therefore, the activation probabilities of the four transmitting antennas are 50%, 25%, 12.5%, 12.5% respectively. The transmitted antenna information is 1.75 bits. For equi probable selection, antenna information is 2 bits which is equivalent to spatial modulation. There is also the probability of only three antennas being selected with probability vector p= [1/2,1/4,1/4,0].

Example 2: For Nt=8, considering probability vector **p**=[1/4,1/4,1/8,1/8,1/16,1/16,1/16,1/16], the Huffman mapping is as shown in Table 2. The incoming antenna information bits are sequentially detected and mapped to different antenna indices. If the sequence is 0110, the Tx-7 is selected for transmitting the signal. Therefore, the activation probabilities of the eight transmitting antennas are, 25%, 25%, 12.5%, 12.5%, 6.25%, 6.25%, 6.25%, 6.25% respectively. The transmitted antenna information is 2.5 bits. For equi probable selection, antenna information is 3 bits which is equivalent to spatial modulation. There is also the probability of subset of antennas being selected for example with probability vector **p**= [1/2, 1/4, 1/4,0,0,0,0,0].

Table I: Huffman mapping scheme for Nt=4(example 1)

Bit sequence	Spatial symbol r	Probability of activation
0	Tx-1	0.5
10	Tx-2	0.25
110	Tx-3	0.125
111	Tx-4	0.125

Table II: Huffman mapping scheme for Nt=8(example 2)

Bit sequence	Spatial symbol r	Probability of activation	Bit sequence	Spatial symbol r	Probability of activation
10	Tx-1	0.25	0100	Tx-5	0.0625
11	Tx-2	0.25	0101	Tx-6	0.0625
00	Tx-3	0.125	0110	Tx-7	0.0625
01	Tx-4	0.125	0111	Tx-8	0.0625

The aim of this work is to find **p** that maximizes the capacity of the system. This can be generalized as

$$P1: \begin{cases} \max \ C(p) \\ p \in \acute{P} \end{cases} \quad (6)$$

Where C (***p***) is the capacity of the system.As binary Huffman coding is used, the feasible domain of p is a discrete set represented as

$$\acute{P} = \{p | \sum_{i=1}^{N_t} p_i = 1, p_i \in [0,1,2^{-1}, \dots \dots \dots \dots \ 2^{-\nu}] \quad (7)$$

and **ν** is an integer (0≤**ν**≤ Nt-1).Larger the value of **ν**, better is the performance because of more transmission modes. But this increases the feedback load on the receiver.

5 Experimental results

Simulation was done using 4 and 8 transmitting antennas. The adaptive scheme performance was compared with that of conventional spatial modulation and for different feedback values **ν.** From figures 2,3,4 , it is seen that that the adaptive scheme provides higher capacity and better performance even at low SNR values. At higher SNR values, performance improves by 2dB. Therefore, transmitter antenna selection is really advantageous in RF systems. Figure 2 indicates that the increase in the value of **ν** results in 2-4 dB increased performance but with increase in receiver feedback load. Table III indicates the cardinality values of $\acute{P}$. For **ν** = 0, there is degradation in performance by about 2dB.

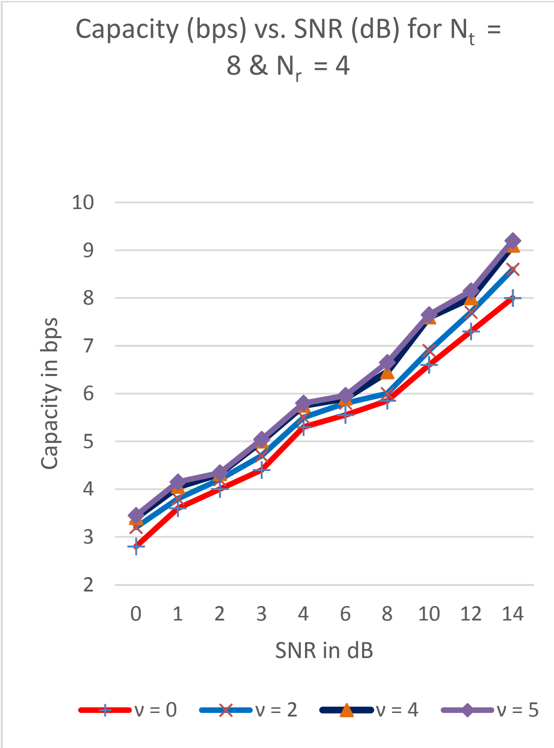

Fig 2: Channel Capacity for different **ν values**

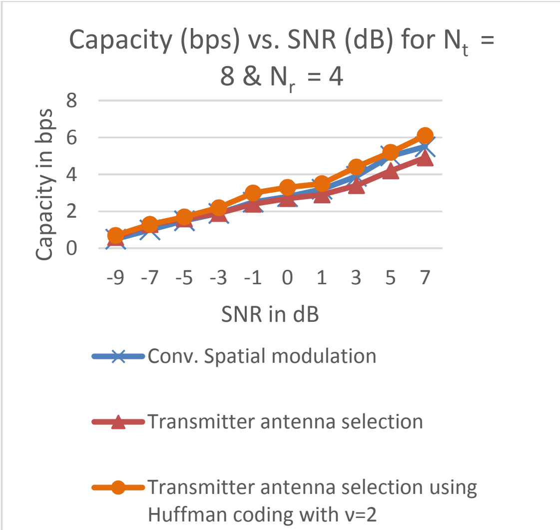

Figure 3: Performance comparison of the conventional spatial modulation scheme with adaptive scheme

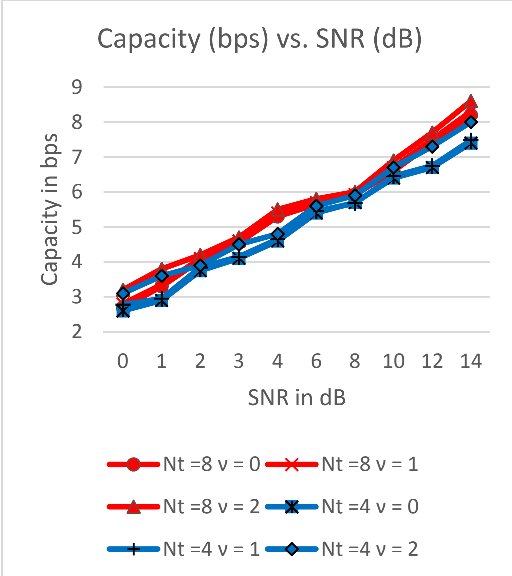

Fig 4: Channel capacity values for Nt=4 and 8 for different **ν values**

Table III: Cardinality values of Ṕ for Nt=4 and Nt=8

Nt=4				Nt=8			
ν	0	1	2	ν	0	1	2
Ṕ	4	10	23	Ṕ	8	36	148

6 Conclusion

The performance of an adaptive scheme using Huffman scheme for a single RF chain system has been discussed in this paper. This scheme allows activating transmitting antennas with different probabilities to maximize channel capacity. Results show that adaptive scheme provides remarkable performance improvement over conventional spatial modulation.

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