Distributed Amplify-and-Forward Cooperation While Maintaining Transmission Freedom

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Abstract—This paper proposes a novel Distributed Amplify-and-Forward (DAF) cooperative scheme, achieving higher diversity order and yet maintaining the same transmission freedom as the conventional Amplify-and-Forward (AF) scheme. In the DAF scheme, a user’s transmitted symbols are partitioned into several sequences in order to be relayed by different users. In the cooperative network, each user still uses half of their transmission time for relaying others’ signals. But instead of relaying one user’s entire transmitted sequence, it helps different users for the relaying. Theoretical analysis of the DAF scheme is carried out in order to justify its advantages over the existing schemes. The outage behaviour and diversity-multiplexing tradeoff analyses of the DAF scheme are presented. Through outage behaviour analysis, it is shown the DAF scheme achieves substantial diversity gains over the AF scheme. Furthermore, the DMT analysis justifies both the scheme’s achievable diversity gains and its ability to maintain the same transmission freedom as the AF scheme. The theoretical analyses are then extended to a general cooperative network consisting of \(N(N \geq 2)\) relays, showing the diversity order can be increased with respect to the number of relays but not at the expense of each user’s transmission freedom.

Index Terms—Amplify-and-Forward, distributed cooperation, outage probability, diversity-multiplexing tradeoff

I. INTRODUCTION

Spatial diversity is a crucial technique to improve communication quality. The multiple transmit/receive antennas (MIMO) system [1] and the cooperative system [2] are introduced due to their nature of creating spatial diversity. Among them, the cooperative system can be applied more widely since it does not impose any size constraint and extra cost to the mobile unit. In the cooperative communication network, each user equipped with a single antenna not only transmits their own information, but also relays other’s information, creating a virtual multiple transmit antennas array. So far, there are three types of cooperative schemes: Amplify-and-Forward (AF) [3], Decode-and-Forward (DF) [3], [2] and Coded Cooperation (CC) [4], [5]. The authors have carried out a comparative investigation of the existing schemes in [6].

For a cooperative network, each user achieves diversity gains at the expense of their transmission freedom, since some of their transmission time is sacrificed relaying other’s signals. In a practical communication system, this freedom loss is translated into spectral efficiency loss. To compensate, Chatzigeorgiou et al. [7] proposed a high-order modulation scheme to be employed in the cooperative system. Later, the authors proposed Trellis Coded Modulation (TCM) scheme [8], achieving better coding gains for high spectral efficiency systems [9]. Laneman et. al. [10] showed that better diversity gains can be achieved if cooperation is performed in a distributed manner, meaning more relays are involved for signal retransmission. In [10], two types of distributed cooperation schemes were proposed: repetition-based cooperation and space-time-coded cooperation. For the repetition-based cooperation, extra spatial diversity is created at the cost of extra transmission freedom (time) loss. As a result, the achievable diversity gain can not be increased according to the number of users. For space-time-coded cooperation, the transmission freedom loss does not apply and hence diversity gains could be further achieved accordingly. Space-time-coded cooperation is operated in DF mode requiring decoding and re-encoding at the relays. The diversity gain is achieved with substantial system complexity increase. Therefore, a distributed cooperative scheme without sacrificing transmission freedom or system complexity, inspires the design of the proposed DAF scheme.

This paper introduces the DAF cooperative scheme, in which each user uses half of their transmission time to relay more than one other user. To achieve this, the transmitted sequence of a user is partitioned into several parts, each of which is relayed by a different user in AF mode. Therefore, diverse transmission paths are created for the relayed symbols while each user still maintains their transmission freedom, half of their transmission time. Theoretical analysis of the DAF scheme is presented in order to verify its performance advantage. Our analysis is drawn from a network with two relaying users and then extended to a larger network with \(N(N \geq 2)\) users. The outage behaviour analysis of the DAF scheme shows that substantial diversity gains could be achieved over the conventional AF scheme. The achievable diversity gains can be increased with respect to the number of relays. The DMT analysis was first introduced by Zheng and Tse in [11], analysing the balance between the performance gain and the transmission freedom loss in MIMO systems. It was then applied to cooperative systems in [2] [10] [12]. Our DMT analysis shows that the DAF scheme has the same maximal multiplexing gain as the AF scheme, but achieves further diversity gains. The diversity gain is increased according to the number of relaying users. Prior to the writing of this paper, the authors’ earlier work [13] of integrating the DAF scheme with channel coding showed significant coding gains can be achieved over the AF scheme.

