Cooperative Communications with Opportunistic Nonorthogonal Amplify-and-Forward Relaying

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***Abstract*—This paper proposes an opportunistic nonorthogonal amplify-and-forward (ONAF) scheme, assisted by intelligent relay selection. Through analysing the mutual information of the scheme, the novel optimal relay selection criterion is proposed along with its implementation strategy. In order to reduce the system complexity, a sub-optimal selection criterion is then provided. The diversity-multiplexing tradeoff (DMT) analysis shows that the proposed scheme can achieve a diversity gain of the order of the number of candidate relays, and a maximal multiplexing gain of 1. Since the previous work on opportunistic relaying were established under the orthogonal constraint, ONAF is one of the most advanced opportunistic relaying schemes. Our numerical results show the ONAF scheme can outperform the existing nonorthogonal and opportunistic relaying schemes where the relays forward the message using the amplify-and-forward (AF) mode. More importantly, it is a flexible cooperative scheme that can reduce network power consumption, alleviate interference caused among relays' re-transmissions and avoid the negative impact of the weak source-relay-destination channels.**

***Index Terms*—Cooperative communications, diversity-multiplexing tradeoff, nonorthogonal amplify-and-forward, opportunistic relaying, outage probability**

I. Introduction

Cooperative communication introduces spatial diversity through collaboration i.e., relaying between network users. Cooperative schemes include amplify-and-forward (AF) [1] [2] and decode-and-forward (DF) [2] [3] [4] [5] [6]. In fact, diversity gain can be further enhanced if user cooperation is performed in a distributed manner [7]. Distributed cooperative schemes [7] [8] [9] show that diversity gain can be enhanced by increasing the number of participating relays. The previously mentioned cooperative schemes were established upon the use of the orthogonal time slot (TS) constraint between the broadcasting transmission and the relaying transmission. Nabar *et al.* [10] proposed a nonorthogonal AF (NAF) scheme by allowing the signal source continue to broadcast during the relaying TS. Azarian *et al.* [11] later extended the NAF scheme to be engaged with more than one relay and showed it can achieve a better diversity-multiplexing tradeoff (DMT) [12] performance than orthogonal cooperative schemes [2] [7].

However, due to the re-transmission by multiple relays, distributed diversity gain is created at the expense of higher system complexity and power consumption. Bletsas *et al.* [13] showed that assisted by intelligent relay selection (also known as opportunistic relaying), always cooperating with the relay that can provide the best source-relay-destination (or end-to-end) channel can also achieve the same diversity gain as the schemes of [7]. Opportunistic relaying can reduce the network power consumption, alleviate network interference and avoid the negative impact of the weak end-to-end channels. Essentially, it is a more flexible cooperation strategy for future wireless networks. The opportunistic AF (OAF) and opportunistic DF (ODF) relaying schemes were presented in [13] - [17].

However, since most of the existing opportunistic cooperation schemes employ the orthogonal constraint, they limit the potentials of the cooperative systems to explore the transmission resources and so enhance the outage performance. Addressing this issue, the first opportunistic nonorthogonal relaying scheme was introduced by the authors in [19], where the opportunistic nonorthogonal amplify-and-forward (ONAF) scheme was proposed. Building upon the work of [19], this paper presents a more comprehensive analysis and discussion of the ONAF relaying scheme. By analysing the scheme's mutual information, an optimal relay selection criterion is now proposed. It can outperform the existing relay selection approach that is referred to as the sub-optimal criterion in this paper. Based on their computational complexity, different implementation strategies are proposed for the cooperative network using these two selection criteria. Our DMT analysis shows that the ONAF scheme is able to achieve a diversity gain of the order of the number of candidate relays and a maximal multiplexing gain of 1. The numerical results on outage probability validate the analysis. It is shown the ONAF scheme can outperform the AF scheme of [2], the NAF scheme of [11] and the OAF scheme of [13]. The newly proposed optimal relay selection criterion outperforms the sub-optimal one. We also reveal that compared to the NAF scheme of [11], the ONAF scheme is able to maintain stable performance gains in a multiple relay network.

II. System Model and Parameterisation

This section presents the system model of the ONAF scheme and defines the commonly used parameters.

