Asymmetric Resource Allocation for OFDMA Networks with Collaborative Relays

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***Abstract*—This work addresses the radio resource allocation problem for cooperative relay assisted OFDMA wireless network. The relays adopt the decode-and-forward protocol and can cooperatively assist the transmission from source to destination. Recent works on the subject have mainly considered symmetric source-to-relay and relay-to-destination resource allocations, which limits the achievable gains through relaying. In this paper we consider the problem of asymmetric radio resource allocation, where the objective is to maximize the system throughput of the source-to-destination link under various constraints. In particular, we consider optimization of the set of cooperative relays and link asymmetries together with subcarrier and power allocations. We derive theoretical expressions for the solutions and illustrate them through simulations. The results validate clearly the additional performance gains through asymmetric cooperative scheme compared to the other recently proposed resource allocation schemes.**

***Index Terms*—OFDMA, relay selection, subcarrier allocation, asymmetric power allocation, and cooperative communications**

I. Introduction

Orthogonal Frequency Division Multiple Access (OFDMA) is an effective technique that exploits the benefits of Orthogonal Frequency Division Multiplexing (OFDM) for combating against channel noise and multipath effects and finally enables high data rate transmissions over fading channels. In addition, OFDMA is able to provide good bandwidth scalability as the number of subcarriers can be flexibly configured. Therefore, OFDMA is widely adopted in many standards of upcoming wireless communication systems, such as IEEE 802.11ac [1], LTE/LTE-A [2] and WiMAX [3].

Meanwhile, cooperative communication has emerged as one of the main trends to reach even better system performance in terms of throughput, energy efficiency or cell coverage. Therefore, the incorporation of OFDMA and cooperative relays is foreseen to result in a promising structure that offers a possibility to reach many desirable objectives for the future wireless networks. However, a combination of a conventional one-to-many (single hop) OFDMA system and a relay network calls for a careful design of the radio resource allocation (RRA) principles. This means a careful design and coordination of the power and subcarrier allocation, selection of relay(s) across different hops and optimizing the resource asymmetries between the hops.

The RRA algorithm plays an important role in the developments of both conventional and relay-aided OFDMA systems. The related works have been widely done in several different areas [4]-[10]. A cross-layer optimization algorithm for resource allocation in conventional OFDMA network has been presented in [4] without considering any relays and an iterative algorithm has proposed to solve the subcarrier assignment together with relay selection in [5]. Then, the power allocation problem is supposed to be solved by another iterative method based on waterfilling algorithm. Authors in [6] introduced a closed-form solution for radio resource allocation for multi-hop cooperative relay network. However, the per-tone power constraint was assumed. The scheme used in [7] considered fairness constraints when selecting relays. In [8], a threshold method was proposed to solve two subproblems, subcarrier allocation and power allocation. Although the performance was shown to improve compared to some other algorithms, the total power constraint was considered instead of per-node power limitation. The work in [9] also proposed a subcarrier and relay pairing algorithm to solve the existing RRA problem but results in higher computational complexity. Moreover, all the previous works have assumed the transmission durations of base-to-relay and relay-to-source links to be equal, which may result in reduced achievable gains. Recently, a study on the asymmetric resource allocation was presented in [10]. However, that work considered single relay in the OFDMA networks without exploring cooperative diversity.

In this paper we take into consideration the shortcomings of the above mentioned approaches. In particular, we consider asymmetric link allocations meaning that the source-to-relay link (first hop) and relay-to-destination link (second hop) are not necessary equal. We then investigate the RRA problem in this setting and propose a method to solve the joint relay set selection for cooperation in addition to asymmetry, subcarrier and power allocations, and hence target to enhance the total system throughput. The use case selected in this paper is cell coverage extension, so we do not consider direct link from source to destination to be utilized. We propose a relay selection scheme, where the selected set of relays will obtain the best overall link data rate through collaboration. The sets of orthogonal frequency subcarriers are then assigned to the selected relays at each hop. Power allocation is performed to the source and relays under per-node constraints, which is more realistic than the scheme e.g. in [8] where only the whole system power sums are considered. We consider only

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downlink direction in this work, but it can be extended further to the uplink case as well. To the best of our knowledge, such joint optimization for asymmetric two hop OFDMA network has not been reported so far.

