Opportunistic Nonorthogonal Cooperative Communications Through Decode-and-Forward Relaying

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***Abstract*—Cooperative Communication is a wireless communication scheme, which gains signal transmission diversity through user cooperation. In cooperative communications, the existing relaying strategies include amplify-and-forward (AF) and decode-and-forward (DF). Moreover, cooperative communications through opportunistic relay selection and nonorthogonal signal transmission can further improve the system performance. In order to improve the cooperative outage probability performance, this paper proposes an advanced scheme called the opportunistic nonorthogonal DF (ONDF) scheme. It integrates the advanced cooperative features of opportunistic relaying and nonorthogonal transmission. The system model of the ONDF scheme is presented, based on which the scheme's outage probability is analyzed. The relay selection criterion is then proposed. By analyzing the diversity-multiplexing tradeoff (DMT) performance of the proposed scheme, it is shown that the ONDF scheme has a superior DMT characteristics compared to the existing cooperative schemes. Finally, the outage probability performance of the scheme is obtained to validate the DMT analysis, showing sizeable performance gain over the existing schemes.**

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

I. Introduction

In wireless communications, by applying several relays to retransmit the signal to the intended destination, cooperative communication is an effective way to improve the system performance. In general, system diversity gain can be improved by increasing the number of participating relays. The earliest work of practical cooperative schemes include amplify-and-forward (AF) [1][2] and decode-and-forward (DF) [3][4][5]. In [1]-[5], the cooperative network includes one relay. Later, more relays were introduced into the system, resulting in distributed cooperation [6][7]. It is proved that distributed cooperation inherits more diversity gains compared to the single relay system.

However, distributed cooperation is at the cost of spectrum efficiency and the usage of transmission freedom. Those issues can be solved by opportunistic relaying [8] and nonorthogonal transmission [9][10], respectively. Under the opportunistic cooperation, the relay that has the best channel quality will be selected to retransmit the signal. It has been shown that opportunistic cooperation can effectively reduce the system energy consumption and gain a diversity on the order of number of candidate relays. Performance analysis of opportunistic relaying over the Rayleigh fading channels was proposed in [11] without considering the use of channel codes. Closed form expressions in terms of the opportunistic relaying schemes' outage probability and bit error probability were derived and they are validated by simulations. On the other hand, nonorthogonal transmission allows the source and relays to transmit simultaneously in orthogonal frequency. It leads to an enhancement of the transmission rate, boosting the usage of transmission freedom for the source. More spectrally efficient opportunistic relaying can be further realized by limiting the feedback load as proposed in [12], in which opportunistic orthogonal relaying with the direct link between source and destination and opportunistic nonorthogonal relaying without the direct link between source and destination were proposed. It is considered as one of the earlier attempts to exploit the nonorthogonality in opportunistic relaying, resulting in a better multiplexing gain for the cooperative system.

Another integration of nonorthogonal transmission and opportunistic relaying was proposed by Chen $et\ al.$ with a so called opportunistic nonorthogonal amplify-and-forward (ONAF) scheme [13][14]. It has been shown that the ONAF scheme has a better system performance than other schemes, including the AF, DF and opportunistic AF (OAF) [8] schemes. However, the ONAF scheme is still prone to the noise interference of the source-relay channel, preventing the performance potential of an opportunistic nonorthogonal cooperative scheme being fully exploited.

In order to fully exploit the advantages of opportunistic nonorthogonal relaying, this paper proposes the opportunistic nonorthogonal decode-and-forward (ONDF) scheme. This paper will first propose the baseband signal model of the ONDF scheme. Based on the signal model, the mutual information of the scheme is determined. With the knowledge of the mutual information, the outage probability of the proposed scheme is further analyzed, leading to a conclusion of the relay selection criterion. Then, we derive the diversity-multiplexing tradeoff (DMT) performance of the ONDF scheme. It shows the scheme can have a DMT with a maximal diversity gain on the order of number of candidate relays and a maximal multiplexing gain of one. It is the same as the ONAF scheme, but superior to the other existing cooperative schemes, e.g., the AF, DF and opportunistic DF (ODF) schemes. The performance

