Adjustable Multiple Relay Selection Based on Steady-State Mean Square Joint Error for Cooperative Communication

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Received March 30, 2016; revised July 7, 2016; accepted August 2, 2016;
published September 30, 2016

Abstract

In this paper, an adjustable multiple relay selection (MRS) scheme for cooperative communication with amplify-and-forward (AF) relay under frequency selective channels is proposed. In the proposed scheme, the relays are ordered firstly by the steady-state mean square error (MSE), then the relays are sequentially selected out from N relays and the number of cooperating relays is adjusted dynamically according to the steady-state mean square joint error (MSJE). The aim of this work is to dynamically estimate the optimum number N_o of cooperating relays. Optimum means the minimum number of cooperating relays, N_o, achieving the minimum level of steady-state MSJE. Numerical results verify the analyses and show that the scheme can adaptively adjust the number of cooperating relays, and outperform conventional relay selection schemes. Hence, the proposed scheme provides better tradeoff between BER performance and spectral efficiency and to save more energy in cooperative wireless networks.

Keywords: Cooperative communication, adjustable multiple relay selection, steady-state mean square joint error

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The work was supported by National Natural Science Foundation of China (61201145, 61371100, 61401164), the Foundation of Key Laboratory of Communication Network Information Transmission and Dissemination, and Graduate Education and Teaching Reform Research Project in Harbin Institute of Technology (JGYJ-201625).

http://dx.doi.org/10.3837/tiis.2016.09.017 **ISSN : 1976-7277**

1. Introduction

Cooperative communications have drawn much attention due to its capability of mitigating the fading effect of wireless channels and achieving spatial diversity [1-2]. A variety of cooperative schemes have been proved and their performances have been analyzed [3-12]. In comparison with other schemes, relay selection (RS) scheme usually achieves full diversity with less synchronization or overhear/feedback requirement [13], and thus it attracts considerable attention. Depending on the strategy that relays utilize for cooperation, the relay networks are generally classified as decode-and-forward (DF) and amplify-and-forward (AF). Among these two strategies, AF is very attractive in terms of having less computational burden at the relays.

Many studies of the relay selection schemes are based on frequency flat fading channel models [14-29]. However, in high data-rate wireless applications, the transmission bandwidth is larger than the coherence bandwidth of the channel which results in a frequency-selective channel [30]. For such high rate communication in cooperative relay networks, existing techniques for frequency flat fading channels need to be adapted, or new techniques need to be designed for frequency-selective channels. A widely used approach to overcome the degrading effects of frequency-selectivity is orthogonal frequency division multiplexing (OFDM) which has been recently applied to cooperative communications [31-34]. Nevertheless, OFDM is not a good option if low peak-to-average power ratios (PAPRs) are desired [35-37]. Single-carrier (SC) transmission can overcome the drawback of OFDM [38-39]. In the literature, research efforts on RS for SC transmission under frequency selective channel are limited, a brief review of which is provided in the following. A single relay selection (SRS) scheme for SC transmission is proposed in [40-43]. SRS is attractive because of its simplicity, but it may fail to meet the QoS performance required by users due to its limited diversity gain. To increase the diversity gain, multiple relay selection (MRS) should be considered. In [44], several MRS schemes are developed. All the schemes [40-44] are investigated under the assumption that full and perfect channel state information (CSI) of all the relayed paths at the receiver is known. In addition, although the MRS scheme in [44] achieves considerable performance gains, the BER performance of system may not be improved much as the number of cooperating relays exceeds a certain value, and more relays than necessary may be selected. The increase of relay nodes would degrade the spectral efficiency and energy saving comparing to single relay selection schemes. To achieve better tradeoff between BER performance and spectral efficiency and to save more energy, the MRS scheme should be able to adaptively adjust the number of nodes according to the current channel state.

In this paper, we propose an adjustable MRS scheme under frequency selective channel that uses orthogonal relay channels, distributed AF relays, and multi-branch joint detector (MJD) at the destination, and without the assumption that full and perfect CSI at the receiver is known. The key concept of adjustable MRS is the adjustment of cooperating relay node number. The proposed scheme is based on the min-max design criterion, which means to minimize the maximum number of selected relays participating in cooperation. According to the criterion, the MRS scheme can adaptively adjust the number of selected relays by comparing the steady-state mean square joint error (MSJE) for different number of relay, and obtain the optimum number N_o. Optimum means the minimum number of selected relay, N_o, achieving the minimum level of steady-state MSJE. Thus, better tradeoff between BER performance and spectral efficiency and to save more energy can be achieved.

