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Impact of Diversity Gain in Cooperative Communication using Amplify & Forward and Decode & Forward Relaying Techniques

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Abstract – **Interest for high data rates is expanding quickly for the future wireless generations, because of the prerequisite of universal coverage for wireless broadband services. More base stations are expected to convey these services, keeping in mind the end goal to adapt to the expanded limit request and intrinsic unreliable nature of remote medium. Moreover, this would straightforwardly compare to high foundation expense and energy utilization in cellular systems. These days, high power utilization in the network is turning into a matter of sympathy toward the administrators, both from ecological and financial perspective. Cooperative communications, which is viewed as a virtual Multiple-Input-Multiple-Output (MIMO) channel, can be extremely proficient in combating fading multipath channels and enhance scope with complexity and expense. With its disseminated structure, cooperative communications can likewise add to the energy productivity of wireless frameworks and green radio communications without bounds. Utilizing network coding at the highest point of cooperative communication, uses the network assets all the more effectively. Moreover, certain fields are not completely investigated yet. Case in point, the type of recognition method utilized at the receiver and its effect on the link performance has not been tended to.**

The paper looks at the performance comparison of different detection schemes and also proposes how to group users at the relay to ensure mutual benefit for the cooperating users. This research work proposes a framework which shows single and multiple relay selection for cooperative communication under Rayleigh Fading environment.

Keywords– **Multiple-Input-Multiple-Output, Rayleigh Fading.**

I. Introduction

In present era people grow-up to depend on wireless technology, interest for high data rate in wireless communication develops significantly more. This issue is brought on not just in light of expansion in the quantity of users who frequently use this technique, additionally due to the way that the data which must be transformed has likewise become altogether. Despite the fact that improvement in the wireless innovation has been rapid, some physical parameters are as yet restricting the utility of the wireless technique. In most of the cases, battery life, limited frequency band and severe fading channel are causes which have get to be difficulties for specialists to succeed.

Cooperative communication has turn into one of the famous research topics as the solution to the battery life issue and expanding the transmission limit and execution. Cooperative communication is a frame work where wireless mobiles can jointly transmit their signals, thus achieving a number of significant improvements in communication over multi-path fading channel: improved clarity and intelligibility for voice communications, increased rates for data communications, lower transmit power and increased battery life.

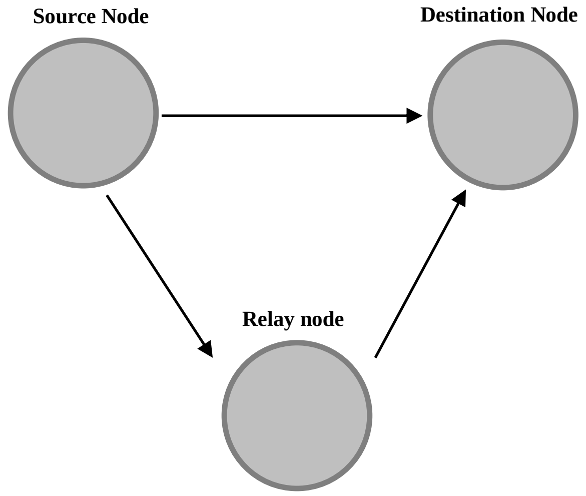

Figure 1: Basic structure of cooperative communication

The basic principle of cooperative communication is using other communication devices to relay transmission. As shown in Figure 1, the source node broadcasts information to both the relay node and the destination node. The relay node then forwards the transmission to the destination node. The source node regards the relay node as a virtual antenna, enabling

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MIMO systems to be used without having to add physical antenna.

In a wireless channel, each user's transmission is receivable, to different degrees, by the other users as well as the base station. Therefore, a mobile may receive and re-transmit the data of a partner to the base station, thus providing assistance to the original mobile because the two streams received via independent fading paths, the spatial diversity will provide an improvement in overall reception, even if we scale the powers (as is required by fairness) so that the overall amount of power per data bit in the system remains the same. The main objective of this research work is to implement a framework which shows single and multiple relay selection for cooperative communication under Rayleigh Fading environment.