The paper is organised as follows: Section II will present the preliminaries of the paper. Section III will present the DAF system model. Section IV will present the outage behaviour analysis.
analysis; Section V will present the DMT analysis. Both the outage behaviour analysis and DMT analysis are extended in a larger cooperative network in Section VI. Section VII concludes the paper and presents our future work.

II. PRELIMINARY

This section presents the preliminaries of the paper. It includes definitions of commonly used parameters and an introduction to the conventional AF scheme which will be used to compare with the proposed DAF scheme.

A. Parameterisations

The ananysed cooperative network is assumed to operate in half-duplex mode, requiring orthogonal time division channel allocation for the receiving and transmitting of each user. The channel quality is measured by the Signal-to-Noise Ratio (SNR) which can be defined as:

\[ \rho = \frac{\varepsilon}{\sigma^2} \]  

(1)

where \( \varepsilon \) denotes the average transmitted symbol energy and \( \sigma^2 \) denotes the variance of noise at the receiver. For simplicity of the analysis, it is assumed that the network has symmetric channels meaning all of them have similar SNR values. The channel between transmitting user \( a \) and receiving user \( b \) is assumed to be Quasi-static Rayleigh fading with fading coefficient \( \alpha_{ab} \). All channels within the cooperative network are assumed to be statistically independent. \( \alpha_{ab} \) is a Gaussian random variable with zero mean and unit variance. The exponential order of \( 1/|\alpha_{ab}|^2 \) is defined as:

\[ \delta_{ab} = - \lim_{\rho \to \infty} \frac{\log(|\alpha_{ab}|^2)}{\log \rho} \]  

(2)

where the base of the logarithm is 2.

If the cooperative system operates with a transmission rate of \( R(\rho) \) bits/s/Hz, which is a function of the SNR, the multiplexing gain of the system can be defined as:

\[ r = \lim_{\rho \to \infty} \frac{R(\rho)}{\log \rho} \]  

(3)

where \( r \) is a normalised value representing the ratio of effective transmission. At a SNR of \( \rho \), if the system can achieve a maximum-likelihood (ML) error probability of \( P_e(\rho) \), its diversity gain is defined as:

\[ d = - \lim_{\rho \to \infty} \frac{\log(P_e(\rho))}{\log \rho} \]  

(4)

The derived result of the relationship between \( d \) and \( r \) is called the Diversity-Multiplexing Tradeoff (DMT), denoted as \( d(r) \). We could further claim protocol A is superior to protocol B if for any multiplexing gain \( r \), \( d_A(r) \geq d_B(r) \).

\( \mathbb{R}^N \) and \( \mathbb{C}^N \) denote the set of real and complex \( N \)-tuples. \( \mathbb{R}^N_+ \) denotes the set of nonnegative \( N \)-tuples. \( \mathbb{O} \) is used to denote the set of outage events in the cooperative system, \( \mathbb{O} \subseteq \mathbb{R}^N_+ \) and \( \mathbb{O}^+=\mathbb{O}\cap\mathbb{R}^N_+ \). According to [11] and [12], the DMT \( (d(r)) \) of a cooperative system with \( N \) users is upper bounded by:

\[ d(r) \leq d_0, \quad d_0 = \inf_{(\delta_1,\ldots,\delta_N)\in\mathbb{O}} \sum_{j=1}^{N} \delta_j. \]  

(5)

The analysed result of this paper is given when \( d(r) \) saturates the bound. Note that in the rest of the paper, \( N \) means the number of the relaying users excluding the transmit user. \( P_{out}^{DAF(N)} \) and \( d_{DAF(N)}(r) \) denote the outage probability and DMT of the DAF scheme with \( N \) relaying users. Furthermore, \( I_N \) denotes the \( N \times N \) identity matrix, \( \det(x) \) denotes the determinant of the matrix \( x \), \( \sum_{j=1}^{N} \) denotes the autocovariance matrix of vector \( x \), \( x^H \) denotes the Hermitian conjugates of matrix \( x \) and \( (x)^+ \) means \( \max\{x, 0\} \).

