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Performance Analysis of Releay Selection Scheme for Amplify and Forward Protocol in Rayleigh Fading Environment

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Abstract —In this paper a relay selection scheme for amplify and forward relaying is proposed to select one relay from multi-relay networks. The selected relay by the proposed algorithm cooperates only if the signal to noise ratio (SNR) of the source-relay-destination link is greater than the SNR of the source-destination link. A theoretical bit error rate performance of the proposed scheme is derived. Computer simulations are performed to validate the theoretical developments. The outage probability of the proposed scheme is simulated for different threshold value. Moreover, a power allocation algorithm based on bit error rate minimization is applied. The performance of the proposed relay selection scheme is compared with other existing schemes. The simulation is performed for known and estimated channels. Channel estimation is performed by least square algorithm and the effect of the channel estimation error on the performance of the algorithm is investigated. Numerical results show that the proposed algorithm has better performance than some of the other relay selection algorithms. Moreover, the proposed algorithm saves the power since the selected relay participates only when the total signal to noise ratio of the direct link is weak.

Index Terms— Fading, Cooperative Communications, relaying system, amplify and forward..

1 INTRODUCTION

Cooperative communications enable efficient utilization of communication resources, by allowing nodes or terminals in a communication network to collaborate with each other in information transmission. It is a promising technique for future communication systems. Cooperative communication allows communication terminals in a network to hear and help the information transmission of each other, by taking advantage of the broadcast nature of wireless communications. It can be used in improving network connectivity, enhancing power and spectrum efficiency, and improving communication reliability. Moreover, comparing to other emerging techniques that could achieve similar performance advantages, such as multiple-input-multiple-output (MIMO) technique, cooperative communication is superior in deployment flexibility and hardware feasibility. The rewarding merits of cooperative communication make it one of the promising techniques for future wireless communication systems [1]. Various cooperation schemes have been designed for enhancing the performance of wireless communication networks [2–6]. Most recently, cooperative communication has been adopted in Long Term Evolution (LTE) Release 10 as a key technology for future generation commercial wireless communication systems.

Different algorithms for relay selection algorithms are provided in literature. In [7] Opportunistic relay selection is proposed where one relay is selected based on maximizing the end-to-end SNR. The best relay k is chosen according to:

$$k = \text{argmax}(\min\{|A_{s,j}|^2, |A_{j,d}|^2\})$$

, where $A_{s,j}$ is the fading gain of the channel between the source and relay j and $A_{j,d}$ is the fading gain of the channel between relay j and destination. In [8] relay selection takes place by comparing the instantaneous SNR (ISNR) from the source to the relay ($\gamma_{s,j}$)and from the relay to the destination ($\gamma_{j,d}$).In [9], the authors proposed a relay selection algorithm that chooses a relay node based on a predetermined threshold that guarantees a satisfying performance. This algorithm compares all the received instantaneous signal to noise ratio (ISNR) at the relay and at the destination which are denoted by ($\gamma_{s,j}$) and ($\gamma_{j,d}$) with a predetermined threshold (γ_t) which is chosen to guarantee a satisfying performance. Then, ISNR of each each relay ($\gamma_{s,j}$) is compared to (γ) if ($\gamma_{s,j}$)is greater than or equal to(γ_t) then ($\gamma_{j,d}$) is compared to (γ_t) if ($\gamma_{j,d}$) is greater than or equal to (γ_t) then the chosen relay is j . If the ISNR of all the relays fail to pass the threshold, the max min rule introduced in [9] is used to select the relay but with comparing the ISNR instead of the fading acording to the following equation

$$k = \arg\max\left(\min\left\{\left|g_{s,j}\right|^2, \left|g_{j,d}\right|^2\right\}\right)$$

In [10] two relay selection algorithms are proposed where one aims to reduce the number of probed relays and the second one aim to increase the maximum spectral efficiency. In [11] multiple relay selection algorithms are investigated, the first one chooses the relay with the maximum SNR, the second one chooses the relay based on the strength of the channel from the source and to the destination. the third one chooses the relay with best worse channel. The relay selection algorithm in [12] deals with cognitive networks in which there are primary and secondary users. The relay selection goes as follows, an interference threshold is predetermined that guarantees there is no interference on the primary users caused by the secondary users then the relays with the best relay-to-destination SNR is chosen. In [13] the paper deals with networks that have 2 users, the relay selection is based on maximizing the reliability of the links between the users and the relays thus the relay with the max worse SNR is chosen. The opportunistic relay selection proposed in [14] deals with two way relaying which offers a solution to the loss in spectral efficiency due to the use of half duplex systems. The incremental-best-relay technique proposed in [15] aims at saving channels by using relays only if the ISNR from the source to the destination is not high enough to offer a reliable transmission. This is performed by comparing the ISNR from the source to destination link by a threshold. If the ISNR from the source to the destination link is less than the threshold, the relay is send the re-encoded data to the destination and then the destination uses MRC to combine the signals coming from the best relay and the source. In [16], a relay selection algorithm is proposed using the availability of the partial channel state information (CSI) at the source and relays. Power is distributed between source and relay through a feedback. The selected relay decides whether to forward the received information or not according to the quality of the received signal. This is performed be comparing the received SNR with a threshold.