II. Cooperative Communication

We propose a new user cooperation framework in which cooperative signaling occurs as part of channel coding. The data for each mobile is divided into blocks; each of these data blocks, as is customary in communication systems, is encoded to produce a codeword. Each codeword is partitioned into two segments, called frames. The codeword segments are designed such that the first frame, if correctly received, is decodable and can yield the information bits. The second frame contains additional parity bits. The length of these two segments need not be equal.

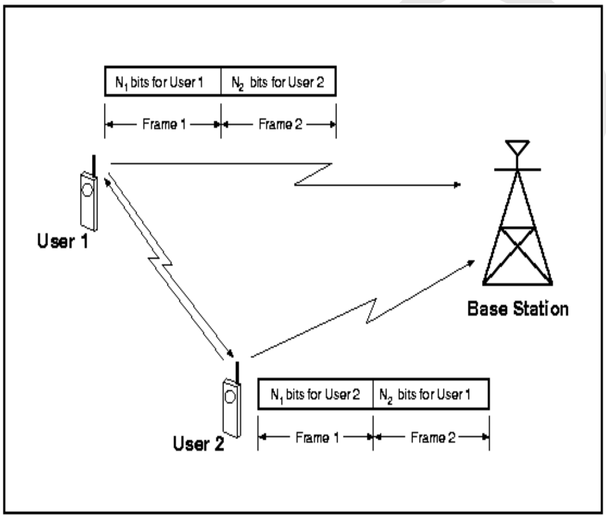

Figure 2: Cooperative communication framework

More specifically, the first frame contains a N_1-bit coded version of the source data. The cooperation process starts by both users transmitting their own first frame. This first frame is received at both base station and the partner, probably with different SNR's. If the partner correctly decodes the user's first frame (determined by checking the CRC), the partner computes and transmits N_2 additional parity bits for the user's data in the second frame, producing a more powerful overall code. The base station will receive both these code components and decode accordingly. Diversity gain arises from the two transmissions arriving via independent fading paths (spatial diversity).

Due to the channel uncertainties, the user's data may sometimes not be received successfully by the partner. In that event, the partner will use the second frame to encode and transmit additional parity bits for himself. Note that each user always transmits a total of N=N1+N2 bits per source block over the two frames, and the users only transmit in their own multiple access channels.

In a single-relay network, data transmitted by the source is captured and processed by the relay node, which forwards this data to the destination of the source. The majority of research in such a three-node network has focused on the forwarding strategy of the relay. The relay strategies can be categorized into several groups, include processing strategies. (Selecting between Decode-and-Forward (DF) [1], Amplify-and-Forward (AF) [1], Estimate-and-Forward (EF) [2] and Demodulate-and-Forward (DemF) [3]), coding strategies for DF systems, and resource allocation strategies (determining the fraction of available power and system bandwidth to allocate between the source and relay).

Because the terminology in the literature is not always consistent, we briefly define the relevant terms as they are used in this paper. Although cooperative diversity and cooperation is sometimes used to refer to two users relaying for one another, here we use the terms cooperation and relaying inter-changeably to represent the scenario where a relay node forwards the source data to the destination which, in turn, combines the data arriving from both source and relay. We use the term multihop for a scenario where the destination does not process the information arriving directly from the source, i.e., the information flow is strictly between the source and relay and relay and destination.

The existence of multiple relays adds a further complication: in addition to relaying strategies, we need a strategy to decide how many and which relays should forward, how they should interact, and in the case of more complex systems, how system resources should be allocated between the nodes.

III. Proposed Methodology

Relaying

There are several cooperative relaying techniques depending on how the relay processes the information. In this research work, we have used two relaying protocols:

- Amplify and Forward (A & F)
- Decode and Forward (D & F)

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Each mobile user employs one antenna at the transmitter (Tx) and there is optional receive diversity in the system. We could possibly ‘m’ antennas at the receiver (Rx) or Destination. LAN is having more than one antenna at the base station. Two nodes T1 and T2 may have common destination for each of the nodes, the information bits are encoded by the channel encoder. The coded symbols are properly multiplexed for cooperation.

