Queue-Aware Resource Allocation for OFDMA-Based Mobile Relay Enhanced Networks

İlhan BAŞTÜRK, Berna ÖZBEK
Electrical and Electronics Engineering Department,
Izmir Institute of Technology Urla, 35430, Izmir, Turkey
Email: ilhanbasturk@iyte.edu.tr,bernaozbek@iyte.edu.tr

Didier LE RUYET
CEDRIC/LAETITIA
CNAM, Paris, France
Email: leruyet@cnam.fr

***Abstract*—Mobile relay assisted OFDMA networks that are considered as a good candidate in future deployment scenarios for coverage extension and lower deployment costs are promising solutions for provision of ubiquitous high-data-rate services in wide coverage areas. However, it is required to design efficient resource allocation algorithms to exploit these opportunities. Thus, this paper designs an heuristic resource allocation algorithm based on the queue and channel state information of the users for mobile relay enhanced OFDMA networks. The proposed queue aware algorithm is appropriate for the realistic scenarios and use system resources efficiently. Numerical results revealed that the mobile-relay enhanced scheme improves coverage and assisting users having unfavorable channel conditions such as cell-edge users by increasing the data rate compared to existing fixed-relay enhanced and non-relaying schemes.**

I. Introduction

One of the key expectations for the future wireless system is to provide ubiquitous high data rate coverage. The combination of Orthogonal Frequency Division Multiple Access (OFDMA) and relaying is one of the key technologies to achieve this objective that can supply great potential multi-user and frequency diversity gains. OFDMA is a very promising candidate for the physical layer in next generation cellular system, due to its inherent robustness against frequency-selective fading and its capacity for achieving high spectral efficiency. In OFDMA, each subcarrier can be allocated to a different user which can best exploit the current channel condition, hence maximizing the achievable capacity. In order to realize ubiquitous high data rate coverage, relaying is an effective method to further improve the throughput of cell edge users, hence it is expected that various forms of relays will be included in the future networks [1]. In the literature two different types of relaying network architecture have been investigated as fixed relay station (FRS) and mobile relay station (MRS) [2]. The FRSs are part of the network infrastructure, thus where and how much FRSs will be deployed in a cell will be processed while the network planning, design and deployment process by operators. Compared to FRS, MRS can be flexible employed in a wireless cellular network. MRSs are effectively a moving aspect of FRSs. The goal of employing MRSs is not to replace FRSs, but rather to act as a complementary solution. In general, there are mainly two different types of scenarios MRSs employed in the wireless cellular networks. One is MRSs fitted on moving vehicle and the other is the Mobile Station (MS) acting as MRS.

In these relay-enhanced networks, potential gain in capacity and coverage is highly dependent on the radio resource management (RRM) strategy [3][4], a topic which draws more and more attention of the research community. Besides the larger coverage and capacity advantages, OFDMA based relaying strategies have challenges that the resource allocation problem becomes more crucial and complicated because of the increased number of links. Recently, many authors have studied on designing the resource allocation scheme in the relay-enhanced OFDMA network that use FRSs [5]-[9] and MRSs [10][11]. These works use the common assumption that users have infinitely backlogged buffers in BS, meaning that they always have data to transmit. However in realistic scenarios, this assumption is not true and users have random and bursty traffic arrival of packets which feed users buffers in BS. Therefore the channel aware scheduling without considering the availability of data, would lead into inefficient use of resources. Queue-aware resource allocation is of great research interest. One way of incorporating queue awareness into RRM schemes is involving the buffer states in the formulation so that the optimization problem can be worked out as sum-utility or sum-demand maximization. The demand metric can be proportional to both the queue length at the source node and the quality of the link to the destination [12]-[14]. [12] and [13] present a fair queue-awareness resource allocation scheme that can significantly reduce the co-channel interference and improve spectrum utilization in OFDMA-based multicellular networks enhanced by fixed relays. In [14], with the throughput-optimal scheduling, a low-complexity iterative algorithm is devised to solve the resource allocation using the queue length and the achievable rates for the fix relay enhanced OFDMA.