B. Amplify-and-Forward

The AF scheme consists of three users: Source (S) and its signal Destination (D), Relay (R) helps S for the transmission. A classical cooperative process contains two Time Slots (TS) with equal duration. The first TS is for initial transmission when S transmits its information to D, D would combine the received signals using ML detection [3]. If \( \alpha_{SD}, \alpha_{SR} \) and \( \alpha_{RD} \) denote the fading coefficients of the channels between \( S-D \), \( S-R \) and \( R-D \) respectively, and \( R \) denotes the transmission rate of the cooperative system, the outage behaviour of the AF scheme can be modelled as [2]:

\[ P_{AF}^{out} = \Pr[1 + |\alpha_{SD}|^2 \rho + |\alpha_{SR}|^2 \rho, |\alpha_{RD}|^2 \rho < 2^{2R}] \]  

(6)

where

\[ f(\mu, \nu) = \frac{\mu \nu}{\mu + \nu + 1}. \]  

(7)

\( \mu \) and \( \nu \) are random variables. The DMT characteristics of the AF scheme can be described by [2]:

\[ d_{AF}(r) \leq 2(1 - 2r)^+. \]  

(8)

It can be seen that diversity order of 2 can be obtained from the AF scheme.

III. SYSTEM MODEL

This section presents the system model for the DAF scheme, detailing this novel transmission protocol. In general, if a DAF cooperative network has \( N \) relaying users, the transmitted signal of S will be equally partitioned into \( N \) sections, each of which will be relayed by a different user. It is not difficult to realise that when \( N = 1 \), it becomes the conventional AF scheme. For simplicity, the description of the DAF system model is given with \( N = 2 \), and it could be easily extended into a larger cooperative network.

A complete cooperative process of the DAF scheme also consists of two TSs, which is shown in Fig.1. In the first TS, S transmits its signal to D as well as to two different relays \( (R_1 \) and \( R_2 \). It is assumed that \( R_1 \) and \( R_2 \) are perfectly synchronised with \( S \), and \( R_1 \) received the first half of \( S \)'s signal while \( R_2 \) received the second half.
The first TS

\[
\begin{align*}
R_1 & \quad y_{1,k} \\
S & \quad D \\
R_2 & \quad y_{3,k}
\end{align*}
\]

The second half of the second TS

\[
\begin{align*}
R_1 & \quad y_{2,k} \\
D & \quad D \\
R_2 & \quad y_{3,k}
\end{align*}
\]

Fig. 1. Cooperation process for the DAF scheme

In the following equations, signals \( (x, y, v, w) \) have double subscripts \((a, b)\) where \( a \) denotes the TS that the signal belongs to and \( b \) denotes the symbol index. \( x \) denotes the transmitted signal and \( y \) denotes the received signal. \( v, w^1 \) and \( w^2 \) are the additive white Gaussian noise (AWGN) at \( D, R_1 \) and \( R_2 \) respectively. They are modelled as mutually independent, zero-mean complex random sequence with variances \( \sigma_v^2, \sigma_{w1}^2 \) and \( \sigma_{w2}^2 \) respectively. The \( S-D \) transmission can be described as:

\[
y_{1,k} = \alpha_{SD}x_{1,k} + v_{1,k}, \quad k = 1, 2, \ldots, l/2,
\]

where \( l \) denotes the length of the signal transmitted during the two TSs and \( l/2N \). The second TS is also partitioned into two equal halves for relaying transmission. In the first half of the second TS, \( R_1 \) amplifies its received signal with gain \( \beta_1 \) and re-transmits to \( D \) as:

\[y_{2,k} = \alpha_{RD}\beta_1(\alpha_{SR_1}x_{1,k-1/2} + w^1_{1,k-1/2}) + v_{2,k}, \quad k = l/2 + 1, l/2 + 2, \ldots, 3l/4,\]

where

\[
\beta_1 \leq \sqrt{\frac{\varepsilon}{\alpha_{SR_1}^2\varepsilon + \sigma_w^2}}.
\]