Node i; i=1,2 transmits the output of the modulator at each discrete time slot ‘t’ is the signal $X_i(t)j$ is the received signal by antenna ‘j’ of the destination at time ‘t’ due to transmission from node ‘i’. Received signal antenna $y_j^d(t)$

$$y_j^d(t) = h_j^{i,d}(t)x^i(t) + \eta_j^d(t) \tag{1}$$

$h_j^{i,d}(t)$ is the coefficient reflects the fading level from transmit antenna on node ‘i’ to the received antenna ‘j’ ,$1 \leq j \leq m$. $x^i(t)$ denoted as channel coefficient, $\eta_j^d(t)$ is the noise samples are modulated as independent realizations of a zero-mean complex GRV (Gaussian random variable) with variance $N_0/2$ per dimension.

We describe a variety of low-complexity cooperative diversity protocols that can be utilized in the network of including fixed, selection, and incremental relaying. These protocols employ different types of processing by the relay terminals, as well as different types of combining at the destination terminals. For fixed relaying, we allow the relays to either amplify their received signals subject to their power constraint, or to decode, re-encode, and retransmit the messages. Amount many possible adaptive strategies, selection relaying builds upon fixed relaying by allowing transmitting terminals to select a suitable cooperative (or non-cooperative) action based upon the measured SNR between them. Incremental relaying improves upon the spectral efficiency of both fixed and selection relaying by exploiting limited feedback from the destination and relaying only when necessary. In any of these cases, the radios may employ repetition or more powerful codes. We focus on repetition coding throughout the sequel, for its low implementation complexity and ease of exposition. Destination radios can appropriately combine their received signals by exploiting control information in the protocol headers.

Amplify and Forward (A & F)

It represents the simplest method among the several cooperative techniques and is a non-regenerative relay. Information is sent to the relay through a noisy channel, where it is amplified and forwarded to the destination without further processing in cooperating Amplify and Forward system, symmetric transmission exists between source and relay.

The source transmitted signal $X_{si}(l)$, the relay transmitted signal $X_{ri}(l)$. Source transmitted signal $X_{si}(l)$ to the destination and it is overhead by the relay as $y_{si,d}(l)$

$$y_{s_i,d}(l) = \sqrt{\varepsilon} h_{s_i d} X_{si}(l) + \eta_{s_i d}(l) \tag{2}$$

Where l=1,2,……..L_1, L_1 is denoted as length of the first segment. In the second segment, the relay amplifies its overhead signal $y_{s_i r_i}(l)$

$$y_{s_i r_i}(l) = \sqrt{\varepsilon} h_{s_i r_i} x_{s_i r_i} + \eta_{s_i r_i}(l) \tag{3}$$

Where l=1,2,………L_2, L_2 denoted as length of the second segment using maximum likelihood detection method

$$X^1{}_{ri}(l) = \beta y_{s_i r_i}(l) \tag{4}$$

$X^1{}_{ri}(l)$ is denoted as transmitted to the destination through relay.

Where $\beta = \sqrt{\frac{1}{|h_{s_i r_i}|^2 \varepsilon + N_{0,s_i,r_i}}}$, $X^1{}_{ri}(l)$ will be transmitted to the destination through relay uplink channel as:

$$y^1{}_{r_i,d}(l) = \sqrt{\varepsilon} h_{r_i d} X_{r_i}(l) + \eta_{r_i d}(l) \tag{5}$$

Where l=1,2……L_2 is indices the length of the second segment signal and $L_1 = L_2$ After the two segments, the destination will be combine the received signal $y_{s_i,d}(l)$ and $y^1{}_{r_i,d}(l)$

Using the Z-F and MMSE detection:

$$r_{s_i,d}(l) = \frac{h^*_{s_i d}\sqrt{\varepsilon}}{N_{0 s_i d}} y_{s_i,d} + \frac{h^*_{r_i d}\ \beta\, h^*_{s_i r_i}\sqrt{\varepsilon}}{|h_{r_i d}|^2 \beta^2 N_{0,s_i r_i} + N_{0,r_i d}} \tag{6}$$

