Interference Cancellation for Relay-Assisted D2D Communication

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Abstract

Relay-assisted D2D communication extends the communication range of the D2D pairs and helps users to form D2D pairs effectively. However, due to the introduction of the multi-hop relaying, the D2D communication has to occupy extra transmission time, which may decrease the efficiency of the communication system. In this paper, we propose a scheme to make node receive D2D signal and BS signal at overlapping time to improve the spectrum efficiency according to ZigZag decoding and successive-interference-cancellation (SIC). In this way, more data can be delivered during the same duration, thus the network throughput can be further improved. Numerical results verify the performance improvement of the proposed scheme when compared with a baseline scheme. Moreover, we expand the proposed scheme from one-hop relay scenario to multi-hop relay scenario.

Keywords: Relay-assisted D2D, Interference Cancellation, Multi-hop relay

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1. Introduction

With the tremendous growing of the demand for user services and data requests, the traditional cellular network may not meet the requirements of massive data link services. Meanwhile the direct data exchange between mobile users is possible via device-to-device (D2D) communication, which has the potential to improve the spectrum efficiency. Recently, D2D communication has attracted much attention from both academic and industrial fields [1][5]. By means of spectrum sharing, D2D users can exploit the network topology to render additional gains in the network throughput[2][3][6].

D2D communication without multi-hop relaying has been widely discussed, and the introduction of relay-assisted D2D communication can significantly reduce the system outage probability[12]. Generally, the relay selection directly affects the performance of relay-assisted D2D communication system [7]. The relaying technology expands the communication range of the D2D pair and enhances the reliability of the D2D communication. Therefore, the relay-assisted D2D communication is attracting more and more attention.

A plethora of studies are about improving the efficiency of the relay-assisted D2D system. In [12], the authors derived out the premise of interference constraint for the relay-assisted D2D communication mode, and gave the advice of criteria based on the optimal path selection and system capacity in cellular network. In [13], authors considered interference constraint conditions using different algorithms such as Kuhn-Munkras (KM) algorithm and greedy algorithm to make the relay routing selection decision. In [7][22], authors developed several distributed resource management schemes for D2D communication underlaying cellular networks. In the distributed resource management scheme, each D2D user could decide the transmission resources and power independently. In [8], authors proposed two types of efficient algorithms, analyzed the optimal design of D2D spatial density and transmit power, and derived the achievable transmission capacity of multi-hop D2D system in closed-form expression, to achieve the maximum capacity while minimizing the total interference power. In [16], authors propose a solution using message passing technique where each user equipment sends and information messages to/from the relay node in an iterative manner with the goal of achieving an optimal allocation. In [9][21], authors proposed a D2D cooperative relay scheme to relieve the congestion problem.

In summary, the introduction of relay-assisted D2D communication will bring many benefits, but there will also be a lot of challenges[10]. Generally, the circumstance of interference and the transmission strategy will have different characteristics, which need to be considered. For example, [12] and [13] have provided solutions to the case of interference constraints. One salient feature of our paper is the utilization of interference cancellation and ZigZag[14][15], i.e., we exploit interferences, and then propose a solution to remove such interferences. Despite the introduction of the interference, the proposed solution can signidicantly improve the spectrum efficiency of D2D communication. We provide an idea that they may work together under the premise of meeting certain delay constraint. It does help some cases like multi video conference or applications which need the help of both BS and other user under the premise of meeting certain delay constraint. Besides, Our strategy can be used not only in one-hop relay assist D2D communication but also in multi-hop relay assisted D2D communication. We expand the sense to multi-hop relay assisted D2D communication and found that it is even better than one-hop case.

2. System Model

The basic scenario with two types of communication mode is depicted in Fig. 1. Specifically, one mode is cellular communication mode, i.e., users communicate with the base station (BS) through the coordination and scheduling of the BS. The other mode is D2D communication mode, in which users communicate with each other directly or via relay nodes. In such scenario, there are several cellular users and D2D users share the downlink frequency of the cellular network in underlaying method.

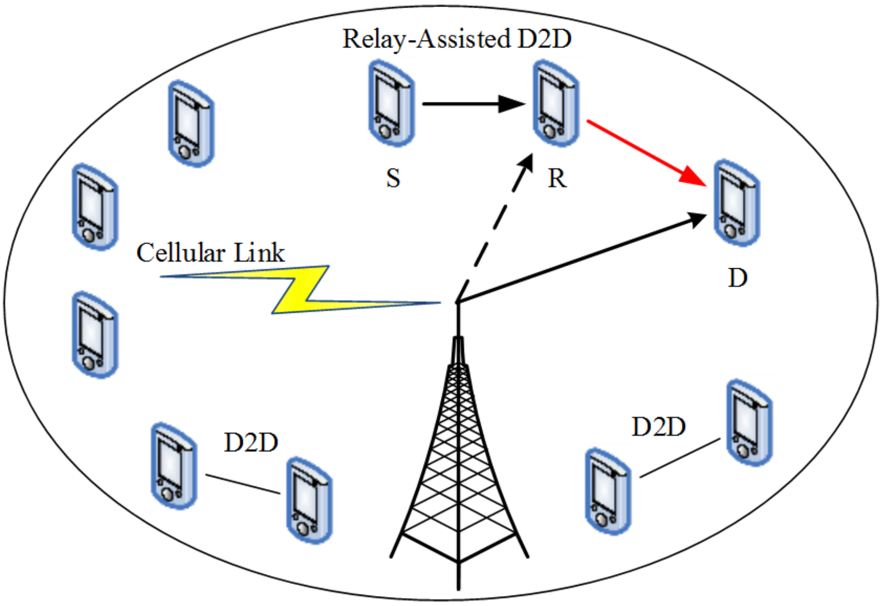

Fig. 1 The cellular network scenario with D2D communication. The solid line represents the signal transmission and the dashed line represents the interference caused by BS to node R

