Performance Analysis of Best Relaying Protocol Selection with Interferences at Relays

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Abstract. *In this paper, we investigate the performance of selecting the best protocol between amplify and forward (AF) and decode and forward (DF) in multiple relay networks with multiple interferences at relays. In the selection scheme, the best protocol between AF and DF is selected depending on the comparisons of signal-to-interference and noise ratio (SINR) for all source-relay links. All relays measure the received SINR to decide whether to forward the signal or not. When SINR is above a certain threshold, then DF is used, otherwise AF is used. Particularly, we develop an accurate mathematical model for best relaying protocol by considering the effect of interferences on our scheme. Firstly, we derive the asymptotic closed form expression for the symbol error rate (SER) of the system under study. Additionally, we derive an upper and lower bound of symbol error rate and show how they were tight with exact SER. Furthermore an approximate expression for the outage probability is derived. Numerical results are finally presented to validate the theoretical analysis with a different number of relays.*

Keywords

Relaying protocol, wireless network, multiple interferences, symbol error rate, outage probability.

1. Introduction

The increasing demand for high data rate that improves communication reliability and system capacity has posed an intriguing challenge for today's wireless system design; therefore, wireless cooperative systems with relay nodes have been widely employed to achieve high diversity gain and provide high quality of service (QOS). Diversity in wireless communications is used to increase link spectral efficiency by mitigating the fading phenomenon. There are many ways to achieve diversity in wireless networks [1],[2], by using multiple-input and multiple-output (MIMO) techniques or relays as in cooperation communication without implementing multiple antennas on small communication terminals. In cooperative communication, the surrounding users act as relays to help in forwarding information to the destination to achieve full diversity [3],[5]. However, the performance gains of cooperative systems are affected by multiuser interference, because the incoming signals can interfere with adjacent cells, especially in urban scenarios with many users and cells close to each other.

Interference is an important issue impacting the efficiency of multiple wireless communication technologies. In multiple transmissions or possible transmission through neighboring nodes, the interference often takes place over a common communication channel. The main objective in such a development is how to manage or even mitigate the interference, which may significantly reduce the reliability of a wireless communication system. In many cooperative relaying techniques such as MIMO systems or wireless sensor networks (WSN), the interfering source broadcasts signals with the same amount of power as the desired source. Therefore, the authors in [6] practically established the interference between Global System for Mobile Communications (GSM) and Digital Terrestrial TV. Whereas, both of them work within the existing UHF spectrum (790 MHz to 862 MHz).

Previous works in cooperative communication [7]–[9] are mainly focused on relay protocol without considering the effect of the presence of interference, which will be very important for practical issues. Motivated by the above discussion, many authors studied the impact of interference in cooperative communication using single protocol AF or DF. The authors in[10]–[12] investigated that the relays can decode and forward or amplify and forward the information if the channel's coefficient is above or below a certain threshold. The authors in [10] proposed a decode-and-forward (DF) relay selection scheme for an interference-limited multiple relay network. J. B. Si et al. [11], proposed a threshold-based relay selection protocol for wireless relay networks with interference. Amplify and forward strategy for interference limited networks is considered in [12], in [13] the authors investigated interference aware relay assignment using a heuristic algorithm (IRA). In [14] the authors developed an optimal power allocation (OPA); that maximized the performance of cognitive radio networks (CR), and mitigated the effect of interference in primary users (PUs). The results showed significant improvement of system quality, using directional relaying. The relays help for forwarding information as an indirect mode when the direct mode between source and cognitive destination has failed. As we know, AF is limited by noise amplification (the relay receives a noisy version of signal and then amplifies it) while DF suffers from error propagation. Moreover, DF suffers performance loss, which is limited by weak channels, because the relay forwards the decoded information correctly only if the channel coefficient is above a certain threshold. Thus, a selection between AF and DF was sufficient.

The novel contribution of this paper is that we proposed the following claim: when the mutual information between the source node and each relay node is above the transmission target rate, the relays use DF as relaying protocol. Otherwise, (when all relays are not able to use DF), the remaining relays amplify and forward. In general m relays can decode and forward when a channel's coefficient is above a certain threshold, and n-m relays can amplify and forward during a silent period. The purpose of this article is to study a wireless network using the best relaying protocol selection between AF and DF with interference consideration.

The rest of this paper is organized as follows: In Section 2, a system model of best relaying protocol with interferences is presented. Section 3 discusses the interference model and SINR analysis and shows how interference affects cooperative systems. Asymptotic SER is analyzed in Section 3 by making some derivation of moment generating function (MGF), probability density function (PDF), and cumulative density function (CDF) expressions for end-to-end SINR. Outage probability and Diversity order are derived in Sections 5 and 6. Numerical results and Conclusion are provided in Sections 7 and 8, respectively.