$r_{s_i,d}(l)$ is further passed to a decoder in to retrieve source information from equation (1) and equation (6).The energy symbol (ε) which is normalized in channel nodes p and q. They change independently from (two segment) process yielding a slow fading channel $n_{pq}(l)$ denoted by the additive noise which is modeled as a zero mean, mutually independent complex Gaussian sequence with variance $N_{0,pq}$. For channel between nodes p and q if the instantaneous channel received signal to noise ratio (SNR) is:

$$\gamma_{pq} = \frac{|h_{pq}|^2 \varepsilon}{N_{0,pq}} \tag{7}$$

The average channel received SNR between nodes p, q expressed as:

$$\overline{\gamma_{pq}} = \frac{E[|h_{ij}|^2]\varepsilon}{N_{0,pq}} \tag{8}$$

If source and relay have similar uplink channel quality as $\overline{\gamma_{s_i d}} = \overline{\gamma_{r_i d}}$, the system is defined as having symmetric up links. If $\overline{\gamma_{s_i d}} \neq \overline{\gamma_{r_i d}}$ the system is defined as having asymmetric uplinks.

Decode and Forward (D & F)

In this case, the relay is regenerative, because it receives the information from the source and it decodes it before

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retransmitting it to the destination. Decode and forward transmission, the appropriate channel model is for cooperative diversity transmission, we model the channel during the first half of the block is:

$$y_{s_i r_i}(l) = h_{s_i r_i} x_{s_i}(l) + \eta_{r_i}(l) \qquad (9)$$

If $l = 1 \ldots \frac{L}{4}$ where $x_{s_i}(l)$ is the source transmitted signal and $y_{r_i}(l)$ is the relay signal. The second half block, we model the received signal

$$y_{s_i d}(l) = h_{r_j, d} x_{r_j}(l) + \eta_d(l) \qquad (10)$$

The source mobile transmits its information as $x_{s_i}(l)$, l=0 . . . $\frac{L}{4}$ during this interval the relay process $y_{r_i}(l)$ by decoding an estimate $x'_{s_i}(l)$ of the source transmitted signal. The relay transmits the signal $x_{r_i}(l) = x'_{s_i}\left(l - \frac{L}{4}\right)$ for l=$\frac{L}{\Delta+1}$- - -- -,$\frac{L}{2}$

Decoding at the relay can take on a variety of forms. For example, the relay might fully decode the source message by estimating the source code word, or it might employ symbol by symbol decoding and allow the destination to perform full decoding. These options allow for trading off performance and complexity at the relay mobile. Because the performance of symbol by symbol decoding varies with the choice coding and modulation. We focus on full decoding in the sequel, symbol by symbol decoding of binary transmissions has been treated form uncoded perspective.

Combining

This research work uses two combining schemes:

- Maximal Ratio Combining
- Selection Combining

Maximal Ratio Combining

Maximal ratio combining (MRC) overcomes the limitations of selection combining: it combines the input signals in all diversity branches. MRC has been considered as the optimal combining technique in the presence of additive white Gaussian noise (AWGN) because of its capacity to boost the instantaneous output SNR. This is demonstrated as below. Assume a system with N_d diversity branches, the instantaneous output SNR is given by:

$$SNR = \left(\frac{E_b}{N_0}\right) \frac{\left|\sum_{i=1}^{N_d} \mu_i \beta_i e^{j\theta_i}\right|^2}{\left|\sum_{i=1}^{N_d} \mu_i\right|^2} \qquad (11)$$

Where E_b is bit energy; N_0 is noise spectral density, μ_i is the combining weight and β_i and θ_i are the magnitude and phase of the received signal respectively.