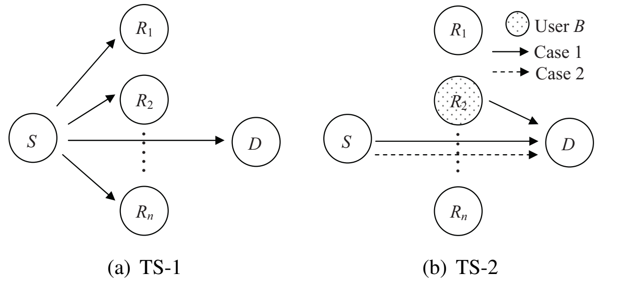

Fig. 1. The cooperative procedure of the ONDF scheme.

advantage of the ONDF scheme over the other cooperative schemes is further validated by our Monte-Carlo simulation. It is shown that the ONDF scheme achieves sizable performance gains over the other cooperative schemes.

The rest of the paper is organized as follows. Section II presents the baseband signal model of the ONDF scheme. Section III analyzes the scheme's outage probability as well as its relay selection strategy. Section IV analyzes the scheme's DMT performance and shows its superiority compared to the other DF relaying schemes. The scheme's outage performance is evaluated and discussed in Section V. Finally, Section VI concludes the paper.

II. Baseband Signal Model

In this paper, it is assumed that all the users operate in a half-duplex mode. The cooperative network consists of three parts: source (S), destination (D) and a number of relays (R). All the users in the system employ the same error-correction code and modulation scheme. Set $S_r = \{R_1, R_2, \cdots R_n\}$ denotes the n relays which are willing to retransmit the signal of S using the DF strategy. Meanwhile, set $S_e = \{R_1, R_2, \cdots R_m\}$ denotes a set of relays which can decode the message of S. Hence, $m \leq n$ and $S_e \subseteq S_r$.

In this paper, a complete ONDF process is divided into two orthogonal time slots (TS), TS-1 and TS-2, which have equal duration. The ONDF cooperation process is illustrated by Fig.1. In TS-1, S broadcasts its signal to D and all the relays. The received signal at D and relay R_k ($R_k \in S_r$) is:

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

$$y_{R_k}[i] = \alpha_{SR_k} x_S[i] + n_{R_k}[i], \tag{2}$$

where $i = 1, 2, \cdot, l/2$ and l equals to the total length of S's transmitted symbols x_S during the two TSs. In this paper, α_{AB} denotes the complex Rayleigh fading coefficient of the channel between nodes A and B. n_A denotes additive white Gaussian noise (AWGN) observed at node A. It is a zero-mean, mutually independent complex random variable with variance ${\sigma_A}^2$. For simplicity, it is assumed that ${\sigma_A}^2 = \sigma^2$ for all the nodes. All the users in the network share the same normalized transmit power $\varepsilon = 1$. Thus, the channel signal-to-noise ratio (SNR) is given by:

$$\rho = \frac{\varepsilon}{\sigma^2} = \sigma^{-2}. \tag{3}$$

Since the noise variances of all nodes are σ^2, it can be seen that all the channels exhibit a similar SNR.

With the received signal y_{R_k}, each relay will try to decode the message of S. After the decoding, they will send an acknowledgement (ACK) packet to S. The ACK packet contains two types of information, the relay's decoding status indicating whether the relay can decode the message of S or not. This would assist S to form the knowledge of the retransmission set S_e. The ACK packet also contains the channel state information (CSI) of each relay's uplink channel, i.e., the relay-destination channel. This would assist S to select the best relay, denoted as B, from the set S_e. The relay selection criterion will later be proposed in Section III. After the selection is made, S will send an activation (ACT) packet that contains the identity of the selected relay B to all the relays and D. It activates B and notifies others to keep silent in TS-2. It also gives D the knowledge of TS-2 transmission. In TS-2, there are two possible cases.

(1) Case 1: there is at least one relay decodes the message of S, i.e., $S_e \neq \emptyset$. In such a case, perfect estimation of x_S is obtained at the relay. The selected relay B will retransmit x_S to D, and S will continue its broadcasting. The received signal at D is:

$$y_D[i] = \alpha_{SD} x_S[i] + \alpha_{BD} x_S[i - l/2] + n_D[i], \tag{4}$$

where $i = l/2 + 1, l/2 + 2, \ldots, l$.

