INTERFERENCE CANCELLATION SCHEME BASED ON INTERFERENCE ALIGNMENT FOR MULTIUSER FULL-DUPEX COMMUNICATION

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ABSTRACT

Full-duplex systems have been proposed as a key technology of fifth generation (5G) mobile communications. For the first time, this paper proposes an interference cancellation scheme by interference alignment to eliminate the self-interference and mutual interference of full-duplex interference channel. The majority of existing work focuses on the suppression of self-interference without considering the effect of mutual interference, so this paper presents an interference cancellation scheme to suppress the self-interference and mutual interference at the same time. In the scheme, the full-duplex channel with self-interference and mutual interference (the original model) is treated as a MIMO channel model with mutual interference (the equivalent model). Firstly, this paper introduces the channel matrix of the corresponding relationship between the equivalent model and the original model. Secondly, based on the corresponding relationship, iterative interference alignment algorithm and maximum signal to interference plus noise ratio algorithm are used to eliminate the self-interference and mutual interference. Finally, we simulate the capacity and average energy efficiency. The simulation results show that the capacity and average energy efficiency are more improved obviously by this scheme than other schemes.

KEYWORDS

Full-duplex, interference alignment, capacity, average energy efficiency

1. INTRODUCTION

With the growth of wireless communication users and the increase of the system bandwidth, the demand of the frequency spectrum resources is also increasing rapidly. Co-frequency and co-time full duplex (CCFD) wireless communication systems transmit and receive signals over the same frequency at the same time. Based on a study, as a potential key technology of 5G, compared with the currently deployed systems, such as frequency division duplex (FDD) and time division duplex (TDD), the maximum spectrum efficiency of the CCFD system can be doubled [1]. While the limiting factor in the performance of CCFD systems is the strong self-interference generated from a node’s own transmitter to its receiver. Hence, effectively mitigating the self-interference in CCFD systems can result in a significant spectral efficiency increase over FDD and TDD systems.

In fact, in addition to in the CCFD systems, the self-interference and mutual interference also exist in small cellular network, wireless D2D (between the two user devices) communication environment etc. Some researches have been done for self-interference elimination of CCFD systems, which relates to three suppression techniques, namely the antenna interference cancellation, radio frequency (RF) interference cancellation and digital interference cancellation [2-8]. However, the current studies can’t eliminate the mutual interference and self-interference of CCFD systems at the same. Furthermore, the above interference cancellation schemes don’t involve interference alignment, so this paper uses interference alignment to eliminate the self-interference and mutual interference at the same time [9].

According to research, interference alignment is able to align interference from all other transmitters into the same interference subspace and keep the desired signal subspace and the interference subspace linearly independent [10]. In theory, interference alignment can completely suppress the self-interference and mutual interference. Thus, the system can achieve a larger freedom and total rate. Interference alignment is used to eliminate the self-interference and mutual interference of full duplex of the adjacent small cellular same frequency network, which is a kind of new mentality and has performance advantages [11].

The remainder of this paper is organized as follows. Section II presents the model of CCFD system, and some definitions and assumptions are given. In Section III the interference cancellation scheme based on interference alignment is presented. Section IV presents the simulation and results of different algorithms. Finally we conclude our paper in Section V.

2. EQUIVALENT MODEL OF DUPLEX COMMUNICATION INTERFERENCE CHANNEL

2.1 Multiuser Full-Duplex Communication Interference Channel

We consider a multiuser CCFD communication channel of the adjacent small cellular same frequency network where users and base stations are working in full duplex mode. We suppose that user $u_i$ $(i = 1, 2)$ only expects to receive the signal from the base station $b_i$ and transmit its signal to the base station $b_i$, at the same time it considers the signals from other users and base stations as well as itself as interference signals. Conversely, it also causes interference to them. Similarly, BS $b_i$ $(i = 1, 2)$ only expects to receive the signal from the user $u_i$ and transmit its signal to the user $u_i$, at the same time it considers the signals from other users and base stations as well as itself as interference signals. Conversely, it also causes interference to them. Figure 1 is a 2-user full-duplex interference channel example, in which the solid line corresponds to the desired channel, and the dotted line corresponds to the interference channel.

Figure 1: 2-user full-duplex interference channel.
Suppose we configure M antennas for the receiver and transmitter of all BS and users. For the receiver of user $u_i (i = 1, 2)$, $H_{b_i}^{u_i} \in \mathbb{C}^{M \times M}$ is the matrix coefficients between the transmitter of BS $b_i (i = 1, 2)$ and the user $u_i$, and $H_{u_i}^{b_i} \in \mathbb{C}^{M \times M}$ is channel matrix from user-transmitter $u_i$ to user receiver $u_i$. It is assumed that the channel is Rayleigh fading; hence, the coefficients in the channel matrices are complex independent identically distributed random variables with zero mean and unit variance. So the received signal vector at user receiver is given by

$$y_i = \sum_{j=1}^{K} H_{b_j}^{u_i} s_j + \sum_{j=1}^{K} H_{u_j}^{b_i} s_j + n_i^n$$