2. System Model

As shown in Fig. 1, the whole system consists of two clusters – A and B; in cluster A the source S' transmits interfered messages to relay nodes as shown by dashed lines, whereas the continuous lines in cluster B stand for desired channels with source S. In Fig. 2, our cooperative relay network system consisting of one source node S and n cooperative relays r_i; (i =1,2. . . ,n) with L interferences at relay nodes and one destination D. The channels from S to R_i and from R_i to D are statistically mutually independent, and identically distributed (i.i.d.). Assuming that the perfect Channel State Information (CSI) at the receiver is available and the main channel gains are known to the transmitter, the system works under Rayleigh fading channel (any two nodes in the network are subject to Rayleigh fading) and additive white Gaussian noise (AWGN)N_0. All signals are transmitted orthogonally using multiple access techniques with time division multiplexing TDMA to facilitate the orthogonal transmission in two phases [3],[4] (code division multiplexing and frequency division multiplexing can also be used).

It follows that the transmitted scheme is divided into two phases. **Phase 1:** The source broadcasts its signal to the destination, and the same information is received by the n relays. The different signals received from the destination, and the i^{th} interference relay can be represented as:

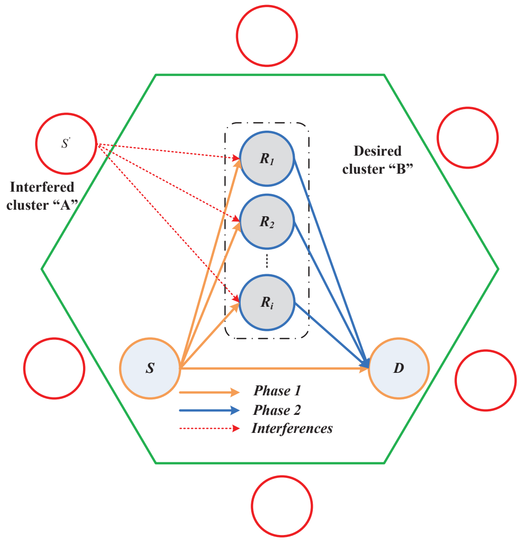

Fig. 1. Cooperative relaying protocol selection between AF and DF, where the continuous lines refer to the required channels and the dashed lines represent the interference channels.

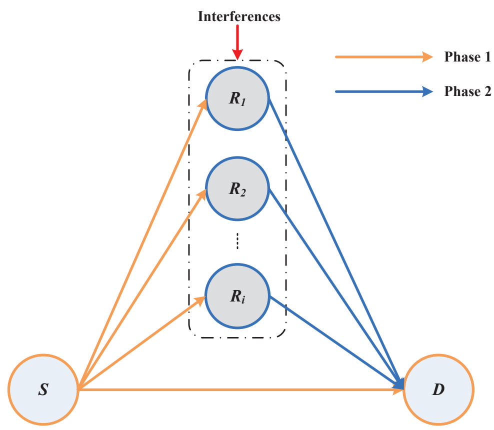

Fig. 2. Cooperation model with interferences at relay nodes.

$$\mathrm{Y_{sd}} = \sqrt{\mathrm{P_S}}\mathrm{h_{sd}}x + \mathrm{n_{sd}}, \quad (1)$$

$$\mathrm{Y_{sr_i}} = \underbrace{\sqrt{\mathrm{P_S}}\mathrm{h_{sr_i}}x}_{desired} + \underbrace{\sqrt{\mathrm{P_{S'}}}\mathrm{h_{s'r_i}}x'}_{\text{interference}} + \mathrm{n_{sr_i}} \quad (2)$$

where $\mathrm{Y_{sd}}$ and $\mathrm{Y_{sr_i}}$ represent the received signal at the destination and i^{th} relay respectively, $\mathrm{h_{sd}}$, $\mathrm{h_{sr_i}}$ are the fading channel coefficient between source to destination and between source and i^{th} relay, $\mathrm{n_{sd}}$ and $\mathrm{n_{sr_i}}$ denote the AWGN, x and $\mathrm{P_S}$ are transmitted information symbol and transmitted source power ($\mathrm{P_S}$ normalized to unity) and x' modeled for interfered cluster as transmitted information symbol with fading channel coefficient $\mathrm{h_{s'r_i}}$. **Phase 2:** The n relays send what they received from source to destination using the best protocol amplify and forward or decode and forward. **The case of AF:** the n relays amplify both received and interference signals with power gain G and forward them to destination. The received signal and interference at destination from i^{th} relay are modeled as follows:

$$\mathrm{Y}_{\mathrm{r_i}d} = G_{r_i}\left(\mathrm{h}_{\mathrm{r_i}d}x + \mathrm{h}_{\mathrm{r_i}d'_\mathrm{i}}x'\right) + \mathrm{n}_{\mathrm{r_i}d} \tag{3}$$

where $\mathrm{h}_{\mathrm{r_i}d}$ and $\mathrm{h}_{\mathrm{r_i}d'_\mathrm{i}}$ represent the fading channel coefficient between i^{th} relay to destination for desired and interfered signal respectively, $\mathrm{n}_{\mathrm{r_i}d}$ is (AWGN), G_{r_i} indicates to the amplification factor (normalization factor) which is modeled with the help of [15],[16] as:

$$G_{r_i} = \sqrt{\frac{P_{r_i}}{P_s|h_{sr_i}|^2 + P_{s'}\left|h_{s'r_i}\right|^2 + N_0}}. \tag{4}$$

This factor scales received signal with factor inversely proportional to received power as given in the model with P_{r_i} the transmitted power at i^{th} relay. **Case of DF:** The n relays re-encode the received signal from the source and forwards it to the destination. The received signal at the destination from i^{th} relay is modeled as:

$$Y_{r_id} = \underbrace{\sqrt{P_{r_i}}h_{r_id}\bar{x}}_{desired} + \underbrace{\sqrt{P_{r'_i}}h_{r'_id}\bar{x}'}_{interference} + n_{r_id} \tag{5}$$

where, $\bar{x}$ and $\bar{x}'$ are the decoded information at the relay (R_i) for both desired and interfered signals respectively.

