Dynamic System of Space Time with Flexible Channel Code Modulation

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Abstract:

Multiple-Input Multiple-Output (MIMO) wireless systems use link adaptation to exploit the dynamic nature of wireless environments. Link adaptation maximizes throughput while maintaining target reliability by adaptively selecting the modulation order and coding rate. One of the most type of adaptive MIMO system based on changing the number of transmitter and receiver antennas depending on received signal strength which means that increasing the number of antennas for week received signal and vice versa. In this paper it has been exploit this property with the advantages of Convolutional Codes (CC) to reduce the errors with variable code rate to establish an effective dynamic system can be used to transfer high speed data rate. Simulation results that have been applied using the MATLAB version R2012a showed that it could double the data speed to eight times during the Signal to Noise Ratio (SNR) band from 2 to 30dB. Which confirm the effectiveness of such system without influence on the spectral efficiency.

Keywords : MIMO, convolution codes, Adaptive Modulation

1- Introduction:

To achieve high data rates in wireless communications systems, usually more bandwidth is required. Due to limitations in the spectrum, it is often impractical and expensive to increase the bandwidth. In this case, multiple transmit and receive antennas are used to increase the spectral efficiency, offering a spatial diversity at both sides of the link and obtaining the well-known MIMO channel. In addition, a capacity gain and improvement of robustness and reliability are obtained [1]. The different diversity techniques (time, space- antenna, frequency, polarization) should be properly exploited by means of coding and transmissions schemes [2]. Alamouti introduced in [3], a simple antenna diversity scheme for two transmit antennas, which provides maximum diversity in flat fading MIMO channels. STC codes, introduced by Tarokh et all in [4], combines traditional channel code design (for temporal diversity) and multi-antenna signal design (for spatial diversity).

Space-Time Adaptive Processing (STAP) algorithms have been proven to be a very effective way to mitigate the effects of multipath and interference in wireless communication systems. STAP is a signal processing technique used to suppress the effects of co-channel interference, Inter Sample Interference (ISI), and jammers in wireless communications system [5]. STAP techniques have been considered in the past to increase the capacity of two major, multiple-access wireless communication systems: Time Division Multiple Access (TDMA) and Code Division Multiple Access (CDMA) [6]. The researcher in [7] proposes a new machine learning framework that exploits past observations of error rate and the associated channel state information to predict the best modulation order and coding rate for new realizations of channel state without modeling the input-output relationship of the wireless transceiver.

In this paper we attempt to increase the amount of data sent by exploiting the time varying in the mobile channel which caused to vary the SNR at received end. In the moment of strong SNR it can be increase the level of constellation and the Code
Rate (CR) that means increasing data rate, and vice versa.

2- The MIMO Channel Model:

The MIMO channel can be represented by the following complex discrete time signal model [8]:

\[ y = Hx + n \] ..........................(1)

where \( x \) is a \( N_r \times 1 \) matrix of complex transmitted symbols (one for each transmitting antenna) with covariance matrix \( C_x \), \( y \) is a \( N_r \times 1 \) matrix of complex received symbols (one for each receive antenna), \( n \) is a \( N_r \times 1 \) matrix of independent and identical distributed (i.i.d.) complex Gaussian noise samples with zero-mean and \( \sigma_n^2 \) variance. The channel matrix \( H \), defined by:

\[
H = \begin{bmatrix}
    h_{11} & h_{12} & \cdots & h_{1N_r} \\
    h_{21} & h_{22} & \cdots & h_{2N_r} \\
    \vdots & \vdots & \ddots & \vdots \\
    h_{N_r1} & h_{N_r2} & \cdots & h_{N_rN_r}
\end{bmatrix}
\] ..........................(2)

\( H \) is a random matrix with complex elements \( h_{ij} \) describing the gain of the radio channel between the \( j \)th transmitting antenna and the \( i \)th receiving antenna. For the block flat fading channel, we assume that the fading coefficients \( h_{ij} \) remains constants within a frame of length \( T \) symbol periods and changes into new independent values from frame to frame.

The mutual information and the information capacity of a general MIMO channel are given by [9]:

\[
I = \log_2 \det \left( I_{N_r} + \frac{1}{\sigma_n^2} HC_x H^H \right) \] ......................................(3)

\[
C = \max I = \max \log_2 \det \left( I_{N_r} + \frac{1}{\sigma_n^2} HC_x H^H \right) \] ......................................(4)

expressed in [bit/s/Hz], where \( \cdot^H \) is the Hermitic operator, \( I_{N_r} \) is the \( N_r \times N_r \) identity matrix and \( \det(\cdot) \) is the determinant. Obviously, the maximization is done by allocating the whole transmit power to the subchannels represented by the eigenvalues of the matrix in such a way that for the stronger subchannels is allocated a higher fraction from the total power.

