Multi-Relay Selection Strategy for Device to Device Communication*

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Abstract - Introducing relaying nodes to D2D (Device to Device) communication system can effectively improve the system performance. However, the quality of direct D2D communication cannot be guaranteed when the users are far from each other, the effect of relaying node becomes particularly important in this case. In this paper, we studied different relaying selection strategies of D2D communication in cellular network, in which we take the mutual interference between the D2D pairs and cellular users into consideration. The selection strategies we proposed can adaptively determine the number of relaying nodes according to specific context. Finally we compare the proposed relaying selection strategy with simulation results and analyze their performances.

Index Terms - Device to Device (D2D); Relay Selection; Network Lifetime.

1. Introduction

With the rapid development of mobile communication, bandwidth below 5G is becoming more and more crowed and the reuse of band resources is particularly urgent in recent years [1]. Introducing Device to Device (D2D) communication into cellular network can effectively increase the utilization of band resources and reduce the load of base station. But the problem (i.e., poor reliability of the edge user in the cellular network) also occurs in the D2D communication system. So it is important to introduce relay scheme into D2D communication to enhance the coverage of the system and provide better services. There are a variety of relay selections at present. SRENG V, YANIKOMEROGLU H, Falconer D D [2] proposed three relay strategies according to the distance between two nodes. It is simple to select the best relay node with shortest relay distance; however the symbol error rate of the whole system will dramatically increase if the channel between two nodes experience deep fading. HASNA M O, ALOUINI M S [3] proposed a relay selection scheme according to the harmonic mean of the SNR of two channels and SU W, IBRAHIM A S, SADEK A K [4] further analyzed the problem of when to cooperate and whom to cooperate with. [5]-[6] are focused on the optimization of above two selection. Although the strategy (i.e., selecting the relay node with best the channel state information) outperforms the relaying node selection based solely on distance, the former selection has higher signaling overhead. This disadvantage must be weighed against its outperformance. There are some other factors to consider, A. Bletsas, A. Khisti, D. P. Reed, and A. Lippman[8] take the network lifetime into consideration during the relaying selection. We should notice that users in traditional cellular network will not interfere to each other as they use different resources. In our case, the D2D users reuse the cellular resources during the communication, so the interference can't be ignored. The selection strategy we propose differs from traditional relaying selection algorithm in two aspects:

(1) The transmission power of D2D users should be confined. The signal transmitted by D2D user may produce interference to base station, which may affect the normal cellular communication.

(2) The number of relaying nodes cannot be predicted, there may be one or more relaying nodes in communication according to specific context.

The rest of the paper is organized as follows: In Section 2, we describe the system model and analyze the interference between base station and D2D users. In Section 3, we propose different relying strategy reusing the uplink (UL) cellular resources. Simulation results are presented in Section 4 and Section 5 concludes the paper.

2. System Model and Problem Formulation

Fig.1 shows the scenario we consider in this paper, there are M cellular users (i.e., $C_1, C_2, ..., C_M$) and one D2D pair (i.e., a

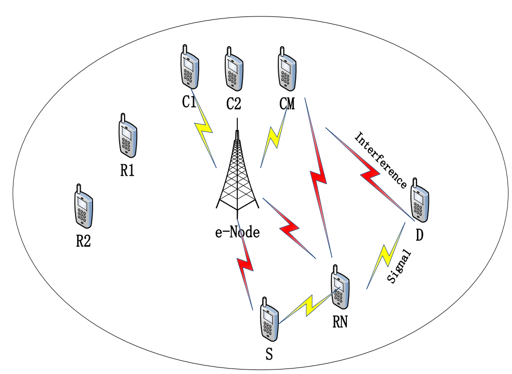

Fig.1 System model of D2D communication

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D2D transmitter, S, and a D2D receiver, D) and N idle users (i.e., $R_1, R_2, ..., R_N$) exist in a single cell[7]. D2D users can reuse both the uplink and downlink resources of the cellular network. However, they have different system performance. If D2D users reuse the uplink resources, the cellular user will interfere to the D2D receiver and the base station will be affected by D2D users at the same time, which are reflected in Fig.2-1 and Fig.2-2. On the contrary, if D2D users reuse the downlink resources, the D2D user will affect the receiving signal of the cellular user and the base station will also interfere to the D2D receiver, which is reflected in Fig.2-3 and Fig.2-4. From the above analysis, we know that reusing the uplink resources outperforms the later with the following reasons: If we reuse the uplink resource, the interference to D2D user comes from cellular user. However, the interference mainly comes from the base station if we reuse the downlink resource. We also know that the base station always has a larger transmit power than the mobile user, thus it will cause more interference to D2D user. So we reuse the uplink resource in this paper. What's more, to prevent the accumulated interference, we assume D2D pairs reuse different cellular resources.