3. Interference and SINR Analysis

The energy of transmitted signal fades with distance, this phenomenon in wireless communication is commonly defined by path loss. The received power P_r of signal can be written as follows[17]:

$$P_r = \frac{P_t}{PL_{tr}} \tag{6}$$

where P_t is transmitted power and PL_{tr} denotes the path loss between the transmitter and receiver, by taking into account the Euclidean distance, we rewrite (6) as

$$P_r = P_t d^{-\alpha} \tag{7}$$

where $(-\alpha)$ is path loss exponent, commonly $\alpha > 2$ [18]. Now we can express the definition and mathematic formulation of the SINR, whereas the SINR defines as a ratio between transmitted signal by the base station to all interfering signals, such as thermal noise, neighboring cells, etc. We use it to measure the quality of communication connection, and we express it in terms of power (P) with the following formulation:

$$SINR = \frac{P_{signal}}{P_{\mathrm{interference}} + P_{noise}}, \tag{8}$$

$$= \frac{P_r}{I + N_0} \tag{9}$$

where I represents the interference power of other neighboring cells, and N_0 is noise power. So, the minimum SINR required for successful reception β is written as follows[15]:

$$SINR = \frac{P_t d^{-\alpha}}{\sum\limits_{t \neq i} P_i d^{-\alpha} + N_0} \geq \beta. \tag{10}$$

Now we define the effect of interference in wireless cooperative networks based on (10). By making use of maximal ratio combiner (MRC) that combines received signals from source and i^{th} relay to enhance the reliability [19]. So the end-to-end signal to interference and noise ratio after combing can be written as:

$$\gamma_{SINR} = \gamma_s + \frac{\sum\limits_{i=1}^{n}\gamma_{r_i}}{\sum\limits_{i=1}^{L}\gamma_{inr} + 1} \tag{11}$$

where γ_S and γ_{r_i} represent the SNR of the direct and the i^{th} relay link (AF_i or DF_i)respectively, and γ_{inr} is interference to noise ratio. So, from (11), the whole model for AF-DF best relaying protocol can be written as follows:

$$\gamma_{best_{AF_i-DF_i}} = \left\{\cap\left(\gamma_{SINR_{sr_i}} < \varepsilon\right) \cap \left(\gamma_s + \frac{\sum\limits_{i=1}^{n}\gamma_{AF_i}}{\sum\limits_{i=1}^{L}\gamma_{inr}+1}\right)\right\} \cup \left\{\cap\left(\gamma_{SINR_{sr_i}} \geq \varepsilon\right) \cap \left(\gamma_s + \frac{\sum\limits_{i=1}^{n}\gamma_{DF_i}}{\sum\limits_{i=1}^{L}\gamma_{inr}+1}\right)\right\}. \tag{12}$$

Equation (12) means that: if the channel coefficients satisfy ($\gamma_{SINR_{sr_i}} < \varepsilon$) which means that the relays are not able to decode the information correctly, because the received information from the source is degraded by strong interferences, then AF protocol is selected to investigate the best relaying protocol that maximizes the received end-to-end SINR to support the transmission scheme for the system under studied, otherwise when the mutual information between the source node and each relay node is above the transmission target rate ($\gamma_{SINR_{sr_i}} \geq \varepsilon$) then all the relays use DF as relaying protocol, it means that the received information at relay nodes is good enough to support the transmission with low interference. The above assumptions are simplified in Fig. 3.

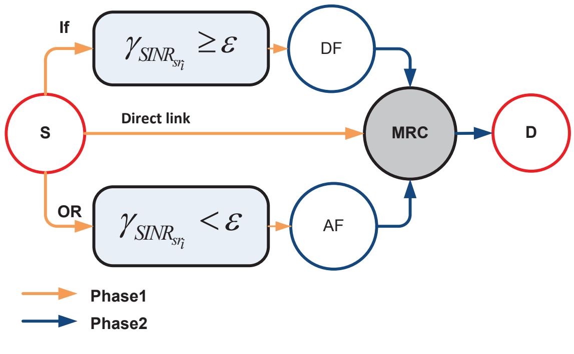

Fig. 3. Selection scheme protocol between AF-DF .