Table 1. The timeline of the conventional scheme

	T1	T2	T3
BS	idle	idle	transmit
S	transmit	idle	idle
R	receive	transmit	idle
D	idle	receive	receive

Table 2. The timeline of the proposed scheme

	T1	T2
BS	transmit	idle
S	transmit	idle
R	receive	transmit
D	idle	receive

A relay-assisted D2D communication model is illustrated in **Fig. 1**, we assume that the data from BS can be transmitted to node D directly while the data from node S cannot be transmitted tonode D directly, thus node S needs to transmit the data via a relay node R. Specifically,, the data has to be transmitted from node S to node R, and then goes ahead from node R to node D. In the conventional inteference avoidance scheme (as show in **Table 1.**), such process needs to occupy three time slots at least. Specifically, the node D needs to keep idle state at the first time slot, since the data is transmitted from node S to node R, and the BS is not allowed to cause interferece to the S-to-R communucation link. At the second time slot, node R forwards the received data to node D, while node S and the BS have to keep silent. At the third time slot, the BS transmits data to node D. Therefore, node D can receive all the packets from the BS and node S. The BS does not transmit data to node D at the first time slot in the conventional scheme to avoid interference to node R, even through node D has the possibility to receive the data. In contrast, when we consider the case that the interference is allowed, i.e., the S-to-R and BS-to-D communcations can occur at the same time slot, a novel interference cancellation scheme can be proposed to improve the system throughput. **Table 2** shows the two-slot operation of the proposed scheme, which is different from the three-slot operation of the conventional schcme. The spectrum efficiency improvement of the proposed scheme can be significant. However, the obtaining the data from the BS and node S at node D correctly via the proposed scheme is a challenging problem. We will solve such problem in the following sections of this paper.

3. Using the interference cancellation scheme to improve the spectrum efficiency

The communication process can be described as follows: at the first time slot, node S sends the packet to relay node R, and the BS transmits packet to the node D at the same time slot. At this instant, we can imagine that node D can decode the complete packet from the BS, which is interference-free, while relay node R gets a collision packet. Since the collision packet consists of two different packets from two different sources, the collision of packets will be slightly staggered over the timeline as shown in **Fig. 2** even though node S and the BS transmit packets at the same time slot.

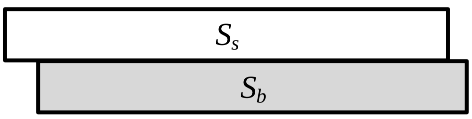

Fig. 2 Packet collision at the relay node. S_b represents the packet from the BS and S_s represents the packet from node S

At the second time slot, since node R cannot decode the collision packet, the collision packet will be amplify-forwarded to node D. The collision packet can be decoded at node D with the assitance of the packet obtained from the BS at the first time slot. Based on this observation, we come up with a interference cancellation scheme to decode the collision packet at node D.

Now we use the equation to describe the communication process. The packet from node S to node D is expressed as S , and the packet fromthe BSto node D is represented by X . At the first time slot T_1, the signals received by node R and node D can be expressed as follows, respectively

$$Y_R^{T_1} = H_{SR}S + H_{BR}X + N_0, \tag{1}$$

$$Y_D^{T_1} = H_{BD}X + N_1. \tag{2}$$

At the second time slot T_2, the signal received by node D can be expressed as:

$$Y_D^{T_2} = H_{RD}\alpha Y_R^{T_1} + N_2, \tag{3}$$

where H represents the channel matrix between two nodes (the subscript) and we suppose that node D and node R can obtain H. We use α to denote the forward amplification factor of node R. N_0, N_1 and N_2 represent Gaussian additive white noises.

Put (1) into (2) and(3), we have two linear equations with two unknown variables, thus node D can get S and X:

$$X = \frac{Y_D^{T_1} - N_1}{H_{BD}} \tag{4}$$

$$S = \frac{1}{H_{SR}}\left(\frac{Y_D^{T_2} - N_2}{\alpha H_{RD}} - \frac{H_{BR}(Y_D^{T_1} - N_1)}{H_{BD}} - N_0\right) \tag{5}$$

If the channel condition is good enough, i.e., the signal-to-noise ratio (SNR) of data from the BS to node D and the SNR of data from node S to node R are adequately high, the noise signal N_0, N_1 and N_2 can be negligible. If the relay forward amplification factor α is 1, then S and X can be simplified as :

$$X = \frac{Y_D^{T_1}}{H_{BD}}, \tag{6}$$

$$S = \frac{1}{H_{SR}}\left(\frac{Y_D^{T_2}}{H_{RD}} - \frac{H_{BR}Y_D^{T_1}}{H_{BD}}\right). \tag{7}$$

Clearly, this is a closed-form expression, which can be solved directly with low complexity.

4. The performance analysis

We assume that the data transmission is synchronous at the packet-level, while it is asynchronous at the symbolic-level. In this section, we will theoretically analyze the impact of the proposed scheme on the system performances of the relay-assisted D2D communication.

