

# Multiple Antenna Selection of multi-Relay System using GSC Scheme

Ahmed El-Mahdy, Seif El-Wakil, and Ahmed Elbakly

German University in Cairo and Arab Academy for Science, Technology & Maritime transport

## 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, we investigate the performance of multi-antenna multi-relay system when the generalized selection combining (GSC) is used to select and combine a number of diversity branches. The performance is measured in terms of bit error rate (BER) and is evaluated for both amplify and forward and decode and forward protocols. The considered channel is a slow flat fading channel. The performance is evaluated for known and estimated channel. The channel is estimated using least square algorithm. The performance of channel estimation algorithm is measured in terms of mean square error of estimation. The result shows that a reduction in complexity and power consumption is achieved for the multi-relay when GSC is used at the expense of some performance degradation.

**Keywords:** multi-antenna relays, wireless communications, diversity combining, and fading channel.

## 1. Introduction

Cooperative communications is a promising approach to achieve high diversity gains in distributed wireless networks [1]. In cooperative communications, the source transmits the signal to the destination not only through the direct link but also through indirect links using cooperative relays. Moreover, cooperative communications allow single terminated wireless device to share the antennas of their intermediate relays during transmission and to form spatial diversity environment and virtual MIMO system. It can increase the reliability of wireless network by combating the effect of fading.

The capacity of the relay networks can be increased and the performance of the network can be enhanced by installing multiple antennas on the relays. There are many references that deal with multi-antenna multi-relay communication systems [2-9]. In [2] 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 [2]. In [3] the benefits of amplify-and-forward relaying in the setup of multi-antenna multi-relay network are investigated. In [4] 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 [5] a low-complexity, near-optimal transmit antenna selection algorithm is proposed for multi-relay networks where all nodes are equipped with multiple antennas. In [6] 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. In [7] 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. In [8], the benefits of amplify-and-forward relaying in the setup of (MIMO) network are investigated. In [9], the design of an optimal beamforming weight matrix of multiple antennas multiple relay networks is considered. Each relay is assumed to work in amplify and forward protocol.

Most of the previous work on multi-antenna relays either assumes that only one relay available in the network without benefiting from relay cooperation or all relays are used to assist the source transmission resulting in extensive loss of spectral efficiency and high burden to the diversity combiner. In this paper, the GSC scheme is used in multi-antenna multi-relay system to reduce the complexity and at the same time to keep a good performance. The considered channel is a slow flat fading channel. The performance is evaluated for known and estimated channel and for amplify and forward (AAF) and decode and forward (DAF) protocols. The channel is estimated using least square algorithm. The performance of the system is compared with the performance when maximal ratio combiner is used for combining the branches.

## 2. System Model

Let us consider a two-hop network model with one source, one destination and  $K$  relays as shown in Fig. 1. For simplicity, we ignore the direct link between the source and the destination. Assume that the source and destination are deployed with single antennas, and the number of

antennas for each relay is fixed to  $N$ . Then, the total number of antennas for the  $K$  relays is  $N_{\text{Tot}}$ . We consider flat fading channel; the coefficient of the channel from the source to the  $i^{\text{th}}$  antenna is given by

$$h_i = A_i e^{j\varphi_i} \quad (1)$$

where  $A_i$  is the random magnitude of the of  $i^{\text{th}}$  channel which has a Rayleigh distribution and  $\varphi_i$  is the random phase of  $i^{\text{th}}$  channel which has a uniform distribution from  $[0, 2\pi]$ . 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  $n$  symbols.