2. System Model

We consider a multiple-relay assisted cooperative wireless communication system with a single source (S), N half-duplex relay terminals (R_i), i = 1, 2, ..., N, and a single destination (D), as depicted in **Fig. 1**. The source, destination, and all relays are equipped with single transmit and receive antenna. We assume the AF relaying and adopt the user cooperation proposed in [1]. Specifically, in the broadcasting phase, the source node transmits to the relay nodes. In the relaying phase, the relay nodes take turn to forward a scaled noisy version of the received signal to the destination node in different time slots. For simplicity, we assume that there is no direct link between the source and the destination, and all relays have the same average power constraint.

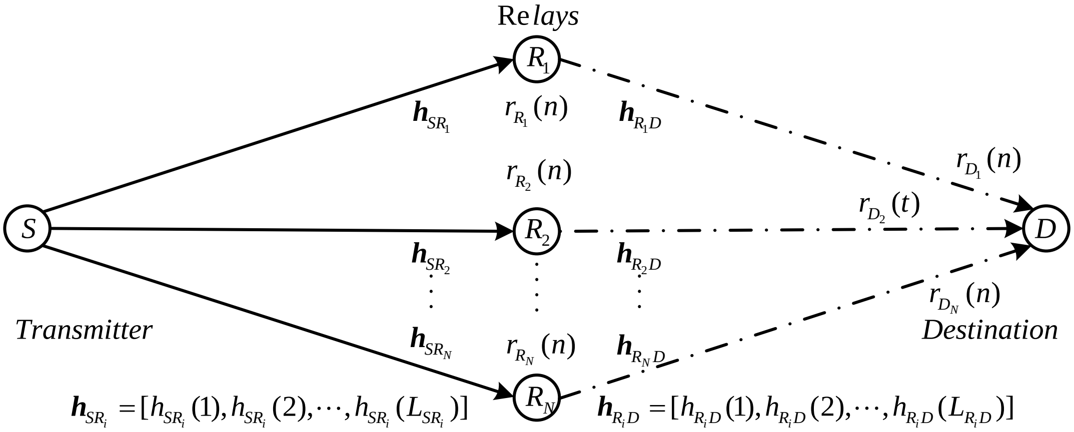

Fig. 1. A cooperative network with one source, multiple relays, and one destination

The channel impulse responses (CIRs) for $S \to R_i$ and $R_i \to D$ links for ith relay terminal are given by $\boldsymbol{h}_{SR_i} = \left[h_{SR_i}[0], \cdots, h_{SR_i}[L_{SR_i}]\right]$ and $\boldsymbol{h}_{R_iD} = \left[h_{R_iD}[0], \cdots, h_{R_iD}[L_{R_iD}]\right]$, respectively, where L_{SR_i} and L_{R_iD} denote the corresponding channel memory lengths. All channel links are assumed to experience frequency selective fading. The discrete-time channel impulse response are modeled as zero-mean Gaussian random variables with an exponential power delay profile [45-47]

$$\boldsymbol{h}(k) = \frac{P_R}{\sigma} \sum_{l=0}^{L_x - 1} e^{-k/\sigma} \delta(k-l) \tag{1}$$

where $L_x \in \{L_{SR_i}, L_{R_iD}\}$ and σ characterizes the delay spread of channel, $\delta(\bullet)$ is the Dirac delta function, P_R is the average power of the multipath components.

During the broadcasting phase I, the received signal at the ith relay terminal is given by

$$r_{R_i}(k) = s(k) * \boldsymbol{h}_{SR_i} + n_{R_i}(k) \tag{2}$$

where $*$ denotes convolution, $s(k)$ is the signal transmitted by the source node, $n_{R_i}(k)$ is additive white Gaussian noise (AWGN) with zero-mean, and its variance is $N_{0,i}$. $s(k)$ can be obtained by sampling the $s(t)$ with analogue-to-digital converter (A/D), $s(t)$ is given by

$$s(t)=\sum_{j=-\infty}^{+\infty} d(j)w(t-jT_f) \tag{3}$$

where $d(j)$'s are equiprobable uncorrelated binary phase-shift keying (BPSK) data and T_f is the symbol duration. $w(t)$ denotes Gaussian pulse waveform, which is a real function, time-limited to the interval $\left[0,T_f\right]$, and normalized, i.e., $\int_0^{T_f} w^2(t)dt=1$.