4.1 The impact on the throughput performance

We first analyze the impact on the system throughput. The rate of D2D communication ($S \to R, R \to D$) is denoted by r_s (in bit/second), the rate of $BS \to D$ is denoted by r_b (in bit/second). The length of the packet, which is defined as the number of contained bits, is denoted by l_s (for packet from node S to node D) and l_b (for packet from BS to node D), they are the same for both schemes. The completion time (in second) of the communication process is t_s (for packet from node S to node D) or t_b (for packet from the BS to node D). For each scheme (**Table 1**, **Table 2**), we have the following equations:

$$t_s = t_{sr} + t_{rd} , \tag{8}$$

$$t_b = \frac{l_b}{r_b} , \tag{9}$$

For the conventional scheme, the total transmission time is

$$t = t_b + t_s = \frac{l_b}{r_b} + t_{sr} + t_{rd} . \tag{10}$$

The total transmission rate is

$$r = \frac{l_s + l_b}{t_b + t_{sr} + t_{rd}} . \tag{11}$$

If we use the interference cancellation scheme, the total transmission time is

$$t_{IC} = t_{sr} + t_b - t_{sb}^{op} + t_{rd} . \tag{12}$$

Here t_{sb}^{op} represents the overlapping time for a collision packet.

Clearly, the total transmission rate is

$$r_{IC} = \frac{l_s + l_b}{t_{sr} + t_b - t_{sb}^{op} + t_{rd}} . \tag{13}$$

The ratio of r_{IC} to r can be obtained as follows

$$\frac{r_{IC}}{r} = \frac{t_{sr} + t_{rd} + t_b}{t_{sr} + t_b - t_{sb}^{op} + t_{rd}} . \tag{14}$$

We assume that $l_s = l_b$ and the data rate in each time slot is the same ($r_{BS \to D} = r_{S \to R} = r_{R \to D}$) for both schemes, thus we have $t_{sr} = t_{rd} = t_b$ for both schemes. The transmission sequence is illustrated in **Fig. 3 .** According to the above equations, we know that the interference cancellation scheme can improve the overall transmission rate by up to 50% if the overlapping time at the first time slot is close to t_b or t_{sr}. However, the throughput would be degraded when the interference caused by the proposed scheme results in a high bit error rate (BER).

4.2 The impact on the BER performance

In this section, we will analyze the impact of the interference cancellation scheme on the BER.

Based on equations (1) - (7), the collision packet can be decoded accordingly.

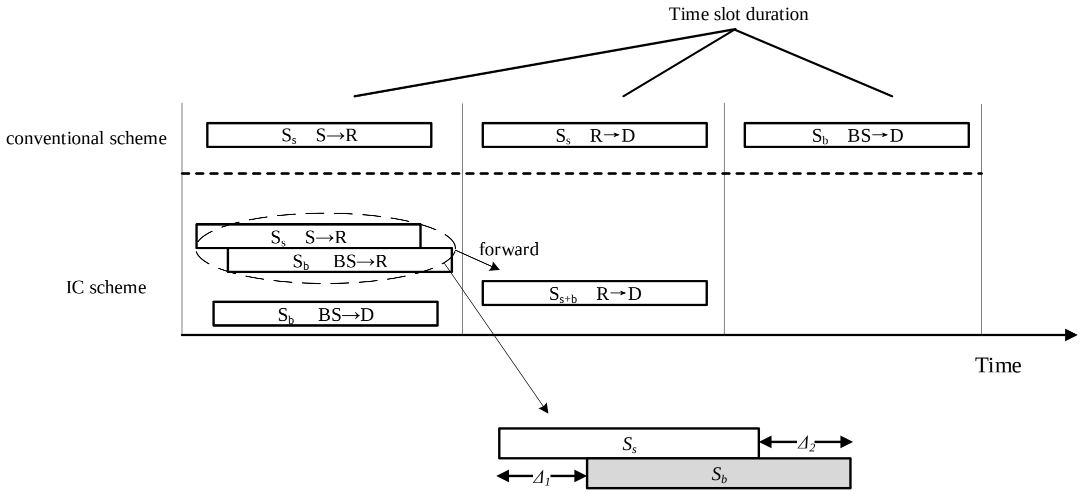

Fig. 3 Transmission sequence and collision packet at the relay node

Generally, the distance between node S and node R is relatively shorter than the distance between the BS and node R. We assume that the packet from node S arrives at node R first. In fact, if the packet from the BS arrives at R first, the process of analysis is similar.

In **Fig. 3**, we suppose that S_s and S_b represent the packets from node S and the packet from the BS, respectively. y_R(t) represents the continuous-time signal received by node R at the first time slot. y_{RD}(t) represents the continuous-time signal received by node D at the first time slot. y_{RD}(t) represents the continuous-time signal received at the second time slot from node R to node D. . Moreover, $y_R[k]=y_R(kT_s)$, k is an integer. To simplify the analysis, we assume that the BPSK (Binary Phase Shift Keying) modulation is adopted in the system, so that in each time slot we have $y_R[k]=y_R(kT_s)$, $y_D[k]=y_D(kT_s)$, $y_{RD}[k]=y_{RD}(kT_s)\in\{-1,1\}^2$ [4]. Notice that, the analysis can also be extended to other modulation cases. The continuous-time signals received by node R and node D can be represented as follows:

$$y_D(t)=h_{BD}s_b(t)+z_1(t), \tag{15}$$

$$y_R(t)=h_{SR}s_s(t)+h_{BR}s_b(t-\Delta_1T_s)+z_2(t), \tag{16}$$

$$y_{RD}(t)=h_{RD}y_R(t)+z_3(t). \tag{17}$$

Combining (15) and (16) with (17), we have

$$y_{RD}(t)=h_{RD}h_{SR}s_s(t)+h_{RD}h_{BR}s_b(t-\Delta_1T_s)+h_{RD}z_2(t)+z_3(t). \tag{18}$$