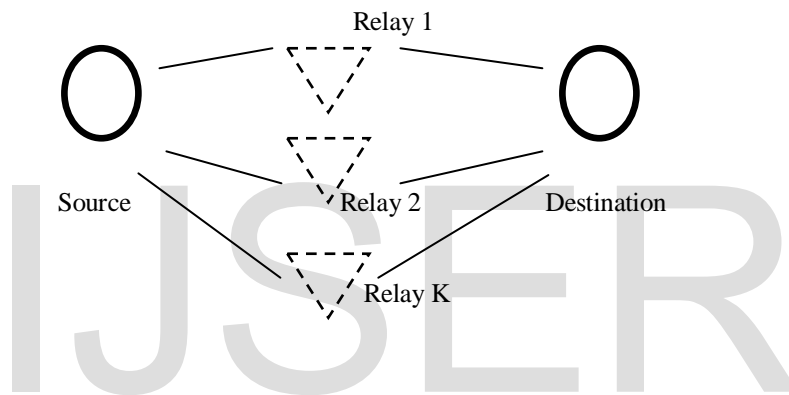


Fig. 1. System model for a two-hop network

The two famous protocols for the relay operation are considered; namely decode and forward and amplify and forward protocols. In decode and forward protocol, the source transmit the signal to the relays and each relay decodes the entire received message, re-encodes it and sends it to the destination. In this protocol, each relay has the same codebook as the source in order to be able to decode and re-encode the received message. In amplify and forward (AF), during the first interval, the transmitter sends the signal to the relays. Then each relay multiplies its received signal by a gain and during the second interval forwards the amplified signal to the destination. The drawback of this method is that, the noise at each relay is also amplified. This method is often used when the relays have limited resources, e.g. processing time or power, available.

### 3. Analysis of Multi-Antenna Selection using GSC Scheme

The signal received at the  $k^{th}$  relay from the source is given by:

$$\mathbf{R}_k^{sr} = \sqrt{E} \mathbf{h}_k^{sr} \mathbf{s}^{sr} + \mathbf{W}_k^{sr} \quad (4)$$

where  $\mathbf{R}_k^{sr}$  is the  $N \times n$  received signal, and  $E$  denotes the transmit power at the source. The vector  $\mathbf{s}^{sr}$  is the  $1 \times n$  transmitted signal from the source to the relays. The Matrix  $\mathbf{W}_k^{sr}$  is the  $N \times n$  additive white noise between the source and the  $K^{th}$  relay. The vector  $\mathbf{h}_k^{sr}$  is the  $N \times 1$  channel parameters vector from the source to the  $k^{th}$  relay, each element in this vector represents the channel from the source to the  $i^{th}$  antenna of the relay.

#### 3.1 Generalized Selection Combining

The general idea of a GSC system is to select a certain number of diversity branches and then apply MRC or EGC on those branches. Different criteria are proposed in the literature to select those certain number of branches. One such diversity system which has been explored widely is Generalized selection combining (GSC) system. In both complexity and performance, GSC falls in between MRC and SC. It needs fewer electronics as well as lower power consumption. GSC can logically be thought of as a SC followed by MRC system, where SC selects a certain number of branches out of total available diversity signals and then those branches are combined in a maximal ratio sense. In traditional GSC system, branches are selected adaptively such that a certain fixed predetermined number of branches with the best SNRs are always selected for maximal ratio combining. When all branches are selected for combining, traditional GSC converges to MRC and when only one branch is selected, GSC converges to SC. The block diagram of the traditional GSC system is shown in Fig. 2. In this figure, the traditional GSC receiver, selects the strongest  $K$  branches of  $L$  diversity branches. This is performed by ordering the  $L$  branches in descending order according to their instantaneous signal to noise ratio. Then, the first  $K$  branches are selected and combined in a maximal ratio sense to produce the decision statistic. Because the GSC system is less complex, it is less sensitive to channel estimation error.

This is because the best branches are adaptively selected and the weakest SNR branches are left out. The left out branches contain more noise and are more sensitive to channel estimation error.

