Multiple Antenna Selection of Multi-Antenna Relays using Threshold-GSC Scheme

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Abstract— **Due to the emergence of very high-data-rate wireless communications, the adaptation of traditional diversity systems is required so that some performance is sacrificed for complexity reduction. With this goal in mind, I investigate the threshold generalized selection combining (T-GSC). This scheme combines all branches whose SNR's exceeds a certain threshold. In this paper, we prove that for any two-dimensional amplitude/phase linear modulation schemes, the bit error rate (BER) of T-GSC is better than the BER of generalized selection combining (GSC) and worse than the BER of maximal ratio combining (MRC). However, the complexity of T-GSC is less than the complexity of MRC which is an advantage as MRC has high complexity and high power consumption. T-GSC will be studied and compared to MRC in a Raleigh flat fading channel. The performance of both combining schemes will be measured in terms of bit error rate (BER).**

Keywords—Diversity, Cooperative Communications, Fading Channel

I. INTRODUCTION (*Heading 1*)

Diversity techniques have long been used to combat the effect of multi-path fading on wireless communication systems. In flat fading channels, when the received multipath components are combined, they sometimes combine destructively causing the SNR to decrease at the receiver's antenna and sometimes they totally cancel each other out [1] .In this case the receiver needs another signal path with high SNR to be able to retrieve the original signal, that is when a secondary branch is needed in order to try to improve the received signal level. The theory is that there is a low probability that uncorrelated diversity branches will be affected by the same fading. Based on the required quality, the receiver may have to add more than one branch. Diversity is achieved by using the information received from the different branches to obtain a signal with high SNR at the combining stage. Having additional branches increases the probability the combined output will have higher SNR than taking only one branch into consideration. Our prime diversity techniques in this paper are MRC and T-GSC combining techniques. However, diversity techniques also include equal gain combining (EGC) and SC. For example, an *N*-branch MRC performs the best with the highest complexity and SC, on the other hand, performs the worst with the least complexity. This motivates the development of other diversity schemes whose complexity and performance lie between these two extreme cases. Therefore, several diversity combining schemes have been proposed and studied recently. Such combining techniques achieve a tradeoff between performance and implementation complexity. T-GSC [2] is a combining technique in which all the branches with SNR higher than a fixed threshold are combined together. The error state of T-GSC in which no branches contribute to the combined output is ignored in the analysis of [3]. This error state occurs when the SNRs of all the branches fall below the threshold value simultaneously. There are many references that deal with multi-antenna multi-relay communication systems references [4-8]. In [4] the performance of an infrastructure based multi-antenna relay network in the absence of a direct link is investigated and an expression of outage probability is derived. Cooperation among relays can achieve spatial diversity, which improves the link quality in a wireless network [4]. In [5] the benefits of amplify-and-forward relaying in the setup of multi-antenna multi-relay network are investigated. In [6] in order to combat the multipath fading, the array gain is introduced to the cooperative system when multiple antennas are applied at relay nodes. However, in [7] a low-complexity, near-optimal transmit antenna selection algorithm is proposed for multi-relay networks where all nodes are equipped with multiple antennas. In [8] the performance of a system of multi-antenna multi-relay channels is studied using maximal ratio combining at the receiving end and transmits beam forming at the transmitting end. On the other hand, in [9] the performance of generalized selection combining scheme is studied over fading channels. Due to the need of a combining technique that serves both complexity and efficiency well T-GSC is studied. In this paper, we will evaluate a communication system that contains a source, a destination and multi-antenna relays (repeaters) between the source and the destination. T-GSC and MRC will be applied at the relays/destination using amplify-and-forward and decode-and-forward relaying modes. We will also evaluate the performances of each combining techniques in a perfect and estimated channel.