In this paper, we propose a queue aware resource allocation scheme for the mobile-relay enhanced OFDMA networks. To the best of our knowledge, there is no previous study that examined the queue-aware resource allocation for the mobile relay enhanced OFDMA networks. Relaying through other users terminal provides more flexibility to the cellular network by increasing the number of relay candidates and lowers the infrastructure cost. Thus, we use mobile relaying concept to increase the capacity of the cell-edge users' in the network. The gain of using mobile relaying over the data rate of cell-edge users is shown through simulation results.

The rest of this paper is organized as follows. We discuss the system model and problem formulation in Section II. The proposed queue aware resource allocation algorithm for mobile-relay enhanced cellular networks is presented in Section III. Simulation results are provided in Section IV. Finally, we conclude the paper in Section V.

ISBN 978-3-8007-3529-7

II. SYSTEM MODEL AND PROBLEM FORMULATION

In this paper, a single cell downlink OFDMA-based mobile relay-enhanced LTE network is used as shown in Figure 1. The BS is located in the centre of the cell and K users are distributed uniformly around it. The cell area is divided into two zones; inner $(0 - 2R/3)$ and outer $(2R/3 - R)$ zones where R is the radius of the cell. It is allowed that the M users which are in the inner zone can communicate to the BS directly and L users which are in the outer zone (cell-edge users) are allowed to communicate with the BS either directly or with the help of another user (mobile relaying). In our system model, only cell-edge users can use mobile relays in order to decrease the feedback load and the computational complexity and inner users are the mobile relay candidates of these users. We can determine the cell edge users' mobile relay candidates using the area whose radius is $R/2$. The inner users, which remain in the coverage area of a cell-edge user, become the mobile relay candidates of this cell-edge user as seen in Figure 1. The BS has K user buffers and M inner users have L user buffers. All users are assumed to utilize the same service and thus have the same traffic arrival statistics. All of the available bandwidth is divided into N subchannels, and each subchannel consists of a set of adjacent OFDM subcarriers.

The radio resource allocation problem definition for the relay-enhanced networks change according to the relaying types such as half duplex (HD) relaying or full duplex (FD) relaying. RS transmits and receives at the same time slot and frequency for the FD relaying that causes the strong interference and it has many limitations in radio implementation. Therefore, we assumed HD relaying in this study. Resource allocation is performed by BS in two time slots, which have equal duration, as shown in Figure 2. In the first time slot called BS subframe, BS sends datas to MSs and RSs and in the second time slot called RS subframe, MSs receive information from RSs and BS. Subchannels are allocated to the BS-MS, BS-RS links at time slot one and RS-MS and BS-MS links at time slot two. At each allocation instant, two separate optimization procedures are performed. The optimization procedures are performed before the BS transmitting the data packets in the BS subframe. After the allocation, the BS sends the allocation results for the RS subframe to the mobile relays through the control channels. During the uplink portion of the frame, mobile relays feedback the status of the updated queues due to the previous downlink transmission.

The optimization problem for that scenario can be defined in two steps such as BS subframe optimization problem and RS subframe optimization problem as follows:

A. BS Subframe Optimization Problem

As mentioned above, BS sends data to all MSs that can be mobile user or mobile relay in this subframe. In order to understand, if a MS is getting data from the BS as a mobile user or mobile relay, a demand metric is calculated. The demand metric of any BS-MS link on subchannel n is given as:

$$W_{0,k,n} = R_{0,k,n} Q_k^0, \quad \forall k \in \mathbb{K} \tag{1}$$

where $\mathbb{K} = \{1, 2, ..., K\}$ is the set of the users in the network. $R_{0,k,n}$ is the achievable rate on the link between BS and MS k and Q_k^0 is the queue length, expressed in bits or bytes, of user k at BS. The link achievable rate between any two nodes $i \rightarrow j$ on subchannel n is calculated by using LTE-CQI table which is a discrete lookup table [15].

