

Mode Selection, User Pairing, Subcarrier Allocation and Power Control in Full-Duplex OFDMA HetNets

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Abstract—Full duplex heterogeneous networks are considered as a mean of boosting the performance of future wireless communication networks. In this paper, we study full duplex orthogonal division multiple access (OFDMA) heterogeneous network. In our model, each node will operate either in full duplex or half duplex multiuser MIMO. In addition, each user will attempt to connect to the macro base station or one of the available small cell access points. Moreover, it is assumed that there exist strict transmission power constraints on each transmitting node and each user. Accordingly, a joint resource allocation problem which maximizes the aggregate network’s throughput by considering mode selection, user pairing, subcarrier allocation and power control is proposed. Additionally, the performance of our proposed scheme is evaluated indicating the effects of different system parameters on the system performance. Finally, our proposed scheme’s performance is compared with that of a network which operates in full-duplex only or half-duplex only.

I. INTRODUCTION

Modern networking topologies as well as adequate allocation of the available communication resources have become very essential to accommodate the tremendous increase in wireless communication users. Accordingly, heterogeneous networks (HetNets) [1], which are capable of increasing the aggregate network capacity by deploying a combination of macro, pico, and femto base stations with traditional macro-cell networks, have been proposed. However, efficient resource allocation is needed to decrease the effect of both cross-tier and inter-tier interference. In [2], the problem of subchannel and power allocation in a dense deployment of femtocells in two-tier OFDMA HetNets is studied. In [3], a joint optimization problem that enfolds time slot, subcarrier, and power-allocation policies is formulated for OFDMA-HetNets. In [4], a distributed resource allocation technique for uplink OFDMA small-cell network is proposed. In [5], a traffic-aware OFDMA hybrid small-cell deployment, and an optimal admission control

policy for next-generation cellular systems are proposed.

On the other hand, full-duplex (FD) operation represents a solution for efficient utilization of communication resources. However, FD was considered to be impractical due to the large self-interference power. Fortunately, recent research work in self-interference cancellation techniques [6], [7] has revived the attention to FD. However, resource allocation in FD-OFDMA networks will differ from the allocation in half-duplex (HD) OFDMA networks in the need for efficient pairing between uplinks (ULs) and downlinks (DLs) into independent transceiver pairs. Generally, users’ pairing aims at decreasing the co-channel interference caused by the UL transmission on the DL transmission. The co-channel interference level is affected by the distance between the transmitting UL and receiving DL and the UL transmitting power, and it increases when frequency reuse is considered. In [8], the joint problem of subcarrier assignment and power allocation in full-duplex OFDMA networks is formulated. In [9], authors address the combinatorial nature of pairing multiple ULs, DLs, and subcarriers in a FD-OFDMA network.

In this paper, we are interested in FD-OFDMA HetNets. It is assumed that the base station (BS) and the small cell access points (SAPs) can work in FD or HD. Additionally, users can connect to the BS or one of the SAPs. Accordingly, the transmission mode, users’ pairing, subcarrier allocation, and power allocation must be determined. Therefore, a joint resource allocation problem is proposed to maximize the aggregate capacity by finding the transmission mode for the BS and SAPs, pairing between mobile users that are connected to FD nodes, finding the best subcarrier allocation for the existing users, determining the transmission power per subcarrier for each of the BS and the SAPs, and determining each user’s transmission power. However, power constraints imposed on the BS, SAPs, and mobile

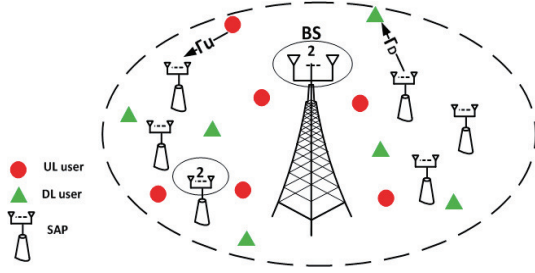


Fig. 1. System Model.

users must be satisfied. Our contributions in this paper are summarized as follows:

- Investigating the difference between different transmission modes in terms of the received power, co-channel interference, and frequency reuse interference;
- Finding the suitable transmission modes for the network's nodes and realizing the best pairing between users connected to FD nodes;
- Finding the best allocation of the available subcarriers to the mobile users;
- Finding both the BS and the SAPs transmission powers per subcarrier. In addition, determining the transmission powers for the users;
- Proposing a joint resource allocation scheme that maximizes the aggregate network's capacity, while keeping power constraints satisfied;
- Studying the proposed scheme's performance and illustrating the effects of different system parameters on the achieved network throughput.