To obtain the maximum instantaneous output SNR, Cauchy-Schwarz inequality is applied, giving the maximum value as:

$$SNR \leq \left(\frac{E_b}{N_0}\right) \frac{\left|\sum_{i=1}^{N_d} \mu_i\right|^2 \left|\sum_{i=1}^{N_d} \beta_i e^{j\theta_i}\right|^2}{\left|\sum_{i=1}^{N_d} \mu_i\right|^2} = \left(\frac{E_b}{N_0}\right) \sum_{i=1}^{N_d} \beta^2{}_i = \sum_{i=1}^{N_d} SNR_i \qquad (12)$$

The only condition to reach this maximum value is to set:

$$\mu_i = c\beta_i e^{-j\theta_i} \; for \; i = 1,2, \ldots . N_d \qquad (13)$$

Where c is some arbitrary complex constant. Therefore, according to (13), in MRC, the magnitude of the combining weight is proportional to the magnitude of the received signal, and the phase of the combining weight is the negative value of the phase of the received signal.

The maximum SNR in (12) also suggests that MRC can produce an output SNR equal to the sum of the individual SNRs in each diversity branch. It follows that MRC can offer the advantage of producing an acceptable output SNR even when none of the SNR in individual branches is acceptable.

Selection Combining

In selection combining, the signal with the largest instantaneous SNR is chosen as the output. Of the N received signals, the strongest signal is selected. When the N signals are independent and Rayleigh distributed, the expected diversity gain has been shown to be $\sum_{k=1}^{N} \frac{1}{k}$ expressed as a power ratio. Therefore, any additional gain diminishes rapidly with the increasing number of channels. This is a more efficient technique than switched combining.

Equalizer

Proposed research work uses two following equalizers:

- Zero Forcing Equalizer
- Minimum Mean Square Error Equalizer

Zero Forcing Equalizer

Zero Forcing Equalizer is a linear equalization algorithm used in communication systems; it inverts the frequency response of the channel. The name Zero forcing corresponds to bringing down the Inter Symbol Interference (ISI) to zero in a noise free case. This will be useful when ISI is more predominant when comparing to the noise.

ZF can be implemented by using the inverse of the channel matrix H to produce the estimate of transmitted vector $\tilde{x}$.

$$\begin{aligned} \tilde{x} &= H^{\dagger} r \\ &= H^{\dagger}(Hx) \\ &= x \end{aligned} \qquad (14)$$

Where $(.)^{\dagger}$ denotes the pseudo-inverse. However when the noise term is taken into account, the post-processing signal is given as fallow:

$$\begin{aligned} \tilde{x} &= H^{\dagger} R \\ &= H^{\dagger}(Hx+n) \\ &= x + H^{\dagger} n \end{aligned} \qquad (15)$$

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With the addition of the noise vector, ZF estimate, that is $\tilde{x}$ consists of the decoded vector *x* plus a combination of the inverted channel matrix and the unknown noise vector. As the pseudo-inverse of the channel matrix may have high power when the channel matrix is ill-conditioned, the noise variance is accordingly improved and the performance is corrupted. To alleviate for the noise improvement introduced by the ZF detector, the MMSE detector was proposed, where the noise variance is taken into account in the construction of the filtering matrix G.

Minimum Mean Square Error Equalizer

Minimum Mean Square Error (MMSE) approach alleviates the noise enhancement problem by taking into consideration the noise power when constructing the filtering matrix using the MMSE performance-based criterion. The vector estimates produced by an MMSE filtering matrix becomes,

$$\tilde{x} = [[(H^H H + (\sigma^2 I))^{-1}]\, H^H]\, r \quad (16)$$

Where σ^2 is the noise variance. The added term ($1/SNR = \sigma^2$, in case of unit transmit power) offers a trade-off between the residual interference and the noise enhancement. Specifically, as the SNR raises large, the MMSE detector converges to the ZF detector, but at low SNR it prevents the worst Eigen values from being inverted. At low SNR, MMSE becomes Matched Filter,

$$[(H^H H + (\sigma^2 I))^{-1}]\, H^H \approx \sigma^2 H^H \quad (17)$$

At high SNR, MMSE becomes ZF:

