Performance Analysis of Cooperative Communication Network with Relay Selection over Rayleigh Fading Channel

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ABSTRACT
Relay selection is a challenging issue in cooperative communication networks. Cooperative diversity uses relays to assist source destination transmissions to reduce link outage rates in multipath fading environments. In this paper an Amplify-and-Forward (AAF) cooperative communication system over Rayleigh fading channel is considered where a source node communicates with a destination node directly and indirectly (through multiple relays). The relay node that achieve the highest signal-to-noise ratio (SNR) at the destination node is selected. The relay selection reduces the amount of required resources. Closed form expressions for outage probability and symbol error probability are obtained from relay selection. Using numerical results, the performances of different cases are evaluated which shows the significant advantages of the relay selection in a cooperative communication.

Keywords
Amplify-and-forward, cooperative communication , outage probability, relay selection

1. INTRODUCTION
Cooperative relay networks have emerged as a powerful technique to combat multipath fading and increase energy efficiency [1, 2]. In a cooperative communication system, users act as information sources as well as relays. There are two main cooperative methods: amplify-and-forward (AF) (non-regenerative relays) and decode-and-forward (DF) (regenerative relays) methods. In the AF method, the relay receives a noisy version of the signal transmitted by the source and then amplifies its received signal and re-transmits it to the destination [3] .

In [4] an asymptotic SER performance evaluation for selection AF relays systems has been presented. The advantages of the cooperative diversity protocols come at the expense of a reduction in the spectral efficiency since the relays must transmit on orthogonal channels in order to avoid interfering with the source node and with each other as well [5]. Hence in cooperative diversity networks with M relaying nodes, M + 1 channel are employed, which incurs a bandwidth penalty. This problem of the inefficient use of the channel resources can be eliminated with the use of the *best-relay selection* scheme. In such a scheme, the “best” relay node only is selected to retransmit to the destination [6]. In [7], the authors proposed to choose the relay depending on its geographic position, based on the geographic random forwarding (GeRaF) protocol proposed in [8]. In [9], the authors considered a selection relay scheme in which only the relay, which has received the transmitted data from the source correctly and has the highest signal-to-noise ratio (SNR) to the destination node, is chosen to forward the source's data. Relay selection based on the distance-based criterion is a scheme where the relay nearest to the source was selected [10]. Relay selection based on the outage probability is the strategy where a relay giving rise to the minimum outage probability was selected [11]. Relay selection based on the channel quality is the strategy where the relay node providing the maximum end-to-end channel quality was selected [12].

In this paper, we focus on amplify-and-forward dual-hop cooperative diversity network to study their end-to-end performance using the *best-relay selection* scheme over Rayleigh fading channel. The main contribution of this paper is the derived closed-form expressions for the probability density function (PDF), the cumulative distribution function (CDF), Moreover, the outage probability (Pout) are determined using closed-form expressions. The remaining of this paper is organized as follows. Section II presents the system model for Amplify-And-Forward cooperative network over Rayleigh fading channel and its performance analysis is given in section III; Numerical results are discussed in section IV . Finally, the conclusions are given in Section V.

2. SYSTEM MODEL
We consider a cooperative communication over Rayleigh fading channel, consisting one direct channel and N amplify-and-forward (AF) dual-hop relay channels.

As shown in Fig. 1, Source has one transmit antenna and destination employs one receive antenna. In the first step, the source terminal transmits the signal x to the relays and to the destination terminal. The signals received at the i-th relay and at the destination terminals are given respectively by

$$\gamma_{SR_i} = h_{SR_i} x + n_{SR_i} \qquad (1)$$

$$\gamma_{SD} = h_{SD} x + n_{SD} \qquad (2)$$

where h_{SR_i} and h_{SD} are the channel gain between the source and the *i*-th relay terminals and the source and the destination. Complex additive white Gaussian noise at the *i*-th relay denoted by $n_{SR_i} \sim CN(0,N_0)$ and at the destination is denoted by $n_{SD} \sim CN(0,N_0)$, where N_0 is the noise variance, x is the transmitted information symbol.