The cooperative network consists of a source node (S) and a destination node (D). There is a set $S_r = \{1, 2, ..., n\}$ of n relay nodes willing to re-transmit S's message using the AF mode [1] [2]. It is assumed that all the nodes transmit with equal energy ε which is normalised as $\varepsilon = 1$. Consequently, the channel signal-to-noise ratio (SNR) is given by:

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$$\rho = \sigma^{-2}, \tag{1}$$

where σ^2 denotes the variance of noise observed at the receiver. For simplicity, it is assumed that all the channels exhibit a similar value of ρ. All users operate with the half-duplex constraint, and employ the same error-correction code and modulation scheme. A complete ONAF cooperation consists of two TS: TS-1 for S to broadcast its message and one (or all) of the relays to listen; TS-2 for one of the relays to retransmit S's message and at the same time S continues to broadcast. The opportunistic relaying can be performed via either a proactive mode in which prior to S's transmission, one of the relays k ($k \in S_r$) is chosen to participate into the cooperation process [14], or a reactive mode in which relay selection is carried out among the relays after TS-1 [13] [14]. The cooperation procedure is indicated in Fig.1.

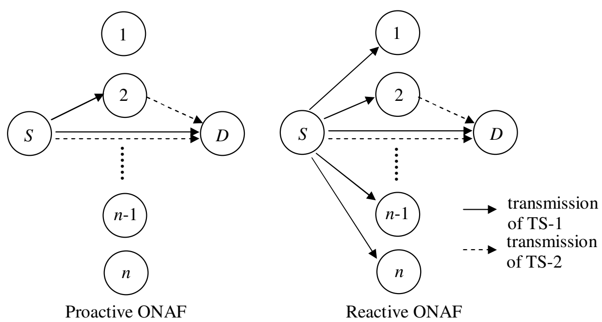

Fig. 1. Opportunistic cooperation modes of ONAF scheme

In TS-1, the received signals at D and relay k are:

$$y_D[i] = \alpha_{SD} x_S[i] + n_D[i], i = 1, 2, ..., l/2, \tag{2}$$

$$y_k[i] = \alpha_{Sk} x_S[i] + n_k[i], i = 1, 2, ..., l/2, \tag{3}$$

where x_S is S's transmitted message and l is an even number denoting the length of transmitted symbols. n_D and n_k denote the additive white Gaussian noise (AWGN) observed at D and relay k. They are modelled as zero-mean, mutually independent complex random sequences with variances σ_D^2 and σ_k^2 respectively. In TS-2, the received signal at D is:

$$y_D[i] = \alpha_{SD} x_S[i] + \alpha_{kD} x_k[i] + n_D[i], i = l/2+1, l/2+2, ..., l, \tag{4}$$

where x_k is an amplified and delayed version of signal y_k:

$$x_k[i] = \beta_k y_k[i - l/2], i = l/2+1, l/2+2, ..., l, \tag{5}$$

and the amplification gain β_k is defined as [1] [2]:

$$\beta_k \le (|\alpha_{Sk}|^2 + \sigma_k^2)^{-\frac{1}{2}}. \tag{6}$$

In these equations, α_{AB} denotes the complex Rayleigh fading coefficient of the channel between nodes A and B. All the channels of the network are statistically independent and exhibit Quasi-Static fading. The average squared channel gain is defined as:

$$\Omega_{AB} = \mathbb{E}\{|\alpha_{AB}|^2\}, \tag{7}$$

which is used to represent the channel *quality* of the network. δ_{AB} denotes the exponential order of $|\alpha_{AB}|^2$ as:

$$\delta_{AB} = -\lim_{\rho\to\infty} \frac{\log|\alpha_{AB}|^2}{\log\rho}. \tag{8}$$

The base of the logarithm is 2 and $|\alpha_{AB}|^2$ can be equivalently denoted as: $|\alpha_{AB}|^2 \doteq \rho^{-\delta_{AB}}$. Note that $\dot{\le}$ is defined similarly. $|\alpha_{AB}|^2$ follows a chi-square distribution giving [13]:

$$\Pr[|\alpha_{AB}|^2 \le \rho^{-v}] = 1 - e^{-\frac{1}{2}\rho^{-v}} \doteq \rho^{-v}, \tag{9}$$

where v is a nonnegative real value.