where $K$ is the number of users $u_j \in \{1, 2\}$ is the data vector from user $u_j (j \in K), s_j \in \mathbb{C}^M$ is the data vector from BS $b_j$, and they are constrained by $E(\|s_j\|^2) = P^t_j$, $E(\|s_i\|^2) = P^r_i$ ($P^t_j$ and $P^r_j$ is the transmit power of BS $b_j$ and user $u_j$, respectively). $H_{b_j}^{u_i} \in \mathbb{C}^{M \times M}$ is a zero mean unit variance circularly symmetric additive white Gaussian noise vector (AWGN) at user receiver $u_i$. In Equation (1),

$$\begin{bmatrix} \sum_{j=1}^{K} H_{b_j}^{u_i} s_j + \sum_{j=1}^{K} H_{u_j}^{b_i} s_j \end{bmatrix}$$

is the mutual interference and self-interference.

Similarly, for the receiver of BS $b_i (i = 1, 2)$, $H_{b_i}^{u_i} \in \mathbb{C}^{M \times M}$ is the matrix of channel coefficients between the transmitter of user $u_j (j = 1, 2)$ and the receiver of BS $b_i$, and $H_i^{u_i} \in \mathbb{C}^{M \times M}$ is the matrix of channel coefficients between the transmitter of BS $b_j (j = 1, 2)$ and the receiver of BS $b_i (i = 1, 2)$. It is assumed that the channel is Rayleigh fading; hence, the coefficients in the channel matrices are complex independent identically distributed random variables with zero mean and unit variance. So the received signal vector at BS receiver is given by

$$y_i = \sum_{j=1}^{M} H_{b_j}^{u_i} s_j + n_i^n$$

where $H_{b_j}^{u_i} \in \mathbb{C}^{M \times M}$ is a zero mean unit variance circularly symmetric additive white Gaussian noise vector at the receiver $b_i$. In (2), $H_{b_j}^{u_i} s_j$ is the desired signal and $\sum_{j=1}^{M} H_{b_j}^{u_i} s_j$ is denoted the interference.

2.2 Equivalent System Model

In Figure 1 the original model is complex, so we design the equivalent model of 2-user link full-duplex interference channel model which is a special 4-user link half-duplex interference channel model in Figure 2.

The equivalent model has a total of 4 transmitting ends and receiving ends. Each transmitting end $T_j (j = 1, 2, 3, 4)$ only expects to transmit its signal to the corresponding receiving end $R_j (j = 1, 2, 3, 4)$, and causes interference to other three receiving ends at the same time. Conversely, each receiving end $R_j$ only expects to receive the signal from the corresponding transmitting end $T_j$, meanwhile, other three transmitting end can also cause interference to the receiving end $R_j$. In this way, the interference (including self-interference and mutual interference) of the equivalent model in Figure 2 can be eliminated by interference alignment.

According to the equivalent model, the transmitting end $T_1$ and $T_2$ correspond to the transmitter of BS $b_1$ and BS $b_2$, respectively. So we get the transmitted signal $s_1 = s_2 = s_3$. The transmitting end $T_3$ and $T_4$ correspond to the transmitter of user $u_1$ and user $u_2$, respectively. So we get the received signal vector $y_1 = y_2 = y_3$. The receiving end $R_1$ and $R_2$ correspond to the receiver of BS $b_1$ and BS $b_2$, respectively. So we get the received signal $y_1 = y_2$. Suppose $H_{b_i}$ is the $M \times M$ matrix of channel between transmitting end $T_i$ and receiving end $R_i$ ($i = 1, 2, 3, 4$). $s_i$ is the transmitted signal vector which satisfies $E(s_i^H s_j) = H_{b_i}^{u_j}$ and $y_j$ is the received signal. The corresponding relationship between the equivalent channel and the original channel is given by

$$H_{b_1}^{u_1} = H_{b_1}^{u_2} = H_{b_2}^{u_3} = H_{b_2}^{u_4} = H_{b_1}^{u_2} = H_{b_2}^{u_4}$$

According to Equation (1), (2), and (3), the equivalent received signal vector is

$$y_i = \sum_{j=1}^{M} H_{b_j}^{u_i} s_j + n_i^n$$

There is a substantial difference between the equivalent channel model and the general 4-user MIMO interference channel model. For the general 4-user MIMO interference channel model, the interference is the transmitted signal from other transmitters, and it is the mutual interference of 4 users. However, the equivalent model is similar to the general 4-user MIMO interference channel model, but it is the essence of the 2-user full-duplex interference channel. Because the interference in the equivalent model not only contains the mutual between different users, different base stations as well as the users and base stations, but also includes the self-interference of base stations and users in the full-duplex communication, i.e. Therefore the part of the channel in the equivalent channel reciprocal, according to the reciprocity of channel we can get the channel matrix which satisfies the following relations:

$$H_{b_1}^{u_1} = H_{b_1}^{u_2} = H_{b_2}^{u_3} = H_{b_2}^{u_4}$$

3. INTERFERENCE ALIGNMENT ALGORITHM

3.1 Iterative Interference Alignment Algorithm

It is assumed that the link from BS to the user is called forward link and the link from user to the BS is called reverse link. In the forward link, the received signal vector at user $u_i (i = 1, 2)$ transmitter is given by

$$y_i = \sum_{j=1}^{K} H_{b_j}^{u_i} V_j s_j + n_i^n$$

where $y_i \in \mathbb{C}^M$ is the received signal vector, $V_j \in \mathbb{C}^{M \times d}$ is the pre-coding matrix.