Similarly, in the second half of the second TS, \( R_2 \) re-transmit \( S \)'s signal to \( D \) as:

\[y_{2,k} = \alpha_{RD}\beta_2(\alpha_{SR_2}x_{1,k-1/2} + w^1_{1,k-1/2}) + v_{2,k}, \quad k = 3l/4 + 1, 3l/4 + 2, \ldots, l,
\]

where

\[
\beta_2 \leq \sqrt{\frac{\varepsilon}{\alpha_{SR_2}^2\varepsilon + \sigma_w^2}}.
\]

After the two TSs, \( D \) combines \( y_{1,k} \) \((k = 1, 2, \ldots, l/4)\) with \( y_{2,k} \) of (10) and \( y_{1,k} \) \((k = l/4 + 1, l/4 + 2, \ldots, l/2)\) with \( y_{2,k} \) of (12) for further signal processing in order to retrieve the transmitted information. Fig.2 shows the time division channel allocation structure of the DAF scheme. It can be seen that half of a user’s total transmission time is used for their own transmission, while the other half is partitioned into smaller divisions in order to help different users. It maintains the same transmission freedom as the conventional AF scheme [2].

IV. OUTAGE BEHAVIOUR

This section presents the outage behaviour analysis for the DAF scheme with two relaying users. Its extension to larger networks will be mentioned in Section VI. The conclusion is drawn by first formalising the transmission signal model, then determining the scheme’s mutual information and finally modelling its outage behaviour. The following theorem models the scheme’s outage behaviour.

**Theorem 1**: For a DAF cooperative scheme with two relaying users, if its transmission rate is \( R \) bits/s/Hz, its outage behaviour can be determined by:

\[
P_{out}^{DAF(2)} = \Pr\left\{ \sum_{i=1}^{2} \left( |\alpha_{SD}|^2 + |\alpha_{SR_1}|^2 |\alpha_{RD}|^2 \right) < 2^R \right\},
\]

**Proof**: To prove Theorem 1, it is necessary to formalise the system model of the DAF scheme into matrix form. Equations (9) to (13) can be alternatively expressed as:

\[
\begin{bmatrix}
y_{1} \\
y_{2} \\
\vdots \\
y_{l}
\end{bmatrix} =
\begin{bmatrix}
\alpha_{SD}I_{l/4} & 0 & 0 & 0 \\
0 & \alpha_{RD}\beta_1\alpha_{SR_1}I_{l/4} & 0 & 0 \\
0 & 0 & \alpha_{RD}\beta_2\alpha_{SR_2}I_{l/4} & 0 \\
0 & 0 & 0 & \alpha_{RD}\beta_3\alpha_{SR_3}I_{l/4}
\end{bmatrix}
\begin{bmatrix}
x_1 \\
x_2 \\
\vdots \\
x_l
\end{bmatrix} +
\begin{bmatrix}
\alpha_{SD}\varepsilon I_{l/4} \\
\alpha_{RD}\beta_1\alpha_{SR_1}\varepsilon I_{l/4} \\
\alpha_{RD}\beta_2\alpha_{SR_2}\varepsilon I_{l/4} \\
\alpha_{RD}\beta_3\alpha_{SR_3}\varepsilon I_{l/4}
\end{bmatrix}
\begin{bmatrix}
v_1 \\
v_2 \\
\vdots \\
v_l
\end{bmatrix},
\]

where \( \varepsilon \in C^{l/2 \times 1} \) denotes vector of transmitted signals, \( \bar{\varepsilon} \in C^{l \times 1} \) denotes the vector of received signals at \( D \), \( \bar{\varepsilon} \in C^{l/4 \times 1} \) denotes the vector of noise samples at \( D \), and \( \bar{\varepsilon} \) and \( \bar{\varepsilon} \) denote the vector of noise samples at \( R_1 \) and \( R_2 \). Let \( x_i \) and \( y_i \) denote the entries of \( \bar{\varepsilon} \) and \( \bar{\varepsilon} \); the relationship between \( x_i \) and \( y_i \) can be categorised into the following two sets. For \( i = 1, 2, \ldots, l/4 \),