In this paper, an algorithm is proposed to select one relay from multi-relay networks. The performance of the relay selection algorithm is investigated for amplify and forward relaying; where one relay is chosen based on instantaneous SNR either between the source and the relay or the relay and the destination. The selected relay participates only if the total SNR of the source-relay-destination link is greater than the SNR of the direct link between source and destination. This overcomes the overheads of determining the value of the optimum threshold used to decide if the relay will participate or not as in [15]. Also, in the proposed algorithm we take into consider ation the dynamic change of the fading since channel estimation is performed in each frame of transmission. Furthermore, and unlike [16], the proposed scheme does not require comparison with the threshold at the relays which can lead to some error propagation. Analytical performance evaluation in terms of the average error rate is derived and validated by simulation. The simulated performance is performed for known and estimated channel and is compared with other existing methods for relay selection. The channel between source and relays and between relays and destination is estimated using least square algorithm. The performance of estimation algorithm is measured in terms of least mean square error.

The rest of the paper is organized as follows. In section 2, the system model is presented. In Section 3, we introduce our proposed relay selection algorithm , channel estimation algorithm, outage probability, and the power allocation algorithm. The mathematical analysis of the performance of the proposed algorithm is presented in Section 4. In Section 5, simulation and results are presented and finally the conclusion is discussed in Section 6.2 Procedure for Paper Submission

2 System Model

The considered system model is shown in Fig. 1, in which a source node, a destination node communicate over a Rayleigh fading channel. A number of relay nodes $R_j\ (j = 1, 2, ..., n)$ are deployed to help the source to send its information to the destination. We consider the direct link between source and destination. The source, relays, and the destination are deployed with single antenna. All relays are assumed to operate in the half duplex mode; hence transmission occurs in two time slots, corresponding to the source to relay j and from relay j to destination respectively. The fading channels between the source and the relays and between the relays and the destinations are assumed to be flat quasi-static fading channels, which are constant within the frame and varying from frame to frame. All the relay nodes are assumed to be located in a two dimensional plane where $d_{S,D}$, d_{S,R_j} , and $d_{R_j,D}$ $(j = 1, 2, ..., n)$ denote the distance of source to destination, source to relay j, and relay j to destination links respectively. As shown in Fig. 1, the received signal at relay R_j from the source is given by:

$$r_{s,R_j}(t) = s(t)h_{s,R_j} + n_{s,R_j}(t) \quad (1)$$

where $s(t)$ is the transmitted signal, h_{s,R_j} is the fading channel parameter between the source and relay R_j which is modeled as zero mean complex Gaussian channel with variance $\sigma^2{}_{s,R_j}$, and $n_{s,R_j}(t)$ is the additive white Gaussian noise between the source and relay R_j which has zero mean and variance $N_o/2$.

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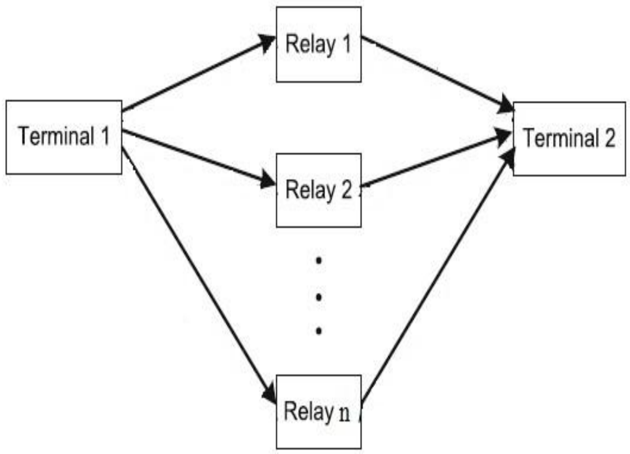

Fig.1. Multi-relay communication system with direct link

The relays use amplify and forward protocol in which each relay amplifies the received signal by an amplifying factor G which is either fixed or variable. The variable gain is given by:

$$G = \sqrt{\frac{1}{P_S|h_{SR}|^2 + N_o}} \quad (2)$$

Thus the received signal at the destination is given by:

$$r_{R_jD}(t) = G\, r_{SR_j}(t) h_{R_jD} + n_{R_jD}(t) \quad (3)$$

Assume that, the instantaneous signal to noise ratio (ISNR) of source and relay j (S- R_j) channel is denoted by γ_{s,R_j} and the ISNR of the channel between relay j and the destination (R_j, D) is denoted by $\gamma_{R_j,D}$.

Finally, we consider the effect of the path loss as $E(h_{S,D}^2) = 1$, $E(h_{S,R_j}^2) = (d_{S,D}/d_{S,R_j})^\alpha$ and $E(h_{R_j,D}^2) = (d_{S,D}/d_{R_j,D})^\alpha$ where α is the path loss exponent and $d_{x,y}$ is the distance between terminal x and y [14].

3 Proposed Relay Selection AlgorithM

3.1 Description of the proposed Algorithm

The proposed algorithm based on the ISNR of the source-destination, source-relays, and relays-destination links. We assume quasi-static channels in these links; that is the channel changes from frame to frame. In each frame, a training sequence is sent in the beginning of the frame to estimate the channels before data transmission. The relays estimate the source-relays and the destination estimates relays-destination and source-destination links. Channel estimation algorithm is described in details in the following section.