3- Adaptive MIMO Transmission Techniques

In MIMO systems it is possible to exploit the channel spatial selectivity by switching between different transmissions modes as a means to improve system performance. Adaptive MIMO switching methods can be designed to increase throughput for a predefined target error rate or reduce the error rate performance for a fixed transmission rate. One of the key design challenges of adaptive MIMO architectures is to define efficient adaptation modules that use a minimal amount of feedback information [10].

Diversity via multiple receive antennas is a direct extension of traditional receive diversity ideas, and many of the results in multi-antenna receive diversity are similar to those in the literature on RAKE receivers [11].

Transmit antenna selection, unlike receive selection, requires a feedback path from the receiver to the transmitter. This feedback rate is rather small, especially for single antenna selection. Aside from that difference, however, transmit antenna selection is very similar to receive antenna selection; the antenna is selected that provides the highest equivalent receive SNR. Therefore, little else need be said about single transmit antenna selection. The selection diversity simultaneously for both the transmitter and receiver (Fig. 1). In this scenario, there are \( M_t \) transmit and \( M_r \) receive antennas [12].

![Figure 1. Transmitter and receiver selection antennas](image-url)
\[ \| H \|^2 = \sum_i |h_{ij}|^2 \] 

Therefore, joint transmit/receive selection strategies must choose a subset of the rows and columns of H to maximize the sum of the squared magnitudes of transmit-receive channel gains [12].

**System Model:**
The system model used in this paper shown in Fig. 2. The data source is a Bernoulli Binary Generator block produces the information source for this simulation. The block generates a frame of random bits. Each frame outside from data source is encoded by Forward Error Correction (FEC).

In this paper Convolution Codes (CC) has been used for its simplicity with 7 constraint length, 1/2 mother code rate, (7 [171 133]) is 7 constraint length and two generator polynomial in octal form, so that the output of FEC is increased by a ratio of inverse code rate. In this research we used puncturer technique to increase the code rate from 1/2 to 2/3 and 3/4. The Modulator block modulates the message data from FEC block to M-QPSK constellation. The output is baseband representation of the modulated signal with an output size reduced by a factor of \( n \), (where \( n = \log_2(n) \)) size of FEC block output size, as every \( n \) input bits produce one modulated symbol. Orthogonal Space-Time Block Codes (OSTBC) Encoder, encodes the information symbols from the M-PSK Modulator by using either the Alamouti code [3] for two transmit antennas or other generalized complex orthogonal codes [13] for three or four transmit antennas. The number of transmit antenna is given to this block as an input. The output of this block is \( (n \times N_T) \) variable-size matrix, where the number of columns \( (N_T) \) corresponds to the number of transmit antennas and the number of rows \( (N_R) \) corresponds to the number of orthogonal code samples transmitted over each transmit antenna in a frame. The MIMO channel is a subsystem-based implementation. It uses the Multipath Rayleigh Fading channel block to simulate the flat Rayleigh fading subchannel. The maximum doppler shift is set to 100 Hz. The reason for using this value is to make the MIMO channel behave like a quasi-static fading channel, i.e., it keeps relatively constant during one frame transmission and varies along multiple frames. The AWGN Channel block adds white Gaussian noise at the receiver end.

The OSTBC decoder block is a combiner that received input signal with the channel state information (CSI), the input signal, to output the estimates of the modulated symbols. The input signal is an \((N_R \times N_T)\) variable-size. In this paper, the CSI is assumed perfectly known at the receiver side. This block implements the OSTBC combiner algorithm for the current number of transmit and receive antennas. The demodulator block demodulates the output of the OSTBC combiner that is the recovered modulated signal using the Log-likelihood Ratio to achieve soft input to the Viterbi decoder block that gives better performance.