During the relaying phase, at the destination terminal, the received signal from ith relay R_i is given by

$$r_{D_i}(k)=\beta_i r_{R_i}(k) * \boldsymbol{h}_{R_iD}+n_{D_i}(k) \tag{4}$$

where $n_{D_i}(k)$ is the corresponding AWGN with zero mean and variance N_{0,D_i}. β_i is the gain of relay R_i, to remain within its power constraint, we follow [1] and set the gain of the relay R_i as

$$\beta_i=\sqrt{\frac{P}{P\sum_{k=0}^{L_{SR_i}}|h_{SR_i}[k]|^2+N_{0,i}}} \tag{5}$$

where P is the average energy per symbol used at each terminal, $h_{SR_i}[k]$ is the kth channel coefficient between the source and the selected relay R_i, and $N_{0,i}$ is the variance of the zero mean additive white Gaussian noise corresponding to the received signal for ith relay R_i at the destination.

3. Proposed Adjustable Multiple Relay Selection Scheme

In this section, we propose an adjustable MRS scheme under frequency selective channel. We assume that the relay nodes use the same transmission bandwidth but employ time division so that the relays transmit on a channel orthogonal to the destination. Optimal MRS can be achieved through an exhaustive search over all the relays. However, its complexity is exponential in the network size. It is obvious that this search method is impracticable for the networks with a large number of relay nodes. To tackle with the problem, we follow [16] and adopt the relay ordering. The MRS can be solved with linear complexity and perform close to the optimal scheme. With such an ordering, we only need to find the number of cooperating relays. In [16], it is assumed that each relay knows its own channels and the receiver knows all channel values (Under frequency flat fading channel, all channels are generated as Gaussian random variables with zero-mean and unit-variance). In this paper, we do not assume that relays or receiver knows the channel values. The receiver adopts the multi-branch joint detector (MJD) proposed in our previous works [48]. We use the steady-state mean square error (MSE) of single-branch detector (SBD) as the measurement to order the relays. Then the adjustable MRS selects sequentially the cooperating relays according to the relay ordering and obtains the optimal number of cooperating relays by comparing steady-state mean square joint error (MSJE) for different number of cooperating relay.

3.1 Preparation

The MJD adopts fractionally spaced linear filter structure, as showed in **Fig. 2**, which is capable of performing the functions of the matched filter, T-spaced equalization of the conventional linear receiver [49], and the combining technique for multiple received signals via diverse paths. The detector will directly process the sampled signals after the analogue-to-digital converter (A/D). For the received signal $r_{D_i}(t)$, the input signal of detector is $r_{D_i}(k)$. In the detector, the signal vector for $r_{D_i}(k)$ is given by

$$\boldsymbol{u}_{D_j}(n)=[r_{D_j}(n-1),r_{D_j}(n-2),\cdots,r_{D_j}(n-L_j)] \tag{6}$$

where L_j is the observation window length (OWL). The corresponding tap coefficient vector is as follows

$$\boldsymbol{c}_{D_j}(n)=[c_{D_j,n1},c_{D_j,n2},\cdots,c_{D_j,nL_j}] \tag{7}$$

where $\boldsymbol{c}_j(n)$ is initialized with $\boldsymbol{c}_j=[0,\cdots,0]$, $j\in\{D_1,D_2,\cdots,D_N\}$.

For convenience, we introduce two column vectors

$$\boldsymbol{u}_N(n)=[\boldsymbol{u}_{D_1}(n)\ \boldsymbol{u}_{D_2}(n)\cdots\boldsymbol{u}_{D_N}(n)]^T \tag{8}$$

$$\boldsymbol{c}_N(n)=[\boldsymbol{c}_{D_1}(n)\ \boldsymbol{c}_{D_2}(n)\cdots\boldsymbol{c}_{D_N}(n)]^T \tag{9}$$