The mutual information between the source node and the i^{th} relay node as a function of the fading coefficient is given by [20]:

$$\mathrm{I_i} = \frac{1}{(n+1)} \ln\left[1+\gamma_{SINR_{sr_i}}\right]. \quad (13)$$

For a given target rate r in the system, a correct decoding scheme from i^{th} relay may be possible if and only if the mutual information is above the target rate (i.e., $I_i \geq r \Rightarrow \gamma_{SINR_{sr_i}} \geq \varepsilon = (2^{2(\mathrm{n}+1)\mathrm{r}} - 1)$. For suitable analysis with the aim to investigate also the performance of relaying protocol selection, statistically similar relay channel gains are considered and can be practically realized by carefully placing the relays ($\sigma^2_{sr_1} = \sigma^2_{sr_2} = \ldots = \sigma^2_{sr\eta}$ & $\sigma^2_{r_1 d} = \sigma^2_{r_2 d} = \ldots = \sigma^2_{r\eta d}$), and that $\sigma^2_{\mathrm{jk}} \propto \mathrm{D}^{-\alpha}_{\mathrm{jk}}$ ($\mathrm{jk} \in \{sr_\mathrm{i}, \mathrm{r_i}d\}$) where D_{jk} represents the distance between node j to node k and α designs the path loss exponent coefficient.

For analytical tractability in deriving the distribution of AF-DF signals, the SINR can be divided in to two schemes:

3.1 SINR Statistical

3.1.1 For Amplify and Forward (AF)

$$\gamma_{SINR_{AF_i}} = \frac{G^2|h_{sr_i}|^2|h_{r_i d}|^2 P_s}{G^2\left|h_{s'r_i}\right|^2|h_{r_i d}|^2 P_{s'} + G^2 N_0 |h_{r_i d}|^2 + N_0}. \quad (14)$$

Substituting (4) in (14), we have

$$\gamma_{SINR_{AF_i}} = \frac{\gamma_{sr_i}\gamma_{r_i d}}{\gamma_{inr}(\gamma_{r_i d}+1) + \gamma_{sr_i} + \gamma_{r_i d} + 1}. \quad (15)$$

3.1.2 For Decode and Forward (DF)

The SINR at the relay $\mathrm{r_i}$ and destination is written from (2) and (5) as

$$\gamma_{SINR_{DF_i}} = \frac{P_{r_i}|h_{r_i d}|^2}{P_{r_i}\left|h_{r' i d}\right|^2 + N_0} \quad (16)$$

$$= \frac{\gamma_{r_i d}}{\gamma_{inr}+1}. \quad (17)$$

3.2 SINR Approximation

3.2.1 For Amplify and Forward (AF)

At a high signal to noise ratio, ($SNR \to \infty$) the one in denominator of equation is ignored and thus (15) reduces to

$$\gamma_{SINR_{AF_i}} = \frac{\gamma_{sr_i}\gamma_{r_i d}}{\gamma_{inr}\gamma_{r_i d} + \gamma_{inr} + \gamma_{sr_i} + \gamma_{r_i d}} \quad (18)$$

and $\gamma_{inr}\gamma_{r_i d} \gg \gamma_{inr} + \gamma_{sr_i} + \gamma_{r_i d}$. Hence, the SINR for AF can be approximated as

$$\gamma_{SINR_{AF_i}} \simeq \frac{\gamma_{sr_i}\gamma_{r_i d}}{\gamma_{inr}\gamma_{r_i d}} = \frac{\gamma_{sr_i}}{\gamma_{inr}}. \quad (19)$$

Equation (19) indicates the ratio of SNR for the first phase to the approximate interference. Therefore, as it is demonstrated in (19), at the high SNRs, the statistical analysis of our scheme is independent of the second phase (relay-destination phase).

3.2.2 For Decode and Forward (DF)

The approximation ratio of SNR for the second phase to the interference can be written as follows:

$$\gamma_{SINR_{DF_i}} = \frac{\gamma_{r_i d}}{\gamma_{inr} + N_0} \simeq \frac{\gamma_{r_i d}}{\gamma_{inr}}. \quad (20)$$

4. Symbol Error Rate Analysis

In this section, we determine the expression of the SER using MPSK signal and after deriving the analytical expressions for the cumulative density function (CDF), the probability density function (PDF) and the moment generating function of the instantaneous received SINR from best relaying protocol selection. Following the order of statics rules [21], the cumulative density function (CDF) of the SINR at the relay nodes is obtained by

$$F_{\gamma_{SINR}} = 1 - \prod_{i=1}^{L}\left(1 + \frac{\bar{\gamma}_{r_i}}{\bar{\gamma}_{inr}} x\right)^{-1} \quad (21)$$

where $\bar{\gamma}_{r_i} = \gamma_{sr_i}$ in case of AF and $\bar{\gamma}_{r_i} = \gamma_{r_i d}$ for DF.