Definition I: Consider a family of codes C_ρ indexed by the operating SNR, achieving an outage probability of $P_O(\rho)$ and an average transmission rate of $R(\rho)$ bits/s/Hz. The diversity gain d and multiplexing gain r are defined as [12]:

$$d = -\lim_{\rho\to\infty} \frac{\log P_O(\rho)}{\log\rho}, r = \lim_{\rho\to\infty} \frac{R(\rho)}{\log\rho}. \tag{10}$$

The derived relationship between d and r is called the diversity-multiplexing tradeoff, denoted as $d(r)$. The outage probability can therefore be expressed as: $P_O \dot{\le} \rho^{-d(r)}$.

III. Opportunistic Relay Selection

This section analyses the mutual information of the ONAF scheme, followed by proposals for optimal and sub-optimal relay selection criteria and their implementation strategies.

The equivalent channel model of equations (2)-(6) can be written in a matrix form as:

$$\begin{bmatrix} y_D[i] \\ y_D[i+l/2] \end{bmatrix} = \underbrace{\begin{bmatrix} \alpha_{SD} & 0 \\ \alpha_{kD}\beta_k\alpha_{Sk} & \alpha_{SD} \end{bmatrix}}_{G_k} \begin{bmatrix} x_S[i] \\ x_S[i+l/2] \end{bmatrix} + \underbrace{\begin{bmatrix} 1 & 0 & 0 \\ 0 & \beta_k\alpha_{kD} & 1 \end{bmatrix}}_{\Upsilon_k} \underbrace{\begin{bmatrix} n_D[i] \\ n_k[i] \\ n_D[i+l/2] \end{bmatrix}}_{N_k}$$

where i = 1, 2, ... $l/2$. Assisted by intelligent relay selection, the selected relay shall maximise the ONAF scheme's mutual information which is determined by:

$$\mathcal{I} = \max_{k\in S_r} \frac{1}{2}\log\det[\mathbf{I}_2 + G_k G_k^\dagger(\Upsilon_k \mathbb{E}\{N_k N_k^\dagger\}\Upsilon_k^\dagger)^{-1}], \tag{11}$$

where $\mathbf{I}_2$ denotes the 2×2 identity matrix. $M^\dagger$ and M^{-1} denotes the Hermitian conjugate and inverse of matrix M. It can be shown that

$$G_k G_k^\dagger = \begin{bmatrix} |\alpha_{SD}|^2 & \alpha_{SD}\alpha_{kD}^*\alpha_{Sk}^*\beta_k \\ \alpha_{SD}^*\alpha_{kD}\alpha_{Sk}\beta_k & |\alpha_{kD}|^2|\alpha_{Sk}|^2\beta_k^2 + |\alpha_{SD}|^2 \end{bmatrix},$$

$$\Upsilon_k \mathbb{E}\{N_k N_k^\dagger\}\Upsilon_k^\dagger = \begin{bmatrix} \sigma_D^2 & 0 \\ 0 & \sigma_D^2 + |\alpha_{kD}|^2\beta_k^2\sigma_k^2 \end{bmatrix}.$$

Since it is assumed that $\sigma_D^{-2} = \sigma_k^{-2} = \rho$, the mutual information of the ONAF scheme can be determined as:

$$\begin{aligned}\mathcal{I} &= \max_{k\in S_r}\frac{1}{2}\log[1+|\alpha_{SD}|^2\rho+\frac{|\alpha_{SD}|^4\rho^2}{1+|\alpha_{kD}|^2\beta_k^2}+\\&\quad\frac{(|\alpha_{SD}|^2+|\alpha_{Sk}|^2|\alpha_{kD}|^2\beta_k^2)\rho}{1+|\alpha_{kD}|^2\beta_k^2}]. \qquad (12)\end{aligned}$$