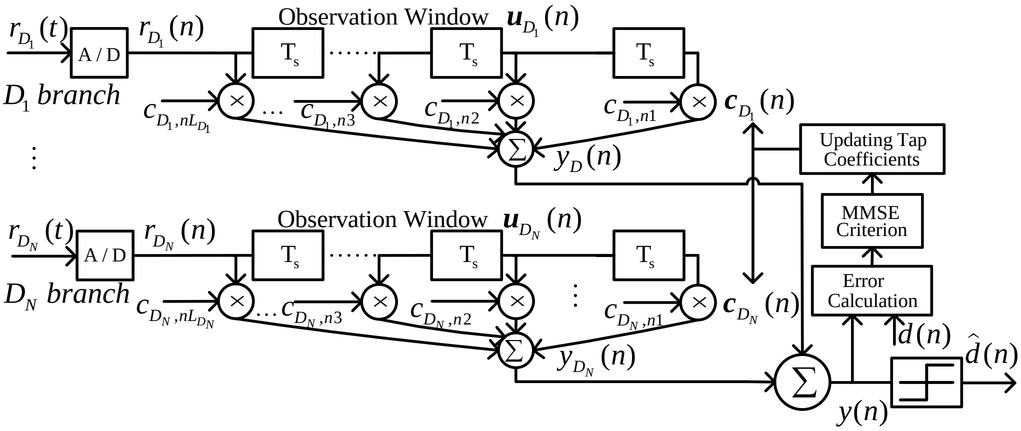

Fig. 2. Structure of MJD

Tap coefficients of the MJD are adjusted using proposed adaptive filtering algorithms in [48].

$$\boldsymbol{c}_N(n+1) = \boldsymbol{c}_N(n) + \frac{\mu}{\delta + \left\|\boldsymbol{u}_N(n)\right\|^2}\boldsymbol{u}_N(n)e_N(n) \tag{10}$$

$$e_N(n) = d(n) - \sum_{i=1}^{N} y_{D_i}(n) \tag{11}$$

$$y_{D_i}(n) = \boldsymbol{u}_{D_i}^T(n)\boldsymbol{c}_{D_i}(n) \tag{12}$$

where both μ and δ are positive constant, $e_N(n)$ is the joint error. Unlike the case in single-branch detector (only one relay participates in cooperation), in MJD, the input signals of all branches should be jointly processed.

3.2 Relay Ordering Based on Steady-State MSE

When N is 1, there is only one relay participating in the cooperation. The MJD will reduce to a single-branch detector (SBD). We will use the SBD to process the received each signal from different relays. For the received signal $r_{D_i}(k)$, the output SNR of the SBD can be given by [50]

$$\gamma_{D_i} = \frac{1 - J_{mse,D_i}}{J_{mse,D_i}} \tag{13}$$

where J_{mse,D_i} denotes the steady-state MSE, which can be obtained by averaging the mean square error signal after the convergence of the algorithm (10), as follows

$$J_{mse,D_i} = E[\left|d(n) - y_{D_i}(n)\right|^2] = \frac{\sum_{i=1}^{N_{mse}} e_{D_i}^2(i)}{N_{TS}} \tag{14}$$

where $e_{D_i}(n) = d(n) - y_{D_i}(n)$, N_{mse} denotes the number used to calculate the J_{mse,D_i}. Here, the J_{mse,D_i} is obtained with N_{mse} training sequences after the algorithm in (10) has achieved the steady-state. The ergodicity of process is assumed, thus the ensemble averages can be transformed into time averages. It is clear from (13) that the smaller the J_{mse,D_i} is, the larger the output SNR is. Therefore, the steady-state MSE can be used as the measurement to order the relays.

Similarly, we can use the method to calculate the steady-state MSE for all the received signals $r_{D_i}(k)$ with equation (14). Based on the calculation results of steady-state MSE for each received signal $r_{D_i}(k)$, the relay nodes can be ordered according to the size of steady-state MSE. If $(1, 2, \cdots, K)$ is a relay ordering for $(R_1, R_2, \cdots, R_K)$, then the ordering of steady-state MSE should satisfy $J_{mse,D_1} < J_{mse,D_2} < \cdots < J_{mse,D_K}$.

3.3 Adjustable Multiple Relay Selection Scheme

The purpose of adjustable MRS is to achieve better performance, thus, the steady-state mean square joint error (MSJE) of MJD is used as a criterion to adjust the number of relays participating in the cooperation. Based on the relay ordering in 3.2, to solve the optimal MRS problem, we only need to find the smallest value among $J_{mje\{1\}}$, $J_{mje\{1,2\}}$, $\cdots$, $J_{mje\{1,\ldots,K\}}$. $J_{mje\{1,\ldots,K\}}$ represents the steady-state MSJE to which the algorithm (10) has converged, after the processing for received multiple signals from relays $(R_1, R_2, \cdots, R_K)$ with the algorithm.