The algorithm of selecting the best relay is described as follows: first the relay with the maximum ISNR from the source to the relay is selected and denoted as R_i where its ISNR from the source to the relay is denoted as γ_{SR_i} and it is given by $\gamma_{SR_i} = \frac{|h_{SR_i}|^2 E_b}{N_o}$ where $\frac{E_b}{N_o}$ is the signal to noise ratio. Then the relay with maximum ISNR from the relay to the destination is selected, which is denoted as R_j where its ISNR from the relay to the destination is denoted as $\gamma_{R_j,d}$ and it is given by $\gamma_{R_jd} = \frac{|h_{R_j,d}|^2 E_b}{N_o}$, then $\gamma_{R_i,d}$ is compared to γ_{SR_j} and the larger one is selected. This algorithm can be summarized as follows:

1. Set c =1, $\gamma_{s,\max} = \gamma_{s,R_c}$ and $\gamma_{\max,d} = \gamma_{R_cd}$
2. If c = n then go to step 6 else c= c+1
3. If $\gamma_{s,R_c} > \gamma_{s,\max}$ then $\gamma_{s,\max} = \gamma_{s,R_c}$ and $x = c$
4. If $\gamma_{R_c,d} > \gamma_{\max,d}$ then $\gamma_{\max,d} = \gamma_{R_c,d}$ and $y = c$
5. Go to step 2
6. If $\gamma_{x,d} > \gamma_{s,y}$ then the chosen relay is x else the chosen relay is y.

In the proposed algorithm, the destination chooses either to receive only from the direct link or to combine the signal coming from the direct link and the selected relay. This is performed by comparing the total ISNR of the source-selected relay-destination ($S - R_s - D$) link denoted by γ_{total} with the ISNR of the source-destination link denoted by γ_{SD}; where in case of AF protocol γ_{total} is given by:

$$\gamma_{total_{AF}} = \frac{\gamma_{SR_s}\gamma_{R_sD}}{\gamma_{SR_s} + \gamma_{R_sD} + 1} \quad (4)$$

If $\gamma_{total} > \gamma_{SD}$, combining is performed at the destination; otherwise the destination uses only the received signal from the source. The illustration of the proposed algorithm is shown in the flow chart given in **Error! Reference source not found.**.

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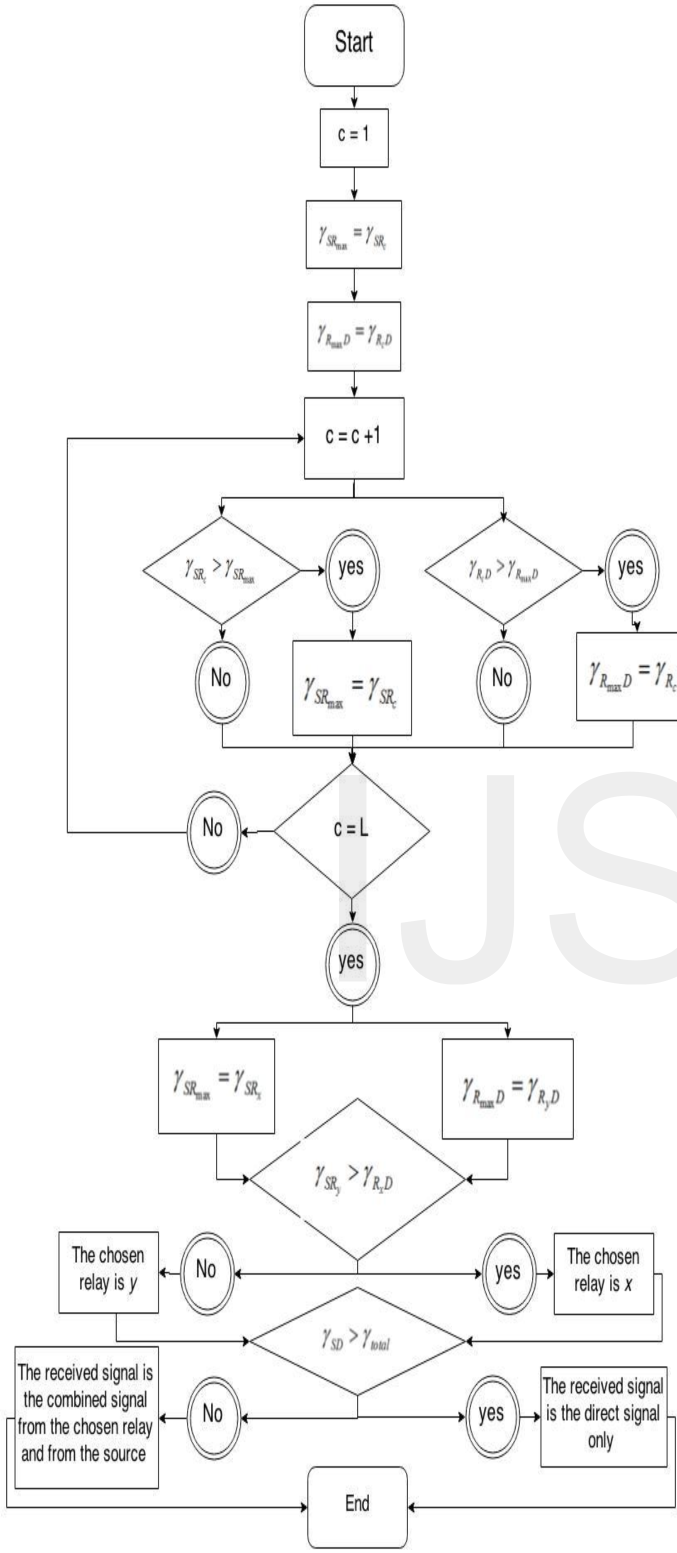