A. Optimal Relay Selection

The optimal relay selection criterion is designed by maximising the mutual information defined by equation (12), which will consequently minimise the outage probability of the scheme. With β_k satisfying the equality of (6) and substituting it into equation (12), then:

$$\mathcal{I} = \max_{k\in S_r}\frac{1}{2}\log[1+|\alpha_{SD}|^2\rho+W_k^{\text{opt}}], \qquad (13)$$

where

$$W_k^{\text{opt}} = \frac{|\alpha_{Sk}|^2|\alpha_{kD}|^2\rho^2+(|\alpha_{Sk}|^2\rho+1)(|\alpha_{SD}|^2\rho+|\alpha_{SD}|^4\rho^2)}{|\alpha_{Sk}|^2\rho+|\alpha_{kD}|^2\rho+1}. \qquad (14)$$

The selected *best* relay b shall maximise W_k^{opt} as:

$$b = \arg\max_{k\in S_r} W_k^{\text{opt}}. \qquad (15)$$

Based on equation (14), it can be noticed that the optimal relay selection requires the global knowledge of the network CSI. It is complex for the relays to coordinate the selection process since large overheads are consumed on network information exchange and computation. Therefore, it is more suitable to be implemented in a proactive mode. Node S shall obtain the CSI of the network through the feedback from relays and D prior to its broadcast. It selects the *best* relay according to criterion of (14)-(15). Before cooperation, a special pilot symbol will be broadcast to activate the selected relay and notify the others to keep silent.

B. Sub-optimal Relay Selection

In order to reduce the CSI exchange overheads, it is desirable that relays can coordinate with themselves and decide which one will participate for signal re-transmission. Since each relay k is capable of obtaining the local CSI i.e., α_{Sk} and α_{kD} through the ready-to-send (RTS) package from S and the clear-to-send (CTS) package from D respectively, relays can coordinate among themselves based on the following relay selection criterion as in [13] [18] [19]:

$$W_k^{\text{sub-opt}} = \min\{|\alpha_{Sk}|^2, |\alpha_{kD}|^2\}. \qquad (16)$$

The relay that can maximise $W_k^{\text{sub-opt}}$ is considered as being able to provide the best end-to-end channel between the S and D nodes. Therefore, the *best* relay can be chosen by:

$$b = \arg\max_{k\in S_r} W_k^{\text{sub-opt}}. \qquad (17)$$

Compared to the optimal relay selection criterion, the sub-optimal relay selection criterion of (16)-(17) only requires the local CSI of each individual relay node, considerably simplifying the determination of the *best* relay. Therefore, it can be implemented in a reactive manner. Each relay will start its own timer with an initial value T_k that is inversely proportional to $W_k^{\text{sub-opt}}$. The *best* relay will have its timer counted down to zero first and will re-transmit S's information. Before its re-transmission, node b will send out a special pilot symbol to notify the other relays to remain idle.

IV. Diversity-Multiplexing Tradeoff

In this section, the DMT performance of the ONAF scheme will be characterised.

The outage probability is determined by the probability of mutual information $\mathcal{I}$ falls below the transmission rate $R(\rho)$:

$$P_O = \Pr[\mathcal{I} \le R(\rho)]. \qquad (18)$$

Based upon *Definition I*, it is known that when $\rho \to \infty$, $R(\rho) = r\log\rho$. According to equation (12), if b is the chosen relay, the outage probability of the ONAF scheme can be determined as:

$$\begin{aligned}P_O &= \Pr[1+|\alpha_{SD}|^2\rho+\frac{|\alpha_{SD}|^2\rho}{1+|\alpha_{bD}|^2\beta_b^2}+\\&\quad\frac{|\alpha_{SD}|^4\rho^2}{1+|\alpha_{bD}|^2\beta_b^2}+\frac{|\alpha_{Sb}|^2|\alpha_{bD}|^2\beta_b^2\rho}{1+|\alpha_{bD}|^2\beta_b^2}\le\rho^{2r}]. \qquad (19)\end{aligned}$$

Since β_b^2 is a function of $|\alpha_{Sb}|^2$, it is also associated with an exponential order δ_{β_b} such that $\beta_b^2 \doteq \rho^{-\delta_{\beta_b}}$. Assuming that δ_{bD} and δ_{β_b} are positive real values, we have

$$1+|\alpha_{bD}|^2\beta_b^2 \doteq 1+\rho^{-(\delta_{bD}+\delta_{\beta_b})} \doteq 1.$$