Then, (15) and (18) need to be solved. Specifically, compute s_{RD}(t) by using (15), which represents the estimate of s_b . Therefore, y_{RD}(t) without interference in (18) can be expressed as:

$$w(t)=h_{RD}h_{SR}s_s(t)+h_{RD}h_{BR}(s_b(t-\Delta_1T_s)-\hat{s}_b(t-\Delta_1T_s))+h_{RD}z_2(t)+z_3(t). \tag{19}$$

If the BER of $s_b(\mathrm{t})$ (the estimate of $\mathrm{s}_b(\mathrm{t})$) is p_b , we have additional estimation error $e_b[\mathrm{k}-\Delta_1]=\mathrm{s}_b[\mathrm{k}-\Delta_1]-\mathrm{s}_b[\mathrm{k}-\Delta_1]\in\{-2,0,2\}$ according to (19),. For a given channel, the BER of the data from node S can be expressed as:

$$p_s[k]=\frac{1}{2}\Pr\{h_{RD}^*h_{SR}^*w[k]<0\,|\,s_s[k]=1\}+\frac{1}{2}\Pr\{h_{RD}^*h_{SR}^*w[k]>0\,|\,s_s[k]=-1\}. \quad (20)$$

If the BPSK modulation Q (which is defined as: $Q(\mathrm{a})=\int_a^\infty\frac{1}{\sqrt{2\pi}}e^{-\frac{y^2}{2}}dy$) is uniformly distributed, in equation (20) the two elements of the right side are equal. So we have

$$p_s[k]=\Pr\{h_{RD}^*h_{SR}^*w[k]<0\,|\,s_s[k]=1\}. \quad (21)$$

According to (19), $w(\mathrm{t})$ consists of three parts actually, due to the method of interference cancellation. Then, the error probability of $w(\mathrm{t})$ also consists of three parts.

$$\begin{aligned}p_s[k]=&\frac{1}{2}p_b[k]\Pr\{|h_{RD}|^2|h_{SR}|^2+\Re(-2|h_{RD}|^2h_{SR}^*h_{BR}+|h_{RD}|^2h_{SR}^*z_2[k]+h_{RD}^*h_{SR}^*z_3[k])<0\}\\&+\frac{1}{2}p_b[k]\Pr\{|h_{RD}|^2|h_{SR}|^2+\Re(2|h_{RD}|^2h_{SR}^*h_{BR}+|h_{RD}|^2h_{SR}^*z_2[k]+h_{RD}^*h_{SR}^*z_3[k])<0\}\\&+(1-p_b[k])\Pr\{|h_{RD}|^2|h_{SR}|^2+\Re(|h_{RD}|^2h_{SR}^*z_2[k]+h_{RD}^*h_{SR}^*z_3[k])<0\}\end{aligned} \quad (22)$$

Here $h_{RD}z_2(t)+z_3(t)$ is AWGN (Additive White Gaussian Noise) with variance $(1+h_{RD}^2)\sigma^2$.

Next, we define $V=|h_{RD}|^2|h_{SR}|^2+\Re(-2|h_{RD}|^2h_{SR}^*h_{BR}+|h_{RD}|^2h_{SR}^*z_2[k]+h_{RD}^*h_{SR}^*z_3[k])$, then, $m_v=|h_{RD}|^2|h_{SR}|^2+\Re(-2|h_{RD}|^2h_{SR}^*h_{BR})$, $\sigma_v=|h_{RD}|^2|h_{SR}|^2(1+h_{RD}^2)\frac{\sigma^2}{2}$, where $\frac{1}{2}$ means that function V just takes the real part. Therefore, the probability of V can be described by function $Q(x)$, where $x=\frac{m_v}{\sqrt{\sigma_v}}$. The two elements in (23) also have similar expressions.

If we define $c_a=\frac{|h_{RD}|^2|h_{SR}|^2}{\sqrt{\frac{\sigma^2}{2}}}$ and $b_a=\frac{\Re(|h_{RD}|^2h_{SR}^*h_{BR})}{\sqrt{|h_{RD}|^2|h_{SR}|^2(1+h_{RD}^2)\frac{\sigma^2}{2}}}$, then $p_s[k]$ can be expressed as

$$\begin{aligned}p_s[k]=&\frac{1}{2}p_b[k-\Delta_1]Q(c_a-2b_a)\\&+\frac{1}{2}p_b[k-\Delta_1]Q(c_a+2b_a)\\&+(1-p_b[k-\Delta_1])Q(c_a)\end{aligned} \quad (23)$$

Here $Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^{\infty} e^{-\frac{u^2}{2}} du$.

4.3 Improve the BER performance

To improve the BER performance of the proposed scheme, the decoding accuracy can be enhanced based on SISO (Soft-In Soft-Out) and iterative decoding, thus the error propagation can be mitigated in the presence of collisions. This section primarily introduces how to further reduce the BER, and how to manage the frequency offset and the sample offset problems that may arise in practical scenarios.

