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Efficient D2D Discovery Scheme for Channel Measurement of Interference Alignment

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Abstract

Co-channel interference among Device-to-device (D2D) users is major issue to be solved when utilizing the same frequency bands. Consequently, interference alignment (IA) as an effective interference management approach has been implemented to D2D communications for the frequency sharing. However, the measurement of channel state information (CSI) between transmitter and receiver of a D2D pair and cross-channel state information (C-CSI) among D2D pairs are the major issues that need to be resolved for the implementation of IA from theory to practical. Therefore, in this paper, we propose an effective D2D discovery scheme to overcome this problem, which can measure the CSI and C-CSI based on the discovery messages. Simulation results show that, under perfect conditions, even though the proposed D2D discovery scheme increases the needed time slots to establish D2D communications by 6.2% compared with the conventional D2D discovery without considering IA, it increases the throughput up to 50% than the conventional D2D without considering IA, i.e., it improves the spectrum efficiency.

***Keywords**: D2D; Interference alignment; D2D discovery; Channel state information*

1. Introduction

As device-to-device (D2D) communications have the advantages of supporting a higher data rate, lowering communication delay, and reducing energy consumption, it has been considered as a key technology for future 5G mobile communication systems [1-2]. Hence, co-channel interference (CCI) among D2D users are major issues that must be resolved for successful transmission when they are utilizing the same frequency bands. To reduce the co-channel interference among D2D users, several techniques have been proposed in the existing literature. In [3], a novel location-based resource allocation scheme is proposed. In this paper, the D2D users which utilize the same frequency bands usually have long distance, therefore, the interferences from others' transmitter are reduced because of the pathloss of interference signal. In [4], an effecitve time-domain interference coordination (ICIC) approach was proposed by using almost blank subframes (ABS). Even though the above proposed schemes can reduce the interferences among D2D users, the spectrum effeicieny becomes low.

Recently, a new interference management scheme called interference alignment (IA) was presented in [5] to align the interference from the different transmitters in a spectific signal demension. Then, the remainder of the dimension becomes interference-free space. Therefore, IA can achieve high multiplexing gain and degrees freedom of the channel. However, the majority of the papers [6-11] which consider the IA technolog for conventional cellular network or D2D communications, they all assumed that the channel state information (CCI) between transmitter and receiver of a D2D pair and cross-channel state information (C-CCI) among D2D pairs are known to each other. Therefore, an effective method which can measure the CCI and C-CCI is inevitable for the applcation of IA from theory to practial.

Fortunately, D2D discovery in D2D communications provides possibility for the measurement of CSI and C-CSI among D2D pairs. Because an accurate description of signaling message exchange between the entities of the network with recpect to the necessaary information for identifying a new D2D pairs. The exchange of discovery messages will provide the network with information about the CSI and C-CSI. Therefore, based on the description provided by above, in this paper, we propose an effective D2D discovery for the channel measurement of IA, which not only can measure the CSI, but also can measure the C-CSI.

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2. System Model and Description of IA

We consider a single-cell network with N D2D users, and we assume that each of D2D user has two antennas (*M=2*). The maximum number of D2D pairs which can form a group to implement IA is three [12]. For the convenience of notation, we represent the three D2D pairs in the same group as $D2D_1$, $D2D_2$ and $D2D_3$. In the discovery process, each D2D user transmits discovery messages with the identity of itself and target user on the selected discovery resource block (DRB), and the DRB is broadcasted by the eNB. Consequently, all the others' D2D users can receive the discovery message if they can decode this message successfully.

The interference channel model for three D2D pairs is shown in Figure 1. We define the three precoding matrics as V_1, V_2, V_3 . To decode the *M/2 =1* non-interference streams along the column vectors of V_i from the *M=2* components of the received vector, the dimension of interference has to be less than or equal to *M/2=1.* The following three interference alignment equations ensure that the dimension of the interference is equal to *M/2=1* at all the receivers.

$$span(H_{12}V_2) = span(H_{13}V_3) \quad (1)$$

$$H_{21}V_1 = H_{23}V_3 \quad (2)$$

$$H_{31}V_1 = H_{32}V_2 \quad (3)$$

Where $span(A)$ represents the vector space spanned by the column vectors of matrix *A*.