From (21) we can obtain the PDF of the γ_{SINR} which is the derivative of CDF with respect to x. So the PDF of γ_{SINR} is given by

$$f_{\gamma_{SINR}}(x) = \prod_{i=1}^{L} y(1+yx)^{-2} \prod_{j=1, j\neq i}^{L} y(1+yx)^{-1} \quad (22)$$

where $y = \frac{\bar{\gamma}_i}{\bar{\gamma}_{inr}}$ denotes the ratio between average SNR and INR. By using Taylor series approximation for first order, [10], [22], we can get:

$$f_{\gamma_{SINR}}(x) = \sum_{i=1}^{L} \frac{1}{y} \exp\left(-\sum_{i=1}^{L} \frac{x}{y}\right) \quad (23)$$

$$= \frac{L}{y} \exp\left(-\frac{L}{y} x\right) \quad (24)$$

where (24) denotes an exponential random variable with parameters:

$$\lambda_{\mathrm{AF}_i} = \tfrac{L}{y} = \tfrac{L\bar{\gamma}_{sr_i}}{\bar{\gamma}_{inr}} \text{ for AF case,}$$

$$\lambda_{\mathrm{DF}_i} = \tfrac{L}{y} = \tfrac{L\bar{\gamma}_{r_i d}}{\bar{\gamma}_{inr}} \text{ for DF case.}$$

using (24) we can define the MGF of γ_{SINR} by

$$M_{\gamma_{SINR}}(w) = \int_0^\infty e^{-wx} f_{\gamma_{SINR}}(x)\, dx. \quad (25)$$

So, substituting (24) into (25) and computing the integral, we can write the expression of the moment generating function of γ_{SINR} as follows:

$$M_{\gamma_{SINR}}(w) = \frac{L}{y}\int_0^\infty e^{-wx} e^{-\frac{L}{y}x} dx. \quad (26)$$

Using the formula

$$\int_0^{\infty} e^{ax}dx = \frac{1}{|a|} \qquad (a<0), \tag{27}$$

the MGF of γ_{SINR} can be expressed as:

$$M_{\gamma_{SINR}}(t) = \frac{L}{yw+L}. \tag{28}$$

From the above formulation, a conditional closed-form expression for the SER with MPSK modulation is written as follows [23],

$$P_{SER} = \frac{1}{\pi}\int_0^{\frac{(M-1)\pi}{M}} MGF_{\gamma}\left(\frac{-b}{\sin^2\theta}\right)d\theta \tag{29}$$

where M is modulation index.

By averaging over Rayleigh fading channels, the moment generating function can be written as follows[23]

$$MGF\gamma\left(\frac{-b}{\sin^2\theta}\right) = \left(1+\frac{b}{\lambda\sin^2\theta}\right)^{-1}, \tag{30}$$

$$P_{SER} = \frac{1}{\pi}\int_0^{\frac{(M-1)\pi}{M}} MGF_{\gamma_s}(-w)\,MGF_{\gamma_{SINR}}(-w)\,d\theta. \tag{31}$$

Substituting the different moment generating functions by their values, then, the SER for the best protocol selection between AF and DF is obtained by averaging (31) over distribution of total SNR, and then we have:

$$\begin{aligned} P_{SER} = & \sum_{m=0}^{n-1} C_{n-1}^{m}\prod_{i=1}^{m} P_{rob}\left(\gamma_{SINR_{sr_i}} \geq \varepsilon\right)\prod_{i=m+1}^{n} P_{rob}\left(\gamma_{SINR_{sr_i}} < \varepsilon\right)\times \\ & \left(\frac{1}{\pi}\int_0^{\frac{(M-1)\pi}{M}} MGF\gamma_S\left(\frac{-b}{\sin^2\theta}\right)\prod_{i=1}^{n} MGF_{\gamma_{AFi}}\left(\frac{-b}{\sin^2\theta}\right)d\theta\right) \\ & + \prod_{i=1}^{n} P_{rob}\left(\gamma_{SINR_{sr_i}} \geq \varepsilon\right)\times \\ & \left(\frac{1}{\pi}\int_0^{\frac{(M-1)\pi}{M}} MGF_{\gamma_S}\left(\frac{-b}{\sin^2\theta}\right)\prod_{i=1}^{n} MGF_{\gamma_{DFi}}\left(\frac{-b}{\sin^2\theta}\right)d\theta\right) \end{aligned} \tag{32}$$

where $C_n^m = \frac{n!}{m!(n-m)!}$ represents the binomial coefficient, and

$$MGF\left(\sum_{i=1}^{n}\gamma_i\right) = \prod_{i=1}^{n} MGF\gamma_i.$$

Therefore, substituting (30) into (32), the equation (32) at high SNR can be written as:

$$P_{SER} = \frac{1}{\pi}\left(\begin{aligned} & \sum_{m=0}^{n-1} C_{n-1}^{m}\prod_{i=m+1}^{n}\frac{\delta}{\gamma_{SINR_{sr_i}}}\times \\ & \int_0^{(M-1)\pi/M}\left(\frac{\sin^2\theta}{\sin^2\theta+\frac{b}{\lambda_S}}\right)\prod_{i=1}^{n}\left(\frac{\sin^2\theta}{\sin^2\theta+\frac{b}{\lambda_{AF_i}}}\right) \\ & + \int_0^{(M-1)\pi/M}\left(\frac{\sin^2\theta}{\sin^2\theta+\frac{b}{\lambda_S}}\right)\prod_{i=1}^{n}\left(\frac{\sin^2\theta}{\sin^2\theta+\frac{b}{\lambda_{DF_i}}}\right) \end{aligned}\right)d\theta \tag{33}$$

where at high SNR we have:

$$\begin{aligned} \prod_{i=m+1}^{n} P_{rob}\left(\gamma_{SINR_{sr_i}} < \varepsilon\right) &= \prod_{i=m+1}^{n}\left(1-e^{\frac{-\delta}{\gamma_{SINR_{sr_i}}}}\right) \\ &= \prod_{i=m+1}^{n}\frac{\delta}{\gamma_{SINR_{sr_i}}} < 1 \end{aligned} \tag{34}$$

and

$$\prod_{i=1}^{n} P_{rob}\left(\gamma_{SINR_{sr_i}} \geq \varepsilon\right) = e^{\frac{-\delta}{\gamma_{SINR_{sr_i}}}} \to 1. \tag{35}$$