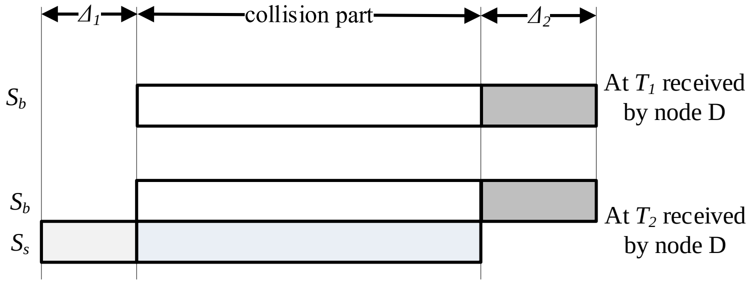

Fig. 4. The decomposition of the collision packet

As shown in **Fig. 4**, at the first time slot, node D decodes packet S_b from the BS correctly. At the second time slot, node D receives the packet from node R, then, it compares the packet with the former one and makes the correlation to get the exact location of the collision point. Notice that, the correlation spikes when the correlated former message aligns with the same part in the second time slot message [14].

If the length of S_b is M, we have $s_b^{T_1}[k], k = M - \Delta_2 + 1, M - \Delta_2 + 2, ..., M$, $s_b^{T_2}[k], k = M - \Delta_2 + 1, M - \Delta_2 + 2, ..., M$, which are exactly the same in fact. If we take interference and different route path into consideration, such two packets can be different. We can decode S_b with SISO and iterative decoding to reduce the BER. The process is shown in **Fig. 5**.

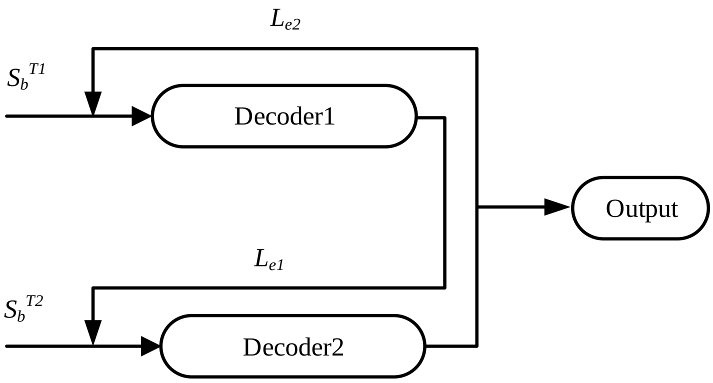

Fig. 5. The flow diagram for iterative decoding

Generally, the decoding process is similar with the Turbo code decoding. The Decoder1 decodes the $S_b^{T_1}$ first, and then the Decoder2 will take Decoder1's output LLR (Loglikelihood Ratio) as extrinsic information to decode $S_b^{T_2}$. Similarly, the Decoder2 decodes $S_b^{T_2}$, and then the Decoder1 will take Decoder2's output LLR as the extrinsic information to decode $S_b^{T_1}$. The iteration is done until the difference between adjacent verdicts is small enough, they will output the final result.

The decoding process uses the time diversity characteristics of signal S_b to reduce the BER. This is also beneficial for other parts of the decoding.

In a practical system, the frequency of the transmitter and the receiver are not often completely uniform, so there is a problem of frequency offset. Frequency offset can result in a time-linear distortion increasing on phase, i.e., $y[k] = Hx[k]e^{j2\pi k\delta fT} + z[k]$, so the receiver has to estimate δf for compensation.

In a time slot, frequency offset will not change dramatically. We can obtain the coarse estimate of the initial deviation from the part without collisions (like S_s at the duration Δ_1 in **Fig. 4**) first. This coarse estimate is not sufficient because any residual error in the sub-packet will affect the next sub-packet and be accumulated in the linear phase distortions of the period. As a result, when we reconstruct the collision packet C (As shown in **Fig. 4**), $s_s[k], k \in \{\Delta_1+1, \Delta_1+2....N\}$; $s_b[k], k \in \{1, 2, ...\Delta_2\}$, we have to track the phase.

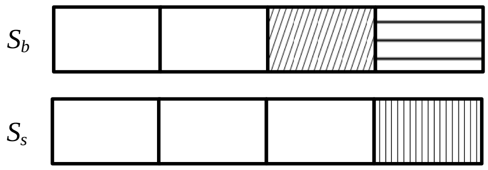

Fig. 6. Part of the subdivision map for part of collision

If we subdivide the part of collision (that is collision part in **Fig. 4**), as showed in **Fig. 6**, then the relationship between adjacent parts, i.e., the block of slash lines and the block of horizontal lines (at right side in **Fig. 6**) of the frequency offset can be estimated by the following formula:

$$\delta f_2 = \delta f_1 + \delta\phi / \delta t \,. \tag{24}$$

We can use the tail of S_b (**Fig. 4**), which is interference-free to estimate δf_1 and $\delta\phi$. The collision part of S_b can be estimated by the signal received by node D at the first time slot. The estimated packet s_b is the block of horizontal lines. Then, compute the estimated value s_s at the corresponding position in S_s ,which is the block of vertical lines in **Fig. 6**.Clearly, when node D estimating value s_s , it does not know the frequency offset in S_s. The frequency offset in S_s can be estimated by the interference-free part in S_s by using (24). We can perform the reconstruction of S_s (the block of vertical lines)with the estimated value of the frequency offset. It can be brought into collision part to re-evaluate the block of slash lines. For the following parts, the method to deal with the white blocks is just like the method to deal with the block of slash lines and the block of horizontal lines before. As depicted in **Fig. 7**, we can step through the iterative manner to calibrate the deviation. Specifically, the iterative termination condition is that the difference between adjacent estimated values of the frequency offset is less than an extremely tiny value.