(2) Case 2: no relay can decode the message of S, i.e., $S_e = \emptyset$. In such a case, S will retransmit its signal in order to secure a reliable transmission of its message. Hence, the received signal at D is:

$$y_D[i] = \alpha_{SD} x_S[i - l/2] + n_D[i], \tag{5}$$

where $i = l/2 + 1, l/2 + 2, \ldots, l$. Notice that since S and B are transmitting using orthogonal frequency, D will be able to distinguish the signal from S and B during TS-2.

It is important to emphasize that in the ONDF scheme, S coordinates the relay selection after TS-1. Such an assumption is made under practical considerations. It is understood that there is another strategy that allows relays to coordinate the selection process by using the synchronized timer [8][14]. However, it raises challenging issues on timer synchronization and propagation delay of the coordination signal. Hence, the proposed relay selection method is more approachable. Since both the ACK and ACT packets contain only a few bits, the proposed relay selection process will only cause a marginal delay and a small transmission resources. Hence, the relay selection would not affect the cooperation efficiency.

III. Outage Probability Analysis

This section analyzes the mutual information of the ONDF scheme, based on which the outage probability will be derived. Moreover, the relay selection strategy will be proposed.

A. Mutual Information

The outage event happens when mutual information ζ falls below the transmission rate $R(\rho)$ which can be seen as a function of ρ:

$$\zeta \leq R(\rho). \quad (6)$$

Now, the mutual information of the ONDF scheme in Case 1 and Case 2 will be analyzed, respectively.

In Case 1, the equivalent signal model of equations (1) - (4) can be written in a matrix form as:

$$\begin{bmatrix} y_D[i] \\ y_D[i+l/2] \end{bmatrix} = \underbrace{\begin{bmatrix} \alpha_{SD} & 0 \\ \alpha_{BD} & \alpha_{SD} \end{bmatrix}}_{G} \begin{bmatrix} x_S[i] \\ x_S[i+l/2] \end{bmatrix} + \underbrace{\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}}_{\Gamma} \underbrace{\begin{bmatrix} n_D[i] \\ n_D[i+l/2] \end{bmatrix}}_{N}, \quad (7)$$

where $i = 1, 2, \cdots, l/2$.

The mutual information of the ONDF scheme in Case 1 is determined by [2]:

$$\zeta = \frac{1}{2}\log_2 \det \left[\mathrm{I}_2 + GG^\dagger \left(\Gamma \mathbb{E}\left\{ NN^\dagger \right\} \Gamma^\dagger \right)^{-1} \right], \quad (8)$$

where I_2 is the 2×2 identity matrix. $\mathrm{M}^\dagger$ and M^{-1} is the Hermitian conjugate and inverse of matrix M, respectively, and det(M) denotes the determinant of matrix M. Since

$$GG^\dagger = \begin{bmatrix} |\alpha_{SD}|^2 & \alpha_{SD}\alpha_{BD}^* \\ \alpha_{SD}^*\alpha_{BD} & |\alpha_{SD}|^2 + |\alpha_{BD}|^2 \end{bmatrix}, \quad (9)$$

$$\left(\Gamma \mathbb{E}\left\{ NN^\dagger \right\} \Gamma^\dagger \right)^{-1} = \begin{bmatrix} \rho & 0 \\ 0 & \rho \end{bmatrix}, \quad (10)$$

by substituting equations (9) and (10) into (8), after a few algebraic manipulations, we can get the mutual information of the ONDF scheme in Case 1 as:

$$\zeta_1 = \frac{1}{2}\log_2 \left[|\alpha_{SD}|^4 \rho^2 + 2|\alpha_{SD}|^2 \rho + |\alpha_{BD}|^2 \rho + 1 \right]. \quad (11)$$

In Case 2, the equivalent channel model of equations (1) and (5) can be written in a matrix form as:

$$\begin{bmatrix} y_D[i] \\ y_D[i+l/2] \end{bmatrix} = \underbrace{\begin{bmatrix} \alpha_{SD} \\ \alpha_{SD} \end{bmatrix}}_{G} x_S[i] + \underbrace{\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}}_{\Gamma} \underbrace{\begin{bmatrix} n_D[i] \\ n_D[i+l/2] \end{bmatrix}}_{N}, \quad (12)$$

where $i = 1, 2, \cdots, l/2$. Therefore, the mutual information of the ONDF scheme in Case 2, which is denoted by ζ_2, can be straightforwardly derived as:

$$\zeta_2 = \frac{1}{2}\log_2 \left[2|\alpha_{SD}|^2 \rho + 1 \right]. \quad (13)$$

B. Outage Probability

Before determining the outage probability of the ONDF scheme, we should have the knowledge of the probabilities of Case 1 and Case 2 happen. They are denoted by Pr[Case 1] and Pr[Case 2], respectively.