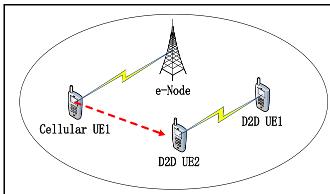

Fig.2-1 Interference from cellular user to D2D user

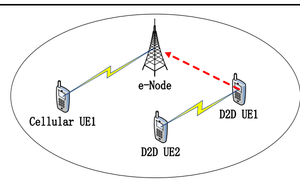

Fig.2-2 Interference from D2D user to base station

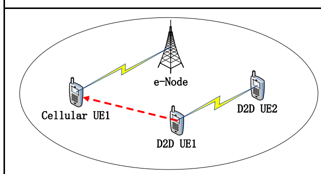

Fig.2-3 Interference from D2D user to cellular user

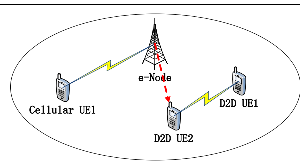

Fig.2-4 Interference from base to D2D user

Each communication in D2D system contains two stages. In the first stage, the source node S transmits its signals (denoted by x) to relaying nodes. The received signal at relaying node and destination node can be denoted by:

$$Y_{SRi} = \sqrt{P_S} h_{SRi} x + I_{Ri}^{j} + n_0 S. \quad (1)$$

$$Y_{SD} = \sqrt{P_S} h_{SD} x + I_{D}^{j'} + n_0. \quad (2)$$

Where I_{Ri}^{j} and $I_{D}^{j'}$ are the interference from the cellular user to the i-th relay and destination respectively. n_0 is the additive white noise, P_S is the transmitted power at source node. h_{SRi} and h_{SD} are the channel coefficients from the source to relay and destination, which are modeled as Rayleigh random variables with variance $d_{SRi}^{-\alpha}$ and $d_{SD}^{-\alpha}$ respectively. α is the path-loss constant and d_{AB} denotes the distance between A and B.

In the second stage, the relaying nodes forward their received signals to the destination node D. The signal forwarded by relaying node i can be written as:

$$Y_{RiD} = \sqrt{P_i} h_{RiD} x + I_{D}^{'} + n_0. \quad (3)$$

Where P_i is the transmitted power at relaying node i and $I_{D}^{'}$ is the interference from cellular to D.

Assuming DF (Decode and Forward) mode is adopted in transmission. From equation (2), we can get the received SNR at destination when S directly transmits signal to D without relaying nodes:

$$SNR_{SD} = \frac{P_S |h_{SD}|^2}{I_D^j + N_0}. \quad (4)$$

We also assume the decode SNR threshold is set to be γ_T. If $SNR_{SD} > \gamma_T$, we know that the channel between S and D is good enough to do the direct communication without relying nodes. However, if $SNR_{SD} < \gamma_T$, the communication must be assisted by suitable relays to guarantee the service quality. The relay selection strategy is discussed in the next section.

3. Relay Selection Strategy

In this section, we propose several relay selection strategies for the scenario shown in Fig.1. We take both the path-loss and interference from cellular user into consideration. There may be one or more relaying nodes according to specific context. The selection process is described as follows:

(1) First, source S sends a flag signal (i.e., RTS) to base station and destination. With the received signal, base station and D can evaluate the channel coefficient between S and them, which can be written as: h_{SB}, h_{SD}. h_{SB} and $|h_{SD}|$ are Rayleigh random variable with variance $d_{SB}^{-\alpha}$, $d_{SD}^{-\alpha}$. d_{SB} (d_{SD}) is the distance between S and base station (D). From section 2, we know that base station bears interference from D2D user if we reusing the uplink resource. To guarantee the normal cellular communication, the interference must be restricted, which means we must restrict the transmit power of source node. If the interfere threshold at base is γ_{th}, the interfere power received at base is $P_S |h_{SB}|^2$, it be smaller than interfere threshold. So we can get $P_S |h_{SB}|^2 < \gamma_{th}$, which mean the largest transmit power of S is

$$P_S = \frac{\gamma_{th}}{|h_{SB}|^2}. \quad (5)$$

With equation (5), the judgment condition of whether a relay is needed can be rewritten as:

$$\frac{|h_{SD}|^2 \gamma_{th}}{|h_{SB}|^2 (I_D^j + N_0)} > \gamma_T \quad (6)$$

If $\frac{|h_{SD}|^2 \gamma_{th}}{|h_{SB}|^2 (I_D^j + N_0)} > \gamma_T$ succeeds, S communicates with D without any relaying nodes, if equation (6) isn't satisfied, S broadcasts a flag ROR (i.e., Request of Relay).