The rest of the paper is organized as follows. Section II describes the relay-assisted OFDMA cooperative wireless network and formulates the problem. In Section III, the proposed resource allocation schemes are presented. We demonstrate the benefits of our proposed algorithm in section IV and finally conclude the paper in Section V.

II. Problem Formulation

This paper investigates the RRA problem for OFDMA network with cooperative relays in the downlink. We consider a two-hop time-division duplex downlink relay system. The whole system consists of source (i.e., access point, AP), destination node (i.e., mobile terminal, MT) and several relays. The first hop is so called broadcast phase, where AP broadcasts information to a cluster of decode-and-forward (DF) relays. At second hop, relays cooperate to transmit data to the MT, so that, e.g., spatial diversity gain can be achieved (relays are assumed to be far enough to each other). The channel state information (CSI) is assumed to be known at receiver and then fed back to the transmitter perfectly. We assume a total of Z relays in the networks, and the selected relay cluster $\mathcal{K}$ contains K potential half-duplex relays. The presented relay-assisted cooperative OFDMA network is as shown in Fig. 1, where $K = 3$.

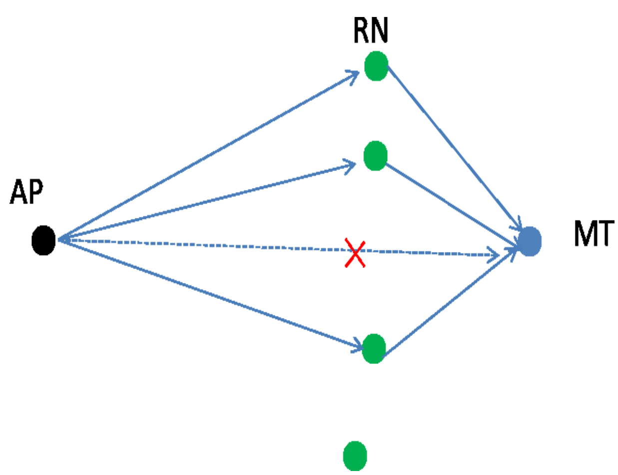

Figure 1. Wireless cooperative relay network scenario.

Suppose h^i is the channel transfer function from transmitter to receiver and we assume the channel to be static within a time slot. For example, $h^i_{s,k}$ means the channel transfer function from AP s to relay node (RN) k over OFDM subcarrier i and $h^j_{k,d}$ means the channel transfer function from RN k to destination d over OFDM subcarrier j. Thus we have the channel gain of the first hop $G^i_{s,k} = |h^i_{s,k}|^2$ and the second hop $G^j_{k,d} = |h^j_{k,d}|^2$. L is the path loss factor and the noise variance for the first and second hops are σ^2_k and σ^2_d, respectively. We denote the transmit power assigned to subcarrier i for transmitting data as P^i. In this work, we do not consider the direct link from AP to MT. This assumption is practical in the case that RNs are used for cell extension or cell edge optimization. One RN k occupies subcarrier i in the first hop and j in the second hop. In this work, we assume that the transmission durations for the first hop and second hop are allowed to differ. We denote these durations as T_1 and T_2. Therefore, in the first hop, the data rate of the broadcast phase is determined by the minimum rate of each link between AP and selected RNs. The achieved throughput of the first hop is as follows:

$$R^{\mathcal{I}}_{s,\mathcal{K}} = \min_{k\in\mathcal{K}} \Big\{ \frac{T_1}{T} log(1 + \sum_{i=1}^{M} \omega^i_{s,k} \rho_k P^i_{s,k} \gamma^i_{s,k}) \Big\}, \tag{1}$$

where $\gamma^i_{s,k} = \frac{L_{s,k} G^i_{s,k}}{\sigma^2_k}$ is the channel SNR and $T = T_1 + T_2$. $\mathcal{M}$ is the subcarrier set of the system that contains M subcarriers. $\mathcal{I}$ is the subcarrier set which contains the subcarriers that are allocated to the selected RNs at the first hop. ρ_k indicates that whether RN k is chosen for subcarrier allocation,

$$\rho_k = \begin{cases} 1 & \text{, if } k \text{ is chosen for relaying,} \\ 0 & \text{, otherwise.} \end{cases}$$