Fig. 2. Flow chart of the proposed algorithm

3.2 Channel Estimation

Channel estimators are used to estimate the channel complex gain. There are many algorithms which are used for channel estimation one of them is the least square algorithm which is discussed here. Channel estimation takes place first by the source, which sends a Ready-to-Send (RTS) packet to the N relays; the RTS packet consists only of pilot bits, which are sent with the same carrier frequency and power as the pay-load data. The N relays after receiving the RTS packets send a Clear-to-send (CTS) packet back to the source. Upon receiving the RTS packet the N relays can estimate the Channel complex gain between the N relays and the source. The N relays then send a RTS packet to the destination, which sends back a CTS packet to the N relays, and upon receiving the RTS packet, the destination can estimate the channel complex gain between the N relays and the destination. The received signal at the relays is given by:

$$r_i(t) = h_i s_Q(t) + n \tag{5}$$

Where, h_i is the required channel complex gain and $s_Q(t)$ is the pilot signal. By using least square method the channel complex gain is estimated as follows:

$$\hat{h}_i = \left(\mathbf{S}_Q^T \mathbf{S}_Q\right)^{-1} \mathbf{S}_Q \mathbf{r}_i \tag{6}$$

Where $\mathbf{S}_Q$ is the pilot signal vector containing the pilot sequence of bits and $\mathbf{r}_i$ is the received vector. The performance of the Least Square algorithm is measured by the Mean Square Error (MSE), which is one of the many ways that measure the accuracy of the perfect versus the estimated channels.

$$MSE = E\left(\left|\hat{h}_i - h_i\right|^2\right) \tag{7}$$

3.3 Outage probability

The outage probability is another performance measure that is used to measure the performance of the relay selection algorithm. It is defined as the probability that the achievable rate falls below a certain rate threshold. Thus it can be interpreted as the falling of the total instantaneous SNR below a certain target SNR where the target rate threshold is related to the threshold SNR as stated in [20] by the following equation:

$$\gamma_{threshold} = 2^r - 1 \tag{8}$$

where $\gamma_{threshold}$ is the SNR threshold and r is the rate threshold. Consequently, the outage probability can be denoted as the probability the sum ISNR falls below a certain threshold

$$P\left(\gamma_{sum} < \gamma_{threshold}\right) \tag{9}$$

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in case of Incremental relay selection with AF:

$$\gamma_{sum} = \begin{cases} \gamma_{total_{AF}} + \gamma_{R_sD} & if\ \gamma_{total_{AF}} > \gamma_{R_sD} \\ \gamma_{R_sD} & if\ \gamma_{total_{AF}} < \gamma_{R_sD} \end{cases} \quad (10)$$

$$\gamma_{threshold} = 2^{r} - 1$$

Where $\gamma_{total_{AF}}$ is given in (4). The outage probability for different threshold values is illustrated in the simulation and results section.

3.4 Power allocation based on Bit Error Rate minimization

Since full CSI is available at the destination to the S-D, S-R and R-D links optimal power could be allocated to ensure better quality of service (QoS) where the QoS is measured in terms of the Bit Error Rate (BER). Considering the system model after relay selection has occurred, the received signal at the destination and at the relays are given by (11) and (12) respectively

$$r_{SD}(t) = \sqrt{k_s P}\, h_{SD} s(t) + n_{SD}(t) \quad (11)$$

$$r_{SR_s}(t) = \sqrt{(1-k_s)P}\, h_{SR_s} s(t) + n_{SR_s}(t) \quad (12)$$

where k_s is an optimization factor that denotes the fraction of power assigned to each node and is used in [21] as a way for power optimization. Assuming that the power is divided between the source and selected relay regardless of the location of this relay, accordingly the power of the source is proportional to k_s P and the power of the relay is $(1-k_s)P$. Power optimization is done with the goal of minimizing the probability of error, thus the optimization problem can be stated as follows:

$$\min_{0<k_s<1} P_e(k_s) \quad (13)$$

Where P_e is the bit error probability of the proposed scheme. The optimum value of could be obtained by Matlab simulations because of the difficulty associated with this optimization problem. Thus by simulating this process the optimum could be assigned to the source and the relay according to the quality of the links at each SNR value. So the scenario would be after the destination gets the full CSI in the first time slot. The optimum would be allocated according to the given database using the controlling node which is the destination.

4 Proposed Relay Selection Algorithm

In this section we derive the average error probability for the proposed scheme for different types of modulation schemes using amplify and forward protocol.

$$P(\varepsilon) = \Pr(direct)P_\varepsilon(direct) + \Pr(combined)P_\varepsilon(combined) \quad (14)$$

where $\Pr(direct)$ is the probability that the direct link is only sending the information to the destination and the selected relay is not transmitting, $P_\varepsilon(direct)$ denotes the average error probability for the direct link from source to destination and $P_\varepsilon(combined)$ is the average error probability at the destination when the selected relay is participating and its signal is combined with the direct link signal (from source to destination). We assume that the best relay is selected using the algorithm described in Section 3. The probability $\Pr(direct)$ is given by $\Pr(direct) = 1 - \Pr(\gamma_{SD} < \gamma_I)$ where γ_I is the total instantaneous signal to noise ratio of the channel between the source and the relay and the channel between the selected relay and the destination using amplify and forward protocol where γ_I is given by:

$$\gamma_I = \frac{\gamma_{SR_s}\gamma_{R_sD}}{\gamma_{SR_s} + \gamma_{R_sD}} \quad (15)$$