\[
\begin{bmatrix}
y_{i} \\
y_{i+1} \\
\vdots \\
y_{i+l/2}
\end{bmatrix} = \bar{G}_i \begin{bmatrix}
x_{i} \\
x_{i+1} \\
\vdots \\
x_{i+l/2}
\end{bmatrix} + \bar{m}_{i}.
\]

where

\[
\bar{G}_i = \begin{bmatrix}
\alpha_{SD} & 0 & 0 & 0 \\
0 & \alpha_{RD}\beta_1\alpha_{SR_1} & 0 & 0 \\
0 & 0 & \alpha_{RD}\beta_2\alpha_{SR_2} & 0 \\
0 & 0 & 0 & \alpha_{RD}\beta_3\alpha_{SR_3}
\end{bmatrix},
\]

\[
\Sigma_{\bar{m}_{i}} = \begin{bmatrix}
\sigma_v^2 & 0 & 0 & 0 \\
0 & \sigma_v^2 + |\alpha_{RD}|^2 |\beta_1|^2\sigma_w^2 & 0 & 0 \\
0 & 0 & \sigma_v^2 + |\alpha_{RD}|^2 |\beta_2|^2\sigma_w^2 & 0 \\
0 & 0 & 0 & \sigma_v^2 + |\alpha_{RD}|^2 |\beta_3|^2\sigma_w^2
\end{bmatrix}.
\]
Similarly, for $i = l/4 + 1, l/4 + 2, \ldots, l/2$,
\[
\bar{y}_i^2 = \left[ \frac{y_i}{y_{i+1/2}} \right] = \bar{G}_i^2 x_i + \bar{n}_i^2,
\]
where
\[
\bar{G}_i^2 = \left[ \begin{array}{c}
\frac{\alpha_{SD}}{\alpha_{RD}/\beta_2 \sigma_{SR2}} \\
\frac{\alpha_{RD}/\beta_2 \sigma_{SR2}}{0}
\end{array} \right],
\]
\[
\Sigma_{\bar{n}_i^2} = \left[ \begin{array}{c}
\sigma^2_v \\
0 \\
\sigma^2_v + |\alpha_{RD}|^2 |\beta_2|^2 \sigma^2_{\bar{n}_i^2}
\end{array} \right].
\]

Now, it is straightforward to see that the mutual information between $\bar{x}$ and $\bar{y}$ can be determined by:
\[
I(\bar{x}, \bar{y}) = \frac{1}{4}[I(x_i, y_i^2) + I(x_i, \bar{y}_i^2)].
\]

The mutual information between $x_i$ and $y_i^2$ is determined by:
\[
I(x_i, \bar{y}_i^2) = \log(\det(I_2 + x_i \bar{G}_i^2 \bar{G}_i^H \Sigma_{\bar{n}_i^2}^{-1}))
\leq \log(\det(I_2 + \epsilon \bar{G}_i^2 \bar{G}_i^H \Sigma_{\bar{n}_i^2}^{-1})),
\]
\[
I(x_i, \bar{y}_i^2) \text{ can only be determined by saturating the bound in (23). By substituting equations (17) and (18) into (23), with a few algebraic manipulations, it can be derived that:}
\]
\[
I(x_i, \bar{y}_i^2) = \log(1 + |\alpha_{SD}|^2 \sigma^2_v + |\alpha_{RD}|^2 |\beta_2|^2 |\alpha_{SR2}|^2 \sigma^2_v),
\]
\[
(27)
\]

Through the same methodology, we can determine that:
\[
I(x_i, \bar{y}_i^2) = \log(1 + |\alpha_{SD}|^2 \sigma^2_v + |\alpha_{RD}|^2 |\beta_2|^2 |\alpha_{SR2}|^2 \sigma^2_v).
\]
\[
(28)
\]

Therefore, by substituting equations (27) and (28) into (22), we have:
\[
I(\bar{x}, \bar{y}) = \frac{1}{4} \sum\limits_{i=1}^{l/4} \log(1 + |\alpha_{SD}|^2 \sigma^2_v + |\alpha_{RD}|^2 |\beta_2|^2 |\alpha_{SR2}|^2 \sigma^2_v).
\]
\[
(29)
\]