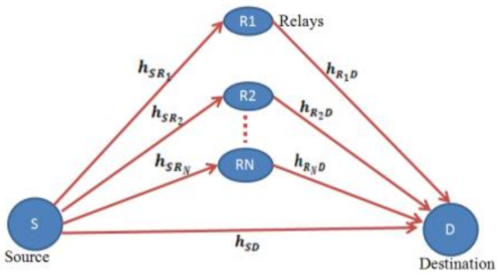

Fig. 1 System model

In the second step of cooperation, the *i*-th relay terminal amplifies its received signal and forwards it to the destination through the channel. The destination terminal receives the relay transmission according to

$$\gamma_{R_iD} = G_i h_{R_iD} \gamma_{SR_i} + n_{R_iD} \qquad (3)$$

where h_{R_iD} is the channel gain between the *i*-th relay terminal and the destination terminal and $n_{R_iD} \sim CN(0,N_0)$ is the complex additive white noise.

The *i*-th relay gain denoted by G_i is chosen as

$$G_i = \frac{E_s}{E_s |h_{SR_i}|^2 + N_o} \qquad (4)$$

where E_s is the average energy per symbol [5].

Relay gain in equation (4) accounts for the situation when $|h_{SR_i}|$ is low (deep fades in the channel). Assuming the maximum ratio combining (MRC) at the destination terminal, the instantaneous equivalent end-to-end SNR can be written as [5].

$$\gamma_D = \gamma_{SD} + \sum_{i=1}^{N} \frac{\gamma_{SR_i}\,\gamma_{R_iD}}{1+\gamma_{SR_i}+\gamma_{R_iD}} \qquad (5)$$

where $\gamma_{SR_i} = \frac{E_s |h_{SR_i}|^2}{N_o}$ and $\gamma_{R_iD} = \frac{E_s |h_{R_iD}|^2}{N_o}$ are the instantaneous SNR of the source and the *i*-th relay terminals , the *i*-th relay terminal and the destination terminal, respectively and $\gamma_{SD} = \frac{E_s |h_{SD}|^2}{N_o}$ denotes the instantaneous SNR of the S − D link.

Assuming the Rayleigh fading channel, the PDF and CDF of the SNR in the links are respectively given by

$$f_{\gamma_v}(\gamma) = \frac{1}{\bar{\gamma}_v} e^{-\gamma/\bar{\gamma}_v} \qquad (6)$$

$$F_{\gamma_v}(\gamma) = 1 - e^{-\gamma/\bar{\gamma}_v} \qquad (7)$$

where $v \in \{SR_i, R_iD, SD\}$ denotes the link index.

In order to simplify the analysis, an upper bound for the second term of the equivalent SNR is given as

$$\gamma_i = \min(\gamma_{SR_i}, \gamma_{R_iD}) \geq \frac{\gamma_{SR_i}\,\gamma_{R_iD}}{1+\gamma_{SR_i}+\gamma_{R_iD}} \qquad (8)$$

Therefore, the upper bound for the equivalent SNR can be written as

$$\gamma_D \leq \gamma_{up} = \gamma_{SD} + \sum_{i=1}^{N} \gamma_i \qquad (9)$$

2.1 Relay selection scheme based on the SNR

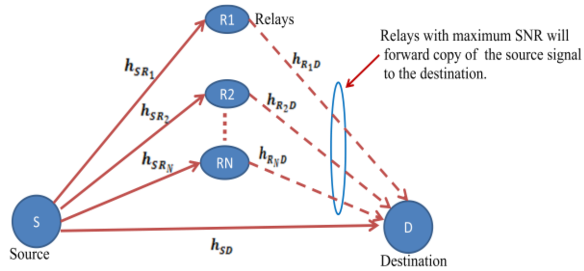

Fig. 2 Cooperative communication network with the Relay selection scheme

As shown in Fig. 2, source node (S) communicates with the destination (D) through the direct link and the indirect link. A number of potential relaying nodes R_i , (i = 1,….,N) are available to relay the signal to provide the destination with another copy of the original signal. All terminals are equipped with a single antenna.