Note that γ_I is the simplified version of the total instantaneous SNR using AF protocol, thus the probability of decoding the signal coming from the direct link only is given by:

$$\begin{aligned} \Pr(direct) &= 1 - \Pr(\gamma_{SD} < \gamma_I) \\ &= \int_{\gamma_I}^{\infty} \frac{1}{\bar{\gamma}_{SD}} \exp\left(\frac{-\gamma}{\bar{\gamma}_{SD}}\right) d\gamma \\ &= \exp\left(\frac{-\gamma_I}{\bar{\gamma}_{SD}}\right) \end{aligned} \quad (16)$$

Finally, $\Pr(combined)$ denotes the probability that the selected relay is qualified to share and it is given by:

$$\begin{aligned} \Pr(combined) &= 1 - \Pr(\gamma_{SD} > \gamma_I) \\ &= 1 - \exp\left(-\frac{\gamma_I}{\bar{\gamma}_{SD}}\right) \end{aligned} \quad (17)$$

The average error probability of the direct link from source to destination is given by:

$$P_\varepsilon(direct) = \int_0^\infty Q\left(a\sqrt{\gamma}\right) f_{\gamma_{SD}}(\gamma \mid \gamma_{SD} > \gamma_I) d\gamma \quad (18)$$

where $f_{\gamma SD}(\gamma|\gamma_{SD}>\gamma_I)$ the conditional probability density function of γ_{SD} given that $\gamma_{SD}>\gamma_I$. This conditional PDF can be obtained as:

$$f_{\gamma_{SD}}(\gamma|\gamma_{SD}>\gamma_I)=\frac{1}{\overline{\gamma_{SD}}}\exp\left(-\frac{\gamma_i}{\overline{\gamma_{SD}}}\right)\exp\left(-\frac{\gamma}{\overline{\gamma_{SD}}}\right) \quad (19)$$

Substituting (19) in (18), the average error probability for the direct link from source to destination can be written as:

$$\begin{aligned}P_e(direct)&=\exp\left(-\frac{\gamma_I}{\overline{\gamma_{SD}}}\right)\int_0^\infty Q\left(a\sqrt{\gamma}\right)\frac{1}{\overline{\gamma_{SD}}}\exp\left(-\frac{\gamma}{\overline{\gamma_{SD}}}\right)d\gamma\\&=\frac{1}{2}\exp\left(-\frac{\gamma_I}{\overline{\gamma_{SD}}}\right)\left(1-\sqrt{\frac{a^2\frac{\overline{\gamma_{SD}}}{2}}{1+a^2\frac{\overline{\gamma_{SD}}}{2}}}\right)\end{aligned} \quad (20)$$

In (20), a is a constant its value depends on the modulation type. For BPSK, $a=\sqrt{2}$, for BFSK, $a=1$, and for on-off-keying, $a=1/\sqrt{2}$. If the selected relay is sharing and the cooperation takes place; $P_\varepsilon(combined)$ can be written as:

$$P_\varepsilon(combined)=\int_0^\infty Q\left(a\sqrt{z}\right)f_{\gamma_{AF}}(z)dz \quad (21)$$

Where $f_{\gamma AF}(\gamma)$ is the probability density function of γ_{AF} where $\gamma_{AF}=\gamma_{SD}+\gamma_{R_sD}$. Since the two links (direct and the selected relay) are independent, the overall probability density function $f_{\gamma AF}(\gamma)$ can be obtained by finding the convolution of the two exponential PDFs and $f_{\gamma SD}(\gamma)$. This convolution is performed as $f_{\gamma_{AF}}(z)=\int^{\infty} f_{\gamma SD}(z-x).f_{\gamma_{R_sD}}(x)dx$ and the result of integration is given by[0]

$$f_{\gamma_{AF}}(z)=\frac{\lambda_1\lambda_2}{\lambda_2-\lambda_1}\left[e^{-\lambda_1 z}-e^{-\lambda_2 z}\right] \quad (22)$$

Where $\lambda_1=1/\bar{\gamma}_{SD}$ and $\lambda_2=1/\bar{\gamma}_{R_sD}$. By substituting (22) in (21) can be written as:

$$\begin{aligned}P_\varepsilon(combined)&=\frac{\lambda_1\lambda_2}{\lambda_2-\lambda_1}\int_0^\infty\frac{1}{\pi}\int_0^{\frac{\pi}{2}}e^{\frac{-a^2z}{2\sin^2\theta}}\left[e^{-\lambda_1 z}-e^{-\lambda_2 z}\right]dz\\&=\frac{\frac{1}{\overline{\gamma_{SD}}}.\frac{1}{\overline{\gamma_I}}}{\frac{1}{\overline{\gamma_{SD}}}-\frac{1}{\overline{\gamma_I}}}\int_0^\infty\frac{1}{\pi}\int_0^{\frac{\pi}{2}}e^{-\frac{a^2z}{2\sin^2\theta}}d\theta\left[e^{-\lambda_1 z}-e^{-\lambda_2 z}\right]dz\\&=\frac{1}{\frac{1}{\overline{\gamma_{SD}}}-\frac{1}{\overline{\gamma_I}}}\int_0^\infty\frac{1}{\pi}\int_0^{\frac{\pi}{2}}e^{-\frac{a^2z}{2\sin^2\theta}}d\theta\left[\frac{1}{\overline{\gamma_{SD}}}.\frac{1}{\overline{\gamma_I}}e^{-\frac{z}{\overline{\gamma_{SD}}}}-\frac{1}{\overline{\gamma_{SD}}}.\frac{1}{\overline{\gamma_I}}e^{-\frac{z}{\overline{\gamma_I}}}\right]\end{aligned} \quad (23)$$