We also define ω as the indicator whether certain subcarrier is assigned to RN k, for example,

$$\omega^i_{s,k} = \begin{cases} 1 & \text{, if } i \text{ is assigned to } k \text{ at first hop,} \\ 0 & \text{, otherwise.} \end{cases}$$

For the second hop, it is assumed that the RNs are perfectly synchronized. Therefore, the second hop can be viewed as a virtual MISO link and the throughput can be expressed as [11]

$$R^{\mathcal{J}}_{\mathcal{K},d} = \frac{T_2}{T} log(1 + \sum_{j=1}^{M} \sum_{k=1}^{K} \omega^j_{k,d} \rho_k P^j_{k,d} \gamma^j_{k,d}), \tag{2}$$

where $\gamma^j_{k,d} = \frac{L_{k,d} G^j_{k,d}}{\sigma^2_d}$. $\mathcal{J}$ is the subcarrier set which contains the subcarriers that are allocated to the selected RNs. For indicator $\omega^j_{k,d}$, we also have

$$\omega^j_{k,d} = \begin{cases} 1 & \text{if } j \text{ is assigned to } k \text{ at second hop,} \\ 0 & \text{otherwise,} \end{cases}$$

Therefore, the total achieved end-to-end throughput of source s to destination d through RN set $\mathcal{K}$ is [12]

$$R_{sd} = min \ \Big\{ R^{\mathcal{I}}_{s,\mathcal{K}}, R^{\mathcal{J}}_{\mathcal{K},d} \Big\}. \tag{3}$$

To proceed, we can formulate our RRA problem as

$$max \ \ R_{sd}, \tag{4}$$

subject to

$$
\begin{aligned}
&T = T_1 + T_2,\\
&\sum_{i=1}^{M}\sum_{k=1}^{K}\omega_{s,k}^{i}P_{s,k}^{i} \le P_{s,max},\\
&\sum_{j=1}^{M}\omega_{k,d}^{j}P_{k,d}^{j} \le P_{k,max},\\
&\sum_{k=1}^{K}\omega_{s,k}^{i} = 1, \omega_{s,k}^{i} \in \{0,1\},\\
&\sum_{k=1}^{K}\omega_{k,d}^{j} = 1, \omega_{k,d}^{j} \in \{0,1\},
\end{aligned} \tag{5}
$$

where $P_{s,max}$ is the maximum transmit power of AP and $P_{k,max}$ is the maximum power of RN k. Therefore, our goal is to find the optimal solutions for relay set, link asymmetry, and subcarrier and power allocations which satisfy the problem (4).

It can be deduced that achieving maximum for (3) implies $R_{s,\mathcal{K}}^{\mathcal{I}} = R_{\mathcal{K},d}^{\mathcal{J}}$ [8]. Thus, (4) can be modified as

$$\arg\max \left(R_{s,\mathcal{K}}^{\mathcal{I}} + R_{\mathcal{K},d}^{\mathcal{J}}\right), \tag{6}$$

subject to conditions in (5) and

$$R_{s,\mathcal{K}}^{\mathcal{I}} = R_{\mathcal{K},d}^{\mathcal{J}}. \tag{7}$$

III. Resource Allocation Scheme

In this section, we introduce an adaptive RRA algorithms to solve the existing problems described in the previous section. Although the resource allocation problem is combinatorial in nature with a non-convex structure, it has been shown in [14] that the duality gap of the optimization problem becomes zero under the condition of time-sharing regardless of its convexity. For the general OFDM system, the condition of time-sharing is always fulfilled as the number of subcarriers is large enough. Therefore, the problem can be solved in the dual domain. The Lagrangian [13] of (6) is

