5.1 INTRODUCTION

Diversity methods in multiple-antenna systems, is now the hot topic of research and improves the reliability of data signal and combats fading and co-channel interference. This method provides replicas of the signal and transmitted over time, space and frequency. MIMO systems utilize multiple antennas at the transmitter and receiver side to increase the diversity gain of wireless communication systems. Alouini and Simon (2000) has presented a performance analysis of the Generalized Selection Combining (GSC) diversity scheme over Rayleigh fading channel and compared with MRC and selection combining. Winters (1998), has applied Monte Carlo simulation to study transmit diversity for independent Rayleigh fading channel Chen et al (2005), investigated the BER of a MIMO scheme, combining transmit antenna selection and receiver maximal-ratio combining for binary phase-shift keying (BPSK) in flat Rayleigh fading channels.

Thoen et al (2001) have shown that an order of diversity will be equal to the product of the number of transmit and receive antennas, over flat Rayleigh fading channel using BPSK and MRC used at receiver.

This chapter presents a simulation study on the two performance measures of MIMO receivers namely Generalized space time Sum-of-Squares (SoS) Selection and Space-time Sum of magnitude(SoM) scheme. The BER
of m-ary Phase Shift Keying (MPSK) in a slow, flat Rayleigh fading channel for a MIMO system was simulated using Matlab communication tool box. The results show that as the number of receivers is increased, the BER of the system is decreased. It is also inferred that generalized Sum of Squares (SoS) scheme is more efficient than generalized Sum of Magnitude (SoM) in terms of BER for various number of receivers and the strongest diversity branches.

5.2 DIVERSITY TECHNIQUES

Diversity techniques such as Spatial, Time, Polarization and Frequency diversity techniques are elaborated below.

5.2.1 Spatial Diversity

Performance in multipath fading environment can be improved by using MIMO system and suitable signal processing. Spatial diversity is also called ‘antenna diversity’ which can be achieved by using multiple antennas at the transmitter and receiver. In this method, signal is transmitted over different propagation paths, using many transmitters. This is called ‘transmit diversity’. Multiple antennas are used at the receiver to collect independently faded copies of the transmitted signal. Then it is called ‘receive diversity’. The spatial diversity does not introduce any type of loss in the bandwidth efficiency which is most important feature.

5.2.2 Polarization Diversity

In this scheme, the copy of the same signal are transmitted and received with different polarization antennas. Different polarization ensures that there is no data correlation of previously transmitted or received signal. This type of technique is called ‘polarization diversity’. In space limiting areas such as urban area, polarization diversity is used. It however provides only
two diversity branches. In environments with a number of reflections, the polarization may ultimately be lost and this technique may no longer be useful. Polarization diversity can be used in Line of Sight (LOS) communications to improve the performance.

5.2.3 Frequency Diversity

This diversity provides replica of original signals in the frequency domain. Signal is transmitted using several frequency channels, (ie) the data is sent on carriers which are sufficiently spaced apart in frequency. Based on this definition, one get different measures of coherence bandwidth depending on how high a value of correlation to be used.

5.2.4 Time Diversity

If the copy of same signal is transmitted at different time instants that are large enough for the channel characteristics to change, the received signals can undergo independent fading. Based on this definition, different measures of coherence time exist depending on how high a value of correlation to use. Thus if data is repeated in time with time duration greater than the coherence time of the channel, time diversity is utilized.

5.3 DIVERSITY COMBINING METHODS

Diversity combining method, combines multiple received signals into a single improved signal. The main characteristic of all the diversity techniques is an improvement in the BER Performance, or stated in other words, there is a very low probability of uneven deep fades. Generally, the performance of communication system employing diversity techniques highly depends upon how the different copies of same signal are combined at the receiver to maximize the overall received SNR. The three most common
space diversity techniques employed at the receiver for combining the received signal replicas are selection combining, maximal ratio combining, and equal gain combining. Li and Beaulieu (2006), have studied the effects of channel estimation errors on receiver selection combining schemes for Alamouti MIMO systems using BPSK.