The mutual information ζ_{SR_k} between S and R_k is given by:

$$\zeta_{SR_k} = \log_2 \left[|\alpha_{SR_k}|^2 \rho + 1 \right], \quad (14)$$

where $k = 1, 2, \cdots, n$. Thus, based on equation (6), the probability that relay R_k cannot the decode signal of S is given by:

$$\Pr[\zeta_{SR_k} \leq R(\rho)] = \Pr\left[\log_2 \left[|\alpha_{SR_k}|^2 \rho + 1 \right] \leq R(\rho) \right]. \quad (15)$$

When Case 2 happens, no relay can decode the message of S, which indicates:

$$\begin{aligned} \Pr[\text{Case 2}] &= \prod_{k=1}^{n} \Pr[\zeta_{SR_k} \leq R(\rho)] \\ &= \prod_{k=1}^{n} \Pr\left[\log_2 \left[|\alpha_{SR_k}|^2 \rho + 1 \right] \leq R(\rho) \right]. \end{aligned} \quad (16)$$

Hence, the probability of Case 1 happens is given by:

$$\begin{aligned} \Pr[\text{Case 1}] &= 1 - \Pr[\text{Case 2}] \\ &= 1 - \prod_{k=1}^{n} \Pr\left[\log_2 \left[|\alpha_{SR_k}|^2 \rho + 1 \right] \leq R(\rho) \right]. \end{aligned} \quad (17)$$

Now, it is sufficient to formulate the outage probability of the ONDF scheme, which is given by:

$$P_O(\rho) = \Pr[\text{Case 1}] \cdot \Pr[\zeta_1 \leq R(\rho)] + \Pr[\text{Case 2}] \cdot \Pr[\zeta_2 \leq R(\rho)]. \quad (18)$$

With the knowledge of equations (11), (13), (16) and (17), $P_O(\rho)$ can be further expressed as:

$$\begin{aligned} P_O(\rho) = &\left(1 - \prod_{k=1}^{n} \Pr\left[\log_2 \left[|\alpha_{SR_k}|^2 \rho + 1 \right] \leq R(\rho) \right] \right) \cdot \\ &\Pr\left[\frac{1}{2}\log_2 \left[|\alpha_{SD}|^4 \rho^2 + 2|\alpha_{SD}|^2 \rho + |\alpha_{BD}|^2 \rho + 1 \right] \leq R(\rho) \right] \\ &+ \left(\prod_{k=1}^{n} \Pr\left[\log_2 \left[|\alpha_{SR_k}|^2 \rho + 1 \right] \leq R(\rho) \right] \right) \cdot \\ &\Pr\left[\frac{1}{2}\log_2 \left[2|\alpha_{SD}|^2 \rho + 1 \right] \leq R(\rho) \right]. \end{aligned} \quad (19)$$

C. Relay Selection Criterion

To select the best relay for signal relaying, we should choose the relay which can minimize the outage probability defined by equation (19). Based on the above descriptions, we can see that the relay selection only happens in Case 1. Therefore, we should minimize the outage probability of Case 1, i.e., $\Pr[\zeta_1 \leq R(\rho)]$. Alternatively, the selected relay should maximize ζ_1 of equation (11).

Therefore, among the relays of S_e, the one that has the largest channel gain $|\alpha_{R_kD}|^2$ should be chosen as the best relay, i.e.,

$$B = \arg\max_{R_k \in S_e} \{|\alpha_{R_kD}|^2\}. \quad (20)$$

Equation (20) is the relay selection criterion for the ONDF scheme. Recall the relay selection procedure mentioned in Section II, with the feedback of the ACK packets, S forms the set S_e. If $S_e \neq \emptyset$, it will then select the best relay based on the CSI of the relay-destination channels, i.e., α_{R_kD}.