In the first time slot, the source sends its signal. All the N relays and the destination receive faded noisy versions of the source signal. Based on the SNR of the received signal at the destination, the destination decides whether relaying is needed or not because at the destination, the SNR of the received signal from the source is compared with SNR threshold (γ_{th}), which defines the minimum SNR for which the destination can detect the signal successfully without the need of the relayed signal. For sufficient signal to noise ratio (SNR) at the destination, all the relays do nothing (the destination performs detection using the source signal) and the source sends a new message in the second time slot.

For insufficient signal to noise ratio (SNR) at the destination, the select-max protocol is used. Select-Max protocol selects relay with maximum SNR, to take part in the communication. In particular, the relay which maximizes an appropriately defined metric is selected. This metric accounts for both the S-Ri and Ri-D links and reflects the quality of the i-th end-to-end path.

$$\gamma_i = \min(\gamma_{SR_i}, \gamma_{R_iD})$$

$$\min(\gamma_{SR_i}, \gamma_{R_iD}) \geq \frac{\gamma_{SR_i}\,\gamma_{R_iD}}{1+\gamma_{SR_i}+\gamma_{R_iD}} \qquad (10)$$

Here, we adopt the minimum value of the intermediate link SNRs, as the quality measure of the i-th end-to-end path. Equation (10) represents an outage-based definition of the selection metric, in the sense that an outage on the i-th end-to-end link occurs if γ_i falls below the outage threshold SNR. Hence, the relay that is activated in the select-max protocol, is selected according to the rule

$$S_r = \arg\max_{i\in R} \{\gamma_i\} , \qquad (11)$$

where R = {1, 2, . . .,N}, γ_i is the instantaneous SNR for the relay i. Therefore the instantaneous SNR for the selected relay is given by

$$\gamma_{Sr} = \max_{i \in R} \{\gamma_i\} \quad (12)$$

The relay that gives the maximum SNR at the destination forwards the received source signal to the destination. The CDF of γ_{Sr} can be expressed as

$$F_{\gamma_{Sr}}(\gamma) = \left[F_{\gamma_i}(\gamma)\right]^N \quad (13)$$

The PDF $f_{Sr}(\gamma)$ can be obtained by taking the derivative of the CDF $F_{\gamma_v}(\gamma)$ in equation (13) with respect to γ, yielding

$$f_{Sr}(\gamma) = N f_i(\gamma)\left[F_{\gamma_i}(\gamma)\right]^{N-1} \quad (14)$$

The relay selection scheme reduces the amount of required resources.

3. PERFORMANCE ANALYSIS

In this section, analytical expressions for outage probability and average symbol error rate are obtained from relay selection.

3.1 Outage Probability

Outage probability is an information-theoretic performance measure of communication systems. For a system transmitting with a higher rate than channel capacity, error-free communication is impossible, and the system is called in outage. Outage probability is probability that a target transmission rate R exceeds channel capacity C, i.e.

$$P_{out} = \Pr(C < R) \quad (15)$$

Therefore, outage probability is defined as the probability that the end-to-end SNR falls below a predefined certain threshold value , γ_{th} .

The outage probability of equation (15) may be rewritten as

$$P_{out} = \int_0^{\gamma_{th}} f_\gamma(\gamma)\, d\gamma \quad (16)$$

where γ_{th} is a predefined threshold value .

As equation (16) demonstrates, the outage probability is cumulative distribution function (CDF) of γ, evaluated at $\gamma = \gamma_{th}$

$$P_{out} = 1 + \sum_{n=1}^{N} \binom{N}{n} \frac{n(-1)^{n-1}}{(\overline{\gamma_c} - n\overline{\gamma_{SD}})} \times \left[\overline{\gamma_{SD}}\, e^{-\alpha/\overline{\gamma_{SD}}} - \frac{\gamma_c}{n} e^{-n\alpha/\overline{\gamma_c}}\right] \quad (17)$$

Here α is considered as the threshold value and $c=m/\rho_i$, m is Nakagami fading parameter an $\rho_i = \overline{\gamma_{SR_i}} = \overline{\gamma_{R_iD}}$