The remainder of this paper is organized as follows. The system model is presented in Section II. The mode selection scheme is proposed in Section III. The resource allocation problem is formulated in Section IV. Numerical results and performance evaluation are presented in Section V. Finally, the paper is concluded in Section VI.

II. SYSTEM MODEL

In this paper, a single cell frequency division duplexing (FDD) OFDMA two-tier network with S subcarriers is considered. The network is assumed to be operating in FDD. Without loss of generality, all subcarriers are assumed to be perfectly synchronized. Therefore, there is no interference between transmissions in different bands. The cell has one macro BS with 2 antennas, K SAPs each equipped with 2 antennas, and N single-antenna users, which are randomly located within the cell. The system model is shown in Fig. 1.

In this paper, the BS and the SAPs are assumed to be able to operate in either FD or HD. The difference

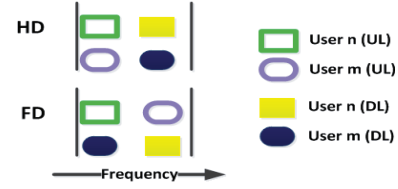


Fig. 2. Difference between FD and HD operation.

between HD and FD operations is illustrated in Fig. 2. If a given node operates in FD, it will assign a certain subcarrier to simultaneously serve the UL and DL transmissions on the n^{th} and the m^{th} users, respectively. However, it will assign another subcarrier to simultaneously serve the UL and DL transmissions on the m^{th} and the n^{th} users, respectively. On the other hand, if the node operates in HD, it will operate in multiuser MIMO (MU-MIMO), in which it will assign a certain subcarrier to serve two simultaneous UL transmissions of the n^{th} and m^{th} users. However, it will assign another subcarrier to serve two simultaneous DL transmissions of the same users.

Moreover, the network's users have the option to either connect to the BS or to one of the SAPs. However, it must be noted that all transmitting nodes including the BS, the SAPs, and the users are constrained by a maximum transmission power whose value is decided according to the transmitting node. In addition, subcarrier allocation is needed to efficiently utilize the available subcarriers among the existing users. However, as mentioned before, FD differs from HD in the necessity of an efficient pairing between ULs and DLs into independent transceiver pairs. Moreover, frequency reuse is considered. For simplicity, it is assumed that each subcarrier is allowed to be reused only one time. Afterwards, each pair is needed to be assigned to the same subset of OFDMA subcarriers. In our model, the network is trying to maximize its sum throughput by fulfilling the following requirements:

- 1) Find the suitable transmission mode for the BS and all the SAPs;
- 2) Find the appropriate users' assignments and subcarrier allocation;
- 3) Keep the maximum power constraints imposed on the BS, SAPs and transmitting ULs;
- 4) Pairing users connected to FD nodes efficiently.

III. MODE SELECTION

Based on the previous assumptions, the achieved throughput by each node will depend on the node's transmission mode, and the interfering node's transmission

mode. Therefore, we are going to have four different cases that will determine the transmission node's aggregate throughput.

1. *Case 1. Both the concerned node and the interfering node operate in FD.*

In that case, if it is assumed that the concerned k^{th} node¹ is allocated to a transceiver pair (n, m) that include the n^{th} and the m^{th} users on the s^{th} subcarrier, and that the k^{th} interfering node is allocated to a transceiver pair (n', m') on the same s^{th} subcarrier. Therefore, the total achieved throughput on the s^{th} subcarrier of the k^{th} node is given by

$$R_{FD-FD} = \log_2(1 + \Gamma_{D11}) + \log_2(1 + \Gamma_{D12}) + \log_2(1 + \Gamma_{U11}) + \log_2(1 + \Gamma_{U12}), \quad (1)$$

where, Γ_{D11} , and Γ_{D12} are the DL received signal-to-interference-noise ratio (SINR) of the m^{th} , and n^{th} users, respectively. Γ_{U11} , and Γ_{U12} are the UL received SINR of the n^{th} , and m^{th} users, respectively. The values of these SINRs are given, respectively, by