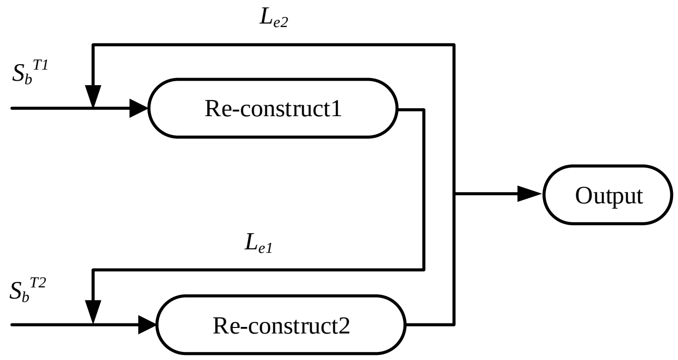

Fig. 7 The flow diagram for iterative reconstruct data decoding

We have just described the way of the forward recovery process. Similarly, the recovery process of S_s can be done in the backward direction. The final output considers both forward and backward results of the recovery processes. The same principles and strategies can be used to solve the transmission problem of the sampling offset and the final result can take all of them into consideration.

5. Numerical Results

In this section, we compare the numerical results of the conventional scheme and the interference cancellation scheme. We focus on the normalized throughput, which is the ratio of the actual rate of correct data to the theoretically maximum data rate at certain duration. It is clear that a higher BER renders a lower throughput.

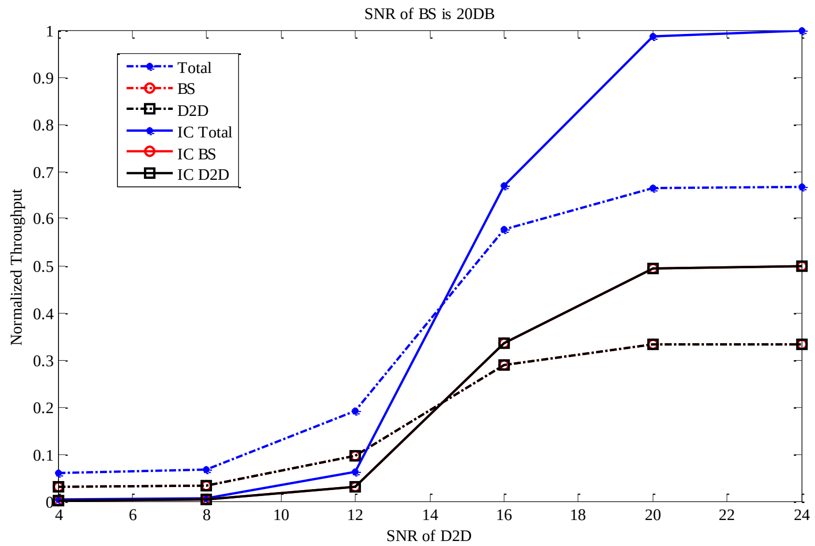

Fig. 8. Normalized throughputs of conventional scheme and interference cancellation scheme when the SNR of the BS is 20DB

Fig. 8 shows the normalized total throughput, throughput of the BS (data from the BS to node D), throughput of D2D (data from node S to node D). The total throughput means the sum throughputs at node D of the data streams from the BS and node S. We can observe that the total throughput will increase when the SNR of the D2D link increases if the SNR of the BS is perfect (e.g., 20DB). When the throughput of the D2D link reaches its maximum value, the proposed scheme can reach a much higher total throughput. If the SNR of the D2D link is good enough (e.g., 20DB or more), the total throughput could reach 1. By contrast, the maximum total throughput of the conventional scheme is around 0.667. It is not difficult to understand why the proposed scheme can reach 1. When the channel condition is good, one half of the valid data comes from the BS (it sends one packet in one time slot and then keep silent for one time slot), the other one half of the valid data comes from node S (it sends one packet in two time slot). In the simulation, we assume that the BS and node S send the same amount of data, and each packet has a fixed length. For the conventional scheme, it has to send two packets at three time-slots even with a good channel condition, so it can just achieve 0.667 throughput as the SNR of the D2D link increases.