With β_b satisfying the equality of (6),

$$\frac{|\alpha_{Sb}|^2|\alpha_{bD}|^2\beta_b^2\rho}{1+|\alpha_{bD}|^2\beta_b^2} = f(|\alpha_{Sb}|^2\rho, |\alpha_{bD}|^2\rho),$$

where $f(\varrho,\tau) = \frac{\varrho\tau}{\varrho+\tau+1}$, ϱ and τ are random variables. Therefore, equation (19) can be further manipulated as:

$$\begin{aligned}P_O &\doteq \Pr[1+2|\alpha_{SD}|^2\rho+|\alpha_{SD}|^4\rho^2+\\&\quad f(|\alpha_{Sb}|^2\rho,|\alpha_{bD}|^2\rho)\le\rho^{2r}]\\&= \Pr[(1+|\alpha_{SD}|^2\rho)^2+f(|\alpha_{Sb}|^2\rho,|\alpha_{bD}|^2\rho)\le\rho^{2r}]\\&\le \Pr[(1+|\alpha_{SD}|^2\rho)^2\le\rho^{2r}]\times\\&\quad \Pr[f(|\alpha_{Sb}|^2\rho,|\alpha_{bD}|^2\rho)\le\rho^{2r}]. \qquad (20)\end{aligned}$$

Based on equation (9), we have:

$$\begin{aligned}\Pr[(1+|\alpha_{SD}|^2\rho)^2\le\rho^{2r}] &= \Pr[1+|\alpha_{SD}|^2\rho\le\rho^r]\\&\dot{\le} \Pr[|\alpha_{SD}|^2\le\rho^{-(1-r)}]\\&\doteq \rho^{-(1-r)}. \qquad (21)\end{aligned}$$

According to Lemma 4 of [13], we have:

$$\begin{aligned}&\Pr[f(|\alpha_{Sb}|^2\rho,|\alpha_{bD}|^2\rho)\le\rho^{2r}]\\&\quad\le \Pr[\min\{|\alpha_{Sb}|^2,|\alpha_{bD}|^2\}\le\rho^{2r-1}+\rho^{r-1}\sqrt{1+\rho^{2r}}]\\&\quad\doteq \Pr[\min\{|\alpha_{Sb}|^2,|\alpha_{bD}|^2\}\le\rho^{-(1-2r)^+}]. \qquad (22)\end{aligned}$$

In these equations, $r \in (0,1)$ and $(\varrho)^+ = \max\{0,\varrho\}$. Since $(|\alpha_{Sb}|^2, |\alpha_{bD}|^2)$ can be seen as a pair of squared channel gains chosen from $\min\{|\alpha_{Sb}|^2, |\alpha_{bD}|^2\} = \max\{\min\{|\alpha_{Sk}|^2, |\alpha_{kD}|^2\}\}$ and $k \in S_r$ by the sub-optimal relay selection criterion,

$$\Pr[\min\{|\alpha_{Sb}|^2, |\alpha_{bD}|^2\} \leq \rho^{-(1-2r)^+}] = \prod_{k=1}^{n} \Pr[\min\{|\alpha_{Sk}|^2, |\alpha_{kD}|^2\} \leq \rho^{-(1-2r)^+}]. \quad (23)$$

Again, based on equation (9), it can be realised that

$$\Pr[\min\{|\alpha_{Sk}|^2, |\alpha_{kD}|^2\} \leq \rho^{-(1-2r)^+}] \doteq \rho^{-(1-2r)^+}, \quad (24)$$

then

$$\begin{aligned} &\Pr[f(|\alpha_{Sb}|^2\rho, |\alpha_{bD}|^2\rho) \leq \rho^{2r}] \\ &\dot{\leq} \quad \Pr[\min\{|\alpha_{Sb}|^2, |\alpha_{bD}|^2\} \leq \rho^{-(1-2r)^+}] \\ &\doteq \quad \rho^{-n(1-2r)^+}. \end{aligned} \quad (25)$$

By substituting equations (21) and (25) into equation (20), it can be derived that:

$$P_O \dot{\leq} \rho^{-[(1-r)+n(1-2r)^+]}. \quad (26)$$

Therefore, the ONAF scheme yields a DMT performance of:

$$d(r) = (1-r) + n(1-2r)^+. \quad (27)$$

It can achieve a maximal diversity gain of $n+1$ and a maximal multiplexing gain of 1, which is the same as the NAF scheme [11]. It is superior to the existing opportunistic relaying schemes [13] - [17] whose DMT performance is $d(r) = (n+1)(1-2r)^+$. Their achievable multiplexing gain is limited to 0.5. The following section will substantiate the theoretical analysis by presenting the numerical results of the scheme's outage probability in various network scenarios.