Unfortunately, it is very difficult to find a closed-form solution for (33) because our equation is too complex. Therefore, we establish a SER higher and lower bound to show the asymptomatic performance, which is tight with the exact SER at high SNR as we can see. Since we have $0 \leq \sin^2\theta \leq 1$, we can derive the following inequalities [24]:

$$\begin{aligned} & \tfrac{b}{\lambda_S} \leq \sin^2\theta + \tfrac{b}{\lambda_S} \leq 1+\tfrac{b}{\lambda_S} \Rightarrow \\ & \frac{\sin^2\theta}{1+\frac{b}{\lambda_S}} \leq \frac{\sin^2\theta}{\sin^2\theta+\frac{b}{\lambda_S}} \leq \frac{\sin^2\theta}{\frac{b}{\lambda_S}}, \end{aligned} \tag{36}$$

$$\frac{\sin^2\theta}{1+\frac{b}{\lambda_{DF_i}}} \leq \prod_{i=1}^{n}\left(\frac{\sin^2\theta}{\sin^2\theta+\frac{b}{\lambda_{DF_i}}}\right) \leq \frac{\sin^2\theta}{\frac{b}{\lambda_{DF_i}}}, \tag{37}$$

$$\frac{\sin^2\theta}{1+\frac{b}{\lambda_{AF_i}}} \leq \prod_{i=m+1}^{n}\left(\frac{\sin^2\theta}{\sin^2\theta+\frac{b}{\lambda_{AF_i}}}\right) \leq \frac{\sin^2\theta}{\frac{b}{\lambda_{AF_i}}}. \tag{38}$$

So, substituting (36), (37) and (38) into (33) we can find the SER upper and lower bound respectively as follows:

$$\begin{aligned} & P_{SER_{UP}} = \\ & \sum_{m=0}^{n-1} C_{n-1}^{m}\prod_{i=m+1}^{n}\frac{\delta}{\gamma_{SINR_{sr_i}}}\frac{\lambda_s}{b^{n+1}}\prod_{i=1}^{n}\lambda_{AF_i}C + \frac{\lambda_s}{b^{n+1}}\prod_{i=1}^{n}\lambda_{DF_i}C. \end{aligned} \tag{39}$$

and

$$\begin{aligned} P_{LOW} = & \sum_{m=0}^{n-1} C_{n-1}^{m}\prod_{i=m+1}^{n}\frac{\delta}{\gamma_{SINR_{sr_i}}} C\left(\frac{1}{1+\frac{b}{\lambda_s}}\right)\prod_{i=1}^{n}\left(\frac{1}{1+\frac{b}{\lambda_{AF_i}}}\right) \\ & + C\left(\frac{1}{1+\frac{b}{\lambda_s}}\right)\prod_{i=1}^{n}\left(\frac{1}{1+\frac{b}{\lambda_{DF_i}}}\right) \end{aligned} \tag{40}$$

$$= \frac{C}{1+\frac{b}{\lambda_s}}\left[\begin{aligned} & \sum_{m=0}^{n-1} C_{n-1}^{m}\prod_{i=m+1}^{n}\frac{\delta}{\gamma_{SINR_{sr_i}}}\left(\frac{\lambda_{AF_i}}{\lambda_{AF_i}+b}\right)^{n} \\ & + \left(\frac{\lambda_{DF_i}}{\lambda_{DF_i}+b}\right)^{n} \end{aligned}\right] \tag{41}$$

where $C = \frac{1}{\pi}\int_0^{\frac{(M-1)\pi}{M}} \sin^{2n+2}\theta\, d\theta$.

5. Outage Probability Analysis

This is an important parameter of measurement that represents the probability that the maximum mutual information between the source and the destination fall below a certain threshold γ_{th}, i.e.,

$$P_{out} = \int_{0}^{\gamma_{th}} f_{SINR}(x)dx. \quad (42)$$

An exact closed-form expression for outage events for best relaying protocol can be obtained by substituting (12) and (24) into (42) as follows:

$$\begin{aligned} \mathrm{P_{out}} = & \sum_{m=0}^{n-1} C_{n-1}^{m} \prod_{\mathrm{i}=1}^{m} \mathrm{P_{rob}}\left(\gamma_{SINR_{sr_i}} \geq \varepsilon\right) \times \\ & \prod_{\mathrm{i}=m+1}^{n} \mathrm{P_{rob}}\left(\gamma_{SINR_{sr_i}} < \varepsilon\right) \times \left(\int_{0}^{\gamma_{th}} \frac{L}{y} \exp\left(-\frac{L}{y}x\right)dx\right)_{AF_i} \\ & + \prod_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{P_{rob}}\left(\gamma_{SINR_{sr_i}} \geq \varepsilon\right) \times \left(\int_{0}^{\gamma_{th}} \frac{L}{y} \exp\left(-\frac{L}{y}x\right)dx\right)_{DF_i}, \end{aligned} \quad (43)$$