$$
\begin{aligned}
\mathcal{L}(\mathbf{P}, T, \boldsymbol{\omega}, \boldsymbol{\rho}, \boldsymbol{\lambda}, \boldsymbol{\mu}) = &\left(R_{s,\mathcal{K}}^{\mathcal{I}} + R_{\mathcal{K},d}^{\mathcal{J}}\right)\\
&-\lambda_s\Big(\sum_{i=1}^{M}\sum_{k=1}^{K}\omega_{s,k}^{i}P_{s,k}^{i} - P_{s,max}\Big)\\
&-\sum_{k=1}^{K}\lambda_{k,d}\Big(\sum_{j=1}^{M}\omega_{k,d}^{j}P_{k,d}^{j} - P_{k,max}\Big)\\
&-\mu(R_{s,\mathcal{K}}^{\mathcal{I}} - R_{\mathcal{K},d}^{\mathcal{J}}),
\end{aligned} \tag{8}
$$

where $\mathbf{P} = \{P_{s,k}^{i}, P_{k,d}^{j}\}$ is the set of power allocations, $\boldsymbol{\omega} = \{\omega_{s,k}^{i}, \omega_{k,d}^{j}\}$ denotes the subcarrier allocations and $\boldsymbol{\rho} = \{\rho_k\}$ is the relay assignment. The λ_s, $\lambda_{k,d}$ and μ are Lagrange multipliers. Then it can be seen that $\boldsymbol{\lambda} = \{\lambda_s, \lambda_{k,d}\} \ge 0$ and $\boldsymbol{\mu} = \{\mu\} \in (-1, 1)$ [10]. The Lagrange dual function can be written as

$$g(\boldsymbol{\lambda}, \boldsymbol{\mu}) = \max \mathcal{L}(\mathbf{P}, T, \boldsymbol{\omega}, \boldsymbol{\rho}, \boldsymbol{\lambda}, \boldsymbol{\mu}). \tag{9}$$

We assume the number of subcarrier is sufficiently large, so that the duality gap between primal problem and dual function can be assumed negligible [14]. Consequently, we can solve the problem (4) by minimizing the dual function,

$$\min\ g(\boldsymbol{\lambda}, \boldsymbol{\mu}). \tag{10}$$

A. Evaluating Dual Variable

Since the dual function is always convex [13], we can choose e.g. sub-gradient or ellipsoid method [14] with guaranteed convergence to minimize $g(\boldsymbol{\lambda}, \boldsymbol{\mu})$. We follow the subgradient method in [14] to derive the subgradient $g(\boldsymbol{\lambda}, \boldsymbol{\mu})$ with the optimal power allocation p^* that will be presented in the following subsection.

Algorithm 1 Evaluating Dual Variable

```
1: Initialize λ^0 and μ^0
2: while (!Convergence) do
3:    Obtain g(λ^a, μ^a) at the a-th iteration;
4:    Update a subgradient for λ^{a+1} and μ^{a+1}, by λ^{a+1} =
      λ^a + υ^a △λ and μ^{a+1} = μ^a + υ^a △μ;
5: end while
```

Here $\triangle\boldsymbol{\lambda} = \{\triangle\lambda_s, \triangle\lambda_{1,d}, ...\triangle\lambda_{K,d}\}$, and moreover $\triangle\lambda_s$, $\triangle\lambda_{k,d}$ and $\triangle\mu$ can be expressed as

$$
\begin{aligned}
&\triangle\lambda_s = P_{s,max} - \sum_{i=1}^{M}\sum_{k=1}^{K}(P_{s,k}^{i})^*\\
&\triangle\lambda_{k,d} = P_{k,max} - \sum_{j=1}^{M}(P_{k,d}^{j})^*\\
&\triangle\mu = (R_{s,\mathcal{K}}^{\mathcal{I}})^* - (R_{\mathcal{K},d}^{\mathcal{J}})^*.
\end{aligned} \tag{11}
$$

Here υ^a is the stepsize and a is the number of iterations. The sub-gradient algorithm (Algorithm 1) is guaranteed to converge to the optimal $\boldsymbol{\lambda}$ and $\boldsymbol{\mu}$. The computational complexity of Algorithm 1 is polynomial in the number of dual variable $K + 1$ [14]. Since (9) can be viewed as a nonlinear integer programming problem, its optimal solution requires high computational cost. Therefore, we are aiming to solve the optimization problem by solving three subproblems, which are relay selection, subcarriers and power allocation. Firstly, we introduce asymmetric power allocation scheme.