When $\beta_2$ saturates the bounds in (11) and (13), and in a symmetric network $\frac{\epsilon}{\sigma^2_v} = \frac{\epsilon}{\sigma^2_{\bar{n}_1}} = \frac{\epsilon}{\sigma^2_{\bar{n}_2}} = \rho$, (26) can be simplified as:
\[
I(\bar{x}, \bar{y}) = \frac{1}{4} \sum\limits_{i=1}^{l/4} \log(1 + |\alpha_{SD}|^2 \rho + f(|\alpha_{SR2}|^2 \rho, |\alpha_{RD}|^2 \rho)).
\]
\[
(30)
\]

V. DIVERSITY-MULTIPLEXING Tradeoff

This section presents the DMT analysis for the proposed scheme. Through the DMT analysis, we are able to determine the scheme’s maximal multiplexing gain and diversity gain. The tradeoff between them can also be reflected from the analysis. First of all, the following theorem is proposed to describe the DMT of the scheme.

**Theorem 2:** For a DAF cooperative scheme with two relaying users, if its transmission rate is $R$ bits/s/Hz, its diversity-multiplexing tradeoff is upper bounded by:
\[
d_{\text{DAF}}(r) \leq 3(1 - 2r)^+.
\]
\[
(31)
\]

**Proof:** Referring to equations (3) and (4), both $d$ and $r$ describe the system’s asymptotic behaviour when $\rho \rightarrow \infty$. To analyse $d_{\text{DAF}}(r)$, we shall also analyse $I(\bar{x}, \bar{y})$’s asymptotic behaviour since it is also a function of $\rho$. Based on equation (26), it can be derived that:
\[
\lim\limits_{\rho \rightarrow \infty} \frac{I(\bar{x}, \bar{y})}{\log \rho} = \frac{1}{4} \sum\limits_{i=1}^{l/4} \frac{\log(1 + |\alpha_{SD}|^2 \rho + f(|\alpha_{SR2}|^2 \rho, |\alpha_{RD}|^2 \rho))}{\log \rho}.
\]
\[
(32)
\]

When $\rho \rightarrow \infty$, we could claim the following approximations:
\[
|\beta_2|^2 \approx 1, \sigma^2_v/\sigma^2_v \approx 1, |\alpha_{SD}|^2 \approx \rho^{-\delta_{SD}},
\]
\[
|\alpha_{SR2}|^2 \approx \rho^{-\delta_{SR2}} \text{ and } |\alpha_{RD}|^2 \approx \rho^{-\delta_{RD}}.
\]

Therefore, equation (30) can be further simplified to:
First, cooperation achieves further diversity gain compared to direct transmission, but loses multiplexing gain, i.e. loss of transmission freedom. Second, the DAF scheme achieves the same maximal multiplexing gain as the AF scheme with one relay, but achieves higher diversity gain. It verifies the achieved diversity gains shown in Fig. 3. Third, the DAF scheme achieves the same maximal diversity gain as the AF scheme with two relays, but achieves higher maximal multiplexing gain – maintaining higher transmission freedom compared to the existing distributed cooperative scheme.

VI. EXTENSION TO MULTIPLE USERS NETWORK

This section extends the analysis proposed in the above two sections to a larger cooperative network with \(N(N \geq 2)\) relaying users. Two theorems describing its outage behaviour and diversity-multiplexing tradeoff will be presented. Since the same methodology to prove Theorem 1 and Theorem 2 is used, the proof given in this section will only state the important generalised equations. In order to substantiate the theorems, the corresponding simulation and analysis results will also be shown.

In a DAF cooperative network with \(N\) relaying users, \(S\) will partition its sequence into \(N\) equal parts of length \(l/2N\), each of which will be relayed by a different user. Its system model can be easily extended from Section III. The following theorem describes its outage behaviour.