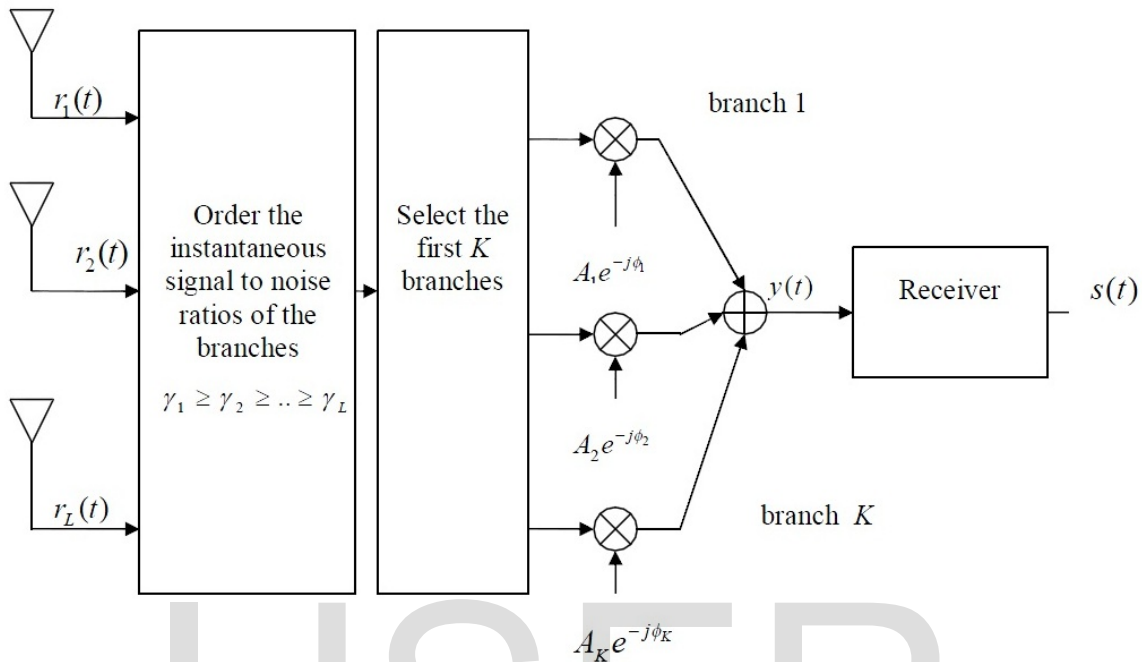


Fig. 1 Traditional GSC receiver

### 3.2 Decode and Forward Relaying

After selecting the  $N_c$  branches from each relay, we multiply each signal by the conjugate of its channel coefficients, then the signal at the output of the  $k^{\text{th}}$  relay receiver is given by

$$\tilde{\mathbf{r}}_k^{\text{SR}} = \sum_{i=1}^{N_c} (\sqrt{E} |h_{i,k}^{\text{SR}}|^2 \mathbf{s}^{\text{SR}} + \mathbf{w}_{i,k}^{\text{SR}}) \quad (5)$$

where the vector  $\tilde{\mathbf{r}}_k^{\text{SR}}$  is a  $1 \times n$  received signal,  $h_{i,k}^{\text{SR}}$  denotes the  $i^{\text{th}}$  antenna coefficient of the relay  $k$ ,  $\mathbf{w}_{i,k}^{\text{SR}}$  is  $1 \times n$  noise vector for the  $i^{\text{th}}$  received input channel and  $\mathbf{s}^{\text{SR}}$  is the  $1 \times n$  transmitted vector. In (5),  $N_c$  represents the number of the combined branches of GSC scheme. The signal to noise ratio (SNR) at the output of the receiver can be written as:

$$\gamma_K^{N_c} = \frac{E}{N_0} \sum_{i=1}^{N_c} |h_{i,k}^{\text{SR}}|^2 \quad (6)$$

The receiver of the relay decodes the signal  $s^{sr}$  and re-encodes it before retransmission, then the received signal at the destination sent from relay  $k$  is given by

$$\tilde{\mathbf{R}}_k^{rd} = \sqrt{E} \mathbf{h}_k^{rd} \tilde{\mathbf{s}}_k^{rd} + \mathbf{W}_k^{rd} \quad (7)$$

where  $\tilde{\mathbf{R}}_k^{rd}$  is the  $N \times n$  estimated received signal, and  $E$  denotes the transmit power at the source. The vector  $\mathbf{h}_k^{rd}$  is the  $N \times 1$  channel transfer vector from the  $k^{\text{th}}$  relay. The vector  $\tilde{\mathbf{s}}_k^{rd}$  is the  $1 \times n$  re-encoded signal from the relays. The Matrix  $\mathbf{W}_k^{rd}$  is the  $N \times n$  additive white Gaussian noise between the relays and the destination at the  $k^{\text{th}}$  relay. Again, the combining scheme is applied at the destination resulting in  $N_d$  combined signals from each relay. Then, the combined signals at the destination after the multiplication of the channel coefficient conjugate is given by

$$\mathbf{z} = \sum_{k=1}^K \sum_{i=1}^{N_d} (\sqrt{E} |h_{i,k}^{rd}|^2 \tilde{\mathbf{s}}_k^{rd} + \mathbf{w}_{i,k}^{rd}) \quad (8)$$

where the vector  $\mathbf{z}$  is a  $1 \times n$  received signal at the destination from all relays,  $h_{i,k}^{rd}$  denotes the  $i^{\text{th}}$  antenna coefficient of the relay  $k$ ,  $\mathbf{w}_{i,k}^{rd}$  is  $1 \times n$  noise vector of the  $i^{\text{th}}$  channel and relay  $k$ , and  $s^{rd}$  is the  $1 \times n$  transmitted vector. In (8),  $N_d$  represents the number of the combined branches at the destination.