$$(H^H H + (\sigma^2 I))^{-1}]\, H^H \approx (H^H H)^{-1} H^H \quad (18)$$

IV. Simulation and Results

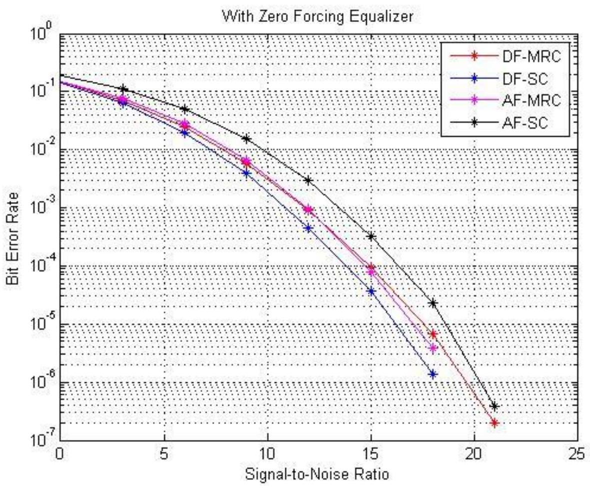

Figure 3: Comparative analysis for BER performance of DF-MRC, DF-SC, AF-MRC and AF-SC with Zero Forcing equalizer

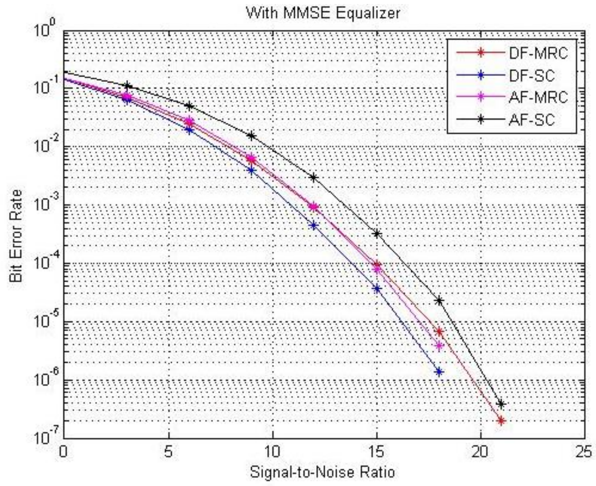

Figure 4: Comparative analysis for BER performance of DF-MRC, DF-SC, AF-MRC and AF-SC with MMSE equalizer

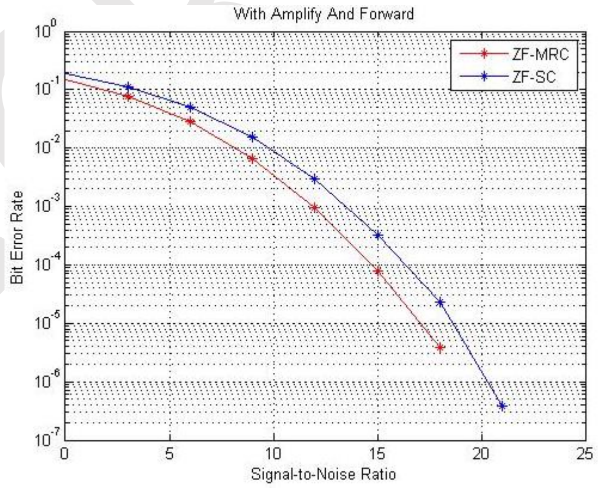

Figure 5: Comparative analysis for BER performance of ZF-MRC and ZF-SC with Amplify-And-Forward scheme

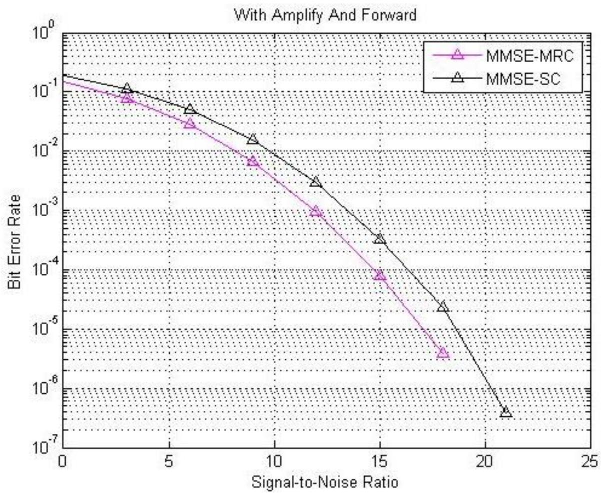

Figure 6: Comparative analysis for BER performance of MMSE-MRC and MMSE-SC with Amplify-And-Forward scheme