Using the approximation of the Q(.) function: $Q\left(a\sqrt{\gamma}\right)=\frac{1}{\pi}\int_0^{\pi/2}e^{\frac{-a^2\gamma}{2\sin^2\theta}}d\theta$, and since the moment generating function $M_\gamma(s)=\int_0^\infty exp(s\gamma)\,f_\gamma(\gamma)\,d\gamma$ is the Laplace transform of $f_\gamma(\gamma)$, (23) can be written as:

$$\begin{aligned}P_\varepsilon(combined)&=\frac{1}{\frac{1}{\overline{\gamma_{SD}}}-\frac{1}{\overline{\gamma_I}}}\left[\frac{1}{\pi}\int_0^{\frac{\pi}{2}}\frac{1}{\overline{\gamma_I}}M_{\gamma_{SD}}-\frac{1}{\overline{\gamma_{SD}}}M_{\gamma_I}d\theta\right]\\&=\frac{1}{\left[\frac{1}{\overline{\gamma_{SD}}}-\frac{1}{\overline{\gamma_I}}\right]}\left[\frac{1}{\pi}\frac{1}{\overline{\gamma_I}}\int_0^{\frac{\pi}{2}}M_{\gamma_{SD}}\left(-\frac{a^2}{2\sin^2\theta}\right)d\theta-\frac{1}{\pi}\frac{1}{\overline{\gamma_{SD}}}\int_0^{\frac{\pi}{2}}M_{\gamma_I}\left(-\frac{a^2}{2\sin^2\theta}\right)d\theta\right]\\&=\frac{1}{\left[\frac{1}{\overline{\gamma_{SD}}}-\frac{1}{\overline{\gamma_I}}\right]}\left[\frac{1}{\overline{\gamma_I}}.\frac{1}{2}\left(1-\sqrt{\frac{a^2\overline{\gamma_{SD}}/2}{1+a^2\overline{\gamma_{SD}}/2}}\right)-\frac{1}{\overline{\gamma_{SD}}}.\frac{1}{2}\left(1-\sqrt{\frac{a^2\overline{\gamma_I}/2}{1+a^2\overline{\gamma_I}/2}}\right)\right]\end{aligned} \quad (24)$$

By substituting in (14)

$$\begin{aligned}P_e&=\exp\left(-\frac{\gamma_I}{\overline{\gamma_{SD}}}\right)\left(1-\sqrt{\frac{a^2\frac{\overline{\gamma_{SD}}}{2}}{1+a^2\frac{\overline{\gamma_{SD}}}{2}}}\right)\\&+\left(1-\exp\left(-\frac{\gamma_I}{\overline{\gamma_{SD}}}\right)\right)\left(\frac{1}{\left[\frac{1}{\overline{\gamma_{SD}}}-\frac{1}{\overline{\gamma_I}}\right]}\left[\frac{1}{\overline{\gamma_I}}.\frac{1}{2}\left(1-\sqrt{\frac{a^2\overline{\gamma_{SD}}/2}{1+a^2\overline{\gamma_{SD}}/2}}\right)-\frac{1}{\overline{\gamma_{SD}}}.\frac{1}{2}\left(1-\sqrt{\frac{a^2\overline{\gamma_I}/2}{1+a^2\overline{\gamma_I}/2}}\right)\right]\right)\end{aligned} \quad (25)$$

After some mathematical manipulations the probability of error in case of AF protocol can be written as:

$$\begin{aligned}P_e&=\frac{1}{2}.\exp\left(-\frac{\gamma_I}{\overline{\gamma_{SD}}}\right)\left(1-\sqrt{\frac{\overline{\gamma_{SD}}}{1+\overline{\gamma_{SD}}}}\right)\\&+\frac{1}{2}\left(1-\exp\left(-\frac{\gamma_I}{\overline{\gamma_{SD}}}\right)\right)\left(\frac{1}{\left[\frac{1}{\overline{\gamma_{SD}}}-\frac{1}{\overline{\gamma_I}}\right]}\left[\frac{1}{\overline{\gamma_I}}\left(1-\sqrt{\frac{\overline{\gamma_{SD}}}{1+\overline{\gamma_{SD}}}}\right)-\frac{1}{\overline{\gamma_{SD}}}\left(1-\sqrt{\frac{\overline{\gamma_I}}{1+\overline{\gamma_I}}}\right)\right]\right)\end{aligned} \quad (26)$$

The theoretical average bit error probability is plotted against SNR for different values of $\bar{\gamma}_{SD}$ in Fig. 3. The figure shows that as $\bar{\gamma}_{SD}$ increases, the BER performance enhances.