$$\Gamma_{D11(12)} = \frac{P_{k,s} D_{k,m(n)}^{-\alpha} |h_{k,m(n)}^s|^2}{\sigma^2 + P_n(m) D_{m,n}^{-\alpha} |h_{m(n),n(m)}^s|^2 + I_{1(2)}}, \quad (2)$$

$$\Gamma_{U11(12)} = \frac{P_n(m) D_{n(m),k}^{-\alpha} |h_{n(m),k}^s|^2}{\sigma^2 + P_{k,s} C_k + I_{3(4)}},$$

where, $P_{k,s}$ is the s^{th} subcarrier BS transmission power for $k = 0$, and the s^{th} subcarrier SAPs transmission power for $k = [1 \cdots K]$, $D_{k,m}^{-\alpha}$ represents the large scale fading between the m^{th} user and the k^{th} node with distance $D_{k,m}$ and path loss exponent α , $h_{k,m}^s$ is the channel coefficient between the m^{th} user and the k^{th} node on the s^{th} subcarrier, σ^2 is the noise variance, $P_n D_{m,n}^{-\alpha} |h_{m,n}^s|^2$ is the interference caused by the n^{th} user's UL transmission, where P_n is the n^{th} user transmission power, $D_{m,n}$ is the distance between the n^{th} user and the m^{th} user and $h_{m,n}^s$ is the channel coefficient between the n^{th} user and the m^{th} user on the s^{th} subcarrier. In addition, $P_{k,s} C_k$ denotes the residual self-interference caused by the DL transmission on the UL transmission with transmission power $P_{k,s}$ and self-interference cancellation parameter C_k which is gained from using special FD radio in node k . $I_{1 \rightarrow 4}$ are the interference terms caused by frequency reuse. The notation 11(12) indicates that we can get Γ_{D12} from Γ_{D11} expression after interchanging user m and user n , and I_1 by I_2 . Similarly, we can get Γ_{U12} from Γ_{U11} expression after interchanging user n by user m , and I_3 by I_4 . The values of $I_{1 \rightarrow 4}$ are given, respectively, by

¹Throughout the paper the word "node" is used to refer to the BS or a SAP.

$$I_{1(2)} = P_{k',s} D_{k',m(n)}^{-\alpha} |h_{k',m(n)}^s|^2 + P_{n'(m')} D_{m(n),n'(m')}^{-\alpha} |h_{m(n),n'(m')}^s|^2, \quad (3)$$

$$I_{3(4)} = P_{k',s} D_{k',k}^{-\alpha} |h_{k',k}^s|^2 + P_{n'(m')} D_{n'(m'),k}^{-\alpha} |h_{n'(m'),k}^s|^2,$$

where the first terms in the interference equations denote the interference caused by the DL transmission and the second terms denote the interference caused from the UL transmission. Similarly, we can get I_2 from I_1 expression after replacing every m in I_1 expression with n . Additionally, I_3 can be calculated from I_4 expression after substituting every n' in I_3 expression with m' .

2. *Case 2. The concerned node operates in FD and the interfering node operates in HD MU-MIMO.*

In that case, the total achieved throughput on the s^{th} subcarrier of the k^{th} node is given by

$$R_{FD-HD} = \log_2(1 + \Gamma_{D21}) + \log_2(1 + \Gamma_{U21}) + \log_2(1 + \Gamma_{D22}) + \log_2(1 + \Gamma_{U22}), \quad (4)$$

where, Γ_{D21} , and Γ_{D22} are the DL received SINR of the m^{th} , and the n^{th} users, respectively. Γ_{U21} , and Γ_{U22} are the UL received SINR of the n^{th} , and the m^{th} users, respectively. The values of these SINRs are given, respectively, by

$$\Gamma_{D21(22)} = \frac{P_{k,s} D_{k,m(n)}^{-\alpha} |h_{k,m(n)}^s|^2}{\sigma^2 + P_n(m) D_{m,n}^{-\alpha} |h_{m(n),n(m)}^s|^2 + I_{5(7)}}, \quad (5)$$

$$\Gamma_{U21(22)} = \frac{P_n(m) D_{n(m),k}^{-\alpha} |h_{n(m),k}^s|^2}{\sigma^2 + P_{k,s} C_k + I_{6(8)}},$$

where, $I_{5 \rightarrow 8}$ are the interference terms caused by frequency reuse. The interference values are given, respectively, by