II. System Model of T-GSC

We consider a two-hop network model with one source, one destination and K relays. For simpler presentation we ignore the direct link between the source and the destination. We assume that the source and the destination are deployed with single antennas, while each relay is deployed with N antennas and the total number of antennas for the K relays is N_{total}. We restrict our discussion to the case where the channels are frequency-flat fading. The data transmission is over two time slots using two hops. In the first transmission time slot, the source broadcasts the signal to all the relays. The transmitted signal consists of n bits. The input/output relation for the source to the Kth relay is given by

$$\boldsymbol{R}_k^{sr} = \sqrt{\epsilon}\,\boldsymbol{h}_k^{sr}\boldsymbol{s}^{sr} + \boldsymbol{W}_k^{sr} \qquad (1)$$

Where $\boldsymbol{R}_k^{sr}$ is the $N \times n$ received signal, and ϵ denotes the transmit power at the source. The vector $\boldsymbol{h}_k^{sr}$ is the $N \times 1$ channel transfer vector from the source to the Kth relay. The vector $\boldsymbol{s}^{sr}$ is the $1 \times n$ transmitted signal from the source to the relays. The Matrix $\boldsymbol{W}_k^{sr}$ is the $N \times n$ additive white Gaussian noise between the source and the relays at the Kth relay.
Where in ideal channel,

$$\boldsymbol{h}_N = A_N\, e^{j\varphi_N} \qquad (2)$$

Where A_N is the random magnitude, φ_N is the random phase shift of Nth diversity branch. Assuming that γ_N indicates the instantaneous SNR of the Nth diversity branch

$$\gamma_N = A_N^2\, \frac{E_s}{N_o} \qquad (3)$$

Where E_s is the average symbol energy and N_o is the spectral density of the noise. Consider a diversity combiner with L branches. Let $\gamma_l\,(l =1,2,\ldots,L)$ denote the instantaneous SNR of the l-th branch. In T-GSC, all the branches with instantaneous SNR higher than a certain fixed threshold are combined to form the output [1], [2], which may be written as

$$\gamma_{at=}\begin{cases} 0, & \text{if all } \gamma_l < \gamma_{th,} \\ \sum_{\gamma_l \geq \gamma_{th}} \gamma_l, & \text{otherwise,} \end{cases} \qquad (4)$$

where γ_{th} is a fixed threshold.

In the second hop, each relay processes its received signals and re-transmits them to the destination. The signal received at the destination can be written as

$$\boldsymbol{Y} = \sum_{k=1}^{k}(\sqrt{\epsilon}\boldsymbol{h}_k^{rd}\boldsymbol{d}_k + \boldsymbol{W}_k^{rd}) \qquad (5)$$

Where $\boldsymbol{Y}$ is the $N \times n$ received signal at the destination, and ϵ denotes the transmit power at the source. The vector $\boldsymbol{h}_k^{rd}$ is the $N \times 1$ channel transfer vector from the Kth relay. The vector $\boldsymbol{d}_k$ is the $1 \times n$ transmitted signal vector from relay k. The Matrix $\boldsymbol{W}_k^{rd}$ is the $N \times n$ additive white Gaussian noise between the relays and the destination at the Kth relay. However, in MRC all the branches are combined to form the output without any SNR threshold.
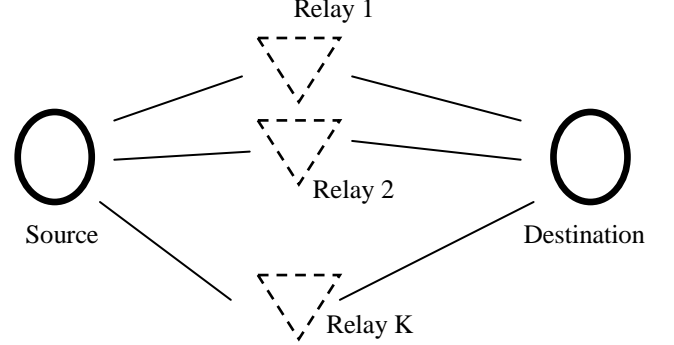

Fig. 1 shows the system model for a two-hop network: source and destination are each deployed with one antenna and each relay with N number of antennas.