V. Numerical Results

This section presents the numerical results of outage probability for the ONAF scheme. It is compared with other schemes assisted by AF relaying, including the AF scheme of [2], the NAF scheme of [11] and the OAF scheme of [13]. All the schemes have the same number of relays n and $n = |S_r|$. In our analytical model, the quality (average squared channel gain) of $S-D$ channel is $\Omega_{SD} = 2.0$. The $S-k$ and $k-D$ channels (or the end-to-end channel) associated with relay k are set to exhibit similar quality, such that $\Omega_{Sk} = \Omega_{kD}$. For simplicity, they are denoted as Ω_k. The cooperative network is further classified into the symmetric network and the asymmetric network. In the symmetric network, all the end-to-end channels exhibit a similar quality, such that $\Omega_k = \Omega_q$ for $(k,q) \in S_r$ and $k \neq q$. In the asymmetric network, the end-to-end channels exhibit different qualities, such that $\Omega_k \neq \Omega_q$. Since the theoretical framework is elaborated with the assumption that all channels exhibit Quasi-Static fading, the following results are also obtained under the Quasi-Static fading channels in which gaining transmission diversity is critical.

Fig.2 shows the performance of the ONAF scheme with transmission rates of 1 bits/s/Hz and 4 bits/s/Hz. It can be observed that the ONAF scheme outperforms all the other cooperative schemes, validating the DMT analysis shown in Section IV. The performance gain of the ONAF scheme is greater for a system with a high transmission rate. For example, when $R(\rho) = 4$ bits/s/Hz, a 2.5dB performance gain can be achieved over the NAF scheme at an outage probability of 10^{-5}. Compared to the AF scheme, the performance advantage of the ONAF scheme is due to it embraces both nonorthogonal transmission and opportunistic relay selection. Specifically, they enable the ONAF scheme to outperform the OAF scheme and the NAF scheme respectively. Compared with the NAF scheme, it is shown that opportunistic relay selection plays an important role in system performance. For the OAF scheme, relay selection is performed according to the sub-optimal criterion mentioned in Section III. Concerning the importance of nonorthogonal transmission and opportunistic relay selection, our results reveal that nonorthogonal transmission outweighs opportunistic relay selection in a high transmission rate system. It can be seen that the NAF scheme starts to outperform the OAF scheme when $R(\rho) = 4$ bits/s/Hz. Furthermore, the newly proposed optimal relay selection criterion outperforms the sub-optimal criterion. Its improvement is greater for a system with a higher transmission rate.

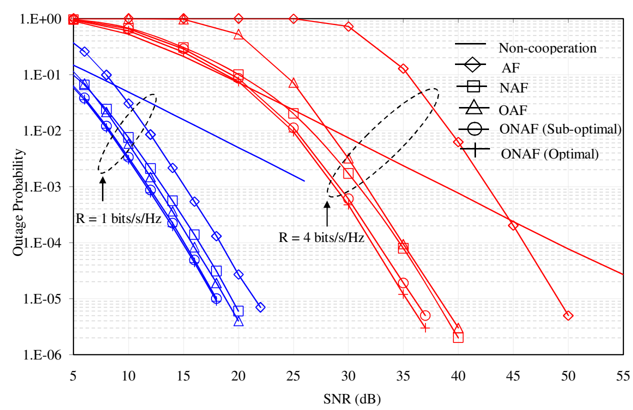

Fig. 2. Outage probability performance of ONAF scheme with 2 relays, $R(\rho)$ = 1 or 4 bits/s/Hz