$$I_{5(6)} = P_{k',s} D_{k',m(k)}^{-\alpha} |\mathbf{h}_{k',m(k)}^s| \mathbf{R}_s^{\frac{1}{2}} \mathbf{w}_{k',m'}^s|^2 + P_{k',s} D_{k',m(k)}^{-\alpha} |\mathbf{h}_{k',m(k)}^s| \mathbf{R}_s^{\frac{1}{2}} \mathbf{w}_{k',n'}^s|^2, \quad (6)$$

$$I_{7(8)} = P_{m'} D_{n(k),m'}^{-\alpha} |h_{n(k),m'}^s|^2 + P_{n'} D_{n(k),n'}^{-\alpha} |h_{n(k),n'}^s|^2,$$

where, $\mathbf{h}_{k',m}^s$ is the HD channel vector between the k' node and the m^{th} user, $\mathbf{R}_s = \begin{bmatrix} 1 & \beta \\ \beta & 1 \end{bmatrix}$ is a 2×2 spatial correlation matrix at the s subcarrier with spatial correlation coefficient $\beta \in [0, 1]$, where $\beta = 0$ indicates the independent channels case. It is assumed that spatial correlation between antennas is the same for all subcarriers for all of the BS and the SAPs. The first equation calculates the interference value caused by two simultaneous DL transmissions. Similarly, the second equation calculates the interference value caused by two simultaneous UL transmissions. $\mathbf{w}_{k',m}^s$ is the

MU-MIMO precoding vector applied by the k' node on the m^{th} user data at the s subcarrier, and is given by [10]

$$\mathbf{w}_{k',m}^s = \frac{R^{\frac{1}{2}} \mathbf{h}_{k',m}^s \dagger}{\|R^{\frac{1}{2}} \mathbf{h}_{k',m}^s \dagger\|_F}, \quad (7)$$

where $(\cdot)^\dagger$ denotes the Hermitian transpose, and $\|\cdot\|_F$ denotes the Frobenius norm.

3. Case 3. The concerned node operates in HD MU-MIMO and the interfering node operates in FD

In that case, the total achieved throughput on the s^{th} subcarrier of the k^{th} node is given by

$$R_{HD-FD} = \log_2(1 + \Gamma_{D31}) + \log_2(1 + \Gamma_{D32}) + \log_2(1 + \Gamma_{U31}) + \log_2(1 + \Gamma_{U32}), \quad (8)$$

where Γ_{D31} , and Γ_{D32} are the received SINRs of the n^{th} , and the m^{th} users, respectively. Γ_{U31} , and Γ_{U32} are the received SINR of the n^{th} , and the m^{th} users, respectively. The values of these SINRs are given, respectively, by

$$\begin{aligned} \Gamma_{D31(32)} &= \frac{P_{k,s} D_{k,n(m)}^{-\alpha} |\mathbf{h}_{k,n(m)}^s \mathbf{R}_s^{\frac{1}{2}} \mathbf{w}_{k,n(m)}^s|^2}{\sigma^2 + P_{k,s} D_{k,n(m)}^{-\alpha} |\mathbf{h}_{k,n(m)}^s \mathbf{R}_s^{\frac{1}{2}} \mathbf{w}_{k,m(n)}^s|^2 + I_{9(10)}}, \\ \Gamma_{U31(32)} &= \frac{P_n(m) D_{k,n(m)}^{-\alpha} |\mathbf{R}_s^{\frac{1}{2}} \mathbf{h}_{k,n(m)}^s|^2}{\sigma^2 + P_m(n) D_{k,m(n)}^{-\alpha} |\mathbf{R}_s^{\frac{1}{2}} \mathbf{h}_{k,m(n)}^s|^2 + I_{11}} \end{aligned} \quad (9)$$

where $I_{9 \rightarrow 11}$ are the interference terms caused by frequency reuse. The interference values are given, respectively, by

$$\begin{aligned} I_{9(10)} &= P_{n'} D_{n',n(m)}^{-\alpha} |h_{n',n(m)}|^2 + P_{k',s} D_{k',n(m)}^{-\alpha} |h_{k',n(m)}|^2, \\ I_{11} &= P_{m'} D_{m',k}^{-\alpha} |h_{m',k}^s|^2 + P_{k',s} D_{k,k'}^{-\alpha} |h_{k,k'}^s|^2. \end{aligned} \quad (10)$$