### 3.3 Amplify-and-forward Relaying

In the amplified relaying, a relay simply amplifies the received signal before retransmission. The received signal from the source to relay  $k$  after GSC combining is given by (5). The transmitted signal at each relay can be expressed by  $G_k \tilde{\mathbf{r}}_k^{sr}$ , then the signal received at the destination from  $k^{\text{th}}$  relay is given by

$$\tilde{\mathbf{R}}_k^{rd} = \sqrt{E} G_k \mathbf{h}_k^{rd} \tilde{\mathbf{r}}_k^{sr} + \mathbf{W}_k^{rd} \quad (9)$$

where the vector  $\tilde{\mathbf{r}}_k^{sr}$  is the  $1 \times n$  received signal from the  $k^{\text{th}}$  relay and  $G_k$  is the gain of the  $k^{\text{th}}$  relay which is given by:

$$G_k = \frac{\frac{EN}{N_{\text{total}}}}{E \sum_{i=1}^{N_c} |h_{i,k}^{sr}|^2 + N_0} \quad (10)$$

where  $N$  is the number of antennas per relay and  $N_{total}$  is the total number of antennas in all relays. Finally, the signal at the output of the destination after multiplying by the conjugate of the channel coefficient is given by

$$\mathbf{x} = \sum_{k=1}^K \sum_{i=1}^{N_d} (\sqrt{E} G_k |h_{i,k}^{rd}|^2 \tilde{r}_{i,k}^{sr} + \mathbf{w}_{i,k}^{rd}) \quad (11)$$

### 3.4. 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 (SQ) which is known by the receiver. Then, it can now be estimated using this equation:

$$\tilde{h}_N = (\mathbf{S}_Q^T \mathbf{S}_Q)^{-1} \mathbf{S}_Q^T \mathbf{r}_N \quad (12)$$

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:

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

## 4. Simulation and Results

In this section, the performance of the multi-antenna multi-relays is evaluated when generalized selection combining (GSC) is used to select and combine the signals. The performance is measured in terms of BER. The performance of the network is evaluated for both amplify and forward (AAF) and decode and forward (DAF) protocols and for known and estimated channels. The simulation parameters are as follows. The number of bits is 10,000, the number of antennas is four in both sides of the relay, the number of relays  $K=1$  and 2, the number of combined branches is the  $N_c = 2$ , the type of modulation is BPSK, and the channel is flat fading. The length of the training sequence for channel estimation is 10 bits.

Figures 3 and 4 illustrate the performance of BER of GSC for the  $N_c=2$  for  $K=1$  and  $K=2$ . Fig. 3 is plotted for DAF and Fig. 4 is plotted AAF. The performance of the MRC is included for comparison purpose. The figures show that as the number of relays increases, the performance is enhanced because the number of combined branches increases. For example, at  $BER=10^{-3}$ , the performance gap of GSC between  $K=1$  and  $K=2$  is about 3.8 dB for DAF and AAF protocols. By comparing figures 3 and 4, we find that the performance of the multi antenna multi relay system using GSC when DAF protocol is employed is better than that one when AAF protocol is used. This is because in AAF protocol, the noise is amplified. Moreover, these figures show that the loss in performance of the system with GSC from the optimum one (with MRC) is about 1 dB for DAF and about 1.5 dB for AAF.

All the channels between source and the relays and between the relays and destination are estimated using the least square algorithm. We present only one channel as an example. The absolute of perfect and estimated channel between source and relay is shown in Fig. 5. The results show that at low SNR, the noise dominates the performance and there is a gap between the true and estimated channel. When SNR increases, the estimated channel converges to the true one. In Fig.6, the Mean Square Error of channel estimation is plotted versus the SNR. The result shows that as the SNR increases the MSE decreases.

In Fig. 7 and Fig. 8, the BER versus the SNR is illustrated for amplify and forward and for decode and forward relaying protocols respectively and for perfect and estimated channels. The MRC is included for comparison purposes. In MRC, all the received signals from all antennas are combined and used for detection. The figures show that the BER for perfect channel outperforms the BER for estimated channel. This is because the channel estimation error affects the BER.