IV. Diversity-Multiplexing Tradeoff

In this section, DMT performance of the ONDF scheme will be analyzed, with which the superiority of the proposed scheme can be demonstrated. First, the exponential order of the squared channel gain and the DMT are defined as follows.

Definition 1: The exponential order of the squared channel gain $|\alpha_{AB}|^2$ is given by [10]:

$$\delta_{AB} = -\lim_{\rho\to\infty} \frac{\log_2|\alpha_{AB}|^2}{\log_2\rho}. \quad (21)$$

$|\alpha_{AB}|^2$ can be equivalently denoted as: $|\alpha_{AB}|^2 \doteq \rho^{-\delta_{AB}}$, where $\doteq$ means that the equality is established when $\rho \to \infty$. Note that $\dot{\leq}$ is defined similarly.

It is assumed that $|\alpha_{AB}|^2$ follows a chi-square distribution, we have [8]:

$$\Pr[|\alpha_{AB}|^2 \leq \rho^{-\nu}] = 1 - e^{-\frac{1}{2}\rho^{-\nu}} \doteq \rho^{-\nu}, \quad (22)$$

where ν is a nonnegative real value.

Definition 2: 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 [15]:

$$d = -\lim_{\rho\to\infty} \frac{\log_2 P_O(\rho)}{\log_2\rho},\ r = \lim_{\rho\to\infty} \frac{R(\rho)}{\log_2\rho}, \quad (23)$$

where the diversity-multiplexing tradeoff $d(r)$ is used to denote the derived relationship between d and r according to equation (23). The outage probability $P_O(\rho)$ can be expressed as $P_O(\rho) \dot{\leq} \rho^{-d(r)}$.

According to equations (16) and (17), when $\rho \to \infty$, we have $|S_e| = n$, Pr[Case 2] = 0 and Pr[Case 1] = 1. Based on $Definition$ 1, $R(\rho) \doteq r\log_2(\rho)$. Therefore, equation (19) can be further expressed as:

$$\begin{aligned} P_O(\rho) &\doteq \Pr\left[\frac{1}{2}\log_2\left[|\alpha_{SD}|^4\rho^2 + 2|\alpha_{SD}|^2\rho + |\alpha_{BD}|^2\rho + 1\right] \leq R(\rho)\right] \\ &\doteq \Pr\left[\left(|\alpha_{SD}|^2\rho+1\right)^2 + |\alpha_{BD}|^2\rho \leq \rho^{2r}\right] \\ &\leq \Pr\left[\left(|\alpha_{SD}|^2\rho+1\right)^2 \leq \rho^{2r}\right] \cdot \Pr\left[|\alpha_{BD}|^2\rho \leq \rho^{2r}\right] \\ &\dot{\leq} \Pr\left[|\alpha_{SD}|^2 \leq \rho^{r-1}\right] \cdot \Pr\left[|\alpha_{BD}|^2 \leq \rho^{2r-1}\right]. \end{aligned} \quad (24)$$

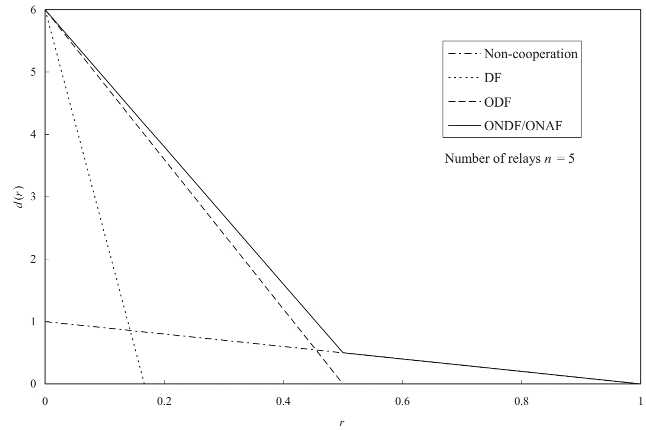

Fig. 2. DMT performance of the ONDF scheme.