4. Case 4. Both nodes operate in HD MU-MIMO

In that case, the total achieved throughput on the s^{th} subcarrier of the k^{th} node is given by

$$R_{HD-HD} = \log_2(1 + \Gamma_{D41}) + \log_2(1 + \Gamma_{D42}) + \log_2(1 + \Gamma_{U41}) + \log_2(1 + \Gamma_{U42}), \quad (11)$$

where Γ_{D41} , and Γ_{D42} are the received SINRs of the n^{th} , and the m^{th} users, respectively. Γ_{U41} , and Γ_{U42} are the received SINRs of the n^{th} , and the m^{th} users, respectively. The values of these SINRs are given, respectively, by

$$\begin{aligned} \Gamma_{D41(42)} &= \frac{P_{k,s} D_{k,n(m)}^{-\alpha} |\mathbf{h}_{k,n(m)}^s \mathbf{R}_s^{\frac{1}{2}} \mathbf{w}_{k,n(m)}^s|^2}{\sigma^2 + P_{k,s} D_{k,n(m)}^{-\alpha} |\mathbf{h}_{k,n(m)}^s \mathbf{R}_s^{\frac{1}{2}} \mathbf{w}_{k,m(n)}^s|^2 + I_{12(13)}}, \\ \Gamma_{U41(42)} &= \frac{P_n(m) D_{k,n(m)}^{-\alpha} |\mathbf{R}_s^{\frac{1}{2}} \mathbf{h}_{k,n(m)}^s|^2}{\sigma^2 + P_m(n) D_{k,m(n)}^{-\alpha} |\mathbf{R}_s^{\frac{1}{2}} \mathbf{h}_{k,m(n)}^s|^2 + I_{14}} \end{aligned} \quad (12)$$

where $I_{12 \rightarrow 14}$ are the interference terms caused by frequency reuse. The interference values are given, respectively, by

$$\begin{aligned} I_{12(13)} &= P_{k',s} D_{k',n(m)}^{-\alpha} |\mathbf{h}_{k',n(m)}^s \mathbf{R}_s^{\frac{1}{2}} \mathbf{w}_{k',n'}^s|^2 \\ &\quad + P_{k',s} D_{k',n(m)}^{-\alpha} |\mathbf{h}_{k',n(m)}^s \mathbf{R}_s^{\frac{1}{2}} \mathbf{w}_{k',m'}^s|^2 \\ I_{14} &= P_{m'} D_{m',k}^{-\alpha} |\mathbf{R}_s^{\frac{1}{2}} \mathbf{h}_{m',k}^s|^2 + P_{n'} D_{n',k}^{-\alpha} |\mathbf{R}_s^{\frac{1}{2}} \mathbf{h}_{n',k}^s|^2. \end{aligned} \quad (13)$$

Therefore, the total achieved throughput of the s^{th} subcarrier on the k^{th} nodes is given by

$$\begin{aligned} R_k^s &= T_k T_{k'} R_{FD-FD} + T_k (1 - T_{k'}) R_{FD-HD} \\ &\quad + (1 - T_k) T_{k'} R_{HD-FD} + (1 - T_k) (1 - T_{k'}) R_{HD-HD}, \end{aligned} \quad (14)$$

where $T_k = 1$ denotes the k^{th} node operates in FD, and $T_k = 0$ denotes the k^{th} node operates in HD. Therefore, the total network throughput is given by

$$R = \sum_{k=0}^K \sum_{s=1}^S \sum_{m=1}^N \sum_{\substack{n=1 \\ n \neq m}}^N \sum_{\substack{n'=1 \\ n' \neq m \\ n' \neq n}}^N \sum_{\substack{m'=1 \\ m' \neq n \\ m' \neq n'}}^N a(m, n, k, s) a(m', n', k', s) R_k^s, \quad (15)$$

where $a(m, n, k, s) = 1$ denotes that the m^{th} and n^{th} users are allocated the same subcarrier s of the k^{th} node either in FD mode or HD mode.

