Application of interference alignment in full-duplex D2D communications

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Abstract. As compared with the wireless half-duplex (HD) transmission, the wireless full-duplex (FD) transmission can potentially double the system throughput if the self-interference can be efficiently cancelled. Accordingly, this paper proposed an interference alignment (IA)-based self-interference suppression method for the FD D2D bidirectional communications. The self-interference and mutual interference are aligned into the null-space at the receiver, and then suppressed by the receive matrices. Performance evaluation demonstrates the effectiveness of proposed self-interference suppression algorithm for the FD D2D networks.

1 Introduction

Existing efforts towards Device-to-Device (D2D) communications have mainly focused on the half-duplex (HD) mode[1-5]. While the feature of short range for D2D communications not only improves the signal-to-interference-plus-noise ratio(SINR), but also enhances the signal-to-self-interference-plus-noise ratio (SSINR). It is efficient to introduce the full-duplex (FD) mode in the D2D communications, which has the potential to double the throughput as compared with the wireless HD transmission mode.

However, the self-interference suppression is a prerequisite when FD transmission mode is applied in D2D communications. Over the past few decades, a great deal of research works have developed the advanced self-interference cancellation and/or suppression techniques[6-10]. These works jointly or separately employ the analog-domain interference cancellation, digital-domain interference cancellation, and propagation-domain interference suppression. On the other hand, another recent emergence of the idea of interference alignment (IA) for wireless networks has shown that the capacity of wireless networks can be much higher than previously believed[11]. As a result, we proposed a heuristic self-interference suppression method called IA-based joint self-and-mutual interference suppression algorithm-IA-JSMISA. By developing the transmit precoding matrix and the receive suppressing matrix, the self and mutual interferences are aligned into the null-space of the receiver, and thus can be entirely cancelled by the receiver.

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2 System Model

2.1 System Model

The bidirectional link in FD D2D networks is shown in figure 1. D2D users reuse the resource of the cellular user underlying the traditional cellular networks. D2D pair is defined as the mobile devices, which is enable to directly communicate to each other bypassing the base station. Moreover, multiple D2D pairs near close assemble together and form a D2D group. Any transmitter and receiver of a FD D2D node suffers from the self-interference problem.

Fig. 1. The bidirectional FD D2D communication underlaying the cellular networks.

2.2 Interference Model

There are two types of interferences in FD D2D communications as shown in figure 1: the mutual-interference between D2D pairs, and the self-interference proprietary for the FD devices. We consider the interference model of the FD D2D communications as illustrated in figure 2, which consists of K FD D2D pairs $(S_i, t_i)_{i=1, \dots, K}$. We assume all nodes are equipped with N antennas, each of which has a single stream to transmit in the network. We denote by $\mathbf{H} \in \mathbb{C}^{NK \times NK}$ the forward channel matrix, $\mathbf{U} \in \mathbb{C}^{NK \times NK}$ the FD channel matrix between the source nodes, and $\mathbf{W} \in \mathbb{C}^{NK \times NK}$ the FD channel matrix between the destination nodes.

Fig. 2. The interference channel model for the bidirectional FD D2D communications underlaying the cellular networks.

At time instant n , $S_i (i = 1, \dots, k)$ transmits the signal $\mathbf{x}_i[n]$ to the receiver t_i , and $t_i (i = 1, \dots, k)$ transmits the signal $\mathbf{v}_i[n]$ to the transmitter S_i . Here, we assume that all the D2D users have the same normalized power constraint and $E\{\|\mathbf{x}_j[n]\|^2\} = 1$, $E\{\|\mathbf{v}_j[n]\|^2\} = 1$. Therefore, the received signals at the receiver node t_i and the source node S_i are, respectively

$$\mathbf{y}_i[n] = \sum_{j=1}^K \mathbf{H}_{ij} \mathbf{F}_j \mathbf{x}_j[n] + \sum_{j=1}^K \mathbf{W}_{ij} \hat{\mathbf{F}}_j' \mathbf{v}_j[n] + \mathbf{z}_i[n], \quad (1)$$