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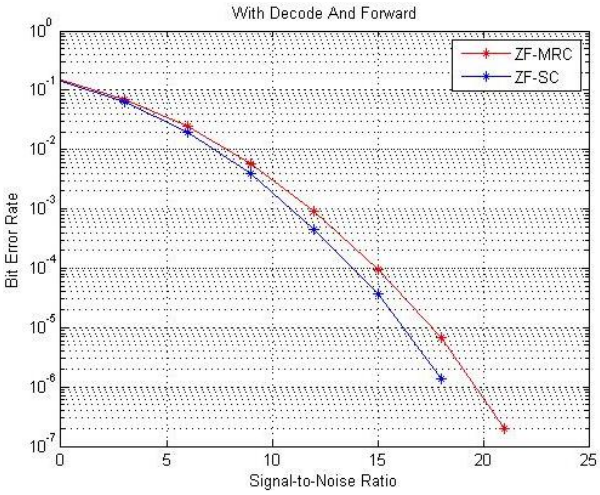

Figure 7: Comparative analysis for BER performance of ZF-MRC and ZF-SC with Decode-And-Forward scheme

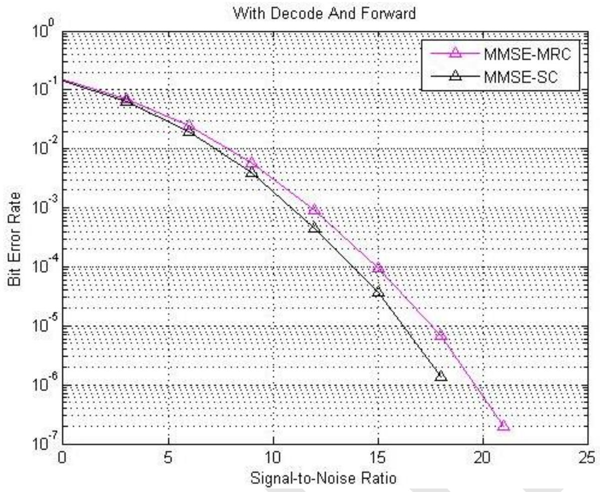

Figure 8: Comparative analysis for BER performance of MMSE-MRC and MMSE-SC with Decode-And-Forward scheme

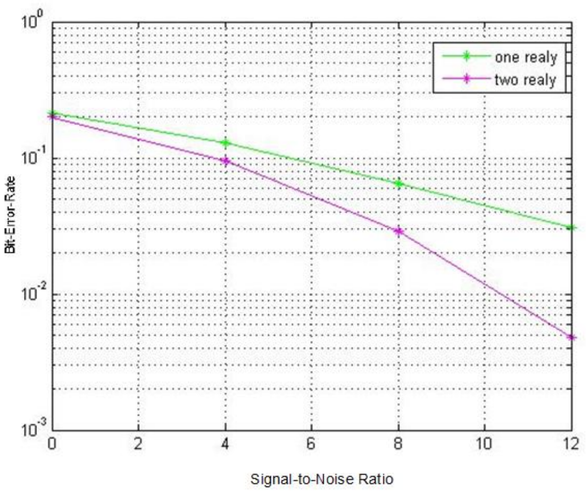

Figure 9: Impact of single and multiple relay selection

V. Conclusion

The proper selection of the relay can effectively improve the overall performance of the network in terms of higher data rate, lower power consumption and better bit error rate performance. This research work utilized ZF and MMSE equalization techniques and for combining, it uses maximal ratio combining and selection combining.

Simulation results shows that the multiple relay selection performs better than the single relay selection in terms of evaluation parameters; BER, SNR.

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