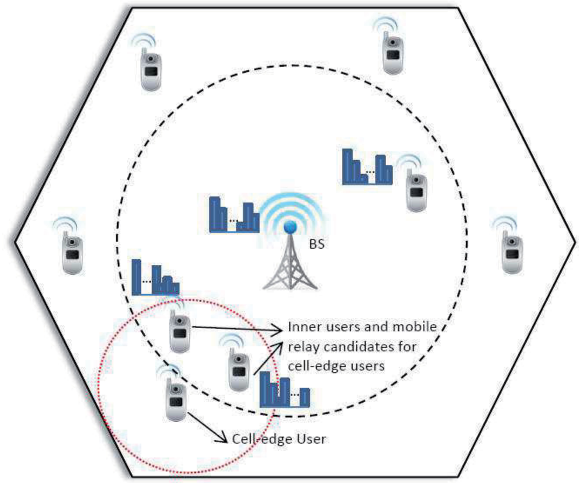

Fig. 1: OFDMA based Mobile-Relay Enhanced Network.

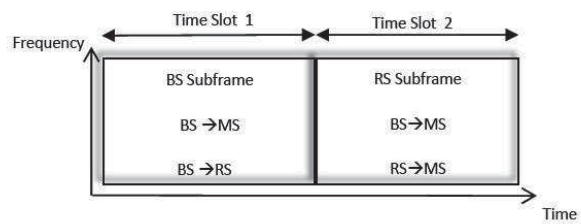

Fig. 2: HD Relaying Slot Structure.

Moreover, the demand metric of any BS-RS link on subchannel n incorporates the maximum differential backlog of the queues of the BS and those at the relay candidate m [16] can be expressed as:

$$W'_{0,m,n} = R_{0,m,n} \max_{j \in \mathbb{S}_m} \{(Q_j^0 - Q_j^m)^+\}, \ \forall m \in \mathbb{M} \tag{2}$$

where $\mathbb{M} = \{1, 2, ..., M\}$ is the inner users set and also relay candidate set for outer users. $\mathbb{S}_m$ is the set of outer users that can be served over relay m. Q_j^m is the queue length of outer user j at node m which is not only the inner user but also the mobile relay candidate. The function $(.)^+$ sets negative values to zero. This metric provides to perform routing and scheduling jointly. If the link between BS and mobile relay m is assigned to subchannel n, then the data flow that is nominated by this maximum differential backlog is scheduled.

The sum demand maximization problem for the BS subframe can be given in detail below:

$$\max_{\rho^{(1)},\sigma^{(1)}} \sum_{n=1}^{N} \sum_{k=1}^{K} \rho_{0,k,n}^{(1)} W_{0,k,n} + \sum_{n=1}^{N} \sum_{m=1}^{M} \sigma_{0,m,n}^{(1)} W'_{0,m,n} \tag{3}$$

ISBN 978-3-8007-3529-7

subject to

$$\rho^{(1)}_{0,k,n} \in \{0,1\}, \forall k, \forall n \tag{4}$$

$$\sigma^{(1)}_{0,m,n} \in \{0,1\}, \forall m, \forall n \tag{5}$$

$$\sum_{k=1}^{K} \rho^{(1)}_{0,k,n} + \sum_{m=1}^{M} \sigma^{(1)}_{0,m,n} \leq 1, \forall n \tag{6}$$

$$\sum_{n=1}^{N} \rho^{(1)}_{0,m,n} R_{0,m,n} \leq Q^0_m, \forall m \in \mathbb{M} \tag{7}$$

$$\sum_{n=1}^{N} \rho^{(1)}_{0,l,n} R_{0,l,n} + \sum_{n=1}^{N} \sum_{m=1}^{M} \sigma^{(1)}_{0,m,n} R_{0,m,n} \gamma^m_l \leq Q^0_l, \forall l \in \mathbb{L} \tag{8}$$

where $\mathbb{L} = \{1, 2, ..., L\}$ is the outer users set.