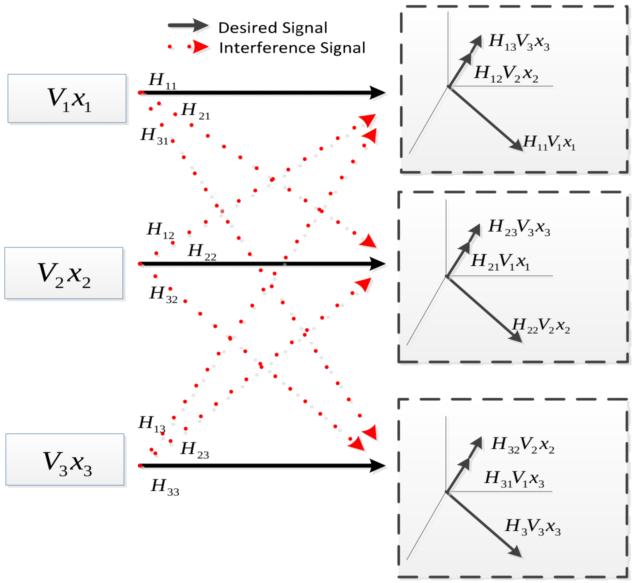

Figure 1. Example of interference channels for three D2D pairs

The selection of V_i for satisfying the above the equations is the key point in the IA. Since the channel has a full rank of *M=2*, the above equations can be equivalently represented as:

$$span(V_1) = span(EV_1) \quad (4)$$

$$V_2 = FV_1 \quad (5)$$

$$V_3 = GV_1 \quad (6)$$

Where:

$$E = (H_{31})^{-1} H_{32} (H_{12})^{-1} H_{13} (H_{23})^{-1} H_{21},$$

$$F = (H_{32})^{-1} H_{31},$$

$$G = (H_{23})^{-1} H_{21}.$$

The received signal at i receiver for the IA communications is given by:

$$Y_i = H_{ii} V_i x_i + \sum \underbrace{H_{ij} V_j x_j}_{Interference} + N_i (i \neq j) \quad (7)$$

Where N_i is the white Gaussian noise.

Then, the interference cancelation matrix U_i is used for canceling the interference from the received signal of (7) for the i reciver is given by:

$$(U_i)^H H_{ij} V_j = 0 \quad (8)$$

$$Y_i = U_i H_{ii} V_i x_i + (U_i)^H N_i \quad (9)$$

From the above analysis, we can see that the measurement of CCI and C-CCI for the acquisition of V_i and U_i are inevitable, and because the detailed calculation of V_i and U_i beyond the scope of this paper, therefore, we do not make further analysis.

3. Proposed D2D Discovery Scheme

The envoled node base station (eNB) is very important because it can coordinate the message in some steps of the scheme, and the whole D2D discovery scheme is displayed in Figure 2.

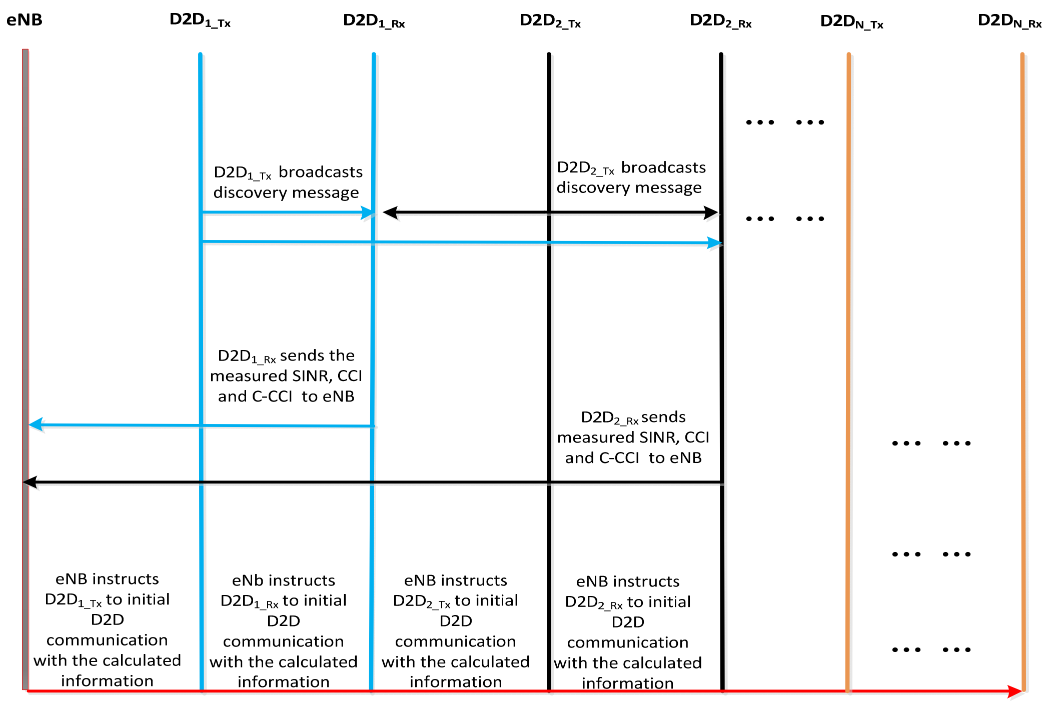

Figure 2. The proposed D2D discovery scheme

Step 1: $D2D_{1\_Tx}$ randomly selects a discovery resource to broadcast its discovery messages which inlcudes the identity of itself and target user $D2D_{1\_Rx}$.The $D2D_{2\_Tx}$ and $D2D_{3\_Tx}$ follow the same process.