5.3.1 SELECTION COMBINING

In Selection Combining (SC), multiple receive antennas are placed at large enough distances so that fading is independent in each receive antenna as shown in Figure 5.1. This method involves sampling of many receiving antenna signals and sends the largest one to the demodulator. It is an easy method for implementation but is not an optimal method, because it does not incorporate all received signals simultaneously.

![Figure 5.1 Selection Combining Technique](image-url)
5.3.2 Maximal Ratio Combining

In Maximal Ratio Combining (MRC), the channel is estimated and the signals from all the receiving antennas are weighted to their individual SNR and then added so as to produce largest possible SNR to the receiver. The individual signals are co phased before the signals are being added. MRC provides an average SNR which is equal to sum of each average SNRs. Figure 5.2 shows a block diagram of a MRC.

![Diagram of Maximal Ratio Combining](image)

**Figure 5.2 Maximal Ratio Combining**

5.3.3 Equal Gain Combining

Equal Gain Combining (EGC) is a similar method to MRC except that weights are all set to unity. In EGC, the weights do not depend on the channel estimates. Signals from each receive antenna are multiplied by the same weight so as to give a lower SNR performance when compared to MRC.
Even though the performance for EGC is lower than for MRC, no channel estimation needs to be done in EGC.

5.4 SYSTEM MODEL

Ning Kong and Milstein (2004), has derived the expression for BERs in the generalized selection combining scheme, over both non-iid and iid channels. Alamouti Coding is a STBC which exploits the diversity scheme in the transmitter side for a two transmitter system proposed by Alamouti (1998). At a given symbol duration, two signals are simultaneously transmitted by two antenna. If ‘$S_1$’ and ‘$S_2$’ are the two symbols then symbols transmitted from the first antenna are ‘$-S_2^*$’ and ‘$S_1$’ and from second antenna the symbols are ‘$S_1^*$’ and ‘$S_2$’. Consider a system where an Alamouti scheme is applied with two transmitting antennas and ‘L’ receiving antennas with MPSK modulation. Each receiver antenna responds to each transmitter antenna through a fading channel coefficient. The received signals are corrupted by additive noise that is statistically independent among the ‘N’ receiver antennas and the symbol periods. The corresponding received signals in these two intervals on the $i^{th}$ branch can be expressed as

$$r_{1,i} = g_{1,i} s_1 + g_{2,i} s_2 + n_{1,i} \quad (5.1a)$$

$$r_{2,i} = -g_{1,i} S_2^* + g_{2,i} S_1^* + n_{2,i} \quad (5.1b)$$

where, \( g_{j,i}, \ j = 1, 2, \ i = 1, \ldots, L \) is the complex gain between the $j^{th}$ Transmitting antenna and the $i^{th}$ receiving antenna and \( n_{j,i}, \ j = 1, 2, \ i = 1, \ldots, L \) represents additive channel noise.

The complex channel gains \( g_{j,i} \) are estimated at the receiver prior to fading compensation. The variances of the real (or imaginary) components of \( g_{j,i} \) and \( n_{j,i} \) are denoted by \( \sigma_g^2 \) and \( \sigma_n^2 \) respectively. The average SNR per
symbol of the received signal is defined as $\overline{V} = 2\sigma_g^2/\sigma_n^2$. At the receiver, the received signal from each receiving antenna is first processed by a space-time (ST) combiner which computes the receiver decision variables as given below:

$$y_{1,i} = \hat{g}_{1,i}^* r_{1,i} + \hat{g}_{2,i}^* r_{2,i}$$  \hspace{1cm} (5.2a)

$$y_{2,i} = \hat{g}_{1,i}^* r_{1,i} - \hat{g}_{1,i} r_{2,i}$$  \hspace{1cm} (5.2b)

Where $\hat{g}_{j,i}$ is the estimate of $g_{j,i}$ with variance $\sigma_{\hat{g}}^2$, in the real and imaginary part. Then the SNRs of the output signals are measured and the $L_s$ out of $L$ signals with the largest SNRs are selected and combined by a MRC combiner. The signal estimate is based on the phase of the MRC combiner output,

$$\sum \ y_{j,i}, \ j=1,2 \quad (i=1 \text{ to } L_s)$$  \hspace{1cm} (5.2c)

with equal SNRs over the receiver branches assumed.