B. Asymmetric Power Allocation

By assuming the relay selection and subcarrier allocation are done, the optimal time slot for each hop can be achieved by using Karush-Kuhn-Tucker (KKT) conditions [13]. This results in

$$T_1 = \frac{1-\mu^*}{2}T, \tag{12}$$

$$T_1 = \frac{1+\mu^*}{2}T. \tag{13}$$

Recalling the Lagrange dual function of (9), the optimal power allocation problem can be determined by solving problem (8) over variables $P^i_{s,k}$ and $P^j_{k,d}$. Applying KKT conditions we obtain the optimal power allocation for the first hop:

$$(P^i_{s,k})^* = \Big\{\frac{(1-\mu^*)^2}{2\lambda^*_s} - \frac{1}{\gamma^i_{s,k}}\Big\}^+, \tag{14}$$

where $\{x\}^+ \triangleq max\{0, x\}$. Similarly, for the cooperation phase (second hop), the optimal RN power allocation is

$$\begin{aligned}(P^j_{k,d})^* =&\Big\{\frac{(1+\mu^*)^2}{2\lambda^*_{k,d}} - \frac{1}{\gamma^j_{k,d}} \\ &- \frac{\sum_{m=1,m\neq k}^{K} L_{m,d}G_{m,d}P_{m,d}}{G^j_{k,d}L_{k,d}}\Big\}^+.\end{aligned} \tag{15}$$

where $G_{m,d}$ denotes the channel gain from relay m to MT and $P_{m,d}$ is the power allocation for relay m on other subcarriers.

C. Optimal Relay Selection (ORS)

We consider a multiple relay selection in this work, unlike some traditional single relay selection algorithms in [9] and [15]. The proposed algorithm is to select K RNs to form a cluster that can maximize the achieved throughput in (3). We can rewrite (8) as

$$\begin{aligned}\mathcal{L}(\mathbf{P}, T, \boldsymbol{\omega}, \boldsymbol{\rho}, \boldsymbol{\lambda}) =& \min_{k\in\mathcal{K}}\Big\{\frac{T_1}{T}log(1+\sum_{i=1}^{M}\omega^i_{s,k}\rho_k P^i_{s,k}\gamma^i_{s,k})\Big\} \\ &+\frac{T_2}{T}log(1+\sum_{i=1}^{M}\sum_{k=1}^{K}\omega^i_{s,k}\rho_k P^j_{k,d}\gamma^j_{k,d}\sigma^2_d) \\ &-\mu\Big(\min_{k\in\mathcal{K}}\Big\{\frac{T_1}{T}log(1+\sum_{i=1}^{M}\omega^i_{s,k}\rho_k P^i_{s,k}\gamma_{s,k})\Big\} \\ &-\frac{T_2}{T}log(1+\sum_{i=1}^{M}\sum_{k=1}^{K}\omega^i_{s,k}\rho_k P^j_{k,d}\gamma^j_{k,d})\Big) \\ &+\lambda_s(\sum_{i=1}^{M}\sum_{k=1}^{K}\omega^i_{s,k}P^i_{s,k} - P_{s,max}) \\ &-\sum_{k=1}^{K}\lambda_{k,d}(\sum_{j=1}^{M}\omega^j_{k,d}P^j_{k,d} - P_{k,max}).\end{aligned} \tag{16}$$

Assuming the subcarrier and power allocations done, then applying KKT condition the RN is selected according to the following rule:

$$\begin{aligned}k^* =&\arg\max_k \ \Bigg(\min_{k\in\mathcal{K}}\Big\{\frac{(1-\mu^*)^2}{2}\Big(\frac{P^i_{s,k}\gamma^i_{s,k}}{1+P^i_{s,k}\gamma^i_{s,k}}\Big)\Big\} \\ &+\frac{(1+\mu^*)^2}{2}\Big(\frac{P^j_{k,d}\gamma^j_{k,d}}{1+\sum_k^K P^j_{k,d}\gamma_{k,d}}\Big)\Bigg).\end{aligned} \tag{17}$$