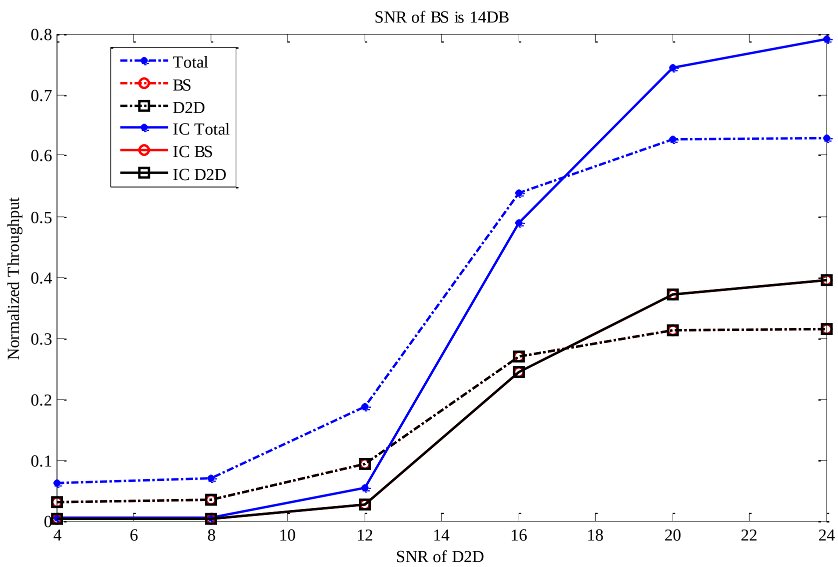

Fig. 9. Normalized throughputs of conventional scheme and interference cancellation scheme when the SNR of the BS is 14DB

In **Fig. 9**, we set the SNR of the BS to 14DB. In such situation, some data from the BS cannot be decoded correctly, thus the BER performance is average. The normalized throughput of the BS is below 0.4, which means that about 20% data had been re-transmitted. As the SNR of the D2D link increases, the proposed scheme performs much better than the conventional scheme. The ratio of maximum normalized throughputs of two schemes is 0.7911 to 0.627, which means the gains can up to 26% when the channel condition of the BS is medium.

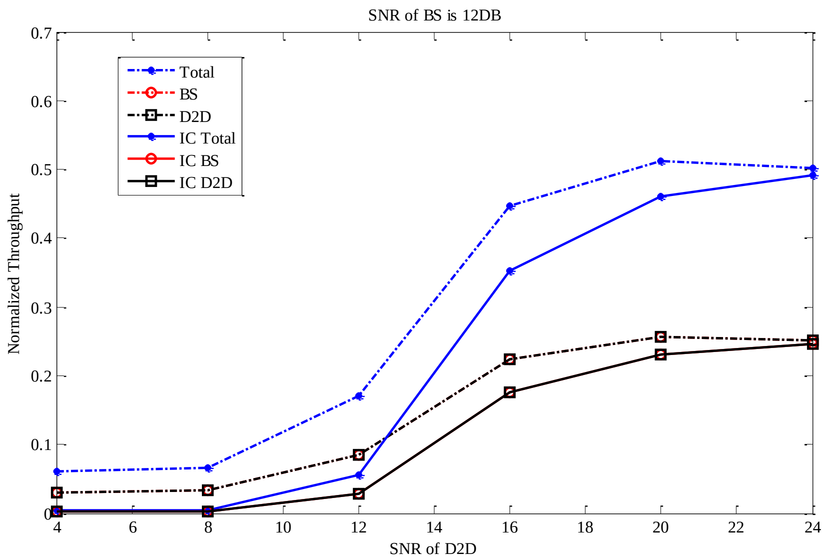

Fig. 10. Normalized throughputs of conventional scheme and interference cancellation scheme when the SNR of the BS is 12DB

In **Fig. 10**, we set the SNR of the BS to 12DB. The throughput of the BS shows really unsatisfactory performance. In such situation, the proposed scheme loses its advantage. The reason lies in the fact that it is difficult for node D to decode the data from the BS, which means it is difficult to figure out the base data of the collision packet. Therefore, the node D cannot perform the interference cancellation effectively. We can find that it is not suitable to utilize the proposed scheme when the channel condition of the BS is bad.

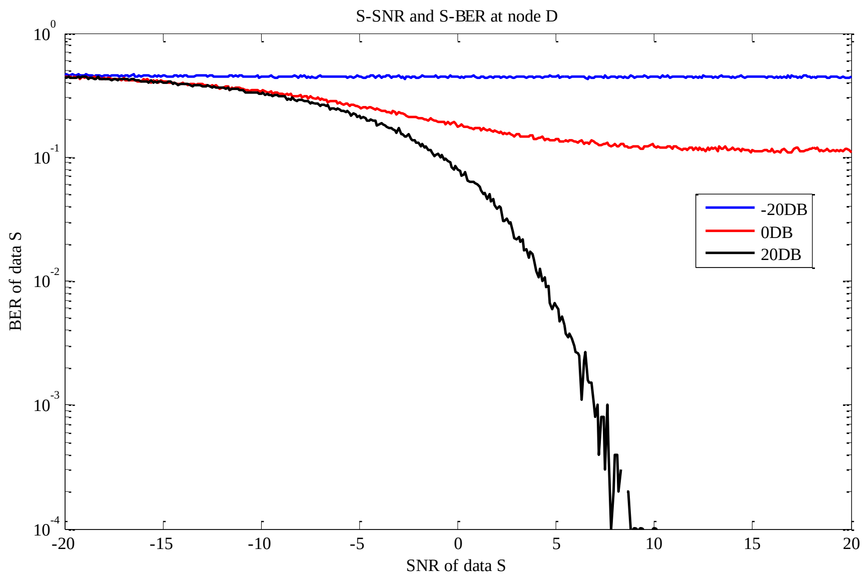

Fig. 11. The relationship between the SNR and the BER of the data from node S when they are decoded at node D, the blue line represents the case that the SNR of the BS is -20DB, the red line represents the case that the SNR of the BS is 0DB, the black line represents the case that the SNR of the BS is 20DB