Research shows that as the number of cooperating relays exceeds a certain value, the performance gains would become smaller [51]. Therefore, there is an optimal value for the number of cooperating relays, which can achieve better tradeoff between BER performance and spectral efficiency and to save more energy. In this section, the optimal value of the number of cooperating relays is defined as the smallest integer N_o that satisfies:

$$J_{mje\{1,\ldots,N\}} - J_{mje\{1,\ldots,N-1\}} \le \varepsilon \quad for \quad all \quad N \ge N_o \tag{15}$$

where N denotes the number of relay nodes, N and N_o are positive integers, and ε is a predetermined value according to the system requirements. The meaning of (15) is to find the minimal N_o satisfying the constraint $J_{mje\{1,\ldots,N\}} - J_{mje\{1,\ldots,N-1\}} \le \varepsilon$. When the number of relay nodes participating in cooperation is larger than N_o, after the algorithm (10) has converged, any two steady-state MSJE corresponding to two successive number of cooperating relays can be regarded as same.

It is immediately clear from (15) that a cost function for searching N_o may be obtained as

$$\min\left\{N \middle| J_{mje\{1,\ldots,N\}} - J_{mje\{1,\ldots,N-1\}} \le \varepsilon\right\} \tag{16}$$

which means that the minimum N that satisfies $J_{mje\{1,\ldots,N\}} - J_{mje\{1,\ldots,N-1\}} \le \varepsilon$. Idealy, we may have $J_{mje\{1,\ldots,N\}} - J_{mje\{1,\ldots,N-1\}} < 0$, but due to the effect of noise, the $J_{mje\{1,\ldots,N\}}$ is not always less than $J_{mje\{1,\ldots,N-1\}}$. In practice, for parameter ε, it may not be chosen absolutely properly, because when N is large enough, all $J_{mje\{1,\ldots,N\}}$ are with a narrow range. In addition, although we can use (16) to obtain the optimum number N_o in the mean, the proposed algorithm may suffer from slow convergence. This is because, on average, the algorithm adjusts the number of cooperating relays by comparing $J_{mje\{1,\ldots,N\}}$ and $J_{mje\{1,\ldots,N-1\}}$, which are the steady-state MSJE of algorithm (10). Therefore, we introduce MSJE as a criterion to adjust the number of cooperating relays. The proposed algorithm is described as follows.

The different outputs of MJD with different number of cooperating relays can be used to compute a corresponding joint error signal with (11). The distinct error signals can be squared and averaged to obtain an output mean square joint error measure for adjustable MRS at each number

$$MSJE_N(n) = E[\left|d(n) - y_N(n)\right|^2] = \frac{\sum_{i=1}^{N_{TS}} e_N^2(n)}{N_{TS}} \tag{17}$$

where N_{TS} denotes the number of trainning sequences used to compute $MSJE_N(n)$, $e_N(n)$ is the joint error, and can be calculated with (11).

At each number of cooperating relays, the $MSJE_N(n)$ is obtained with N_{TS} training sequences. Ideally, each $MSJE_N(n)$ would be smaller than the previous one, $MSJE_{N-1}(n)$. In practice, this may not hold owing to errors introduced by the adaptive filtering algorithm in the form of excess MSJE (EMSJE). The aim of the number update algorithm is to detect the number of relays at which the MSJE level becomes insignificantly smaller or even larger than the previous number.

The process of adjusting the number of cooperating relays is as follows

If $MSJE_N(n) < MSJE_{N-1}(n) \Rightarrow$ add a relay

$$N(n+1) = N(n) + 1 \tag{18}$$

$$\boldsymbol{u}_N^{'}(n) = [\boldsymbol{u}_N(n)\ \boldsymbol{u}_{D_{N+1}}(n)] \tag{19}$$

$$\boldsymbol{c}_N^{'}(n) = \left[\ \boldsymbol{c}_N(n)\overbrace{00\cdots0}^{L_{N+1}}\ \right] \tag{20}$$

where $N(k)$ denotes the current number of cooperating relay at discrete time k.

