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An Opportunistic Relaying Selection Scheme Based on Relay Fairness

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Abstract

Opportunistic relaying scheme is a single cooperative relay selection method based on Channel State Information. However, the failure probability of the best relay selection may become unacceptable when the number of relays increases. Although most of the existing solutions can reduce the failure probability of relay selection, they ignore the fairness of the relay selection. In order to improve the fairness of the relay selection without affecting the failure probability of the best relay selection, we propose a modified practical best relay selection scheme in this paper, and by introducing proportional fair algorithm, the relay timer will be given a smaller correlation coefficient. The proposed method makes the probability of selection be improved. In the light of defined fairness factor, the relay fairness is represented. Simulation results show that the new algorithm can improve the fairness of the relay selection on the basis of maintaining the original failure probability of relay selection.

Keywords*: cooperative diversity, best relay, relay selection, proportional fairness*

1. Introduction

Cooperative communication technology is a kind of virtual multi-antenna technology, by the way that multiple users in the network share each other's antenna to realize communication between terminals, so as to constitute a virtual multi-antenna array to obtain the significant spatial diversity gain [1]. Its basic method is to provide an additional communication transmission path by using relay nodes for the communication between the source node and destination node, so as to improve the network throughput and enhance the network coverage. Literature [2] points out that the communication between the relay node and destination node which adopts distributed space-time coded technique can obtain the same diversity–multiplexing gain as the traditional way of MIMO. However, there are some fundamental differences between the space-time coding used in the cooperative relay channel and that used in the traditional MIMO link channel, and the application of the space-time coded in cooperative relay channel environment is still an open and challenging problem.

The literature [3] proposes a simple and practical method to choose the best relay node, which serves as an alternative solution of relay space-time coding system, and the basic idea which is choosing a relay that has the best instantaneous channel quality to participate in synergy each time. Through theoretical analysis, the article further proves that the method without using complex space-time coding technique can get the same diversity gain as the traditional cooperative diversity technology, so the method simplifies the interaction process between collaboration terminals. However, in the best relay selection algorithm proposed in [3], the selection failure may happen because of the collision when multiple nodes compete for the best relay at the same time. And as the number of competing nodes increases, the probability of the selection failure will increase further. Therefore, on the basis of the method, the literature [4] further introduces the CSMA protocol. The simulation results show that the failure probability of relay selection is reduced by two orders of magnitude because of the introduction of this scheme. But this program dose not take into account the fairness of the relay selection in the optimal relay selection process, which will lead to serious imbalance of the node's power distribution. So a new opportunistic cooperation scheme is proposed in this paper, and by introducing proportional fair algorithm, this scheme is improved. Through the simulation, the

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performance of the scheme is verified via the relay fairness and the failure probability of the best relay selection.

2. Description of the system model

As is shown in Figure 1, the system is a half-duplex two-hop wireless cooperative communication system; constituted by a source node, a destination node, and M number of candidate relay nodes. The system utilizes DF (Decode and Forward) synergistic manner, and the work can be divided into two steps. The first step, the source node sends packets to the relay nodes, and the relay monitors and decodes. The second step, the candidate relay which can decode properly triggers the timer and selects the best relay whose link performance is the best to forward data [4]. During this process, we assume that the system does not satisfy the requirement of the direct communication between the source node and the destination node. And the control packet between the relay nodes and the destination node can exchange without delay and error.