III. Decode And Forward Relaying

We assume that threshold generalized selection combining (T-GSC) is performed on the received signals at each relay and at the destination, by multiplying the received signal vector by the vector $h_R^H/\|h\|_F$, where h_R^H denotes the complex conjugate transpose of $\mathbf{h}_k$. The signal at the output of the relay receiver is given by

$$\tilde{\boldsymbol{r}}_{d,k}^{sr} = \sum_{i=1}^{N_c}(\sqrt{\epsilon}\, h_{i,k}^{sr}\boldsymbol{s}^{sr} + \boldsymbol{w}_{i,k}^{sr}) \qquad (6)$$

The vector $\widetilde{\boldsymbol{r}_{d,k}^{sr}}$ is the $1 \times n$ estimated received signal. Where $h_{i,k}^{sr}$ denotes the channel at the ith antenna at relay k, $\boldsymbol{w}_{i,k}^{sr}$ $1 \times n$ vector denotes the noise factor for the ith received input branch and $\boldsymbol{s}^{sr}$ $1 \times n$ vector denotes the transmitted signal. Summation of the signals occurs only if the signal to noise ratio of the signal exceeds the threshold signal to noise ratio (SNR), and N_c is the number of branches that exceed such threshold. The signal to noise ratio (SNR) at the output of the receiver can be written as

$$\rho_K^{N_c} = \sqrt{\epsilon}\sum_{i=1}^{N_c}|h_{i.k}^{sr}|^2 \qquad (7)$$

Given that the summation takes place only if the signal to noise ratio of the received signal from each antenna is greater than the threshold signal to noise ratio, and N_c is the number of branches that exceed such threshold. On the other hand, the signal received at the destination is given by

$$\widetilde{\boldsymbol{R}}_k^{drd} = \sqrt{\epsilon}\boldsymbol{h}_k^{rd}\,\tilde{\boldsymbol{s}}_k^{sr} + \boldsymbol{W}_k^{rd} \qquad (8)$$

Where $\widetilde{\boldsymbol{R}}_k^{drd}$ is the $N \times n$ estimated received signal, and ϵ denotes the transmit power at the source. The vector $\boldsymbol{h}_k^{rd}$ is the $N \times 1$ channel transfer vector from the Kth relay.

The vector $\tilde{s}_k^{sr}$ is the $1 \times n$ estimated received signal from the relays. The Matrix W_k^{rd} is the $N \times n$ additive white Gaussian noise between the relays and the destination at the Kth relay. However, the signal at the output of the destination is given by

$$\tilde{q} = \sum_{k=1}^{k} \sum_{i=1}^{N_c} (\sqrt{\epsilon} h_k^{rd} \, \tilde{s}_k^{sr} + W_k^{rd}) \qquad (9)$$

IV. AMPLIFY AND FORWARD RELAYING

For amplify-and-forward relaying, after combining takes place at each relay, the signal is then amplified (5) by a factor that can meet the power constraint (4). The amplifying factor can be computed as:

$$G_k = \frac{\frac{\epsilon N}{N_{total}}}{\epsilon \sum_{i=1}^{N_c} |h_{i,k}^{sr}|^2} \qquad (10)$$

Where N is the number of antennas per Relay and N_{total} is the total number of antennas in all relays. The transmitted signal t_R at each relay can be expressed by $t_k = G_k \tilde{r}_{d,k}^{sr}$.
On the other hand, the signal received at the destination is given by

$$\tilde{R}_k^{ard} = \sqrt{\epsilon} \, G_k h_k^{rd} \, \tilde{r}_k^{sr} + W_k^{rd} \qquad (11)$$

Where $\tilde{R}_k^{ard}$ is the $N \times n$ estimated received signal, and ϵ denotes the transmit power at the source. The vector h_k^{rd} is the $N \times 1$ channel transfer vector from the Kth relay. The vector $\tilde{r}_k^{sr}$ is the $1 \times n$ received signal from the relays. The Matrix W_k^{rd} is the $N \times n$ additive white Gaussian noise between the relays and the destination at the Kth relay. However, the signal at the output of the destination is given by

$$\tilde{p} = \sum_{k=1}^{k} \sum_{i=1}^{N_c} (\sqrt{\epsilon} \, G_k h_k^{rd} \, \tilde{r}_k^{sr} + W_k^{rd}) \qquad (12)$$