If $\alpha MSJE_N(n) > MSJE_{N-1}(n) \Rightarrow$ remove a relay

$$N(n+1) = N(n) - 1 \tag{21}$$

$$\boldsymbol{u}_N^{'}(n) = [\boldsymbol{u}_{N-1}(n)] \tag{22}$$

$$\boldsymbol{c}_N^{'}(n) = \left[\boldsymbol{c}_{N-1}(n)\right] \tag{23}$$

where $0 < \alpha < 1$. The function of α is to determine the amount of worsening necessary to force the proposed algorithm to decrease the number of cooperating relays. The larger α is, the more frequently the algorithm will decrease the number of cooperating relays. If the value of α is too large, due to the influence of noise, the number of relays will be adjusted frequently, which makes it impossible to converge to the optimal relay number (only converge to a number which is less than the optimal number). Especially when the number of relays reaches a certain value, with the increase of the number of relays, the difference of MSJE between successive two numbers of relays becomes smaller and smaller, the increase of a relay is not enough to make the MSJE significantly reduced. The α works like a threshold, which makes the number of relays would not be easily reduced. Only when the condition $\alpha MSJE_N(n) > MSJE_{N-1}(n)$ is met, the number of relays would be reduced. If α is too small, when reaching a certain number of relays, the condition $\alpha MSJE_N(n) > MSJE_{N-1}(n)$ is difficult to be met. Then, the number of relays would only have the increasing trend, which may lead to the algorithm converge to a larger number of relays (larger than the optimal number).

Else $\Rightarrow$ the number of cooperating relay remains stable.

With the current adjusted number of cooperating relay, the tap coefficient vectors of all the branches are then jointly updated by the adaptive algorithm in (10).

The proposed MRS algorithm continually computes and compares the successive two MSJE for different number of cooperating relays at each iteration, then evaluates the impact the last added relay has on the MSJE level. If $MSJE_N(n)$ is much smaller than $MSJE_{N-1}(n)$, then most likely another relay node will improve the steady-state MSJE, therefore an extra relay node is added. If $\alpha MSJE_N(n)$ is larger than $MSJE_{N-1}(n)$, then the last added relay is not contributing significantly to steady-state MSJE of the MJD and can be removed. Otherwise, the number of relay nodes remains stable.

4. Simulation Results

In this section, we give simulation results to justify our analysis and to evaluate the performance of the proposed adjustable MRS scheme. Binary phase-shift keying (BPSK) is used as the modulation scheme. All nodes are assumed to have the same power. In the simulations, we consider a cooperative network with one transmit-and-receive pair and 20 relays. All channel links are assumed to be quasi-static frequency selective channels. The channel impulse response coefficients are modeled with (1), the parameters are set as $P_R = 1$, $L_{SR_i} = L_{R_iD} = 10T_f / T_s$, . $\sigma_{SR_i} = \sigma_{R_iD} = 10T_f$. and $T_s = T_f / 5$, T_s is sampling period of A/D. The OWL L_j of all the branch is set as $10T_f / T_s$ in (6).

4.1 Validation of Method of Relay Ordering

We first verify the method of relay ordering. The relay ordering is based on the comparison of steady-state MSE of SBD. Thus, we only need to verify the consistency of relay ordering based on SNR and steady-state MSE. We consider a communication system with one relay. For each calculated steady-state MSE J_{mse,D_i} with (14), a data packet is transmitted, which has 500 symbols, these symbols are used as training sequences. All calculated J_{mse,D_i} were obtained by averaging the MSE after the convergence of algorithm with (14).

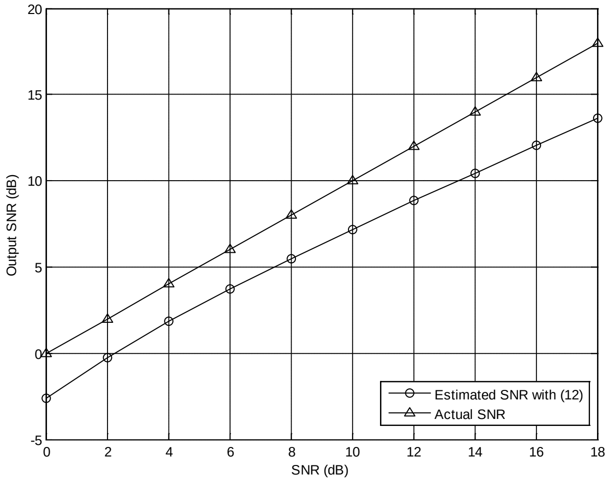

Fig. 3. Consistency validation of relay ordering

In **Fig. 3**, we compare the estimated SNR γ_{D_i} with (13) and actual SNR. It is observed that the calculation with (13) for SNR is not very accurate, which deviate from the actual SNR. However, it is noted that the estimated SNR remain the same trend as the actual SNR, that is to say, the size of estimated SNR keep the same ordering with that of actual SNR. According to the simulation results, it is proved that the method of relay ordering is feasible, we can use the steady-state MSE as the measurement to order the relay node.