$$\mathbf{f}_i[n] = \sum_{j=1}^K \mathbf{H}_{ji} \hat{\mathbf{F}}_j \mathbf{v}_j[n] + \sum_{j=1}^K \mathbf{U}_{ij} \mathbf{F}_j' \mathbf{x}_j[n] + \tilde{\mathbf{z}}_i[n], \quad (2)$$

where $\mathbf{F}_j \in C^{N \times 1}$ and $\mathbf{F}_j' \in C^{N \times 1}$ are the transmit precoding vectors which are related to the desired and the self-interference signals at the transmitter node j , respectively. $\hat{\mathbf{F}}_j \in C^{N \times 1}$ and $\hat{\mathbf{F}}_j' \in C^{N \times 1}$ separately denote the transmit precoding vectors which are related to the desired and the self-interference signals at the receiver node j . $\mathbf{H}_{ij}$ denotes the channel matrix between the transmitter j and the receiver i . $\mathbf{z}_i[n] \in C^{N \times 1}$ is an additive white Gaussian noise (AWGN) vector at the receiver and $\tilde{\mathbf{z}}_i[n]$ means AWGN at the source.

3 Our Proposed IA-JSMISA

In this section, we focus on the application of IA in the bidirectional FD D2D communications. First, we briefly consider a scenario where there are three pairs of FD D2D users, each of which has one transmit unit and one receive unit. Without loss of generality, we can denote the precoding matrices during the forward transmission as follows:

$$\mathbf{F} = \begin{bmatrix} \mathbf{F}_1 & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{F}_2 & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{F}_3 \end{bmatrix}, \quad (3)$$

$$\hat{\mathbf{F}}' = \begin{bmatrix} \hat{\mathbf{F}}_1' & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \hat{\mathbf{F}}_2' & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \hat{\mathbf{F}}_3' \end{bmatrix}. \quad (4)$$

For the forward transmission of the D2D pair (S_1, t_1) , the received signals at the destination node t_1 and the source node S_1 are expressed as

$$\mathbf{y}_1 = \mathbf{H}_{11} \mathbf{F}_1 \mathbf{x}_1 + \mathbf{H}_{12} \mathbf{F}_2 \mathbf{x}_2 + \mathbf{H}_{13} \mathbf{F}_3 \mathbf{x}_3 + \mathbf{W}_{11} \hat{\mathbf{F}}_1' \mathbf{v}_1 + \mathbf{Z}_1 \quad (5)$$

$$\mathbf{f}_1 = \mathbf{H}_{11} \hat{\mathbf{F}}_1 \mathbf{v}_1 + \mathbf{H}_{21} \hat{\mathbf{F}}_2 \mathbf{v}_2 + \mathbf{H}_{31} \hat{\mathbf{F}}_3 \mathbf{v}_3 + \mathbf{U}_{11} \mathbf{F}_1' \mathbf{x}_1 + \mathbf{Z}_1 \quad (6)$$

Secondly, we formulate the proposed IA-JSMISA algorithm, to align the joint self-and-mutual interference as follows:

$$\mathbf{H}_{12} \mathbf{F}_2 = \mathbf{H}_{13} \mathbf{F}_3 = \mathbf{W}_{11} \hat{\mathbf{F}}_1'. \quad (7)$$

Without loss of generality, we can define $\mathbf{F}_2$ as the $N \times 1$ all-one vector, and the relevant transmit precoding matrices $\hat{\mathbf{F}}_1'$ and $\mathbf{F}_3$ are given by, respectively

$$\hat{\mathbf{F}}_1' = (\mathbf{W}_{11})^{-1} \mathbf{H}_{12} \mathbf{I}_{N \times 1}, \quad (8)$$

$$\mathbf{F}_3 = (\mathbf{H}_{13})^{-1} \mathbf{H}_{12} \mathbf{I}_{N \times 1}. \quad (9)$$

Similarly, the interference alignment equation for the backward transmission of the FD D2D communications is given by

$$\mathbf{H}_{21} \hat{\mathbf{F}}_2 = \mathbf{H}_{31} \hat{\mathbf{F}}_3 = \mathbf{U}_{11} \mathbf{F}'_1 \quad (10)$$

