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Error rate analysis of AF-relay wireless networks under different *SNR* levels

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ABSTRACT

This paper presents a new method for analyzing the Bit Error Rate (BER) performance of two-hop Amplify-and-Forward Multiple Relay (AF-MR) networks. This paper considers, a flat-fading channel and a relay selection scheme to select a relay with the highest Signal-to-Noise Ratio (*SNR*). The method aims to unify the BER calculation under low, high and optimal *SNR* levels. Asymptotic BER (ABER) performance at high *SNR* value is calculated first, and standard expressions for exact BER (EBER) performance at low and optimal *SNR*s are then derived. The analytic method depends on the conventional BER (CBER) approach of one-hop communication systems. The optimal *SNR* is obtained by balancing energy efficiency and spectral efficiency. The proposed method is found to be effective for calculating the BER of AF-MR network performance under any *SNR* conditions. Moreover, it improves the accuracy of ABER performance by reducing disparity computation errors between ABER and EBER performances and this allows the BER of AF-MR networks to be accurately calculated using either ABER or EBER. The outcome expressions for the method are validated by simulation results.

1. Introduction

Wireless relay networks have emerged as one of the most promising techniques for enhancing the performance of wireless networks by replacing the direct transmission link (one-hop) into two links (two-hop) [1]. They achieve considerable performance improvement in link reliability, spectral efficiency (SE) [2], Energy Efficiency (EE) [3] and BER performance [4]. The relay networks are classified into two main protocols, Amplify-and-Forward (AF) and Decode-and-Forward (DF) [5]. The AF relay acts as a repeater which amplifies input signals without any further processing, while the DF relay decodes the input signal and re-encodes it prior to retransmission [6]. The AF relay is of relatively low complexity, requires less hardware and is expected to be widely employed in future cellular networks, where a base station (or equivalent source node) can broadcast signals to mobile phones (i.e., destinations) through intermediate relay nodes [7]. It is, however, not without problems. One major problem with the AF-relay network is that it amplifies both the source signal and noise [8]. Therefore, such networks will be limited by the noise, which in turn increases error rate of the transmission signal, especially at low *SNR* level [1]. This paper aims to examine a new method that allows us to calculate the BER of an AF-MR network, which is defined as the number of errors in a given number of transmitted bits.

Various methods have been proposed to analyze the BER performance of wireless networks. An early method was investigated by [9] to calculate the ABER of one hop communication system using various diversity techniques. In this study, a high *SNR* level for fading channels was adopted and different M-ary Phase Shift keying (MPSK) modulation schemes were used. It was found that the high *SNR* approximations are very useful for wireless performance analysis.

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The error rate for two hop AF relay and DF-relay networks were analyzed by [10,11]. Both studies presented a new statistical method that depends on one kind of Pythagorean mean. Their results demonstrated that a DF-relay network performs better at low *SNR* values than an AF-relay network, while at higher *SNR*, both demonstrate similar BER performance. However, the BER analysis in both studies was limited to one relay networks.

In [12], multi-hops and multi-relay networks were involved in the analysis of the error rate of AF relay networks. This study used a high *SNR* level to calculate Symbol Error Probability (SER) performance. It found that the SEP of AF-MR networks improve performance by increasing the number of relays. Similar studies [13–15] have investigated SER performance of AF-MR networks, with the authors in [13] obtaining the exact SER performance of AF parallel relays over a Rayleigh-fading channels. They used the Moment Generating Function (MGF) of half the harmonic mean to calculate SER performance. In [14], the harmonic mean approximation was used to calculate upper and lower bounds for exact SER and outage probability performances. Further, Laplace transform of the Cumulative Distribution Function (CDF) and Probability Density Function (pdf) of the exact *SNR* were used in [15] to obtain asymptotic and actual Frame Error Rate (FER) performance. The results of [15] revealed that the selection of one optimum relay achieves better FER performance than multiple relay selection under transmitting power constraints. However, all above SER studies require more processing to determine BER which is a more useful metric than SER [16]. Moreover, calculating FER depends on the required BER [17].