4.2 Validation of Adjustable Multiple Relay Selection Scheme

Next, we would evaluate the adjustment ability of the proposed adjustable MRS scheme for the number of cooperating relays. We assume that the relay ordering $(R_1, R_2, \cdots, R_{20})$ has been obtained and $SNR_{D_i} = SNR_{D_1} - 0.4(i-1), i = 2, \cdots, 20$. To validate that the proposed adjustable MRS scheme can adaptively adjust the number of cooperating relays, at first, we would obtain the optimal number N_o by simulation.

Fig. 4 shows the BER performance when using different number of cooperating relays, the horizontal axis indicates the SNR SNR_{D_1} . In the simulation, a frequency selective channel is generated with (1). For the same frequency selective channel, a data packet of 10000 symbols is transmitted, 500 of these symbols are used as training sequences. The same received signal corresponding to the data packet is processed 200 times by the MJD. The point on BER curve is obtained by averaging the BER on each time. It is seen that the BER performance is close when the number of cooperating relays is set as 12-20. In order to achieve better tradeoff between BER performance and spectral efficiency and to save more energy, the optimal number N_o of cooperating relays is defined as the minimum number of relays which make the cooperative communication system approximate the optimal BER performance. It is observed from **Fig. 4** that the optimum number N_o is about 12.

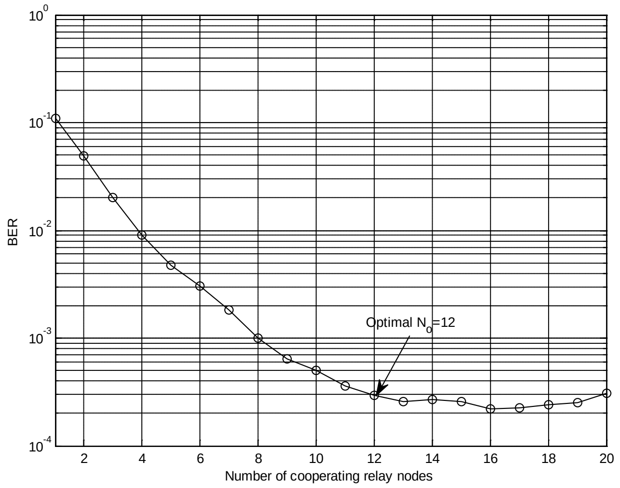

Fig. 4. BER performance for different number of relay nodes at $SNR_{D_1} = 4dB$

Then, we would evaluate the adjustment ability for the number of cooperating relays with the proposed adjustable MRS scheme. In the simulation, for the same frequency selective channel, a training sequence packet of 1000 symbols is transmitted. The same received signal corresponding to the packet is processed 20 times by the proposed adjustable MRS. The convergence curve is obtained by averaging the curve on each times. In the adjustable MRS scheme, the α is set as $\alpha = 0.979$. A full study of the effect of the parameter on performance is not reported here. **Fig. 5** shows the evolution curve of the number of cooperating relays, the horizontal axis indicates the SNR SNR_{D_1} . It is observed that the proposed adjustable MRS scheme can adaptively adjust the number of cooperating relays to about 12. The obtained number of cooperating relays approximates the optimal (minimum) number N_o in **Fig. 4**.

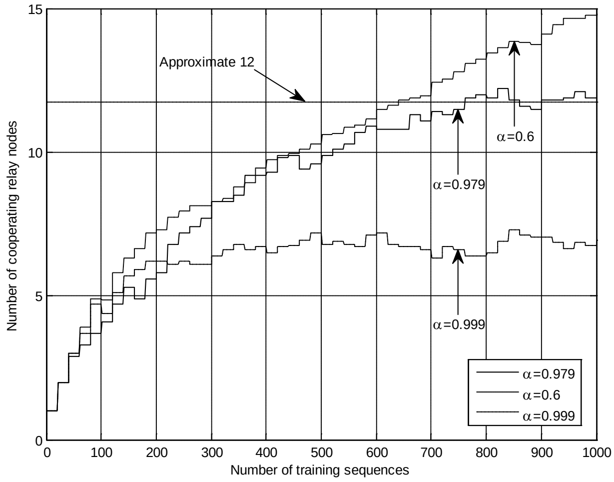

Fig. 5. Evolution curve of number of cooperating relays at $SNR_{D_1} = 4dB$

In addition, the comparison of evolution curve with different values of α is also given in the **Fig. 5**. It is observed that when α is set as 0.979, the proposed algorithm can converge to optimal number of relays as showed in **Fig. 4**. However, when α is set as 0.999 or 0.6, the number of relays can not be adjusted to optimal value N_o . This is because the α is an important parameter on adjustment of number of relays, by setting the size of α , the amount of adjusting to decrease the number of relays can be controlled.