$$\begin{aligned} \mathrm{P_{out}} = & \sum_{m=0}^{n-1} C_{n-1}^{m} \prod_{\mathrm{i}=m+1}^{n} \frac{\delta}{\gamma_{SINR_{sr_i}}} \times \left(\int_{0}^{\gamma_{th}} \frac{L}{y} \exp\left(-\frac{L}{y}x\right)dx\right)_{AF_i} \\ & + \prod_{\mathrm{i}=1}^{\mathrm{n}} \left(\int_{0}^{\gamma_{th}} \frac{L}{y} \exp\left(-\frac{L}{y}x\right)dx\right)_{DF_i}. \end{aligned} \quad (44)$$

6. Diversity Order

In this section, it is important to express the SER in terms of diversity gain to validate that our scheme attains full diversity. Diversity order is a significant parameter indicating the probability of error at high SNR it gave in [16] as follows:

$$\mathrm{d} = -\lim_{\mathrm{SNR}\to\infty} \frac{\log \mathrm{P_{SER}}}{\log \mathrm{SNR}}. \quad (45)$$

So, substituting (39) and (41) into (45) we can get the diversity order for upper and lower bound respectively as

$$\mathrm{d}_{\mathrm{P_{SER_{UP}}}} = -\lim_{\mathrm{SNR}\to\infty} \frac{\log\left(\begin{array}{c} \sum_{m=0}^{n-1} C_{n-1}^{m} \prod_{\mathrm{i}=m+1}^{\mathrm{n}} \frac{\delta}{\gamma_{SINR_{sr_i}}} \frac{\lambda_s}{\mathrm{b^{n+1}}} \prod_{\mathrm{i}=1}^{\mathrm{n}} \lambda_{\mathrm{AF_i}} \mathrm{C} \\ + \frac{\lambda_s}{\mathrm{b^{n+1}}} \prod_{\mathrm{i}=1}^{\mathrm{n}} \lambda_{\mathrm{DF_i}} \mathrm{C} \end{array}\right)}{\log \mathrm{P}} \quad (46)$$

$$= \frac{-(-n-1)\log P_s}{\log P} = n+1, \quad (47)$$

$$\mathrm{d}_{\mathrm{P_{SER_{LOW}}}} = -\lim_{\mathrm{SNR}\to\infty} \frac{\log\left(= \frac{C}{1+\frac{b}{\lambda_s}} \left[\begin{array}{c} \sum_{m=0}^{n-1} C_{n-1}^{m} \prod_{i=m+1}^{n} \frac{\delta}{\gamma_{SINR_{sr_i}}} \left(\frac{\lambda_{AF_i}}{\lambda_{AF_i}+b}\right)^n \\ + \left(\frac{\lambda_{DF_i}}{\lambda_{DF_i}+b}\right)^n \end{array}\right]\right)}{\log \mathrm{P}} \quad (48)$$

$$= -\frac{\log \lambda_s - n\log P_s}{\log P} = -\frac{-\log P_s - n\log P_s}{\log P} = n+1. \quad (49)$$

Therefore, our scheme achieves full diversity of order n+1 for both upper and lower bound for n relays, which means that the destination receives n+1 copies of signal from source. Thus, the probability of having all the signals being corrupted is very low according to the number of relays, this means our system performance with n relays to increase the performance by decreasing the probability of error, which shows also the good performances of our scheme compared to the one in [25] and [10] with single protocol.

Parameter	*Value*
Channel model	Rayleigh fading
Channel variance and power	Normalize as unity
Number of relays	1-10
Coding - modulation	(B,Q,16,32)PSK
The ratio between average SNR and INR (y)	30
Channel estimation	Perfect
Transmission target rate (r)	1

Tab. 1. Simulation Parameters.

7. Simulation Results

To validate the mathematical expression obtained in the previous sections, the simulation results were carried out following the system model in Section 2 and asset of parameters given in Tab. 1, using MATLAB. The curves of the analytical upper bound and lower bound were compared with the simulation curve and presented in Fig. 4, using (39), (41) and (33) respectively. It is mentioned that the analysis is done under BPSK modulation when the number of relays n and interferences L is 1. On the other hand, Fig. 5 shows the representation of SER by using QPSK modulation for the calculated Lower bound, and the simulation curves, compared with the best AF-DF protocol with no interference, when $n = L = 2$, and the ratio between average SNR and INR $y = 30$. Consequently, it can be observed that SINR measured by best AF-DF displays a visible gain over best AF-DF based on no interference. Meanwhile, the information is usually transferred via best relaying protocol selection path, applying AF-DF along with the direct path. Records dealing with the average SER versus SNR with MPSK using (33) for the different number of relays and interferences $(n = L = 1,2,3,4,10)$ when using BPSK, QPSK, and 32PSK modulation were shown in Fig. 6 and Fig. 7. Moreover, it can be noticed that when the number of relays increased the SER decreased significantly and the low SER values were obtained at high SNR. By using (44) the outage probability versus SNR with BPSK modulation results were obtained from the system model as shown in Fig. 8.