IV. PROBLEM FORMULATION

In this section, we try to find the best transmission mode, user pairing, user assignment, power allocation, and subcarrier allocation that maximize the network sum throughput given in (15). It should be noted that each subcarrier can be allocated to two user pairs due to the consideration of frequency reuse. Additionally, in case of the FD operation, each user is only permitted to be paired one. Therefore, the optimization problem can be formulated as

$$\begin{aligned} &\text{maximize} && R \\ &\mathbf{T}^*, \mathbf{A}^*, \mathbf{P}_k^*, \mathbf{P}_U^* \\ \text{s.t.} & T_k \in \{0, 1\}, \forall k \in [0 \cdots K], \\ & \sum_{s=1}^S P_{s,k} \leq P_{k_{max}} \forall k \in [0 \cdots K], \\ & P_m \leq P_{U_{max}} \forall m \in [1 \cdots N], \\ & \sum_{k=0}^K \sum_{s=1}^S \sum_{\substack{m=1 \\ m \neq n^*}}^N a(m, n^*, k, s) = 1 \forall n^* \in [1 \cdots N], \\ & \sum_{k=0}^K \sum_{s=1}^S \sum_{\substack{n=1 \\ n \neq m^*}}^N a(m^*, n, k, s) = 1 \forall m^* \in [1 \cdots N], \\ & \sum_{k=0}^K \sum_{n=1}^N \sum_{\substack{m=1 \\ m \neq n}}^N a(n, m, k, s) \in \{1, 2\} \forall s \in [1 \cdots S], \end{aligned} \quad (16)$$

Algorithm 1: Mode Selection, User Pairing, Subcarrier Allocation and Power Control

Data: $P_{k_{max}} \forall k \in [0 \cdots K]$, PU_{max} , σ^2 , $C_k \forall k \in [0 \cdots K]$, step size (μ), tolerance (ε), All CSI information, X_0

Result: $X^* = [\mathbf{T}^*; \mathbf{A}^*; \mathbf{P}_k^*; \mathbf{P}_U^*]$ maximizing R

1. Define $T_{k_c} \in [0, 1]$, $a_c(m, n, k, s) \in [0, 1] \forall k \in [0 \cdots K]$, $\forall m, n \in [1 \cdots N]$, $\forall s \in [1 \cdots S]$;
 2. Determine $X^*(t)$ minimizing $(-tR + \Phi(X))$
 3. Update $X = X^*(t)$
 4. **if** $\frac{m}{t} \neq \varepsilon$ **then**
 - Increase $t = \mu t$
 - Return to step 2.
 - end**
 - else**
 - $T_k^* \approx T_{k_c}$
 - $a(m, n, k, s) \approx a_c(m, n, k, s)$
 - end**
 - end**
-

where \mathbf{T}^* includes the parameter $T_k \forall k \in [0 \cdots K]$, \mathbf{A}^* contains all the $a(m, n, k, s)$ parameters for all combinations of user, transmitting nodes and subcarriers, \mathbf{P}_k^* contains every node transmitting power on every subcarrier, \mathbf{P}_U^* includes all the ULs transmitting power, $P_{k_{max}}$ is the maximum allowed transmission power for the k^{th} node and PU_{max} is the maximum transmission power for all users. The second constraint ensures that each node will not exceed $P_{k_{max}}$. The third constraint guarantees that all users will not exceed PU_{max} . The fourth and the fifth constraints ensure that regardless of the transmission mode, every user is paired once. Finally, the last constraint allows each subcarrier either to be used by one node or two nodes if frequency reuse is needed. The optimization problem given in (16) is a non-linear integer programming problem, which is an NP hard problem. Therefore, in order to solve this optimization problem, the binary variables T_k , and $a(m, n, k, s)$ are relaxed to be T_{k_c} , and $a_c(m, n, k, s)$, respectively, which are in the continuous domain $[0, 1]$, then after solving the relaxed optimization problem using interior point algorithm [11], these variables are re-mapped to the binary domain $\{0, 1\}$. The solution algorithm is shown in Algorithm 1. In the beginning, a tolerance value ε , a step size $\mu > 0$, an initial point in the feasible set X_0 , the log barrier function $\Phi(X)$ for m constraints are determined. Afterwards, the interior point algorithm is applied to the relaxed optimization problem. Finally, the variables T_{k_c} , and $a_c(m, n, k, s)$ are

rounded obtaining T_k , and $a(m, n, k, s)$, respectively in the binary domain. We use standard MATLAB function to implement the above algorithm.