Finally, the relationship between the SNR and the BER of the data from node S to node D is illustrated in **Fig. 11**, where X-axis represents the SNR of data S and Y-axis represents the BER of data S. The blue curve represents that the SNR of the BS is -20DB. The red curve represents that the SNR of the BS is 0DB. The black curve represents that the SNR of the BS is 20DB.We could obtain that, when the SNR of the data from the BS is -20DB, p_b (the BER of the data from the BS) varies from 0.4325 to 0.4667. The blue curve shows that the BER of data S is around 0.44. From the previous derivation, we know that the vibration range is related to the variance of the noise. A smaller variance shows a gradual decreasing trend. In this simulation, the variance of the noise does not change, and therefore the vibration range is substantially similar during the whole process. p_s (the BER of data from node S) does not increase as the SNR of data S increases. However, it approaches a stable value as the SNR of data S increases. The red curve represents that node D receives the data from the BS when the SNR of the data from the BS is 0DB. At this time, p_b approaches 0.10. We can find that, under such scenario, the BER of data S is related to both p_b and p_s . When the SNR of data S becomes larger, p_s becomes smaller and approaches a stable value as the SNR of data S increases. From the previous derivation, we know that p_s is related to p_b at this time. Similar to the blue curve, the vibration range is related to the variance of the noise. The black curve represents that node D receives the data from the BS when the SNR of data from BS is 20DB. As the SNR of data S increases, p_s approaches zero. Clearly, the numerical results are consistent with our theoretical derivations.

In short, the simulation told us when the channel condition of the BS is good or not too bad, the proposed scheme performs much better than the conventional scheme. However, when the channel condition of the BS is really bad, the node D cannot perform the interference cancellation effectively.

6. Multi relay-forward case

Multi-hop relay-assisted D2D seems to be a field which is still untapped. In this section, we will discuss the proposed scheme applied to a multi-hop relay-assisted D2D case.

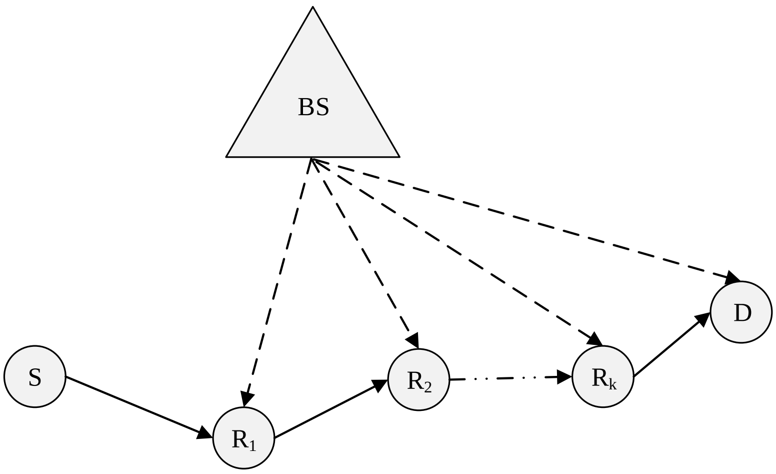

Fig. 12. Multi relay-forward case

As illustrated in **Fig. 12**, the proposed scheme is applied to a multiple relay-assisted case. Specifically, before each forwarding behavior, each relay node is required to exclude the known interference of the previous relay node first, and then forwards the received data to the next relay node. Since the current relay could receive the packet from the BS, which is the interference at the former relay, the current relay has the condition to figure it out. That means the last packet from the BS received by the current relay can be excluded from the collision packet comes from the former relay.

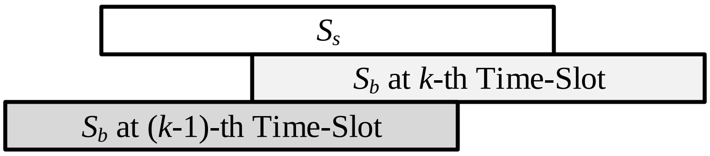

Fig. 13. Collision packet in a multi relay-forward case

As illustrated in **Fig. 13**, it needs to eliminate the white part packet first since the relay can receive the complete white part packet. The correlation calculation can find the exact location in the collision packet, and it can be removed. In this case, if it needs k relay nodes to complete D2D communication, the conventional scheme takes $k+1$ time slots to obtain the data from node S. By using the interference cancellation scheme, node D not only obtains one packet from node S in the $k+1$ time slots but also obtains k packets from the BS.

Considering the number of data packets transferred per unit time, the packets rate R, in conventional scheme:

$$R_c = \frac{1}{K+1} \tag{24}$$

By using the interference cancellation scheme:

$$R_{IC} = \frac{K+1}{2K+1} \tag{25}$$

compare (25) and (24) we have:

$$\frac{K^2}{2K+1}+1 \xrightarrow{K\to\infty} \frac{K}{2}+1 \tag{26}$$

We can see that as K become larger, using the interference cancellation scheme will have greater improvement in relay-assisted D2D communication, under the condition that a certain level of BER is tolerable.

Thus, the total throughput of node D can be significantly increased.

7. Conclusions

In this paper, we have presented a scheme to improve the performance of the relay-assisted D2D communication system in cellular communication networks, with the help of ZigZag decoding and interference cancellation. The proposed scheme can guarantee that both cellular communication and D2D communication achieve higher total throughputs in the condition of good BS channel. Moreover, we have theoretically proved that the proposed scheme can achieve a satisfactory BER performance. Numerical results have verified the effectiveness of the proposed scheme compared to the conventional scheme.

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