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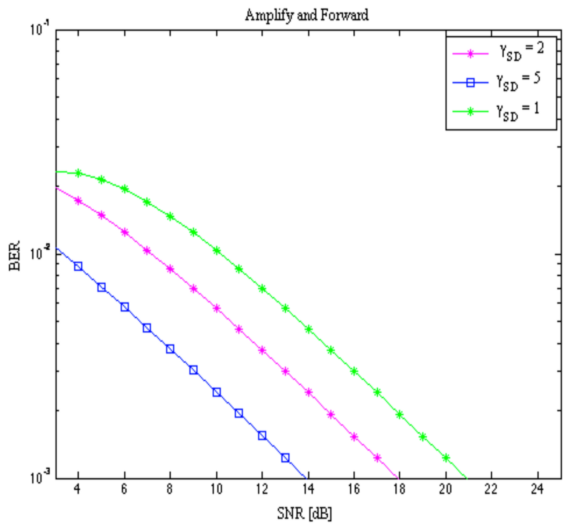

Fig. 0. Theoretical performance of the proposed scheme for different values of average signal to noise ratio of source to destination link.

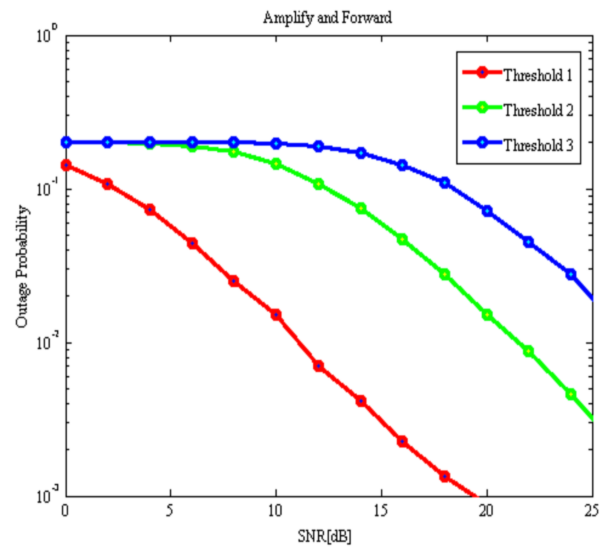

Fig. 4. Outage Probability of the proposed algorithm for three different threshold values.

5 Simulation And Results

In this section, numerical results are presented to evaluate the performance of the proposed relay selection algorithm and to validate the theoretical error probability. The results are obtained for known and estimated channels. The performance curves of average bit error rate (BER), outage probability, and the mean square error of estimation are plotted versus the signal to noise ratio. The BER performance of the proposed algorithm is compared with other existing relay selection schemes through simulation. The simulation parameters are as follows. The number of bits is N=1000,000; the type of modulation is binary phase shift key (BPSK), the number of relays is four relays, and the number of pilot bits used for channel estimation is 5 bits.

The outage probability of the proposed scheme is illustrated in Fig. 4 for three different threshold values: g_{Th} =5 dB, 10 dB, and 13 dB. These values are selected to show the dependence of the outage probability on the selected threshold. The figure shows that as the threshold value increases, the outage probability becomes worse. This is because the probability of the total ISNR to be lower than the threshold increases.

Fig. 5 shows a performance comparison between the proposed relay selection algorithm, best relay selection and partial relay selection algorithms and the direct link using a path loss factor of 1.6 which depicts free space communication. The performance of the direct link is included to measure the enhancement in the performance using the relaying system. The figure shows that the proposed algorithm outperforms the best and partial relay selection algorithms and consequently the direct link. This is because the proposed scheme sometimes combines the signal of the direct link with the signal of the selected relay at the destination and this enhances the BER performance. Finally, the figure illustrates the benefits of cooperative communications when comparing the performance of the direct link with the other relay selection schemes. For example, at BER , the proposed relay selection outperforms the best relay selection algorithm by about 1 dB.

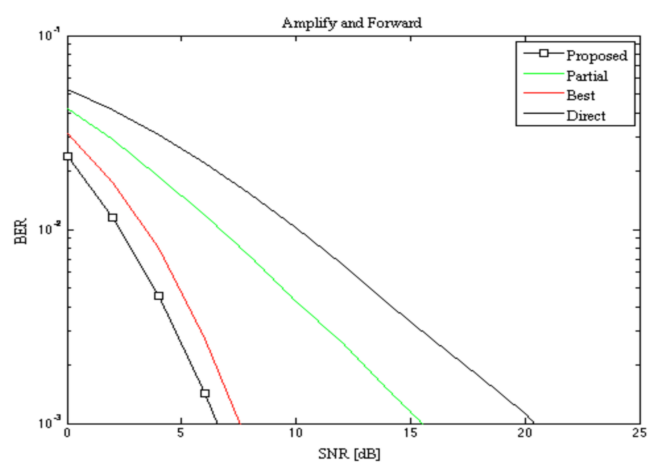

Fig. 5. Performance comparison of the proposed scheme, direct link and other relay selectio algorithms

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Practically, the channels from source to destination, source to relays, relays to destination are unknown. Estimation algorithms are used to estimate these channels. In this sequel, we use least square algorithm to estimate these channels. The effect of channel estimation errors on the BER performance of the proposed scheme is shown in Fig. 6. The figure shows that the performance of the proposed algorithm using known and estimated channel parameters is nearly similar. This implies that channel estimation is accurate due to good choosing of the number of pilot bits. It is noted that, increasing the number of pilot bits for channel estimation leads to accurate estimation but decreases the throughput because the useful information bits in the frame decreases. On the other hand, decreasing the number of pilot bits leads to inaccurate estimation.