**4- Simulation and results:**

This section consists of two parts, first is to assess the performance of the system manually change the number of antennas with and without FEC to note that the results of which can formulate a proposed model from which to deliver the largest possible amount of data with lowest error rate. Also the code rate of FEC has been changed to achieve various profile of date rate for different value of SNR. The second is to evaluate the adaptive MIMO system with the selection of transmitter and receiver antennas. The output of modulator is 60 symbols. Each symbol contains a number of bit depending on level of constellation, for example if the modulator is set to 8PSK that means each symbol contains 3 bits, and for 60 symbols the whole transmitted data becomes 180 bits per frame. This group of transmitted bits include information data in addition to redundancy bit of FEC code. Therefore, the standard measure the amount of data sent is the number of bits generated by the data source block.

**5-1 Manually change the number of antennas**

**5-1-1- (1/2) Code rate of FEC:**

The first step of this subsection is to evaluate the performance of our system shown in Fig. 2 by changing number of antennas in the manner of
(1x1, 2x2, 3x3, and 4x4). Starting with QPSK modulator that means 2 bits for each output modulator symbol. Thus 120 bits is the input of modulator, which is the output of FEC, that means the information bits generated by the data source is 60 bits because the code rate of the encoder is 1/2. Fig. 3 illustrates the results of each above sets of antennas.

The soiled style of curves are the performances of such system without code, while dashed curves indicate the existence of the FEC code within the system. For example heavenly color with square mark refer to 4x4 antennas. Thus the code gain for this combination as it is clear in Fig.3 is 4 dB at 10^-4 FER. This means that the uses of FEC achieve profit distinct, but reduces the bandwidth efficiency by half, and this is useful for lower SNR applications.

The second step is the same as in first but only increase the constellation to 8PSK. In this case 3 bits for each modulator output symbol, 180 bits are the output of encoder, and 90 bits are the source generator. Fig.4 shows the performance of such step, it is clear that the level of SNR of all curves are increased, but the code gain for the same case of first step is doubled (9 dB at 10^-4 FER as shown in Fig.4).

The third step is with 16PSK constellation, which means that increase the source generator to 120 bits, because of 4 bits for each symbol out of modulator. Fig.5 illustrates all curves that clear-out the response of antenna sets used in previous two steps. As expected, the high band of SNR, but the profit also increased, especially at low level of FER, as is evident from Fig.5, the code gain is exceed 10 dB at 10^-2 FER for 3x3 antennas.

In the final step back to the lowest level of modulator for Binary Phase Shift Key (BPSK) to get the response at low values of SNR. Fig.6 shows the results with same parameters of previous cases except the modulator is set to BPSK. In this case would be the lowest level of the data sent, but in return is obtained on the error rate in a few small of SNR. For example in the case of BPSK it can be achieved 10^-4 FER at 6.3 dB for 4x4 antennas scheme with FEC. While it needs 12 dB for the same environments of QPSK.

From the results obtained we will select some of them and summarized in Table 1. It is clear that we have the number of schemes each of which contains the type of modulation, number of antennas used, amount of SNR and amount of data sent. It is clear that the amount of data increases with the increase in SNR. Since our research focuses on enhancing the amount of data sent so we are trying to design a system in which to send data in different ranges of SNR to be the system in case of sending data even in difficult circumstances especially in mobile communications.

5-1-2- Other values of FEC code rate:

In this subsection has been evaluating the performance of the system to change the rate code to 2/3 and 4/3, each case has been used 4 levels of constellation (BPSK, QPSK, 8QPSK, and 16QPSK), each used 3 schemes of antennas (2x2, 3x3, and 4x4) and drawn for each its curve of SNR versus FER, thus we achieve 32 curves to all those cases. It has selected 8 curves illustrated both in 7 and 8.

Our results enable us to design a system that can respond to all levels of SNR, but in different quantities of information when error rate is fixed. This design from which to make a profit at the speed of data transmitted in the field of mobile communications. The fact that the channels in this case be of different strengths of the signal. Where the moments of a strong signal it can be sending a high amount of information and vice versa. This will be clarified in the next section.

5-2 Adaptive system:

From all results obtained in the 5-1 subsection it can now propose a system designed with ability to change the number of antennas as well as the level of modulation and the rate of FEC. Fig.9 illustrates such system; it is the same as in Fig.2 after conducting the proposed amendment.

Not that only 30 bits per frame are sent when BPSK modulation used with 1/2 code rate of FEC while 240 bits can be sent for 16QPSK and 1 CR of FEC for each frame which is represent maximum value of this system. It is worth mentioning that the change in the number of antennas is for the purpose of increasing SNR and thus increases the amount of information sent.