3.2 Average Symbol Error Rate

The average symbol error rate (*SER*) for M-PSK can be written as [13]

$$\overline{SER} = \int_0^{\infty} M\left(\frac{gpsk}{\sin^2\theta}\right) d\theta \quad (18)$$

where gpsk=sin(πM)

The average SER expressions for BPSK (Binary phase shift Keying)

$$\overline{SER} = \sum_{n=1}^{N} \binom{N}{n} \frac{(-1)^{n-1}}{(1-2n)} \left[I_1\left(\frac{\gamma_o}{2n}\right) - 2nI_1(\gamma_o)\right] \quad (19)$$

where the closed-form expression for $I_1(.)$ is given by [13] (eq.5A.9)

$$I_1(c) = \frac{1}{2}\left(1 - \sqrt{\frac{c}{1+c}}\right) \quad (20)$$

4. NUMERICAL RESULT

In this section, results are obtained from the mathematical expressions presented in the previous section .Using MATLAB coding the performance curves are plotted in the terms of P_{out} versus the SNR of the transmitted signal (E_s/N_0 dB) where E_s is the transmit energy signal.

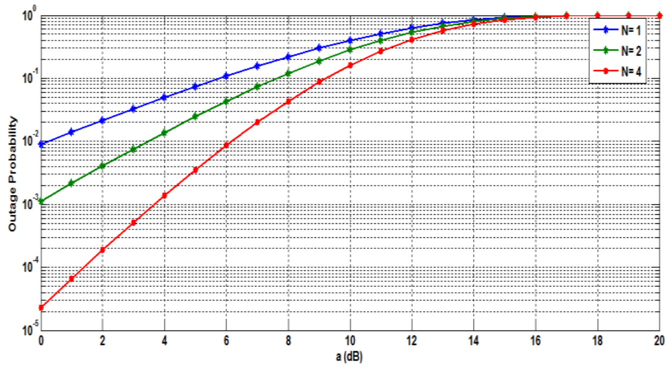

Fig. 3 Plot between Outage probability and α (threshold SNR)

Fig. 3 shows the outage probability verses α for different values of N and using the formula given in (17), for $\overline{\gamma_0}$= 10 dB. It can be seen that increasing the number of relays, N, decreases the outage probability, and hence that when the number of relays is large, the outage event (no transmission) becomes less likely.

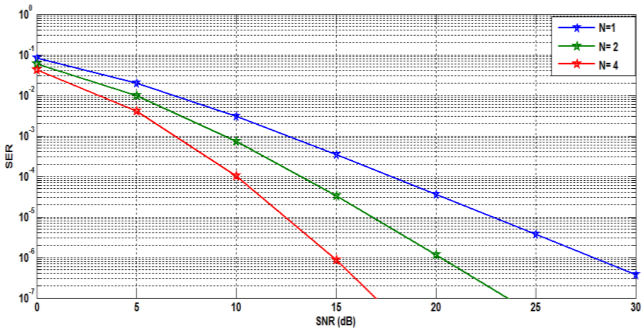

Fig 4. Plot between Average SER versus SNR for BPSK signals

Fig 4. is the performance curves with BPSK modulation in terms of average SER versus average SNR of the transmitted signal (E_s/N_o dB) , where E_s is the transmit energy signal. SER performance of the relay selection scheme for different values of the number of relays (N) is obtained using the formula given in (18). It can be observed that, in all cases, increasing the number of relays decreases the average SER.

5. CONCLUSION

The performance of the relay selection scheme for cooperative communication networks operating over Rayleigh fading channel is analyzed. It should be emphasized that the relay selection scheme has a strong advantage in saving the channel resources. The problem of the inefficient use of the channel resources can be eliminated with the use of the relay selection scheme.

Some closed-form expressions for the average symbol error rate and the outage probability are obtained from relay selection for the system. Numerical results are provided to show the significant advantages of the relay selection in a cooperative communication system. The system gives better performance for high value of Nakagami fading factor (m). It is clear from the simulation results that for higher values of m, better performance is achieved.

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