V. CHANNEL ESTIMATION

Since a known channel is never the case an estimated channel should be calculated. Practically, any receiver does not know what fading parameter (h) was multiplied by the transmitted signal; thus, a channel estimation algorithm is followed. There are many methods that can be used to estimate the fading parameter of any channel, one of these methods is the Least Square Estimation algorithm (LSE). This algorithm is achieved by allocating a certain number of bits from the data and uses them as a training sequence (S_Q) which is known by the receiver. Then, it can now be estimated using this equation

$$\tilde{h}_N = (S_Q^T S_Q)^{-1} S_Q^T r_N \qquad (13)$$

In order to estimate the performance of the LSE, we use the Mean Square Error (MSE) method in order to calculate the difference between the accurate and the estimated fading parameter and it is given by

$$MSE = mean(|\tilde{h}_N - h_N|^2) \qquad (14)$$

VI. SIMULATION AND RESULTS

In my simulation we created a random signal of 10,000 bits, 4 antennas at the relays at each receiving and transmitting end, given that the relays are (MIMO) systems and a single relay and the average signal energy ϵ=4. We created perfect and estimated channels and modulated the transmitted signal by BPSK modulation/demodulation. However the number of antennas at each relay, the number of relays and the number of bits are all variables that could be changed. We simulated amplify-and-forward and decode-and-forward relaying modes in communication system with a perfect and estimated channel. We used threshold generalized selection combining (T-GSC) and maximal ratio combining MRC at the relays/destination, with different thresholds, as seen in Fig. 1. MRC has the least BER, because combining all the received branches will result to a most accurate output. As seen in fig. 3 for a perfectly estimated channel the difference between the BER of MRC and T-GSC is around 2 to 4 decibels. Also for an estimated channel the difference is almost the same but shifted approximately 10 decibels due to the effect of the estimated (unknown) channel. In both figures 2 and 3 amplify and forward relaying technique was used. In fig. 4 and 5 it is shown that the difference between the BER between MRC and T-GSC using decode and forward relaying decreases to almost 1 decibel in both cases perfectly estimated (known) channel and estimated (unknown) channel. That is because the performance of decode and forward relaying is better than the performance of amplify and forward relaying but its complexity is higher. In fig. 7and 8 the MSE is plotted with the SNR as SNR increase MSE decreases.
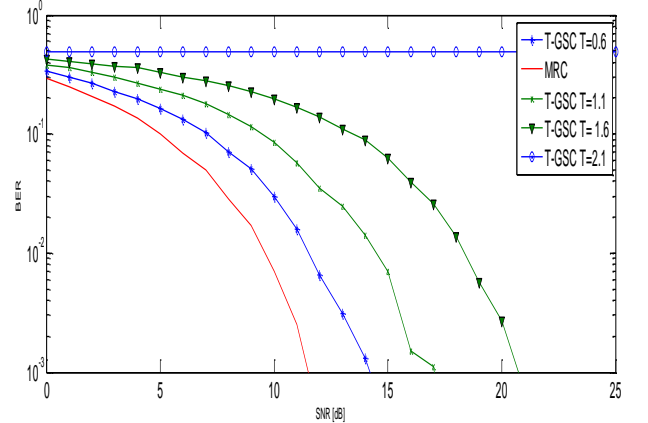