**Theorem 3:** For a DAF cooperative scheme with \(N(N \geq 2)\) relaying users, if its transmission rate is \(R\) bits/s/Hz, its outage behaviour can be determined by:

\[
P_{\text{out}}^{\text{DAF}(N)} = \text{Pr} \left\{ \prod_{i=1}^{N} (1 + |\alpha SD|^2) < 2^{N^2R} \right\}. \tag{35}\]

**Proof:** Similar to the proof of Theorem 1, by formalising its system model into matrix form, we can have the following \(N\) signal tuples \((x_1, \tilde{y}_1), (x_2, \tilde{y}_2), \ldots, (x_N, \tilde{y}_N)\) with length \(l/2N\). The mutual information between the transmitted signal \(\tilde{x}\) and received signal \(\tilde{y}\) can be determined by:

\[
I(\tilde{x}, \tilde{y}) = \frac{1}{2N} \sum_{i=1}^{N} I(x_i, \tilde{y}_i). \tag{36}\]

Applying the derived results of equations (24) and (25), we have:

\[
I(\tilde{x}, \tilde{y}) = \frac{1}{2N} \sum_{i=1}^{N} \log(1 + |\alpha SD|^2 + |\alpha_{RiD}|^2 |\beta_i|^2 |\alpha_{SRi}|^2). \tag{37}\]

By substituting equation (37) into (28), after a few algebraic manipulations, we can obtain (35) and the proof is complete.

The Monte-Carlo simulation results of the DAF scheme with different numbers of relaying users is shown in Fig. 5. It can be seen that further diversity gains can be achieved by increasing the number of relaying users.

**Theorem 4:** For a DAF cooperative scheme with \(N(N \geq 2)\) relaying users, if its transmission rate is \(R\) bits/s/Hz, its diversity-multiplexing tradeoff is upper bounded by:
conclude that; Scheme was proposed. For each user in the DAF cooperative transmission freedom is maintained. The same diversity gains shown by Fig. 5. More importantly, it shows different numbers of relaying users. It verifies the achievable $\rho^t$.

Fig. 6. DMT analysis of DAF scheme with different number of relaying users, $R = 1$ bits/s/Hz.

$$d_{DAF(N)}(r) \leq (N + 1)(1 - 2r)^t. \quad (38)$$

Proof: Similar to the proof of Theorem 2, by analysing the asymptotic behaviour of $I(\alpha, \gamma)$ given by (37), we can conclude that;

$$\lim_{\rho \to \infty} \frac{I(\alpha, \gamma)}{\log \rho} \simeq \frac{1}{2N} \sum_{t=1}^{N} [\max\{1 - \delta_{SD}, 1 - (\delta_{SR} + \delta_{RD})\}]^+. \quad (39)$$

By defining its outage event set of $\mathcal{O}$ and $\mathcal{O}^+$, it is not difficult to calculate that $1 - 2r < \delta_{SD} < 1$ and $N - 2Nr < \sum_{t=1}^{N} (\delta_{SR} + \delta_{RD}) < N$. Therefore, the $d_{DAF(N)}(r)$ upper bound given by equation (38) can obtained and the proof is complete.

Fig. 6 shows the DMT analysis of the DAF scheme with different numbers of relaying users. It verifies the achievable diversity gains shown by Fig. 5. More importantly, it shows the maximal multiplexing gain remains the same as the AF scheme regardless of the number of relaying users. The same transmission freedom is maintained.

VII. CONCLUSIONS AND FUTURE WORK

A novel distributed amplify-and-forward cooperation scheme was proposed. For each user in the DAF cooperative network, it uses half of their transmission time for their own information transmission, while the other half is used for relaying others’ information. Therefore, it is able to maintain the same transmission freedom allowed in the conventional AF network. Outage behaviour of the DAF scheme was analysed, showing a 5dB diversity gain can be achieved over the AF scheme at BER of $10^{-5}$. Further diversity gains can be achieved by increasing the number of relaying users. A diversity-multiplexing tradeoff analysis of the DAF scheme was also presented. It not only verified that the DAF scheme can achieve higher diversity gain than the AF scheme, but also justified it can maintain the same transmission freedom. However, it is also worthwhile to point out that the DAF scheme requires higher system complexity, since better synchronisation and more complex channel information shall be provided among cooperative users. Our future work includes: First, to obtain a closed form expression for the DAF scheme’s outage behaviour, in order to mathematically quantify the achievable diversity gain over the existing cooperative schemes; Second, to integrate the DAF scheme with different channel coding techniques, in order to investigate the distributed transmission impact on the performance of the codes.

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