Figs.3 and 4 compare the performance of the ONAF scheme and the NAF scheme with different number of relays in a symmetric network and an asymmetric network respectively. In the symmetric network, $\Omega_k = 2.0$ for $k = 1$ to 5. In the asymmetric network, $\{\Omega_1, \Omega_2, \Omega_3, \Omega_4, \Omega_5\} = \{2.0, 1.0, 0.7, 0.5, 0.3\}$. It can be noticed that by increasing the number of relays, the ONAF scheme can achieve more significant performance gains over the NAF scheme. For example, at an outage probability of 10^{-5}, the achievable performance gain with $n = 4$ is 3.3dB compared to 1.5dB with $n = 2$. It can also be noticed that in the asymmetric network, the NAF scheme loses performance by increasing the number of relays in the low SNR region. This is because the NAF scheme is engaged with multiple relays constantly and cannot avoid the negative impact of the weak end-to-end channels, i.e., $\Omega_3, \Omega_4, \Omega_5$. However, the ONAF scheme can avoid this drawback by always choosing the *best* relay for signal re-transmission. Again, the optimal relay selection criterion outperforms the sub-optimal one.

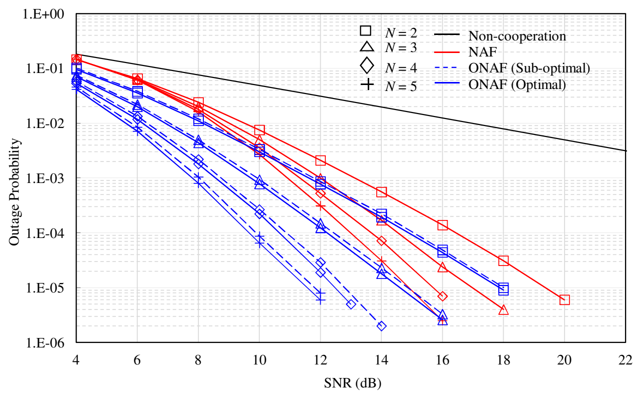

Fig. 3. Outage probability performance of ONAF scheme over the symmetric network with 2 - 5 relays, $R(\rho) = 1$ bits/s/Hz

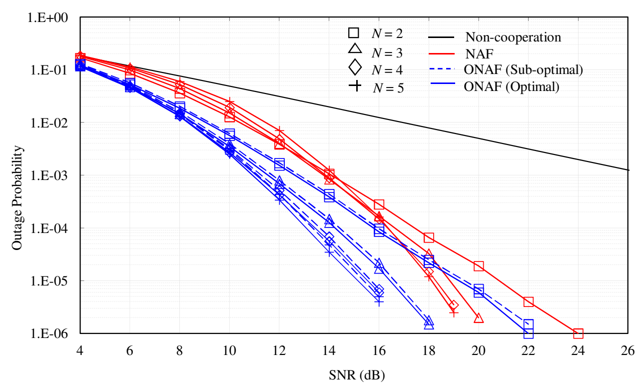

Fig. 4. Outage probability performance of ONAF scheme over the asymmetric network with 2 - 5 relays, $R(\rho) = 1$ bits/s/Hz

VI. Conclusions

This paper has proposed an opportunistic nonorthogonal relaying scheme in which the relay forwards the message using the AF mode. It embraces two important features that provide a superior performance for a cooperative system: nonorthogonal transmission and opportunistic relay selection. The optimal and sub-optimal relay selection criteria were proposed along with their implementation strategies. Since the optimal relay selection requires the global CSI, it is suitable for implementation in a proactive manner in which S coordinates the relay selection process. The sub-optimal relay selection requires only the local CSI and therefore is more suitable for implementation in a reactive manner in which relays coordinate the selection. The DMT analysis of the proposed scheme shows that it can achieve a DMT performance that is superior to most of the current opportunistic relaying schemes. Our numerical results show that the ONAF scheme can substantially outperform the existing AF type cooperative schemes, especially in a system with a high transmission rate. Therefore, the proposed scheme is a flexible and well-performing cooperation strategy that is suitable for adoption in future wireless communication systems.

Acknowledgement

This work is supported by the National Basic Research Program of China (973 Program) with project ID 2012CB316100, the National Natural Science Foundation of China (NSFC) with project ID 61001094 and the Guangdong Natural Science Foundation (GDNSF) with project ID 10451027501005078.

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