Step 2: $D2D_{1\_Rx}$ sends to eNB with the received signal to interference plus noise ratio (SINR) and measured CCI. Furthermore, $D2D_{2\_Rx}$ and $D2D_{3\_Rx}$ send the measued C-CCI between $D2D_{1\_Tx}$ and $D2D_{2\_Rx}$ & $D2D_{3\_Rx}$ respectively to the eNB. In this step, if the messages are not received by $D2D_{1\_Rx}$ & $D2D_{2\_Rx}$ & $D2D_{3\_Rx}$, which means that the received SINR in $D2D_{1\_Rx}$ & $D2D_{2\_Rx}$ & $D2D_{3\_Rx}$ is not satisfied, retransmissions occurs. The $D2D_{2\_Rx}$ and $D2D_{3\_Rx}$ also send the similar messages to eNB and follow the same process. In this paper, we assume that the $D2D_{Rx}$ can decode the discovery messages successfully.

Step 3: The eNB calculates the precoder vector V_i and interference cancelation matrix U_i based on the measued CCI and C-CCI of all the D2D users. Then, the eNB sends system informations to all the $D2D_{Tx}$ and $D2D_{Rx}$ with the precoder vector V_i and interference cancelation matrix U_i, respectively.

Step 4: All the D2D users no matter tansmitters and rceivers intiate the D2D communication by using the IA technology after receiving the system information from eNB.

As multiple D2D pairs may send discovery messages concurrently, which follows the random access process, thus the $D2D_{Tx}$ should transmit the discovery messages in the beginning of each time slot by using a certain transmission probability to avoid the collision. We assume that successful discovery messge reception can take place if there is no collision. Let *N* denotes the number of D2D pairs which will potentially participate in the discovery process at the same time. *N* also stands for the number of discovery messages simultaneously transmitted, and it should be estimated by the $D2D_{Rx}$. Also, let p_t denotes the optimal transmission probability that can be utilized by $D2D_{Tx}$. The probability of a successful transmission of a discovery message in one time slot for one $D2D_{Tx}$ is the probability that only one $D2D_{Tx}$ is transmitting while all the other $D2D_{Tx}$ are idle. This probability is given by:

$$p_{success} = p_t\,(1-p_t)^{N-1} \tag{10}$$

The optimal transmission probability is the one that maximizes the success probability in (10), i.e. [13]:

$$p_t = \frac{1}{N} \tag{11}$$

Now, let *X* denotes the number of successful transmission of one $D2D_{Tx}$ in *n* time slots. In order to implement IA, the probability of having more than one successful transmission in *n* time slots is:

$$\begin{aligned}\Pr[X \geq 1] &= 1 - \Pr[X = 0] \\ &= 1 - (1 - p_{success})^n\end{aligned} \tag{12}$$

If we need to satisfy (12) with the success probability higher than η in *n* time slots, then:

$$\Pr[X \geq 1] \geq \eta \tag{13}$$

Thus, we have:

$$n \geq \frac{\ln(1-\eta)}{\ln(1-p_{success})} \quad (14)$$

The result of (14) gives the number of needed time slots which one D2D user can transmit successfully. Furthermore, as the number of successful transmission for our proposed scheme is at least three, therefore, we have:

$$\Pr[X \geq 3] = 1 - \sum_{X=0}^{3-1} \binom{n}{X} (p_{success})^X (1-p_{success})^{n-X} \geq \eta \quad (15)$$

Which leads:

$$\begin{aligned}
&\Pr[X \geq 3] \geq \eta \\
&\Rightarrow 1 - \sum_{X=0}^{2} \binom{n}{X} (p_{success})^X (1-p_{success})^{n-X} \geq \eta \\
&\Rightarrow \left((1-p_{success})^n \frac{1+p_{success}{}^2 - p_{success}}{(1-p)^2}) \right) \leq (1-\eta) \\
&\Rightarrow (1-p_{success})^n \leq \frac{(1-\eta)(1-p_{success})^2}{1+p^2{}_{success} - p_{success}} \\
&\because\ 0 < (1-p_{success}) < 1 \ \therefore \ln(1-p_{success}) < 0, \\
&\Rightarrow n \geq \ln\left(\frac{(1-\eta)(1-p_{success})^2}{1+p^2{}_{success} - p_{success}} \right) / \ln(1-p_{success}).
\end{aligned} \quad (16)$$

The result of (16) gives the number of needed time slots which a group can implement IA successfully.