Hence, equation (24) can be further manipulated as:

$$\begin{aligned} P_O(\rho) &\dot{\leq} \Pr[|\alpha_{SD}|^2 \leq \rho^{r-1}] \cdot \Pr[\max\{|\alpha_{R_kD}|^2\} \leq \rho^{2r-1}] \\ &\doteq \rho^{-(1-r)} \cdot \prod_{k\in S_e} \Pr[|\alpha_{R_kD}|^2 \leq \rho^{2r-1}] \\ &\doteq \rho^{-(1-r)} \cdot \rho^{-|S_e|(1-2r)^+}, \end{aligned} \quad (25)$$

where $(a)^+ = \max\{0, a\}$ and a is a random variable. Since when $\rho \to \infty$, $|S_e| = n$ and $P_O(\rho)$ can be derived as:

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

Therefore, the DMT performance of the ONDF scheme is given by:

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

Therefore, the ONDF scheme has a maximal diversity gain on the order of number of candidate relays and a maximal multiplexing gain of one. Its DMT performance is shown by Fig.2. It has the same DMT performance as the ONAF scheme [13][14], and it is better than the other cooperative schemes, e.g., the DF and ODF schemes. However, it is known that the DMT performance only indicates a scheme's asymptotic behavior with $\rho \to \infty$. Since the DMT performance of the ONDF scheme is better than the DF and ODF schemes, it is expected to have a superior outage performance compared to the two. But the DMT performance falls short in telling the performance difference between the ONDF and the ONAF schemes. In order to further investigate their outage performance difference, as well as quantize the performance gain of the ONDF scheme over the DF and ODF schemes, the schemes' outage performance would have to be evaluated and it is shown in the following section.

V. Outage Performance Evaluation

In order to validate the above analysis, the outage probability of the ONDF scheme and its comparison with the other schemes will be presented.

In this paper, the channel condition is represented by the average squared channel gain Ω_{AB} and $\Omega_{AB} = \mathbb{E}\{|\alpha_{AB}|^2\}$.

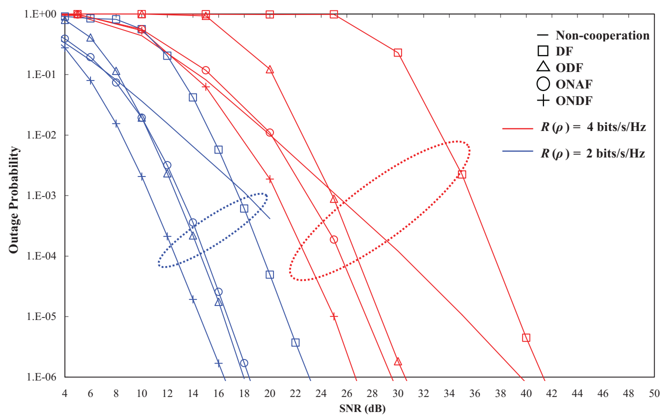

Fig. 3. Outage probability of the ONDF scheme with 2 relays, $R(\rho) = 2$ or $R(\rho) = 4$ bits/s/Hz.

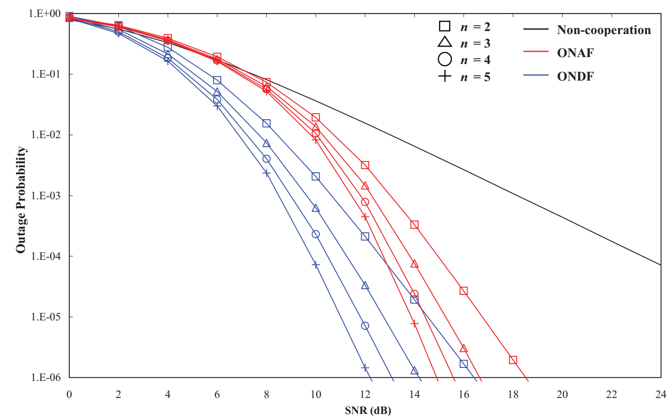

Fig. 4. Outage probability of the ONDF scheme and the ONAF scheme with 2 to 5 relays, $R(\rho) = 2$ bits/s/Hz.