V. NUMERICAL ANALYSIS

In this section, we are going to evaluate our proposed scheme performance and the effect of different system parameters on the aggregate throughput. In addition, we will compare our system performance with FD and HD operation. A rectangular grid is considered with one BS, one SAP, and 4 users. The network operates OFDMA with 4 subcarriers. The simulation parameters used are given in Table. I.

TABLE I
SIMULATION PARAMETERS

$P_{BS_{max}}$	20W	$P_{SAP_{max}}$	1W
P_U	0.2 W	α	2.5
σ^2	$10^{-7}W$	c_k [7]	70 dB

A. Variation of the System Throughput with Spatial Correlation Coefficient

We are going to study the effect of the spatial correlation β on the aggregate throughput. It is anticipated that increasing β will degrade the HD performance. Fig. 3 shows the variation of the aggregate throughput with β . For small values of β , the HD throughput is greater than the FD throughput. However, as β increases, the spatial correlation between the HD channel increases and the HD performance starts to degrade until FD outperforms HD. It can be verified from Fig. 3 that the proposed scheme always selects the best transmission mode as follows: for a small β value, the HD performance is better than the FD performance; accordingly, the proposed scheme chooses to operate in HD. However, after $\beta = 0.6$, FD performance becomes better than that of HD. Therefore, the proposed scheme switches its operation from HD to FD for $\beta > 0.6$ in our simulation setup.

B. Variation of the System Throughput with Distance between Users

The distance between users affects the users' pairing choice because it influences the co-channel interference between users communicating with FD nodes. Furthermore, changing the distance between users will definitely change the distance between users and transmission nodes. Accordingly, we are expecting to find a variation in the system performance either in FD operation or HD operation. However, the variation in HD performance

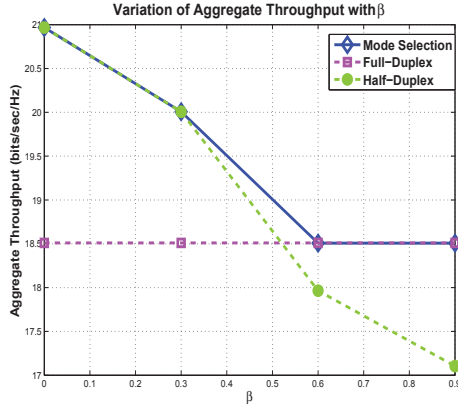


Fig. 3. Variation of Aggregate Throughput with Spatial Correlation Coefficient β .

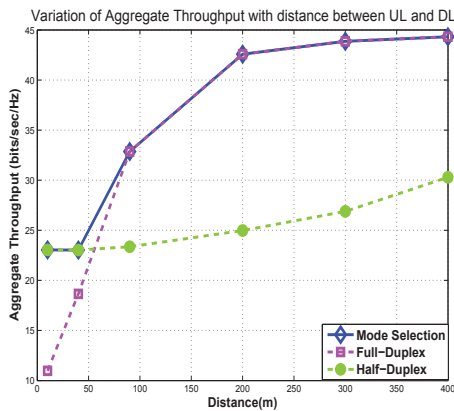


Fig. 4. Variation of Aggregate Throughput with The Distance between Users.

will not be as significant as the variation in FD performance.

Fig. 4 shows the variation of the total system throughput with changing the distance between users and keeping $\beta = 0.1$. For small distance between users, it can be seen that HD is better than FD due to high co-channel interference. However, as the distance increase, the co-channel interference decreases. Accordingly, the FD throughput starts to be larger than that of HD. It can be verified from Fig. 4 that the proposed model selects the best transmission mode.

VI. CONCLUSION

In this paper, we have proposed a joint mode selection, user pairing, subcarrier and power allocation in an OFDMA HetNet. The proposed model maximizes the total network throughput by switching the BS and the

SAPs between FD and HD, adjusting their transmission powers per subcarrier, pairing users into transceiver pairs, allocating available subcarriers to existing users, and determining the users' transmission power. In addition, the performance of the proposed model has been evaluated when changing the spatial correlation coefficient and the distance between users. Furthermore, it has been verified from the numerical results that the proposed scheme switches the nodes' operation mode to achieve the maximum aggregate throughput. Currently, we are planning to extend our proposed model to the multi-cell network case. Actually, having multiple cells in the network will affect the interference signals, and hence the joint resource allocation problem solution.

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