Radio Resource Allocation for Full-Duplex OFDMA Networks Using Matching Theory

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I. Introduction

Wireless radio links are generally half-duplex, i.e., they can either transmit or receive in a single channel but not both simultaneously. To achieve single band simultaneous bidirectional communication, full-duplex radio links are recently utilized in wireless networks. Adoption of OFDMA scheme in the full-duplex radio links has also stimulated new research interest to improve the wireless networks' transmission rate even further [1]. Typically, a full-duplex OFDMA network consists of a common base station (BS), and multiple users as transmitters (TXs) and receivers (RXs). To achieve a satisfying sum-rate in the network, the TXs and RXs need to be properly paired into separate transceiver units, and a suitable subcarrier should be assigned to each transceiver unit. The BS also allocates proper power level to each transceiver unit such that the rate performance of the whole network is maximized. Due to the combinatorial nature of pairing multiple TXs, RXs, and subcarriers, and also the complexity of optimal power allocation to each subcarrier-transceiver pair, resource allocation in such a full-duplex OFDMA network can be very challenging.

In this work, we formulate the resource allocation as a joint optimization problem, and then model it as a TX-RX-subcarrier matching problem utilizing the *matching theory* [2], [3]. We efficiently solve this problem proposing a near optimal matching algorithm in which a stable matching is achieved with consideration to the BS's power allocation.

II. System Model

We consider a single-cell full-duplex OFDMA network, as shown in Fig. 1, with one BS, equipped with two antennas a and b, and multiple users each of which equipped with an antenna. The BS needs to allocate a limited number of non-overlapping subcarriers to the users, and get the users paired so that each pair of users and the BS form a full-duplex transceiver unit, in which one user acts as a TX and the other acts as a RX. Note that each subcarrier is assigned to a transceiver unit only. Let $\mathcal{K} = \{1, 2, \cdots K\}$ denote the set of subcarriers, $\mathcal{M}_T = \{1, 2, \cdots M\}$ denote the set of users acting as TXs, and $\mathcal{M}_R = \{1, 2, \cdots M\}$ denote the set of users acting as RXs. We assume that $K \geq M$, and the TXs are selected from $\mathcal{M}_T$, while the pairing RXs are chosen from $\mathcal{M}_R$.

In this scenario, the channel coefficients are $h_{k,b,j}$, $h_{k,i,a}$, $h_{k,b,a}$ and $h_{k,i,j}$, respectively. Thus, the sum-rate of uplink-downlink transmission of a user pair (i, j), with $i \in \mathcal{M}_T$ and $j \in \mathcal{M}_R$, over subcarrier $k \in \mathcal{K}$ can be expressed as

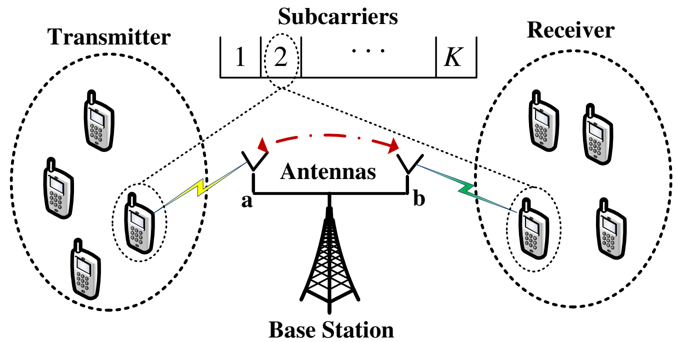

Fig. 1. System model: full-duplex OFDMA networks.

$$S_{k,i,j} = \log_2\left(1 + \frac{p_{s,j,k}|h_{k,b,j}|^2}{{\sigma_n}^2 + p_u|h_{k,i,j}|^2}\right) + \log_2\left(1 + \frac{p_u|h_{k,i,a}|^2}{{\sigma_n}^2 + \eta p_{s,j,k}|h_{k,b,a}|^2}\right), \quad (1)$$

where ${\sigma_n}^2$ represents the channel variance, η is the interference cancellation coefficient, and p_u is the transmitted power of each user, which is fixed in our scenario.

To better express the user and subcarrier pairing, we define a three-dimensional $M \times M \times K$ pairing matrix $\mathbf{X} = \{0, 1\}$, in which $x_{k,i,j} = 1$ denotes that TX_i and RX_j are paired and use subcarrier k. Our objective is to maximize the sum-rate of the system by jointly optimizing the pairing variables $\{x_{k,i,j}\}$ and the power variables $\{p_{s,j,k}\}$. The optimization problem can be formulated as:

$$\max_{\{\mathbf{X},\mathbf{p}_s\}} \sum_{k=1}^{K}\sum_{i=1}^{M}\sum_{j=1}^{M} x_{k,i,j} S_{k,i,j}(p_{s,j,k}) \quad (2)$$

s.t. constraints,

where $\mathbf{p}_s \in \mathbb{R}_+^{M \times K}$ is a vector with elements $p_{s,j,k}$. Note that the constraints include: 1) each TX can only be paired with one RX and vice versa; 2) each subcarrier can only be assigned to one transceiver unit and vice versa; 3) the total transmit power of the BS is subject to its peak power constraint P_s.

III. Matching Algorithms

The aim of the proposed algorithm is to match the TXs, RXs and subcarriers to each other and adjust the BS power

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level in each subcarrier such that the total network's sum-rate is maximized.