Fig. 2 shows the relation between the bit error rate and the signal to noise ratio between both combining techniques MRC and T-GSC with more than one threshold in a perfectly estimated channel using amplify and forward relaying mode.
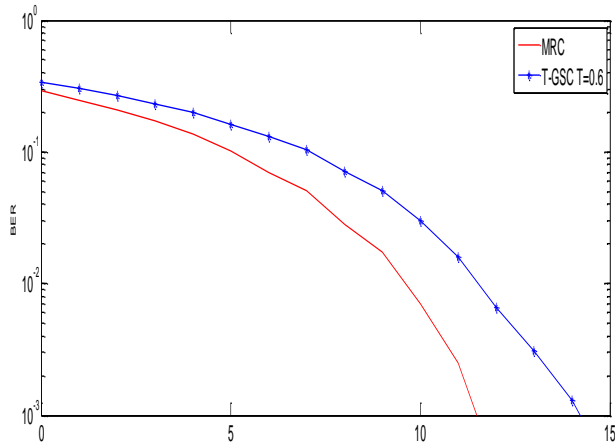
Fig. 3 shows the relation between the bit error rate and the signal to noise ratio between both combining techniques MRC and T-GSC with a threshold of 0.6 in a perfectly estimated channel using amplify and forward relaying mode.
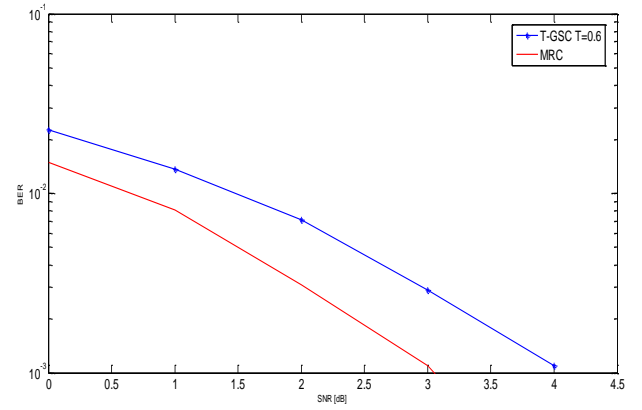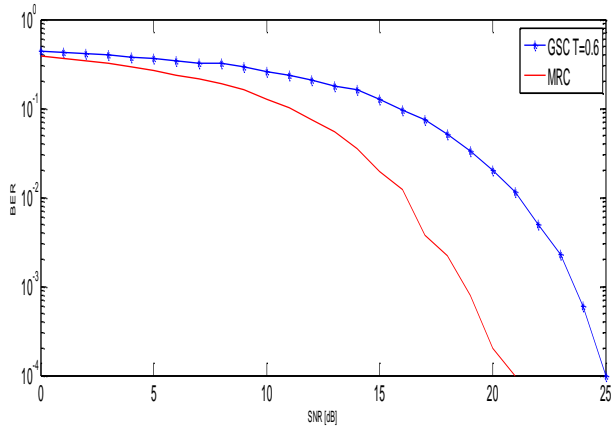

Fig. 4 shows the relation between the bit error rate and the signal to noise ratio between both combining techniques MRC and T-GSC with a threshold of 0.6 in an estimated channel using amplify and forward relaying mode.

Fig. 5 shows the relation between the bit error rate and the signal to noise ratio between both combining techniques MRC and T-GSC with a threshold of 0.6 in a perfectly estimated channel using decode and forward relaying mode.