## 5. Conclusions

The performance of multi-antenna multi-relays network has been investigated when the GSC scheme is used to select and combine a number of antennas. Channel estimation is performed using least square algorithm. The performance is evaluated for known and estimated channel and for amplify and forward and decode and forward protocols. The result shows that a reduction in complexity and power consumption is achieved for the multi-relay when GSC is used at the expense of some performance degradation.

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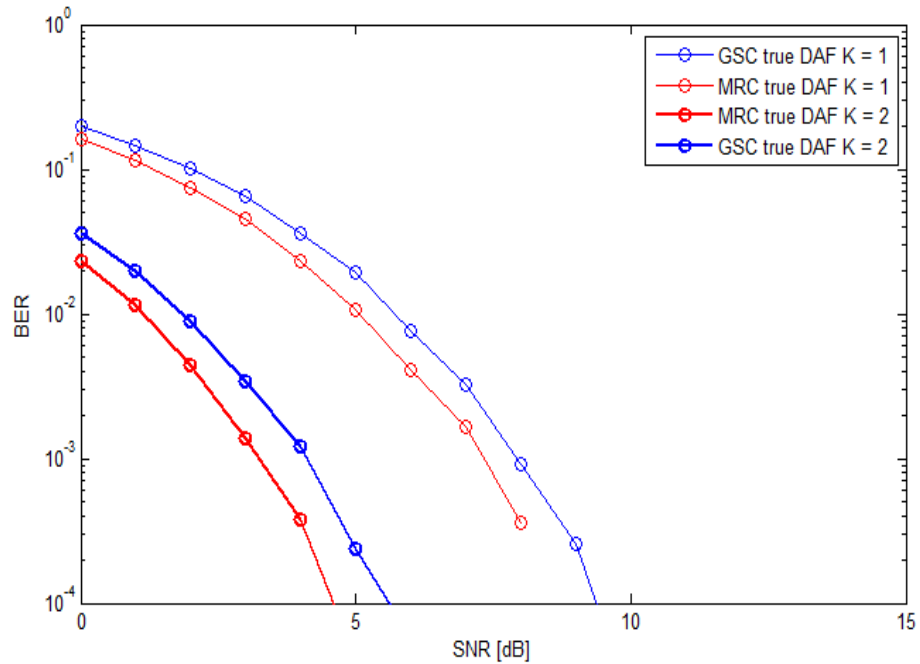


Fig. 3 Comparison between performance of multi antenna relay system for K=1 and K =2 for decode and forward protocol

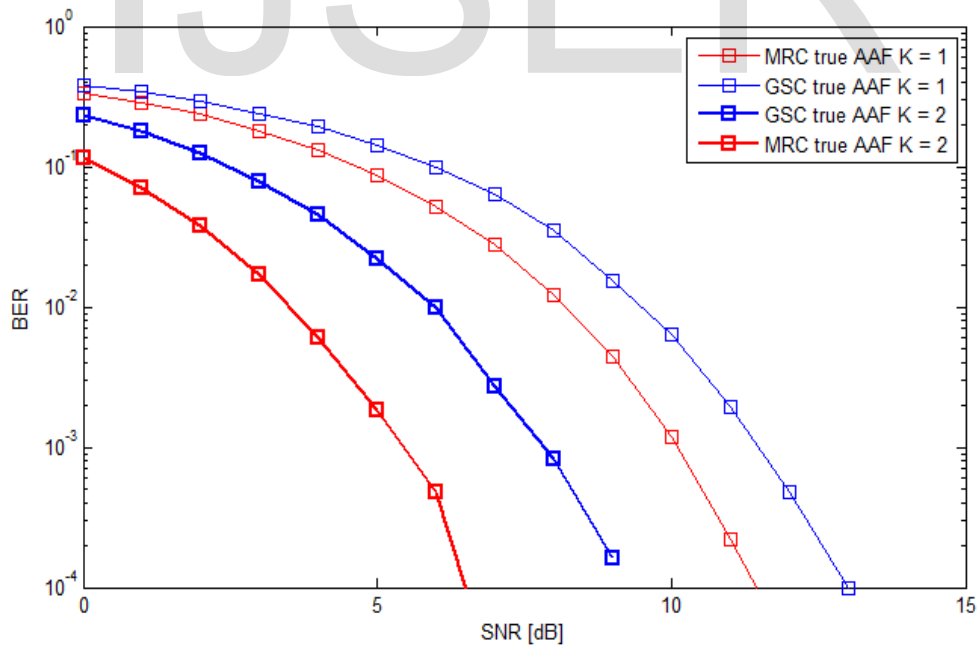


Fig. 4. comparison between performance of multi antenna relay system for K=1 and K =2 for amplify and forward protocol