4. Performance Evaluation

In this section, we describe the simulation environment and results of the performance for the proposed scheme. Firstly, from the Figure 3, we can get that the satisfaction of three D2D transmitters' successful sending will increase the time delay compared with one D2D transmitter's successful sending by 6.2%, which can also see from the equations (14) and (16), i.e., obviously: $\ln\left(\frac{(1-\eta)(1-p_{success})^2}{1+p^2{}_{success} - p_{success}} \right) / \ln(1-p_{success}) > \frac{\ln(1-\eta)}{\ln(1-p_{success})}$.

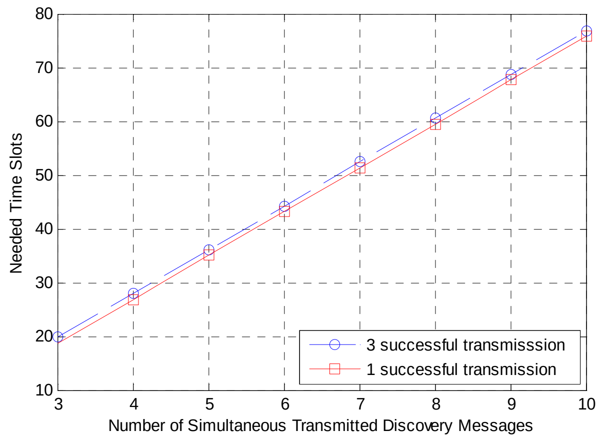

Figure 3. Needed time slots with the increased number of simultaneous transmitted discovery messages

Then, we analyze the performance comparison with the obtained throughput after the establishment of D2D communications. The detailed simulation parameters are listed in Table 1. In addition, we assume that the performance degradation of amplifying noise is negligible due to the U_i, i.e, $(U_i)^H N_i$ in equation (9), which is because the optimal degrees freedom of the channel can be obtained in the case of high signal-to-noise (SNR) [14]. Furthermore, we use the location of the $D2D_{Rx}$ as the reference location of the D2D pair, because the relative distance between the $D2D_{Tx}$ and $D2D_{Rx}$ of a D2D pair is significantly smaller than the cell radius. Therefore, we can regard the coordinates of $D2D_{Rx}$ as the position of a D2D pair.

Table 1. Simulation Parameters

Parameters	Values
Carrier Frequency	2.62 GHz
Number of RBs	1
Number of Tx antennas	2
Number of Rx antennas	2
Cell Radius	500 (m)
Path Loss	PL(dB)=35.4+22.7log10(R)
Shadowing Standard Deviation	4 dB
Noise Figure	5 dB
Noise Spectrum Density	-175 dBm/Hz
Maximum D2D Tx Power	23 dBm
Traffic Model	Full buffer
Carrier Frequency	2.62 GHz
Number of RBs	1

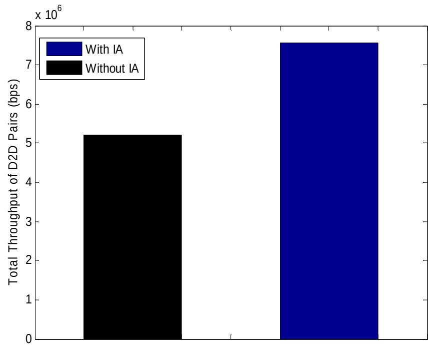

Figure 4. Throughput of D2D pairs: With IA and Without IA

According to Figure 4, we can observe that the implementation of IA improves the D2D pairs' throughput compared with no IA by 50%. This is because by using IA, one resource block (RB) can support three D2D pairs' communication at the same time, and each D2D pairs can get 1/2 of RB without interferences among different D2D pairs. However, for the D2D communications without IA, each D2D pairs can only get 1/3 of RB by using orthogonal frequency band.

5. Conclusion

In this paper, an effective D2D discovery scheme is proposed for the purpose of measuring the CSI and C-CSI among D2D pairs, which is used for the implementation of IA. Firstly, the D2D users measure the CSI and C-CSI by using the feedbacks of the discovery messages from each other, and then send these feedbacks to the base station. Furthermore, the base station calculates the transmitter and receiver precodings of IA by using the CSI and C-CSI. Finally, the base station sends these calculated precodings to all the D2D users based on the flexible solution of IA. Simulation results show that, under perfect conditions, the proposed D2D discovery scheme lowers the needed time slots to establish D2D communications compared with the conventional D2D discovery without considering IA by 6.2%, it increases the throughput up to 50% than the conventional D2D communications without considering IA, i.e., it improves the spectrum efficiency.

Acknowledgements

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