![Figure 9, Block diagram of proposed adaptive system model](image-url)
5-2-1 Simulation of proposed scheme:

The simulation was carried out of the system shown in Fig.10. Results showed that this system has the potential to exploit the change in SNR to increase the speed of transmitted data while helping to keep sending data even when the level of a few SNR. System maintains the error rate fixed FER where it was installed at 10^{-5}. Fig. 10 also shows the steady increase in data rate the higher the signal strength doubles the amount of data.

Note that less the amount of data to be at around 2 dB and increase up to 90-bits per frame at the range of 10 dB, and so continue to increase until it reaches its maximum value when more than 25 dB. We would like to mention here that in this experiment was to select the length of frame to 60 symbols per frame where its length can be doubled to more than that, according to the system design. And the increase reached in this research is in the range of 30-240 bits meaning that it doubles the number of bits to 8 times per frame. The number of frame and thus the total amount of data sent is the subject outside the attention of this research. For the purpose of reaching the above results the system is change the code rate, modulation level and the number of antennas. Figure 11 shows the change in the rate of the code through the strength of the signal.

Note that increasing the number of antennas increases the value of the signal strength. Fig.12 shows the distribution of the level of constellation in the range of SNR. It is natural to have high levels of constellation at high SNR, of the fact that the rise in the level of modulation cause the increase in the rate of error, but the increases in SNR reduces it.

Finally, Figure No. 13 shows the number of transmitter and receiver antennas are distributed according to the value of signal strength, we note that the number of antennas to be more at low SNR to enable the system to maintain a constant rate of error at value specified (10^{-5}).

5- Conclusions

In this paper we evaluate the performance of a wireless transmission system in the field of mobile communications used space time code concatenated with FEC. Was obtained several results by changing the number of antennas, the level of modulation and coding rate. Space time provides us more than 12 dB gains for 4x4 antennas over 1x1 scheme as it is clear in results of 5-1-1-subsection for figures 3, 4, 5, and 6 at FER of 10^{-5}. This possibility has been exploited to increase the transmitted data rate by designing multiple schemes each combine a specific code rate of FEC, limited constellation, and number of antennas that sent a certain amount of data at specific SNR. System designed covered a range of 2-30 dB which can send limited amount of data increases with the increasing of SNR. The results confirm that the data rate increases to 8 times within the above specific rang.

6- References:


Figure 3, The performance of conventional system with QPSK

Figure 4, Conventional system with 8QPSK

Figure 5, The performance with 16QPSK
Figure 6, Low FER for BPSK

Table 1: Summary results of section 5-1

<table>
<thead>
<tr>
<th>Constellation</th>
<th>No. of antennas</th>
<th>Code rate of FCE</th>
<th>Data source bits per frame</th>
<th>SNR dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>BPSK</td>
<td>4x4</td>
<td>1/2</td>
<td>30</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>3x3</td>
<td>1/2</td>
<td>30</td>
<td>3.5</td>
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<td>2x2</td>
<td>1/2</td>
<td>30</td>
<td>7</td>
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<tr>
<td></td>
<td>4x4</td>
<td>1</td>
<td>60</td>
<td>8.5</td>
</tr>
<tr>
<td>QPSK</td>
<td>4x4</td>
<td>1/2</td>
<td>60</td>
<td>7.5</td>
</tr>
<tr>
<td></td>
<td>3x3</td>
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<td>9</td>
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<tr>
<td></td>
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<td>1</td>
<td>120</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>3x3</td>
<td>1</td>
<td>120</td>
<td>14</td>
</tr>
<tr>
<td>8QPSK</td>
<td>4x4</td>
<td>1/2</td>
<td>90</td>
<td>8.5</td>
</tr>
<tr>
<td></td>
<td>3x3</td>
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<td></td>
<td>4x4</td>
<td>1</td>
<td>180</td>
<td>17</td>
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<tr>
<td>16QPSK</td>
<td>4x4</td>
<td>1/2</td>
<td>120</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>3x3</td>
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<td>1/2</td>
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<td>18</td>
</tr>
<tr>
<td></td>
<td>4x4</td>
<td>1</td>
<td>240</td>
<td>23</td>
</tr>
</tbody>
</table>

Figure 7, Four selected schemes for OSTBC with 2/3 code rate of FEC
Figure 8: Four selected schemes for OSTBC with 3/4 code rate of FEC

Figure 10, Rate of data through SNR band

Figure 11, Change of code rate through SNR band

Figure 12, The distribution of modulation order

Figure 13, Number of $T_x$ & $R_x$