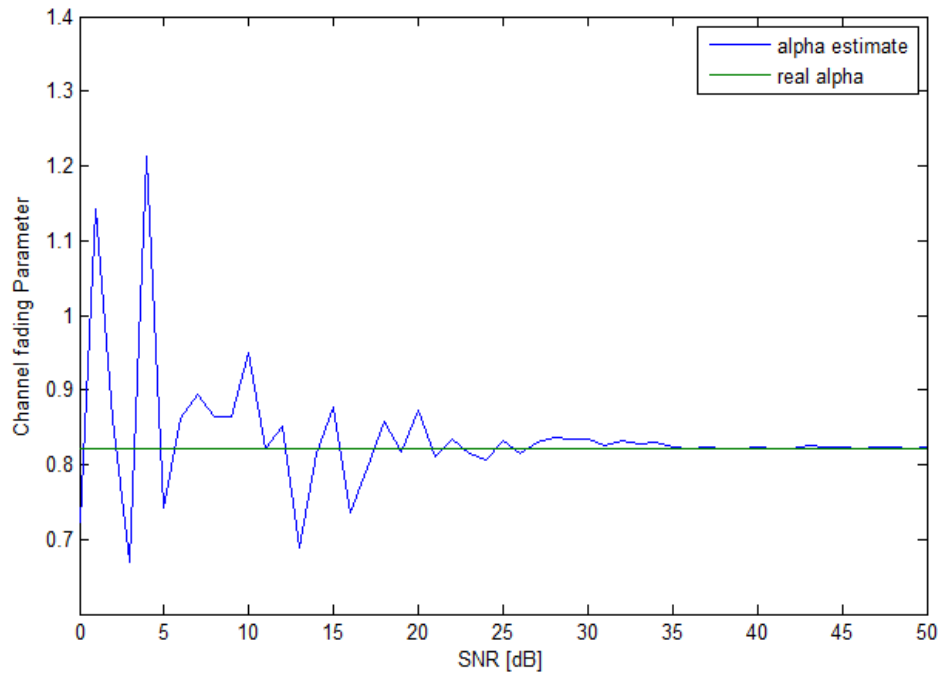


Fig. 5. True and estimate fading parameters for the 4th branch from source to relay

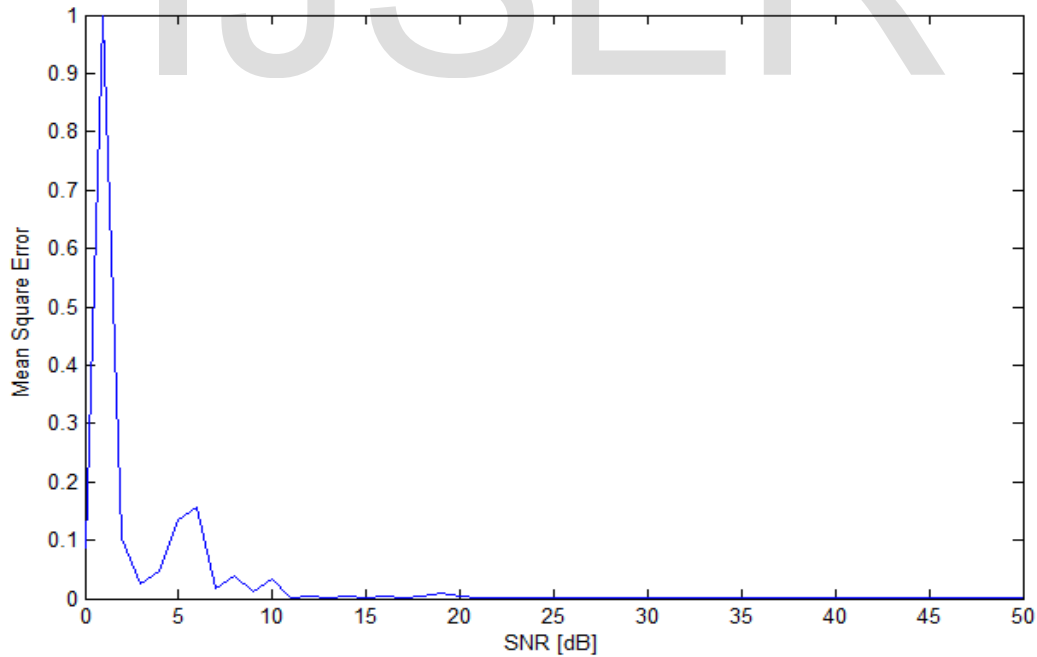


Fig. 6. Mean Square Error of estimation of the 1st branch from relay to destination