Similarly, we can define $\hat{\mathbf{F}}_2$ as the $N \times 1$ all-one vector, and the relevant transmit precoding matrices $\mathbf{F}'_1$ and $\hat{\mathbf{F}}_3$ are given by, respectively

$$\mathbf{F}'_1 = (\mathbf{U}_{11})^{-1} \mathbf{H}_{21} \mathbf{I}_{N \times 1}, \quad (11)$$

$$\hat{\mathbf{F}}_3 = (\mathbf{H}_{31})^{-1} \mathbf{H}_{21} \mathbf{I}_{N \times 1}. \quad (12)$$

As a result, we can obtain the receive precoding matrices which are related to the forward link and the backward link as represented by, respectively

$$\mathbf{Q}_1 = \text{null}([\mathbf{H}_{12} \mathbf{F}_2]^H) = \text{null}([\mathbf{H}_{13} \mathbf{F}_3]^H) = \text{null}([\mathbf{W}_{11} \hat{\mathbf{F}}_1]^H), \quad (13)$$

$$\mathbf{Q}_2 = \text{null}([\mathbf{H}_{21} \hat{\mathbf{F}}_2]^H) = \text{null}([\mathbf{H}_{31} \hat{\mathbf{F}}_3]^H) = \text{null}([\mathbf{U}_{11} \mathbf{F}'_1]^H). \quad (14)$$

In addition, when the channel matrix between the source node S_1 and the destination node t_1 is symmetric as $\mathbf{H}_{12} = \mathbf{H}_{21}$, we can align the self-interferences of both nodes as expressed by

$$\mathbf{W}_{11} \hat{\mathbf{F}}_1 = \mathbf{U}_{11} \mathbf{F}'_1. \quad (15)$$

4 Numerical Results

In this section, we evaluate the performance of our proposed FD IA-JSMISA scheme, as compared with the IA-based HD scheme and the conventional FD schemes which can partly cancel the self-interference. We use the Nakagami-m channel model which is suitable for indoor mobile multiple propagations. Throughout our simulations, we set the bandwidth for each D2D pair as $B = 10\text{MHz}$ and the fading parameter of Nakagami-m distribution $m = 2$. Furthermore, we assume that the distance constraint between one D2D pair is $d = 25\text{m}$, and the noise spectrum density is -174dBm/Hz . For the wireless half-duplex D2D communications, we assume $B_1 = B_2 = B/2$.

Fig. 3. The capacities comparison among the wireless full-duplex D2D communications with IA-JSMISA, the wireless half-duplex D2D communications with IA, and the traditional wireless full-duplex D2D communications with residual self-interference (SIC), respectively.

Figure 3 compares the capacities between the wireless full-duplex D2D communications and the wireless half-duplex D2D communications, where we set the average transmit power constraint for the D2D pair, $\bar{P} = 100\text{mW}$, and we assume that the conventional full-duplex D2D communications can partly cancel the self-interference by 70dB, 80dB, and 90dB. As shown in figure 3, when the self-interference is only partly mitigated by 70dB, the ergodic capacity of full-duplex D2D communications is even smaller than that of the half-duplex D2D communications, especially when the transmit power of D2D user gets higher than 12dBm. However, when the self-interference can be efficiently mitigated by 80dB, the ergodic capacity of full-duplex D2D communications will always be larger than that of the half-duplex D2D communications as the transmit power of D2D user increases. As soon as the self-interference cancellation achieves by 90dB, the ergodic capacity of full-duplex D2D communications will be very close to our developed IA-JSMISA scheme. Moreover, we find that the proposed IA-JSMISA scheme consistently double the capacity of the system throughput due to the total alignment and the cancellation of the overwhelmed self-interferences.

5 Conclusion

Based on interference alignment, we developed to analyze the impact of self-interference on FD bidirectional D2D networks. We proposed an IA-based joint self-and-mutual-interference suppression algorithm (IA-JSMISA) to maximize the ergodic capacity of the wireless FD D2D networks, where the self-and-mutual-interferences are entirely be aligned and suppressed. The obtained simulation results have verified that our developed IA-JSMISA scheme can achieve the double ergodic capacity compared to half-duplex D2D systems.

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