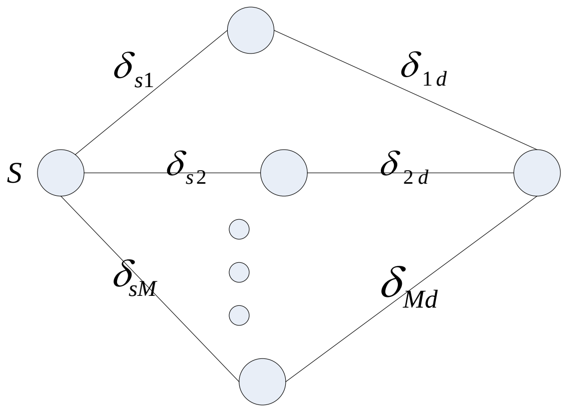

Figure 1. System Model

Assuming that the transmission channel of the system has quasi-static Rayleigh slow fading characteristics, the characteristics remain unchanged in every transmitting process and the transmissions are mutually independent. Assuming that channel gain between any node i($i \in \{s,1,\cdots,M\}$) and j($j \in \{1,\cdots,M,d\}$) is h_{ij} . Furthermore, since the opportunistic relay makes a measurement of channel at the moment of transmission packets of RTS and CTS between the source node and the destination node, so each node has known the state information about instantaneous channel of itself. We make a further suppose that the transmitter-side power keeps constant in a transmission process, and AWGN (Additive White Gaussian Noise) with zero mean and variance of N_0 exists in receiving end, so the average signal-to-noise ratio of the nodes can be expressed as $\gamma = {p_o}/{N_o}$, and we define the instantaneous received signal-to-noise ratio is $\gamma_{ij} = \gamma\left|h_{ij}\right|^2$.

As is known from the theory of opportunistic relay, relay selection algorithm selects the best relay quickly from the M candidate relay nodes according to the instantaneous channel conditions to participate in cooperative communication between the source node and the destination node at the the coherence time before the channel's variations. It should be emphasized that relay nodes have been listening instant channel conditions, and then decide which node has the best channel relay information before the channel changs, and make a choice of the best path in such conditions [5]. Specifically, each candidate relay has been listening RTS packets in transmitter and CTS packets in receiving end. From the reception of these two packets determine whether they are suitable for participation in the cooperative diversity or not. After receiving the CTS packets, each relay node i will start a timer. Instantaneous received SNR represents the performance of the link, and the initial value of the timer T_i is inversely proportional to the channel instantaneous received SNR of the corresponding relay node γ_{id}, i.e. $T_i = \lambda / \gamma_{id}$, where λ is a time constant. All relay in the process of timing is in a listening state. Assuming that all relay is visible mutually and that is to say each candidate relay node can hear each other's information. Therefore, the timer which has the maximum γ_{id}, that is to say a relay which has the best performance of instantaneous channel completes time at first, and then sends a flag logo package to inform the source node, the destination node and the other relay nodes. When other relay nodes intercept that any node has been sending logo packages or transmitting information, then the relay gives up competing automatically. After the best relay is selected, it can be used to forward information to the sink.

3. Program Description

3.1. Opportunistic Cooperation Scheme Based on CSMA Protocol

It can be seen from the above processing, when the completion time of timing of two or more relay timer is so close that the collision turns out, which will lead to the failure probability of the best relay selection [5]. For example, the timing completion time of the relay nodes i and the relay node j is too close. When relay node j firstly completes timing and sends a package flag, however, the relay i dose not detect the flag which is sent by the relay j after the completion of the timing, since the two-node time is too close. Relay i thinks itself is the best relay and send the flag. Then, there is a conflict when selecting the best relay, and with the increase of the number of competitive nodes, the probability of failure will further increase.

In order to reduce the probability of the selection failure, the literature [6] puts forward a further introduction of CSMA protocol, which is based on the method. That is to say, when the relay nodes get a conflict on the link, the nodes involved in the conflict will go back for a period of random time and then re-send the flag package. Thus, the probability of the selection failure will be greatly reduced. Even the suboptimal relay node takes participate in the communication after the backward a period of random time, the theoretical analysis shows that the similar diversity gain can be achieved, and that the more cooperative relay nodes, the smaller impact on its performance. The results of simulation also show that by introducing the scheme, the probability of the selection failure is reduced by two orders of magnitude.

In the above process, D(s) represents the relay collection which can decode properly, and we can assume that in the collection of D(s) the nth relay gets the best channel relaying information, and the maximum of instantaneous signal-to-noise ratio is γ_{nd}, then the probability of being selected of the best relay n is:

$$Pn = \sum_{D(s)} \Pr\{n \in D(s)\} \Pr\{\gamma_{kd} > \max_{\substack{i \in D(s) \\ i \neq n}} \{\gamma_{id}\}\} = \sum_{m=1}^{M} \sum_{k=1}^{\binom{M-1}{k-1}} \Pr\{\gamma_{rd} > \max_{\substack{i \in S^n_{m,k} \\ i \neq n}} \{\gamma_{id}\}\} \prod_{i \in S^n_{m,k}} \Pr\{i \in D(s)\} \prod_{i \in \overline{S}^n_{m,k}} (1 - \Pr\{i \in D(s)\}) \quad (1)$$