Optimal value of $\mathbf{P}$ are given in (14) and (15). Therefore, (17) can be viewed as multi-objective optimization problem, which aims at obtaining the trade-off of the first hop and second hop. Termination criteria for the whole RRA scheme is to find an optimal subcarrier set $\mathcal{K}^*$ that satisfies:

$$\begin{aligned}&max \ \Bigg(\min_{k\in\mathcal{K}^*}\Big\{\frac{(1-\mu^*)^2}{2}\Big(\frac{P^i_{s,k}\gamma^i_{s,k}}{1+P^i_{s,k}\gamma^i_{s,k}}\Big)\Big\} \\ &+\frac{(1+\mu^*)^2}{2}\Big(\frac{P^j_{k,d}\gamma^j_{k,d}}{1+\sum_k^K P^j_{k,d}\gamma_{k,d}}\Big)\Bigg).\end{aligned} \tag{18}$$

Therefore, the relay selection strategy can be chosen according to

$$\rho_k = \begin{cases} 1 & \text{, if } k\in\mathcal{K}^*, \\ 0 & \text{, otherwise.}\end{cases}$$

D. Optimal Subcarrier Allocation (OSA)

The goal of subcarrier allocation strategy is to assign subcarriers to given RNs that can obtain the best throughput performance. Following the same procedure as the relay selection, we can obtain the subcarrier allocation criteria as follows:

$$I^* = \arg\max \ \Bigg(\min_{k\in\mathcal{K}}\Big\{\frac{(1-\mu^*)^2}{2}\Big(\frac{P^i_{s,k}\gamma^i_{s,k}}{1+P^i_{s,k}\gamma^i_{s,k}}\Big)\Big\}\Bigg), \tag{19}$$

$$J^* = \arg\max \ \Bigg(\frac{(1+\mu^*)^2}{2}\Big(\frac{P^j_{k,d}\gamma^j_{k,d}}{1+\sum_k^K P^j_{k,d}\gamma^j_{k,d}}\Big)\Bigg). \tag{20}$$

If we denote the optimal subcarrier sets for the first and second hop as $\mathcal{I}^*$ and $\mathcal{J}^*$, respectively, the indicator for optimal subcarrier allocations can be expressed as

$$\omega_i = \begin{cases} 1 & \text{, if } i\in\mathcal{I}^*, \\ 0 & \text{, otherwise,}\end{cases}$$

$$\omega_j = \begin{cases} 1 & \text{, if } j\in\mathcal{J}^* \text{ ,} \\ 0 & \text{, otherwise.}\end{cases}$$

E. Joint Asymmetric Relay, Subcarrier and Power Allocation

We have described the algorithms for relay selection, subcarrier and power allocation in the previous subsections. Combining the above three procedures together with asymmetric time design, we can obtain optimal solution for (4). The flow chart of the whole algorithm is shown in Fig. 2. We can see that these three steps are conducted alternatively until the convergence is reached.

IV. Performance Evaluation

In this section we illustrate the performance of the RRA algorithm with couple of examples. We assume five RNs located between AP and MT, and MT is 1.8km away from AP. One example of RN distribution is shown in Fig. 3 when four RNs are selected for transmission. The Stanford University SUI-3 channel model is employed without considering multi-path effect [16], in which the central frequency is 1.9GHz. A three-tap channel is invoked and signal fading follows Rician distribution. We choose the number of subcarriers N to be 32, so the duality gap can be ignored [9]. Flat quasi-static fading channels are considered, hence the channel coefficients are assumed to be constant during a complete frame, and can