From all figures, we can observe as expected that the tightness of the simulation result with analytical in high SNR regime as in calculation analysis.

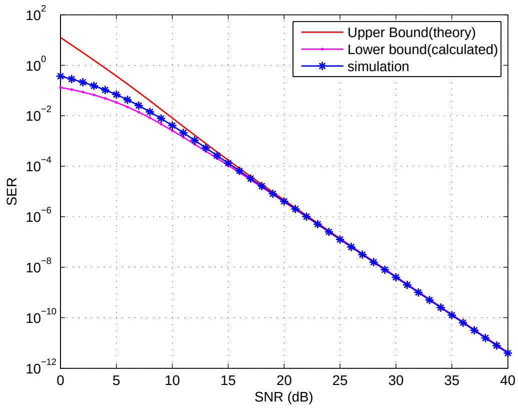

Fig. 4. Comparison of an upper bound and lower bound with simulation using QPSK signal for a one-relay system.

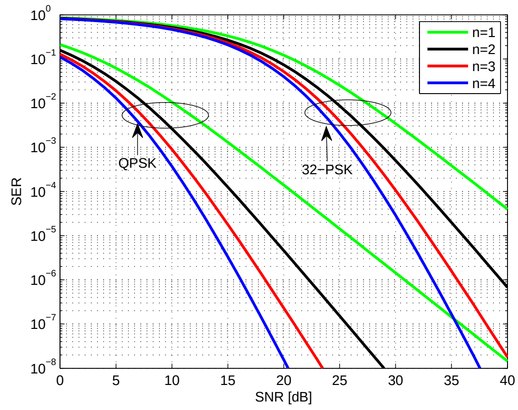

Fig. 7. SER versus SNR with (1, 2, 3 and 4) relays using QPSK and 32PSK modulation signals.

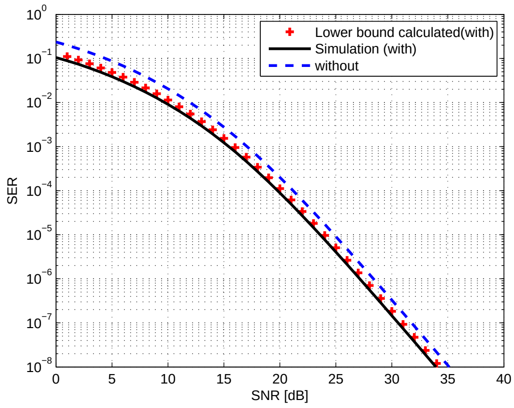

Fig. 5. Representation of SER using QPSK modulation for lower bound (calculated) and simulation curves compared with best AF-DF protocol with no interference.

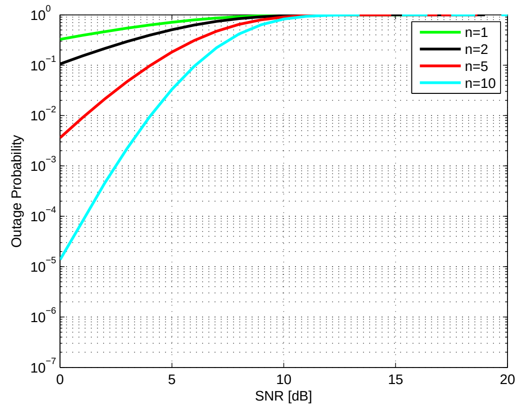

Fig. 8. Outage probability with BPSK signals .

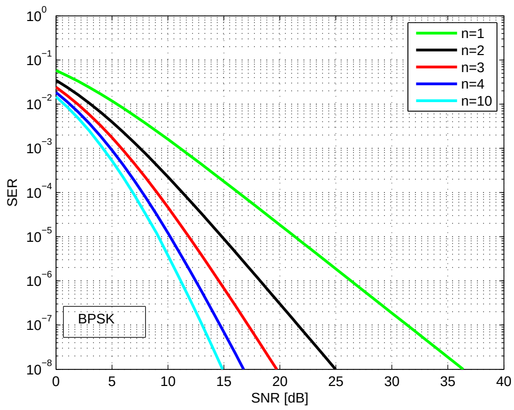

Fig. 6. Symbol error rate for BPSK signals.

8. Conclusion

In this work, we have presented the concept of combining the best protocol between AF and DF cooperative relaying in wireless communication systems with interference calculation at relay nodes, with mean channel gains over the Rayleigh fading channel in high SNR. After establishing the expressions for the SINR, the PDF, the CDF and the MGF of SINR for the system under study, an exact closed form for SER using MPSK signal in the system are obtained. Furthermore, we have found a tight SER upper and lower bound. We have shown that our selection protocol model maintains full diversity of order $(n+1)$ for both upper and lower bound with the different number of relays. Numerical results have been also given to validate the theoretical analysis and to show the advantage of using relaying protocol selection with interferences at relay nodes in wireless cooperative communication systems.

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