The authors in [18] considered different network scenarios including: multi-hop, multi-relay, and multi-relay multi-hop to analyze ABER and outage probability by using a high *SNR* level, which was also adopted by [19] to calculate the ABER of an AF-relay network selection scheme and using the harmonic mean of two variables. The study of [19] found that increasing the number of relays with a high *SNR* level enhances ABER performance. A similar system was also investigated in [20] using a low-complexity relay selection scheme to obtain accurate approximations for both BER and outage probability. Study [21] analyzed BER performance of AF relays network using approximated and exact *SNR* for cascaded and disintegrated slowly fading Rayleigh channels. The above [18–21] studies, however, have showed accurate results when calculating BER at high *SNR* domain, without considering the BER at low or intermediate *SNR* regions. Thus, the ABER of these studies was limited when computing the error rate at *SNR* domains that were too high.

Evaluating error rate performance of AF-relay networks under an optimal *SNR* level has been investigated by a few studies such as [22,7]. In [22], SER performance of a single AF relay network was investigated in two cases; the first considered equal source and relay powers, while the second optimized both powers. It found that SER performance using optimum powers was slightly better than that of the equal powers case. The optimal *SNR* for a given BER was calculated by [23,7]. Both studies aimed to reduce energy consumption in relay networks. Most other researchers, such as [24,25], have achieved optimal *SNR* levels by balancing EE and SE optimally, but such studies have not considered error performance behavior.

The aforementioned studies indicate that the error rate analysis of AF-MR is limited by *SNR* levels that are either low, high or optimal. Given the complexity associated with error rate analysis at low and optimal *SNR*, most of those studies have considered approximated *SNR* at a high level to simplify the calculation. However, each of the above error rate analyses is limited to particular types of applications, e.g., the error rate analysis at high *SNR* is not appropriate to be employed for applications working at a low *SNR* level. Therefore, each application associated with a particular *SNR* may require an error rate analysis. Motivated by this issue, this paper proposes a unified method that allows the calculation of the BER of AF-MR networks under low, high and optimal *SNR* levels. To the best of the authors' knowledge, this idea has not yet been proposed in the literature.

In the proposed method, a high *SNR* level is used to compute BER approximately (i.e. ABER), while BER at all *SNR* levels can be calculated exactly by using the same analysis of ABER. Furthermore, the proposed ABER scheme is unlike the existing ABER techniques in [19,26,27,15], as it provides lowest disparity between ABER and EBER. This BER calculation by either ABER or EBER achieves almost the same result. This is because the proposed scheme is achieved by following the Conventional one-hop BER (CBER) analysis. Thus, BER evaluation of two hop AF-MR at various *SNR* levels (i.e. low high and optimal) is roughly the same as in one hop communication network.

Furthermore, our proposal presents a new approach to optimize *SNR* by balancing average Energy Efficiency ($\overline{EE}$) and average Spectrum Efficiency ($\overline{SE}$). This approach allowed us to calculate BER performance at an optimal *SNR* level. In the literature, a number of studies, such as [28,24,25], have investigated an optimal *SNR* based on EE and SE without considering error rate analysis, due to the complexity in their optimal *SNR* outcomes. Such investigations are incomplete, since error rate analysis is an important parameter for evaluating the performance of many wireless network applications [29].

The paper is organized as follows. Section 2 outlines the system model and an expression used to calculate the *SNR*. Section 3 presents the proposed method to analyze two-hop system performance with one relay. Section 4 analyzes the asymptotic BER performance of multi-relay systems. Section 5 presents the analysis of EBER under the optimal *SNR* level. In Section 6 simulation results are demonstrated and, finally, conclusions are drawn in Section 7.

2. System model

We consider two wireless nodes S and D, which are communicating via relay node r_i among n relays as shown in Fig. 1. The node r_i which has the highest *SNR* is chosen by the selection scheme. All the nodes (i.e. S, D and r_i) are equipped with one antenna. The D-node is considered to be out of the S-node coverage area. In this model, the Binary PSK (BPSK) modulation is adopted by S-node which broadcasts symbol x with average power p_s to all relays.