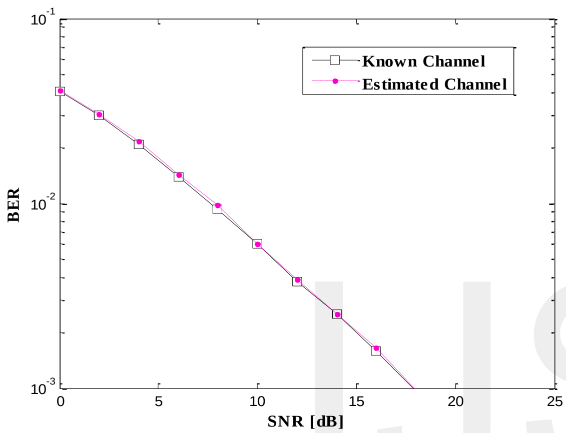

Fig. 6. BER performance of the proposed algorithm for known and estimated channel

All the channels between source and the relays and between the relays and destination are estimated using the least square algorithm. Fig.7. and Fig.8. show the real and imaginary values of the known and estimated channels. The figures show nearly perfect channel estimation which confirm the result of Fig. 6. The Mean Square Error of channel estimation is plotted versus the SNR and the result is shown in Fig.9. The figure shows that as at low SNR, the noise is dominant and the error between the actual and estimated channel is large. When SNR increases, this error decreases.

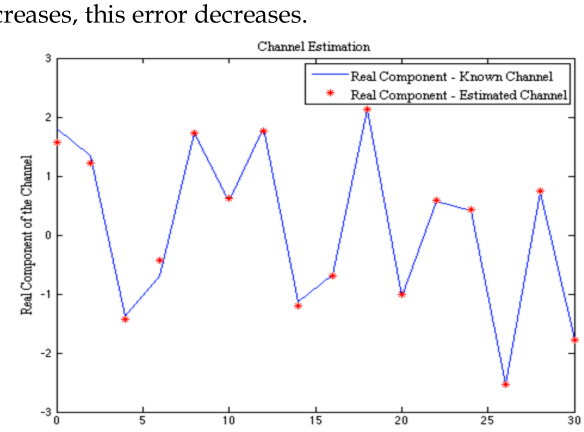

Fig. 7. Real part of the known and estimated channel

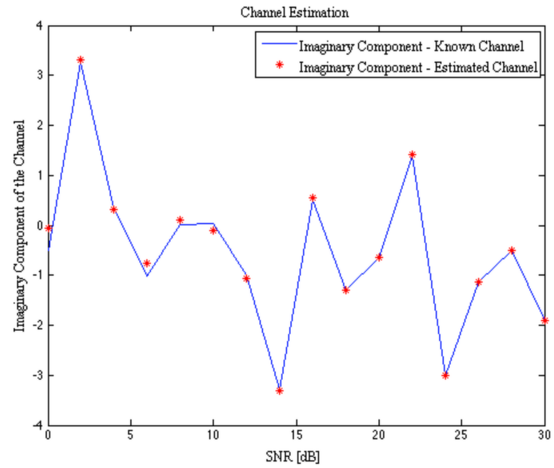

Fig. 8. Imaginary part of the known and estimated channel parameters

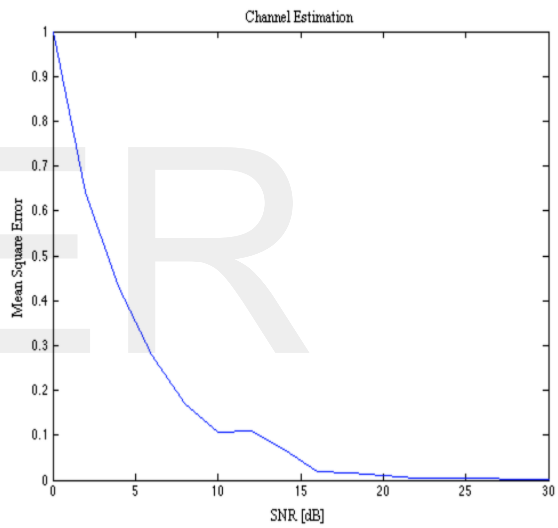

Fig. 9. Mean square error of estimated channels

The result of the power allocation method described in Section 3.4 for AF protocol is summarized in Table 1. The method of power allocation aimed to determine the optimum value of the parameter k_s that minimizes the BER. Table 1 shows the optimum value of the parameter k_s for AF protocol that minimizes the BER along with the corresponding BER for different values of SNR. This power allocation parameter optimization results in a much better performance resulting in nearly no errors at any signal to noise ratio.

Table 1 Probability of error minimization based power allocation

SNR	Ks	BER
0	0.65	0.0001
5	0.19	0.0001
10	0.09	0.0001
15	0.03	0.0001
20	0.01	0.0001
25	0.01	0.0001
30	0.01	0.0001

6 Conclusion

The performances of a relay selection scheme for amplify and forward protocol in Rayleigh fading channel has been evaluated. Mathematical analysis of the BER performance of the algorithm has been derived. Computer simulations are performed to validate the theoretical analysis. A power allocation algorithm based on bit error rate minimization has been applied. Channel estimation has been performed by least square algorithm and the effect of the channel estimation error on the performance of the algorithm has been investigated. It has been shown than the performance of the proposed algorithm has better performance than best relay selection and partial relay selection algorithms. Moreover, the proposed algorithm saves the power since the relay participates only when the total signal to noise ratio of the direct link is weak.

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