Fig. 6 shows the relation between the bit error rate and the signal to noise ratio between both combining techniques MRC and T-GSC with a threshold of 0.6 in an estimated channel using decode and forward relaying mode.
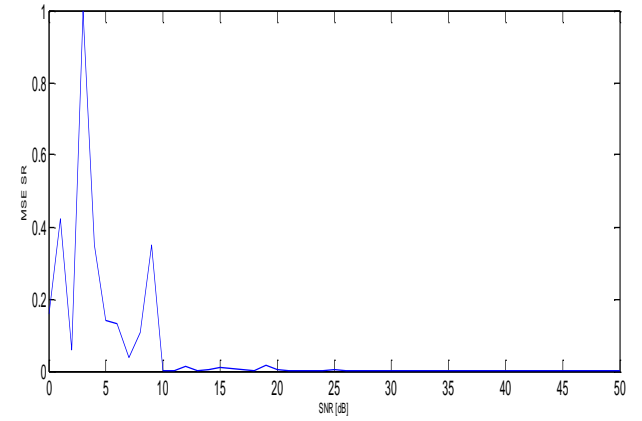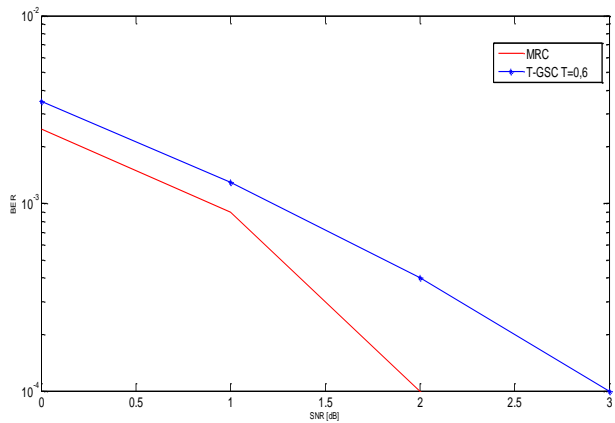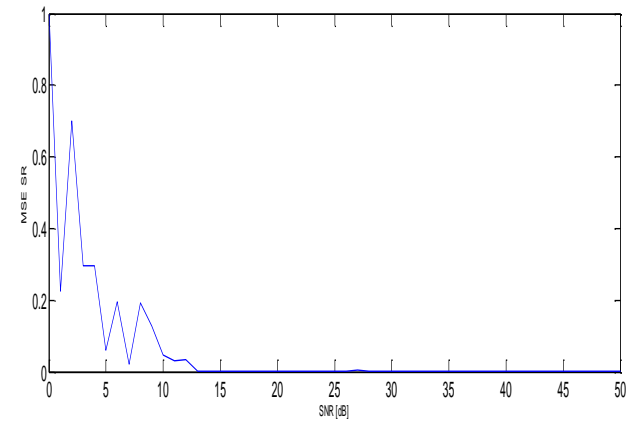

Fig. 7 shows the relation between the mean square error that is between the source and the relay and the signal to noise ratio for the first channel using (T-GSC) and by applying amplify and forward relaying mode for an estimated channel.

Fig. 8 shows the relation between the mean square error that is between the source and the relay and the signal to noise ratio for the first channel using (T-GSC) and by applying decode and forward relaying mode for an estimated channel.
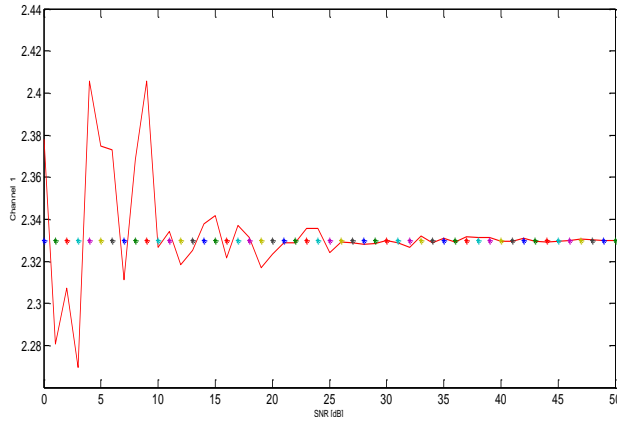
Fig. 9 shows the relation between the absolute perfect and estimated channel 1 and the signal to noise ratio between the source and the relay for amplify-and-forward relaying with a SNR range of 50 decibels.
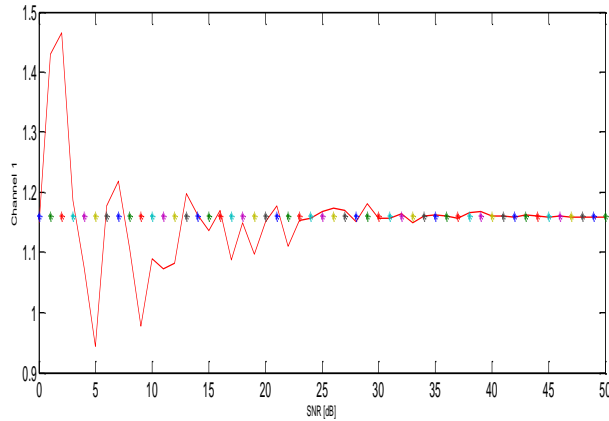

Fig. 10 shows the relation between the absolute perfect and estimated channel 1 and the signal to noise ratio between the relay and the destination for amplify-and-forward relaying with a SNR range of 50 decibels.

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