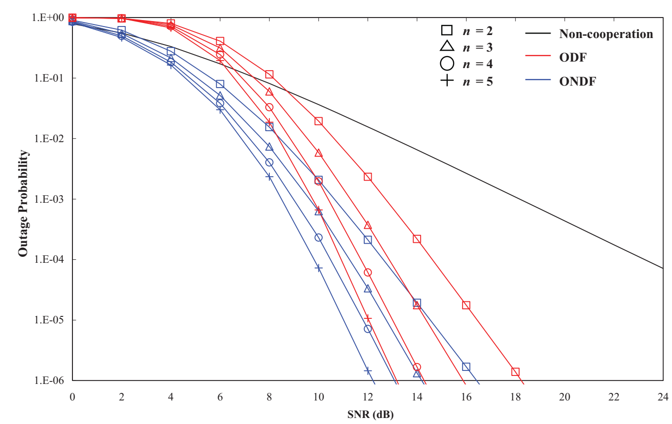

Fig. 5. Outage probability of the ONDF scheme and the ODF scheme with 2 to 5 relays, $R(\rho) = 2$ bits/s/Hz.

In the simulation setup, it is assumed that all the channels have a similar quality with the average squared channel gains of 2.0, i.e., $\Omega_{SD} = \Omega_{SR_k} = \Omega_{R_k D} = 2.0$.

Fig.3 shows the outage probability performance for the ONDF scheme with 2 relays, $R(\rho) = 2$ or 4 bits/s/Hz. It can be seen that the ONDF scheme outperforms other schemes in both transmission scenarios. The performance gain of the ONDF scheme over the other schemes is more significant when the transmission rate is higher. Compared with the ONAF scheme that utilizes the optimal relay selection criterion [14], the ONDF scheme achieves 2 dB and 3 dB performance gains with $R(\rho) = 2$ and $R(\rho) = 4$ bits/s/Hz at an outage probability of 10^{-6}, respectively. Such a performance advantage is mainly due to the DF relaying strategy allowing the relay only transmits the decoded and re-encoded signal to destination. It prevents the propagation of errors introduced in the source-relay channels. Meanwhile, it can be observed that the ONDF scheme outperforms the DF scheme by a large margin, which results from the advantages of opportunistic relay selection and nonorthogonal transmission. Moreover, it is shown that the ODF scheme outperforms the ONAF scheme at $R(\rho) = 2$ bits/s/Hz but not at $R(\rho) = 4$ bits/s/Hz. It indicates the nonorthogonal transmission outweighs the opportunistic DF relaying at a higher transmission rate scenario.

Fig.4 compares the outage probability performance of the ONDF scheme and the ONAF scheme with 2 to 5 relays. Given the same number of relays, the ONDF scheme always exhibits a performance gain of 2dB over the ONAF scheme. This fixed performance gain is due to the difference between DF relaying strategy and AF relaying strategy. Fig.5 compares the outage probability performance of the ONDF scheme and ODF scheme with 2 to 5 relays. The ONDF schemes has a larger performance gain over the ODF scheme when there are less relays. For example, at an outage probability of 10^{-6}, if $n = 2$, the performance gain is 2dB. When $n = 5$, the performance gain declines to 0.8dB. The reason of such a phenomenon is with a small number of relays, nonorthogonal transmission plays a leading role in obtaining performance gain. While by increasing the number of relays, its contribution becomes less significant.

It is important to recognize that the ONDF scheme's performance advantage is achieved at the cost of system complexity and transmission resources. On one hand, nonorthogonal transmission requires extra frequency spectrum for the simultaneous transmissions of S and B. On the other hand, opportunistic relaying requires feedbacks of the network CSI to S and S's effort in coordinating the relay selection. However, investigating those costs is beyond the scope of this paper but left as a future work.

VI. Conclusion

This paper has proposed a novel cooperative communication scheme called the opportunistic nonorthogonal decode-and-forward (ONDF) scheme. It integrates two important features of cooperative communications, the opportunistic relaying and the nonorthogonal transmission. The system model has been presented, based on which the scheme's outage probability model has been characterized. Then, the relay selection criterion is proposed. Moreover, based on the derived outage probability model, the DMT performance of the ONDF scheme has also been analyzed. The DMT analysis was further validated by our Monte-Carlo simulation. It showed that the ONDF scheme outperforms most of the current cooperative schemes, including the ONAF scheme, the ODF scheme and the DF scheme. Its performance gain is more significant in a high transmission rate scenario. The superiority of the ONDF scheme over the other schemes is mainly due to its three features: the DF signal retransmission strategy, the nonorthogonal transmission and the opportunistic relaying. Thus, the ONDF scheme is a well performing scheme with a promising transmission rate. It can be considered in future wireless communication networks.

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