Therefore, in the reverse link, based on the reciprocity of channel the received signal vector at the transmitter of BS is given by
Step 1: At the receivers, initialize the pre-coding matrix \( V \).

Step 2: Start iteration, compute interference covariance matrix \( Q \).

Step 3: Compute the interference suppression matrix: \( U = v^{\text{min}}(Q) \), where \( v^{\text{min}}(Q) \) is denoted the eigenvector corresponding to the \( d \) smallest eigen value of the matrix \( Q \).

Step 4: Reverse the communication direction and set \( V_i = U_i \).

Step 5: In the reverse link, compute interference covariance matrix at receiver \( i \) (BS receiver and user receiver):

\[
Q_i = \sum_{j=1,d(i)}^{K} \frac{P(j)}{d(j)} \overline{H}_i \overline{V}_i \overline{V}_j \overline{H}_j^H
\]

Step 6: In the reverse link, compute the interference suppression matrix at each receiver (that is, the pre-coding matrix in the forward link): \( \overline{U}_i = v^d(Q) \).

Step 7: Reverse the communication direction and set \( V_i = \overline{U}_i \).

Step 8: Continue iteration till convergence.

3.2 Maximum Signal to Interference plus Noise Ratio Algorithm

Above the iterative algorithm, because it does not consider the path of the desired signal, so the signal to interference plus noise ratio is not optimal at the receiver. In the case of high SNR, it almost doesn’t affect the sum rate, but in small SNR causes a great influence. So we consider the SINR of the \( k \)th stream of the \( i \)th receiver is

\[
\text{SINR}_{ki} = \frac{U_{ik} H_i V_i H_i^H}{\| (B_{ik})^{-1} H_i V_i \| ^2} \] (15)

Where \( B_{ik} \) is the interference-plus-noise covariance matrix

\[
B_{ik} = \sum_{j=1}^{K} \frac{P(j)}{d(j)} \overline{H}_i \overline{V}_i \overline{V}_j \overline{H}_j^H + I_{N_i}
\] (16)

Based on maximum signal to interference plus noise ratio algorithm, the interference suppression matrix of the \( k \)th stream of the \( i \)th receiver is

\[
U_{ki} = (B_{ik})^{-1} H_i V_i \| (B_{ik})^{-1} H_i V_i \| \] (17)

According to the reciprocity of channel, the algorithm process of maximum signal to interference plus noise ratio algorithm is described as follows:

Algorithm 2: Maximum signal to interference plus noise ratio algorithm (Max-SINR)

Step 1: At the receivers, initialize the pre-coding matrix \( V \) randomly.

Step 2: Start iteration, compute covariance matrix \( B \) of the \( k \)th stream of the \( i \)th receiver according to Equation (16). \( 1 \leq i \leq K, 1 \leq k \leq d(i) \).

Step 3: Compute interference suppression matrix of the \( k \)th stream of the \( i \)th receiver \( U_{ki} \) according to (17). \( 1 \leq i \leq K, 1 \leq k \leq d(i) \).

Step 4: Reverse the communication direction and set \( V_i = U_i \).

Step 5: In the reverse link, compute covariance matrix \( B_{ik} \) of the \( k \)th stream of \( i \)th receiver \( 1 \leq i \leq K, 1 \leq k \leq d(i) \).

Step 6: Compute the interference suppression matrix \( U_{ki} \).

Step 7: Reverse the communication direction and set \( V = U \).

Step 8: Continue iteration till convergence.

4. PERFORMANCE SIMULATION AND RESULTS

Consider 2 or 4 (K=2 or 4) user full-duplex interference channel where each node is equipped with 2 (M=2) antenna, all channel coefficients complex independent identically Gaussian distributed random variables with zero mean and unit variance. Each transmitter only transmits the target signal to the corresponding receiver, and the receiver treats the signals from other transmitters as interference. We imitate the capacity and energy efficiency of the two algorithms this paper, the antenna interference cancellation and radio frequency interference cancellation, respectively. The simulation results are shown in figures 3-5.
interference and mutual interference of CCFD systems. This paper applies interference alignment to suppress the self-improved than that in references [4] and [5].

Figure 5, the average energy efficiency in this paper is more greatly given by $\eta = \log(1+ S/ N) / E_b$, where $E_b$ is the unit bit energy. In the equation, the average energy efficiency is the number of bits per joule, and the equation is used to eliminate self-interference and mutual interference. Finally, the simulation results show that the capacity and average energy efficiency are more improved obviously by this scheme than other schemes.

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**REFERENCE**


5. CONCLUSIONS

This paper applies interference alignment to suppress the self-interference and mutual interference of CCFD systems.