Figure 5.3 Generalized Sum of Squares Method
5.5 GENERALISED SPACE–TIME SUM-OF-SQUARES (SOS) SELECTION SCHEME

Figure 5.3 shows the system model of SoS selection combining scheme. In the transmitter side the information to be transmitted is converted into symbols $s_1$, $s_2$. Here two transmitters are used since Alamouti scheme is been considered. At any time instant ‘t’ the two symbols ‘$s_1$’, ‘$s_2$’ are transmitted through two antennas. Again at time instant ‘t+T’, the negative conjugate of $s_2$ ($-s_2^*$) and conjugate of $s_1$ ($s_1^*$) are transmitted through the same antennas. In the receiver side, the symbols transmitted by both the antennas are received by each of the ‘L’ receiver antennas. Then the SNRs of the received signals are measured and ‘$L_s$’ out of ‘L’ signals with the largest SNRs are selected. The selected signals are then processed using space-time combiner and then combined in an MRC combiner.

Figure 5.3 Block diagram of MIMO system using Alamouti scheme and SoS

The basic block diagram for sum of selection is as shown in Figure 5.4 The SoS selection scheme does not require knowledge of the
channel gains to make the Rx antenna selection. Furthermore, the branch selection is done before the space–time decoding, so that channel estimation for the space–time decoding is only performed for the branch selected. By doing this process, a significant complexity reduction is achieved. The SoS scheme requires squaring the amplitudes of the received bit signals.

$$R_{\text{out}} = 2r_{1,i}^2 + 2r_{2,i}^2$$

$$R_{\text{out}} = |r_{1,i} + r_{2,i}|^2$$

$$R_{\text{out}} = |g_{1,i}(s_1 - s_2) + g_{2,i}(s_1 + s_2) + n_{1,i} + n_{2,i}|^2 +$$

$$|g_{1,i}(s_1 + s_2) + g_{2,i}(s_2 - s_1) + n_{1,i} - n_{2,i}|^2$$

and, observe further that $s_1 + s_2 = 2$ and $s_1 - s_2 = 0$ or $s_1 + s_2 = 0$ and $s_2 - s_1 = +/-$ 2 so that

$$R_{\text{out}} = |r_{1,i} + r_{2,i}|^2 + |r_{1,i} + r_{2,i}|^2$$

$$R_{\text{out}} = \begin{cases} 
|\pm 2g_{1,i} + n_{1,i} + n_{2,i}|^2 + |\pm 2g_{2,i} + n_{1,i} - n_{2,i}|^2, & s_1 = - s_2 \\
|\pm 2g_{2,i} + n_{1,i} + n_{2,i}|^2 + |\pm 2g_{1,i} + n_{1,i} - n_{2,i}|^2, & s_1 = - s_2 
\end{cases}$$

(5.4)

Thus, selecting the branch having the maximum value of $r_{1,i}^2 + |r_{2,i}|^2$ is equivalent to selecting the branch with the maximum value of

$$|g_{1,i} + n_1|^2 + |g_{2,i} + n_2|^2$$

(5.5)

where $n_1$ and $n_2$ are independent, complex noise samples, each of variance $\sigma_n^2/2$ in each of the real and imaginary components.
5.6 GENERALIZED SPACE-TIME SUM-OF-MAGNITUDES SELECTION SCHEME

In order to further simplify the hardware implementation, another scheme is proposed which selects the branch with the largest sum, \(|r_{1,i}| + |r_{2,i}|\). Similar to SoS selection, this scheme, called generalized space-time sum-of-magnitudes (SoM) selection does not require channel estimation. It is simpler than SoS selection because the receiver only needs to take the absolute values of the two received signals \(r_{1,i}\) and \(r_{2,i}\) and then form the sum.