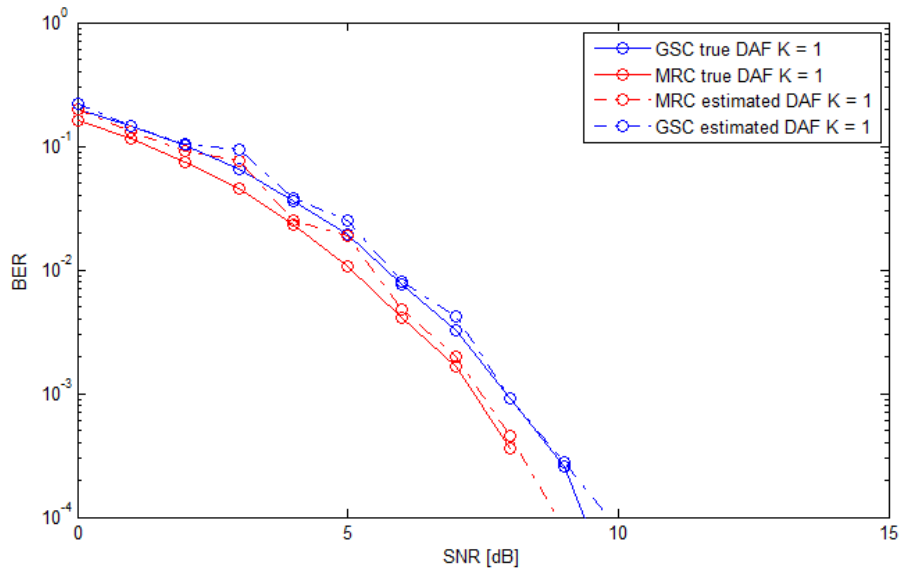


Fig. 7 Performance of multi antenna relay system for estimated and known channels using decode and forward protocol

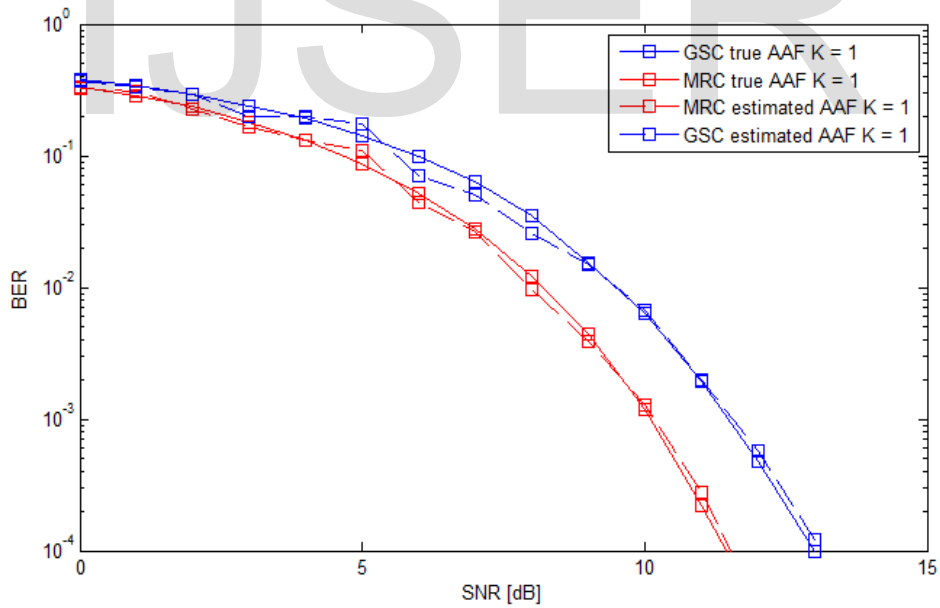


Fig. 8 Performance of multi antenna relay system for estimated and known channels using amplify and forward protocol.