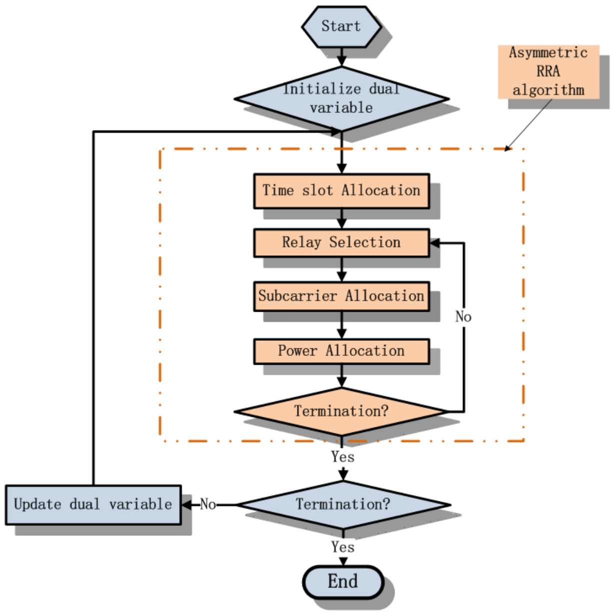

Figure 2. Algorithm flow chart

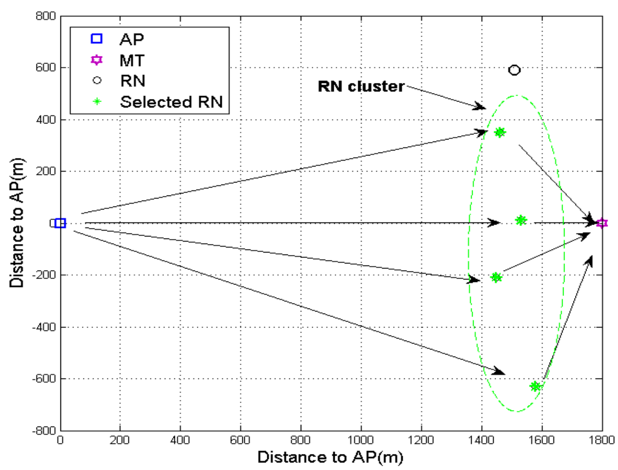

Figure 3. Relay node distribution and 4 RNs are selected

vary from a frame to another independently. The noise variance of the two hops are set to be 1 for simplicity. The path loss factor varies according to the different distances from RNs to AP and MT and the exponent is fixed to 3.5. The maximum transmit power of AP and RN are set to 40 dBm and 20 dBm, respectively.

We demonstrate our results compared with the performance of recently reported symmetric or asymmetric schemes:

1) Equal power allocation combined with proposed subcarrier allocation scheme and relay selection (EPA);

2) Waterfilling power allocation combined with proposed subcarrier allocation scheme and relay selection (Waterfilling);

3) Proportional Allocation scheme in [8] with fairness consideration (Fairness SA);

4) Asymmetric Resource Allocation scheme in [10] without cooperative relay assisted (ARA);

Fig. 4 demonstrates the impact of maximum transmit power

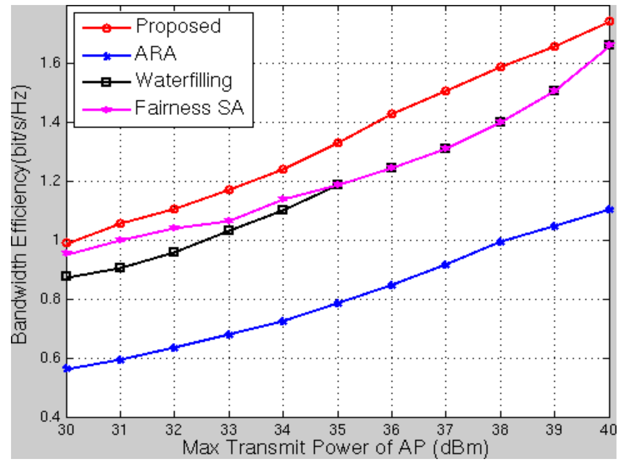

Figure 4. Impact of maximum transmit power $P_{s,max}$ on system bandwidth Efficiency

of AP on the system bandwidth efficiency. We denote $D_{s,d}$ as the distance between AP and MT, and $D_{s,k}$ as the distance between AP and RNs. In Fig. 4, we have $D_{s,d} = 1800\ m$ and $D_{s,k}$ from $1500\ m$ to $1600\ m$. The considered channel SNR at the RN k is varied from $\gamma_{s,k} = -20dB$ to $\gamma_{s,k} = -30dB$ and at MT d it is varied from $\gamma_{k,d} = -15dB$ to $\gamma_{k,d} = -25dB$. It can be seen that the proposed scheme achieves the best performance. The performance gain over other methods in comparison is up to 20%. It can also be noticed that if Waterfilling is used as the power allocation scheme (instead of our proposed scheme), the throughput performance is comparable with Fairness SA. Another performance gain can be seen in power consumption. We can see that with a fixed data rate requirement, our proposed scheme provides a clear power saving gain. For instance, at the level of 1.2 bit/s/Hz bandwidth efficiency our proposed scheme can reach a power saving around 2 dB compared to the other schemes.