5.7 SIMULATION RESULTS FOR THE PROPOSED DIVERSITY SCHEMES

The simulation was carried out using Matlab tool box. Figures 5.5 (a-b) shows the Performance comparison of SoS scheme by varying the number of receivers. Figure 5.5 (a) shows the performance of SoS method by varying the receiver configuration. The number of transmitters are kept as two and by varying the number of receivers as 2,4,8,16,32,64,128,256, the performance is analyzed. From Figure 5.5 (b), it is inferred that as the number of receivers is increased the Bit Error Rate (BER) of the system is decreased. As the number strongest diversity branches is varied from 2 to 16 the BER decreases from 0.325 to 0.265. Figures 5.7 (a-b) shows the performance of comparison of SoM scheme by varying the number of receivers.
BER for GSTSoS by varying the no. of receivers (Ls=4)

Figure 5.5 (a-b) Performance comparison of SoS scheme
Figure 5.6 (a-b) Performance comparison of SoS for various number of strongest diversity branches (Ls)
Figure 5.7 (a-b) Performance comparison of SoM scheme by varying the number of receivers.
Figure 5.8 (a-b) Performance comparison of SoS and SoM by varying the number of Receivers.
Further, the simulation results show the performance of Sum of Squares (SoS) selection combining scheme by varying number of strongest diversity branches. The number of transmitters is kept as two and the number of receivers as 16, varying the number of strongest diversity branches as 2, 4, 8, 16. It is shown that as the number of the selected branches is increased, the BER of the system is decreased.

In SoS, the plot of $E_b/N_0$ Vs BER is a decreasing graph. The value of BER decreases as the value of $E_b/N_0$ increases. The number of receivers considered are 2, 4, 16, 32 and 64 while having the constant number of transmitters ($n_{Tx}=2$). The value of BER decreases as the number of receivers is increased. Thus by increasing the number of receivers, the average BER of a MIMO system can be reduced and therefore obtain a strong signal at the receiver. In the case of Sum of Magnitude (SoM), the average BER decreases for a maximum number of receivers in a system which is less considered to that of the other scheme SoS. On the other hand, for increasing values of $E_b/N_0$ in a system of particular number of receivers, the value of BER remains constant.

5.8 CONCLUSION

It is inferred that as the number of receiver configurations is increased, the Bit Error Rate of the system is decreased. Better and accurate BER performance is achieved by having 256 number of receivers. From Table 5.1 it is observed that for smaller 2xn, the BER for both SoM and SoS are similar for higher number of receivers SoS method gives a superior in terms of BER than SoM.
Table 5.1  BER of different number of receivers for SoS and SoM scheme

<table>
<thead>
<tr>
<th>No of Receivers</th>
<th>BER of GSTSoS scheme</th>
<th>BER of GSTSoM scheme</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0.478</td>
<td>0.479</td>
</tr>
<tr>
<td>4</td>
<td>0.467</td>
<td>0.469</td>
</tr>
<tr>
<td>8</td>
<td>0.468</td>
<td>0.479</td>
</tr>
<tr>
<td>16</td>
<td>0.44</td>
<td>0.473</td>
</tr>
<tr>
<td>32</td>
<td>0.45</td>
<td>0.47</td>
</tr>
<tr>
<td>64</td>
<td>0.44</td>
<td>0.46</td>
</tr>
<tr>
<td>128</td>
<td>0.44</td>
<td>0.45</td>
</tr>
<tr>
<td>256</td>
<td>0.432</td>
<td>0.44</td>
</tr>
</tbody>
</table>

The advantage of this selection scheme is that it does not require channel estimation to perform the selection. In order to implement conventional GSC, the gains of all the diversity channels must be estimated. However, no channel estimation is required to implement the SoS selection. In the case of SoS only $2L_s$ channel gains need to be estimated instead of $2L$ channel gains in the case of conventional GSC to implement the branch selection. In this system although there is additional circuitry needed to calculate the sum-of-squares for SoS, it is only simple arithmetic circuitry that requires much simpler implementation compared to that of more complicated channel estimators.