$s^n{}_{m,k}$ represents a subset ranked k which contains relay n among relay collection {1, 2, ..., M}. As the program uses the DF synergistic manner, assume that the relay ranked i can decode properly, and its condition is $\gamma_{si} > \mu$. Here $u = 2^{2R} - 1$, R is the efficiency of spectral. Where γ_{si} is subject to exponential distribution of parameter δ_{si} / λ, and then:

$$\Pr\{i \in D(s)\} = \Pr\{\gamma_{si} > u\} = \exp(-\frac{\lambda_{si}}{\lambda} u) \quad (2)$$

Put (2) into (1), we can get the probability of selecting the best relay node n:

$$Pn=\sum_{m=1}^{M}\sum_{k=1}^{\binom{M-1}{k-1}}\int_0^{\infty}\frac{\lambda_{nd}}{\rho}\exp(-\frac{\lambda_{nd}}{\rho}y)\prod_{\substack{i\in S_{m,k}^n\\ i\neq n}}(1-\exp(-\frac{\lambda_{id}}{\rho}y))dy$$
$$\prod_{i\in S_{m,k}^n}\exp(-\frac{\lambda_{si}}{\rho}u)\prod_{i\in \overline{S}_{m,k}^n}(1-\exp(-\frac{\lambda_{si}}{\rho}u)) \quad (3)$$

3.2. Proposed Opportunistic Cooperation Scheme

The best opportunistic relay selection scheme based on CSMA protocol only considered the performance of the relay nodes, reducing the failure probability of the best relay selection while ignoring the fairness of the candidate collaborative relay. If a candidate relay is always selected as the best node, that will lead to serious imbalance of the node power allocation. The battery of the best relay will be consumed in short time, while the other candidate partners are not be used. It is very unfair for the entire collaborative network, especially the best relay. In order to improve the fairness of the relay selection, this article introduces a proportional fair algorithm on the basis of the above program. In the improved scheme, the collection $D^{'}(s)$ is composed of candidate relay nodes which are able to decode properly and have good enough link performance of relay-destination node. And we can assume that these relay can be informed of the complete information about channel state, the i-th relay in $D^{'}(s)$ meets the condition min{γ_{si},γ_{id}}>u , and then the timing time of the best relay is :

$$T_i^{'}=\frac{\lambda^{'}}{(\delta_{si}+\delta_{id})\min\{\gamma_{si},\gamma_{id}\}} \quad (4)$$

It can be seen from the formula, in order to definite each relay's channel quality, we should take the link performance of source node-relay nodes and relay nodes- destination node into consideration. For example, the relay i has poor quality on its channel (i.e $\delta_{si}+\delta_{id}$ is larger), however, when $D^{'}(s)$ includes the relay, the relay timer will be given a smaller correlation coefficient. That brings the improvement of selecting probability, and thus the fairness of the relay has been improved.

γ_i represents min{γ_{si},γ_{id}}, and obeys exponential distribution of parameter $(\delta_{si}+\delta_{id})/\gamma_i$. $\overline{\gamma_i}$ represents $(\delta_{si}+\delta_{id})\gamma_i$, which obeys exponential distribution of parameter $1/\delta$. In this case, the probability of the n-th relay being selected is:

$$Pn=\sum_{m=1}^{M}\sum_{k=1}^{\binom{M-1}{k-1}}\Pr\{\overline{\gamma_n}>\max_{\substack{i\in S_{m,k}^n\\ i\neq n}}\{\overline{\gamma}_i\},\gamma_n>u,\gamma_i>u\}, \quad (5)$$