(2) Upon receiving the signal ROR, each relay estimate their channel coefficient to S, which can be denoted by h_{SRi}. $|h_{SRi}|$ is Rayleigh random variable with variance $d_{SRi}^{-\alpha}$, if

$$P_S |h_{SRi}|^2 = \frac{\gamma_{th}}{|h_{SB}|^2} |h_{SRi}|^2 < \gamma_T. \quad (7)$$

the i-th node is not suitable to act as relay and Ri backs off, otherwise the we add Ri the into candidate relay set C_1.

(3) Sort the candidate relays in C_1 according to some criterion (which will be discussed later).

(4) Assume the final relay set is C_2 (initialized to be $\varnothing$ first). Sequentially adding the nodes in C_1 to C_2 until the accumulated SNR at D is larger than decode threshold γ_T.

We discuss the criterion in step (3) in detail here.

- Sort according to the received SNR at D

Each node R_i in set C_1 sends a flag to D and base station, with this flag they can estimate their channel coefficient to R_i, which can be denoted by h_{RiB} and h_{RiD}. Similar to step (1), we can estimate the maximum transmit power of R_i, that is $P_i = \frac{\gamma_{th}}{|h_{RiB}|^2}$. So the received SNR at D is:

$$SNR_i = \frac{\gamma_{th}}{|h_{RiB}|^2} |h_{RiD}|^2. \quad (8)$$

Then we can sort relays in C_1 according to SNR_i. To simplify the SNR_i, we ignore the interference from cellular user to D, but we take the interference into consideration when the relays are determined. Here we use a distributed method to sort these nodes. For each node in C_1, we set up a timer with initial value:

$$T_i = \frac{\lambda}{\frac{\gamma_{th}}{|h_{RiB}|^2} |h_{RiD}|^2}. \quad (9)$$

Where λ is a const with unit of time [8]. From (7), we know that the smaller T_i is, the earlier R_i will be selected out.

- Sort according to the distance between R_i and D

To sort nodes with method above, we need to exchange a lot of flag signals between R_i and base station or D, which brings extra overhead to the system. To simplify the selection process, we can sort nodes just according to their distance to D. We set a timer with initial value:

$$T_i = \lambda d_{RiD} \quad (10)$$

The smaller d_{RiD} is, the earlier R_i will be selected out.

- Sort according to both SNR and network lifetime

If a node is selected as relay at last round, there is a big possibility that it will still be a relay at next round. The relay will be prematurely depleted out due to excessively act as relay. So we need to take both the SNR and network lifetime into consideration. Here we define network lifetime as the duration that all nodes can work normally. The weighted metric is set to:

$$\mu_i = \varepsilon(\frac{E_i}{E})^{1/2} + (1-\varepsilon)(1-2^{-0.1 h_{RiD}}). \quad (11)$$

Where E_i is the remaining energy of R_i, E is the initial energy of each node. ε is the weighed coefficient. Each node sets its timer with initial value:

$$T_i = \frac{\lambda}{\mu_i}. \quad (12)$$

After step (3), we can get the final relay nodes set C_2. To further decrease the interference between cellular user and D in the second stage, it's necessary to optimize the resources scheduling. The method is discussed as follows:

Select out a node in C_2, then this node sends a flag to all M cellular users, with this flag signal we can get the channel coefficient between R_i and all these M cellular users. Resource of cellular user whose channel coefficient is the worst to R_i will be reused by R_i, thus we can guarantee the interference to be the smallest. Assume the transmit power of cellular user is P_e, the interference it produces to D can be written as:

$$I_i = P_e |h_{eD}|^2. \quad (13)$$

It should be pointed out that all the channels are assumed to be symmetrical. Repeating this process until all nodes in C_2 are selected out.

4. Simulation and Analysis

In this section, we compare the performances with different relay selection strategies. We assume the radius of the base station is 500 meters and D2D pairs are located at half the radius to base station. Number of the idle users (i.e., they are random distributed at circle domain) varies from 15 to 40, the decode threshold is set to be 10 dB.

Fig.3 depicts the total power needed with different relay selection strategies. From this picture, we can see that to sort according to SNR has the smallest transmit power, which is followed by selection according to distance. Here we assume there is no deep fading in the transmitting link (i.e., the path-loss varies from 3 to 3.3); the required total transmit power with consideration of network lifetime is about 20% larger with respect to the "SNR" selection algorithm. We still find the required power of these algorithms decrease with the increasing of idle users; this is as possibility to select out a better relaying node increase with the increasing of idle user number.

Fig.4 depicts the needed relay number for each selection strategy. Similar to Fig.3, selection according to the received signal needs the least relay numbers, the random selection still has the worst performance.