A. Matching Definitions

For convenience, we first define a subcarrier-RX (SR) unit that consists of one subcarrier and one RX. Since there exist K subcarriers and M RXs, there are MK different SR units, $\mathcal{SR} = \{SR_{k,j}\}_{k=1,j=1}^{k=K,j=M}$. Thus we have a matching with M TXs on one side and MK SR units on the other side. In our scenario, a matching can be mathematically defined as:

Definition 1: A *matching* Ψ is a one-to-one correspondence $\mathcal{M_T} \cup \mathcal{SR} \rightarrow (\mathcal{M_T} \cup \mathcal{SR} \cup \{\emptyset\}) \times \mathbb{R}^+$ such that

1) $\Psi(TX_i) \in (\mathcal{SR} \cup \{\emptyset\}) \times \mathbb{R}^+$ and $|\Psi(TX_i)| \in \{0, 1\}$;

2) $\Psi(SR_{k,j}) \in (\mathcal{M_T} \cup \{\emptyset\}) \times \mathbb{R}^+$ and $|\Psi(SR_{k,j})| \in \{0, 1\}$;

where $\Psi(SR_{k,j}) = TX_i$ indicates that TX_i is matched with the SR unit $SR_{k,j}$.

Due to the system constraint that each TX, RX and subcarrier can only be matched once, if $\Psi(TX_i) = SR_{k,j}$, then $\forall i' \in \mathcal{M}_T - \{i\}$, $\Psi(TX_{i'}) \in \{\{\mathcal{SR} - \{k \cup j\}\} \cup \{\emptyset\}\} \times \mathbb{R}^+$. Besides, a *matching* Ψ is *stable* if there is no pair consisting of TX_i and a SR unit, $SR_{k,j}$ such that TX_i and $SR_{k,j}$ are not already matched together under Ψ, but prefer each other to their current assignments under matching Ψ.

B. Proposed Algorithm

We first assume that the BS allocates equal power levels to all the transceiver units. The BS then runs an optimal matching algorithm that optimally matches the TXs with the SR units. After pairing the transceivers and subcarriers, the BS utilizes an interior point method [4] to optimally adjust the power levels.

We now briefly describe the proposed matching algorithm. First we define a price for each SR unit and set the price to zero. These prices are fictitious money without any physical meanings that are considered as the matching cost for each TX. The price of any SR unit, $SR_{k,j}$ is the sum of RX_j's price and subcarrier k's price. Then in each step, any TX_i that is still not matched proposes to its most preferred $SR_{k,j}$ according to the achieved sum-rate and the cost of the corresponding TX_i-SR unit. If RX_j or subcarrier k receives offers from more than two TXs, they increase their prices with a price step number, ϵ until only one offer is received. When RX_j and subcarrier k both receive only one offer, which comes from TX_i, they will be matched together. The matching algorithm is iterative and ends if all the TXs are matched and no new offer is being made. This point is called the *equilibrium point* of the matching, which also indicates that the convergence has been achieved.

IV. Simulation Results

For the simulations, we set the BS's peak power, P_s to 46dBm, noise variance, σ^2 to -90dBm, interference cancellation coefficient, η to 0.5, and price step number, ϵ to 0.05. We also consider a slowly varying block fading channel model with a sufficiently long coherence time. To evaluate the performance of our proposed matching algorithm, we compare our results with the results of the centralized solution of the problem in (2). Besides, we utilize a random matching algorithm, in which the TXs, the RXs and the subcarriers are randomly matched with each other while satisfying the system constraints. These two algorithms are considered as upper and lower bound solutions in terms of the complexity.

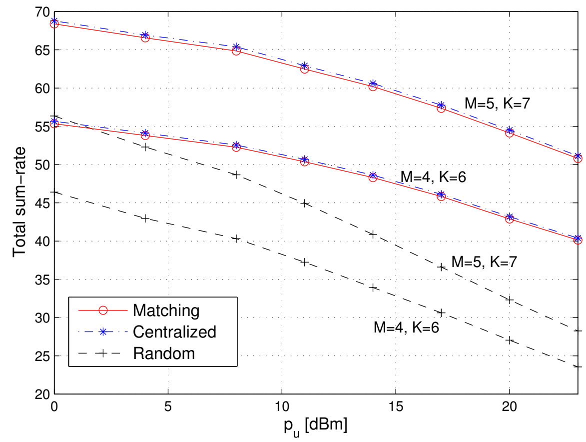

Fig. 2. Total sum-rate vs. transmitted power of each user p_u.

Fig. 2 illustrates the total sum-rate vs. transmitted power of each user, p_u. We see that our proposed matching algorithm provides a total sum-rate of the network quite close to the centralized algorithm. For example, when $p_u = 5$dBm, $M = 5$, and $K = 7$, our proposed algorithm reaches 99.46% of the performance of the centralized algorithm. Besides, the complexity level of our proposed algorithm is much lower than that of the centralized algorithm such that when $Pu = 5$dBm, $M = 5$, and $K = 7$, the number of iterations in the centralized algorithm is 7200, which is 928.57% higher than that in our proposed algorithm which is no more than 700. Also, the proposed matching algorithm performs significantly better than the random matching.

V. Conclusion

In this paper, we studied resource allocation in a full-duplex OFDMA wireless network. We proposed a near optimal approach in which a low-complexity matching algorithm is applied to optimally match the TXs, RXs, and subcarriers, and an interior-point method to optimally allocate the transmitted power of the BS. Simulation results show that with a much lower complexity, our proposed matching algorithm achieves a performance very close to that of the centralized algorithm, and significantly better than the random matching algorithm.

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