Where,

$$\Pr\{\overline{\gamma_n}>\max_{\substack{i\in S_{m,k}^n\\ i\neq n}}\{\overline{\gamma_i}\},\gamma_n>u,\gamma_i>u\}=\int_{(\lambda_{si}+\lambda_{id})u}^{\infty}f_{\overline{\gamma_n}}(y)\prod_{\substack{i\in S_{m,k}^n\\ i\neq k}}\Pr\{\overline{\gamma_i}<\overline{\gamma_n},\gamma_i>u\}=$$
$$\int_{\lambda_{m,k}^n}^{\infty}\frac{1}{\delta}\exp(-\frac{1}{\delta}y)\times\prod_{\substack{i\in S_{m,k}^n\\ i\neq k}}(\exp(-\frac{\lambda_{si}+\lambda_{id}}{\delta}u)-\exp(-\frac{1}{\delta}y))dy, \quad (6)$$

Put (6) into (5), then further expand it，we can get:

$$\Pr\{\overline{\gamma_n} > \max_{\substack{i\in S^n_{m,k}\\ i\neq n}}\{\overline{\gamma_i}\}, \gamma_n > u, \gamma_i > u\} = \int_{(\lambda_{si}+\lambda_{id})u}^{\infty} f_{\overline{\gamma_n}}(y) \prod_{\substack{i\in S^n_{m,k}\\ i\neq k}} \Pr\{\overline{\gamma_i} < \overline{\gamma_n}, \gamma_i > u\} =$$
$$\int_{\lambda^n_{m,k}}^{\infty} \frac{1}{\delta}\exp(-\frac{1}{\delta}y)\times \prod_{\substack{i\in S^n_{m,k}\\ i\neq k}} (\exp(-\frac{\lambda_{si}+\lambda_{id}}{\delta}u) - \exp(-\frac{1}{\delta}y))dy, \quad (7)$$

Fairness factor is given by [7] as follows:

$$F \overset{\Delta}{=} -\sum_{n=1}^{M} \overline{P_n}\frac{\log_2(\overline{P_n})}{\log_2(M)} \quad (8)$$

In the formula $\overline{P_n} = P_n / \sum_{n=1}^{M} P_n$ represents the proportional of n-th relay selection. Where $\sum_{n=1}^{M}\overline{P_n} = 1$ and 0≤F≤1. According to the definition of fairness factor, it can be seen that every relay has the same fairness when F=1, i.e P1=...=PM=1/M; and the value of the fairness factor will reduce when the relay partially involved in the communication transmitting data. Put (3) and (7) into equation (8) respectively, we can get the value of the fairness factors of the two schemes mentioned above, which can reflect different fairness of relay in these two schemes.

4. Simulation Results and Analysis

Monte Carlo simulation method is adopted in this paper, according to the established system model and assumes that the channel is quasi-static Rayleigh flat fading channel. The number of the candidate relay nodes is taken M=5 and the spectral efficiency is taken R=1 (b/s/Hz), and the value of λ is within the interval [1ms, 2ms]. On this condition, the improved opportunistic cooperation scheme was simulated, and the simulation results are shown in Figure 2. From the simulation diagram of the fairness factor and signal-to-noise ratio under different schemes we can know some results as follows. In actual program, compared with the maximum of the resulting fairness from analysis, the fairness of the best relay selections has been significantly improved in the proposed opportunistic cooperation scheme and the numeric approaches to the ideal value of 1 under the conditions of a high signal-to-noise ratio.

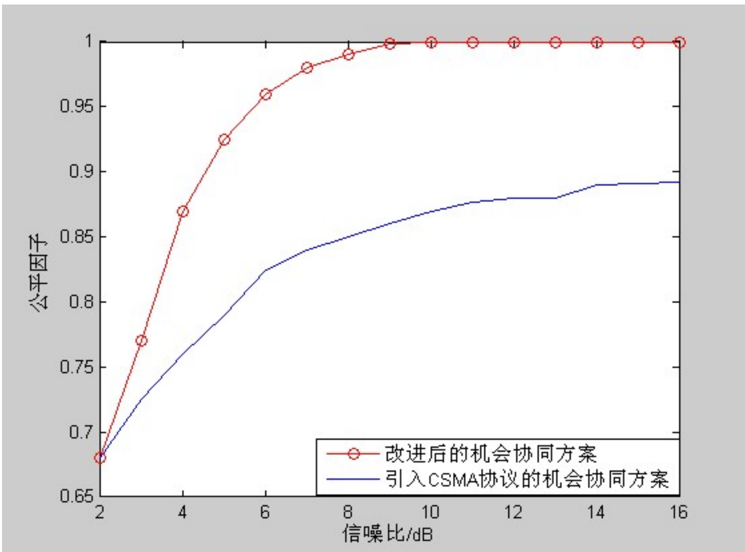

Figure 2. The Comparison of the Fair Factor Performance

Viewing from the improved process, the relay candidate set is changed from D(s) to $D^{'}(s)$ when the fairness factor is introduced to the best relay selection scheme based on CSMA protocol, and then the range of choices was expanded.