Fig.5 depicts the network lifetime of each selection strategy. From this picture, we know that SNR-based selection strategy has almost the same lifetime compared with random strategy; this is because the random strategy has the largest relay number, which leads to a low lifetime of the whole network. Lifetime of the strategy that take both the remaining energy and SNR is 50% larger than SNR-based algorithm.

Fig. 6 shows the comparison of transmit power before and after resource scheduling. We assume there are 50 cellular users in the region and the distance between S and D is 40 meters, the iteration number is 1000. It is clear that after the resource scheduling the needed transmit power is reduced by 20%.

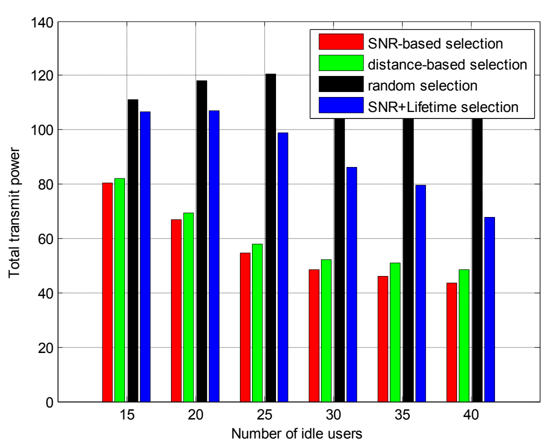

Fig.3 Transmit power of different selection strategies

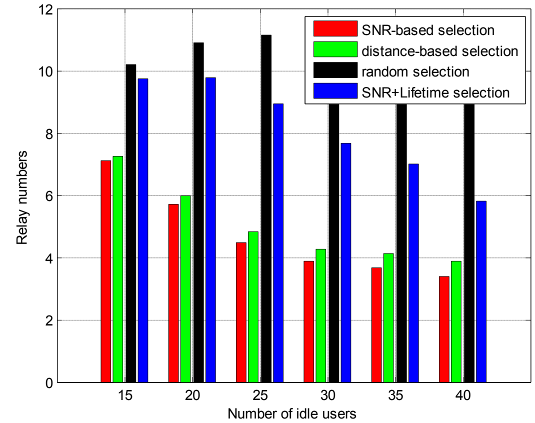

Fig.4 Relay number for each selection strategy

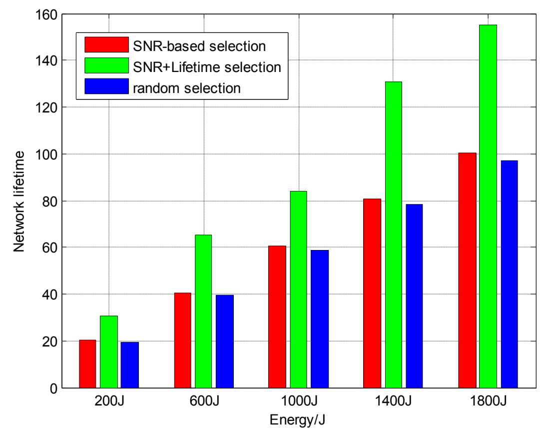

Fig.5 Network lifetime of different selection strategy

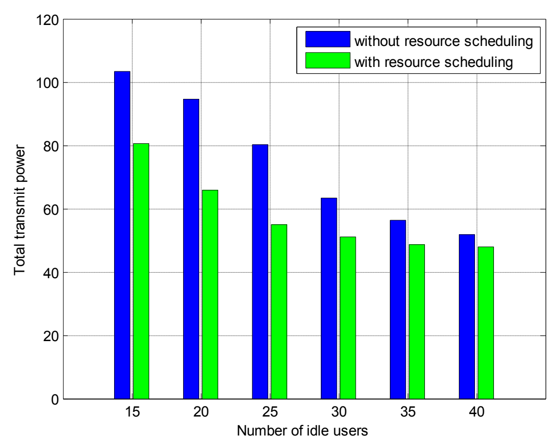

Fig.6 Comparison of transmit power with and without resource scheduling

5. Conclusions

In this paper, we propose three relay selection strategies and compare their system performance. SNR-based selection strategy is better than distance-based selection strategy; however, the later outperforms the former one in terms of complexity. Therefore, in system with stringent energy requirements, SNR-based selection strategy is superior. While in the system that is more sensitive to transmission delay, the distance-based selection strategy is better; as the selection process is very simple. However, neither of the two algorithms considers the lifetime of the system, this paper also propose a relay selection, which take both SNR and remaining energy into consideration; this method can extend the lifetime of the entire system at the expense of the transmission power, which is very useful in energy-constrained terminals (i.e., mobile phones). Finally, we carried out resource scheduling for the above-described relay algorithms, which can further reduce the energy consumption of the entire system.

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