Figs. 5 and 6 show the impact of distance between the AP and RNs on the system performance. The distances between AP and RNs are normalized to $D_{s,d}$ and varies from 0.1 to 0.9. In Fig. 5, we set the maximum AP power to $P_{s,max} = 35\ dBm$ and the maximum power of each RN to $P_{k,max} = 20\ dBm$, whereas we assume maximum power of each node to be 20 dBm in Fig. 6. From Fig. 5, we can see that the proposed algorithm obtains the highest system capacity when the normalized distance is less than 0.9. When the average normalized distance between AP and RNs is around 0.9, we can find that the proposed scheme has comparable performance with the EPA algorithm. This results from the fact that some RNs are already very close to the MT so the achieved SNR is relatively high leaving less impact to power allocation schemes. The same situation can be observed in Fig. 6 where less AP power is considered. It can be concluded that the proposed algorithm can provide a noticeable performance gain over other existing algorithms even with rather low limits for AP maximum power.

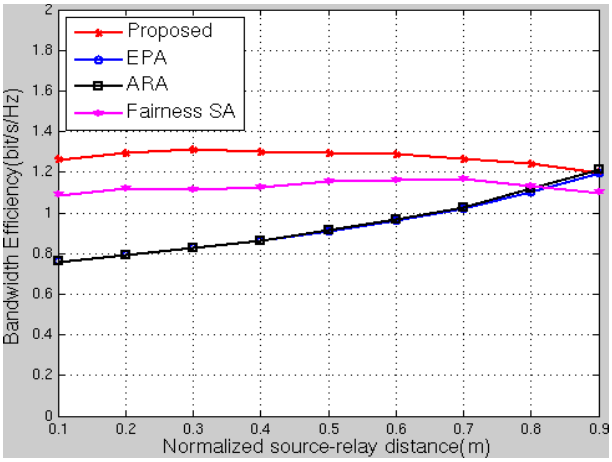

Figure 5. Impact of distance between AP and Relay on the system bandwidth efficiency, maximum AP power is 35 dBm, maximum RN power is 20 dBm

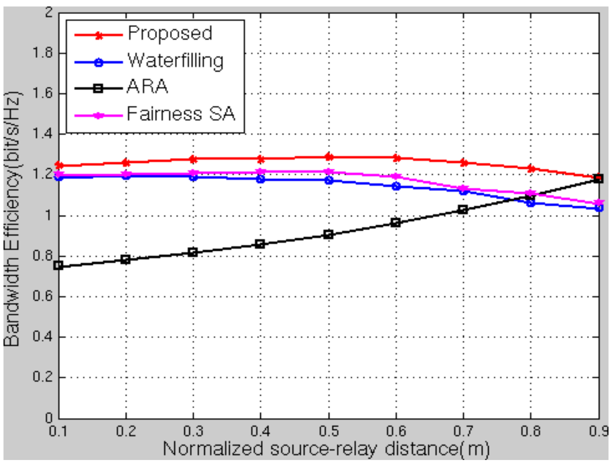

Figure 6. Impact of distance between AP and Relay on the system bandwidth efficiency, maximum power of each node is 20 dBm

V. Conclusion

In this paper we investigated the problem of asymmetric resource allocation for cooperative multi-relay assisted OFDMA networks. The joint optimization problem for radio resource allocation was solved by addressing three subproblems including optimal selection of collaborative relays, subcarriers and power with the objective of maximizing the system throughput. Theoretical expressions were derived for the optimal selections. It was shown that by designing asymmetric time slots for different hops, it is possible to reach a noticeable gain in the cell-edge throughput. This was also illustrated with simulation examples.

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