In view of the aforementioned results, it is testified that the proposed adjustable MRS can adjust adaptively the number of cooperating relays.

4.3 Comparison of BER Performance

To compare the BER performance of different RS schemes, a Monte-Carlo simulation is set up based on the channel model (1). For each channel realization, a data packet of 10000 symbols is transmitted, 500 and 1000 of these symbols are used as training sequences for conventional RS and the proposed scheme, respectively. For comparison purposes, 500 of 10000 symbols used as the training sequences are also simulated for the proposed scheme.

In **Fig. 6**, we check the BER performance of optimal SRS [40-43], optimal MRS [44] and the proposed adjustable MRS scheme, the horizontal axis indicates the SNR SNR_{D_1} . Both optimal SRS and MRS schemes assume that full and perfect CSI of all the relayed paths at the receiver is known, while the proposed adjustable MRS scheme doesn't make the assumption. It is observed that the proposed adjustable MRS and MRS in [44] have evident BER performance improvement than optimal SRS scheme. This is because diversity gain of SRS scheme is limited. The more the number of cooperating relays is, the more diversity gain can be achieved. To meet the QoS performance required by users, multiple relays should be considered to participate in the cooperation. It is also noted that the proposed adjustable MRS with 1000 training sequences and MRS scheme in [44] achieve similar BER performance. However, compared with the MRS in [44], the proposed MRS scheme doesn't need to know the CSI at the destination node, and use less cooperating relays. For example, it is observed from **Fig. 4** that the optimal number of cooperating relays is 16 according to the MRS in [44], whereas the optimal (minimum) number is about 12 by the proposed adjustable MRS scheme. The increase of cooperating relays would degrade the spectral efficiency and energy saving. Thus, the proposed adjustable MRS scheme can achieve better tradeoff between BER performance and spectral efficiency and to save more energy. Moreover, the proposed scheme is able to adaptively adjust the number of cooperating relays according to the current CSI. Hence, the proposed scheme is more suitable for practical cooperative communication systems. In addition, it is also seen that the BER performance with 1000 training sequences is better than that with 500 training sequences. This is mainly because the proposed algorithm needs enough length of training sequences to achieve convergence, as showed in **Fig. 5**.

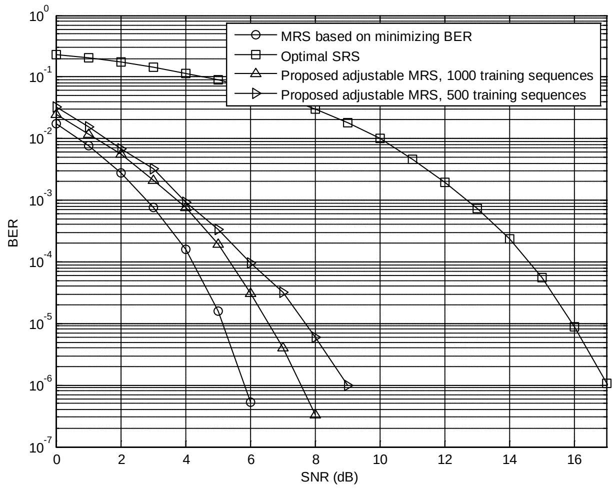

Fig. 6. BER performance of optimal SRS, MRS based on minimizing BER and the proposed adjustable MRS scheme

5. Conclusion

In this paper, an adjustable MRS scheme under frequency selective channel is proposed. The proposed scheme takes into account better tradeoffs among spectral efficiency, BER performance, and energy saving in cooperative relay networks. The proposed scheme can adaptively adjust the number of cooperating relays according to the comparison of steady-state MSJE for different number of cooperating relays, and obtain the optimal number of cooperating relays (means the minimum number of relay nodes, N_o, achieving the minimum level of steady-state MSJE).

To evaluate the performance of the proposed scheme, simulations were run using frequency selective channel model. The simulation results for the proposed scheme were compared with those of the optimal SRS and optimal MRS scheme based on minimizing BER. The BER performance of proposed MRS scheme outperforms the optimal SRS schemes, and is similar to MRS based on minimizing BER. Simulation results also show the proposed scheme can adaptively adjust the number of relay nodes according to the steady-state MSJE.

Therefore, the proposed scheme provides flexibility to adapt in fading, and enables better tradeoffs between BER performance and spectral efficiency and to save more energy in cooperative relay networks.

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