According to the analysis of [6], the timing completion time of two or more relay timers was so close that lead to the collision, and then the resulting the failure probability of the best relay selection was :

$$P_{rc} = P_r(anyT_j < T_b + c / T_j \neq T_b)$$
$$j \in [1, M] = P_r[\frac{1}{h_{(2)}} < \frac{1}{h_{(1)}} + \frac{c}{\lambda}] \quad (9)$$

Where c is collision's time, $h_1, h_2 \cdots > h_M$ is the new sequence from the descending sorting of {hi, i=1, ..., M}.

When the set that constituted by the candidate relay changed into the set $D^{'}(s)$, the timing time of the best relay was shown in formula (4). Compared with the original timing time, the timer only has been given a small correlation coefficients. Then the failure probability of the best relay selection was:

$$P_{rc} = P_r(anyT_j < T_b + c^{'} / T_j \neq T_b)$$
$$j \in [1, M] = P_r[\frac{\delta_{si} + \delta_{id}}{h^{'}_{(2)}} < \frac{\delta_{si} + \delta_{id}}{h^{'}_{(1)}} + \frac{c^{'}}{\lambda}] \quad (10)$$

Figure 3 shows the comparison of the failure probability of the best relay selection under different scenarios. The Simulation results show that the failure probability of the best relay selection in the proposed opportunistic cooperation scheme is substantially equal to that of the opportunistic cooperation scheme based on CSMA protocol. It improves the fairness of relay selection, and the performance of the best relay selection was not affected.

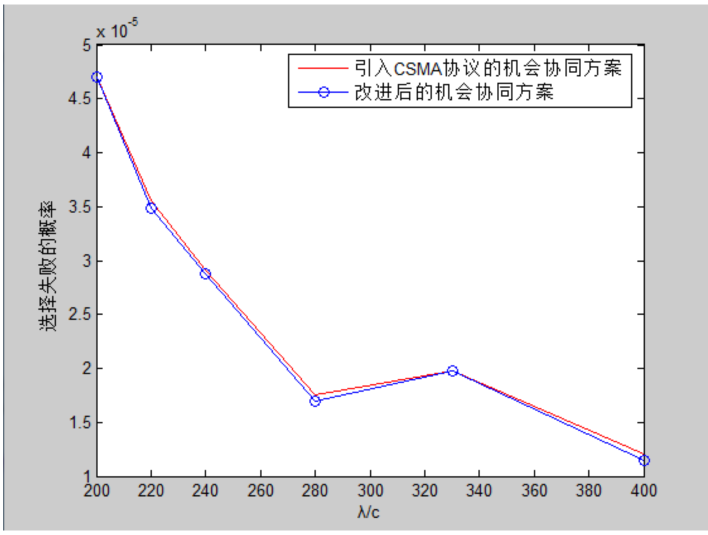

Figure 3. The Comparison of the Failure Probability of the Best Relay Selection

5. Conclusion

In cooperative diversity system, the best relay selection method based on CSMA scheme can effectively reduce the probability of the selection failure which may happen because of the collision, and the failure probability of relay selection is reduced by two orders of magnitude. But this program dose not take into account the fairness of the relay selection in the best relay selection process, which will lead to serious imbalance of the node's power distribution. Based on the constructed system model, a new opportunistic cooperation scheme is proposed, and by introducing proportional fair algorithm, this scheme is improved. At the same time, the fairness and the failure probability of the best relay selection are analyzed. Numerical simulation indicates that the proposed opportunistic cooperation scheme could greatly improve the relay fairness, and it will not affect the probability of failure of the original relay selection. This program can optimize the overall performance of the system and contribute to the practical application of cooperative communication technology.

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