In Eq. (3)-(8), $\rho^{(1)}_{0,k,n}$ and $\sigma^{(1)}_{0,m,n}$ are the kth mobile user and mth mobile relay binary assignment variables to the BS (node 0) on the nth subchannel during the BS sub-frame. The constraints (4)-(6) guarantee that the subchannel n is allocated to only one link which can be a user link or relay link. The constraints (7) and (8) ensure not giving resources more than queue lenght to any inner user and outer user in order to avoid wasting resources, respectively. The γ^m_l, which is given in Eq. (8), indicates that outer user l will be served by relay m at subchannel n and defined as below:

$$\gamma^m_l = \begin{cases} 1, & l = \underset{j \in \mathbb{S}_m}{\text{argmax}} \{Q^0_j - Q^m_j\}^+ \\ 0, & o.w. \end{cases} \tag{9}$$

B. RS Subframe Optimization Problem

In this subframe, not only the BS but also the inner users that are used as mobile relays transmit data to the cell-edge users. Here, the BS shares the system resource, i.e., subchannels, with the RSs to communicate directly with some selected users. The demand metric for any BS-MS and RS-MS links are expressed in Eq. (10) and (11) , respectively.

$$\tilde{W}_{0,k,n} = R_{0,k,n} \tilde{Q}^0_k, \; \forall k \in \mathbb{K} \tag{10}$$
$$\tilde{W}_{m,j,n} = R_{m,j,n} \tilde{Q}^m_j, \forall m \in \mathbb{M}, \forall j \in \mathbb{S}_m \tag{11}$$

where $\tilde{Q}^0_k$ is the new queue length of mobile user k at BS and $\tilde{Q}^m_j$ is the new queue length of cell-edge user j at mobile relay m, after BS subframe resource allocation. The RS subframe optimization problem can be expressed as below:

$$\max_{\rho^{(2)}, \sigma^{(2)}} \sum_{n=1}^{N} \sum_{k=1}^{K} \rho^{(2)}_{0,k,n} \tilde{W}_{0,k,n} + \sum_{n=1}^{N} \sum_{m=1}^{M} \sum_{j \in \mathbb{S}_m} \sigma^{(2)}_{m,j,n} \tilde{W}_{m,j,n} \tag{12}$$

subject to

$$\rho^{(2)}_{0,k,n} \in \{0,1\}, \forall k, \forall n \tag{13}$$

$$\sigma^{(2)}_{m,j,n} \in \{0,1\}, \forall m, \forall j \in \mathbb{S}_m, \forall n \tag{14}$$

$$\sum_{k=1}^{K} \rho^{(2)}_{0,k,n} + \sum_{m=1}^{M} \sum_{j \in \mathbb{S}_m} \sigma^{(2)}_{m,j,n} \leq 1, \forall n \tag{15}$$

$$\sum_{n=1}^{N} \rho^{(2)}_{0,k,n} R_{0,k,n} \leq \tilde{Q}^0_k, \forall k \tag{16}$$

$$\sum_{n=1}^{N} \rho^{(2)}_{m,j,n} R_{m,j,n} \leq \tilde{Q}^m_j, \forall m, \forall j \in \mathbb{S}_m \tag{17}$$

The $\rho^{(2)}_{0,k,n}$ is the binary assignment variable of user k at the BS on subchannel n, during the RS subframe. The variable $\sigma^{(2)}_{m,j,n}$ is the mth relay binary indicator that assigns subchannel n to the cell-edge user j at RS m during the RS subframe. The constraint given in Eq. (15) guarantee that only one link is active for the subchannel n and the constraints (16) and (17) ensure to transmit data from BS to any mobile user k not more than $\tilde{Q}^0_k$ and RS m to cell-edge user j not more than $\tilde{Q}^m_j$, respectively. Thus, resource waste is avoided and rather efficient resource utilization is achieved.

III. The Proposed Queue Aware Resource Allocation Algorithm for Mobile-relay Enhanced Cellular Networks

In this part, we propose a low complexity iterative two steps sub-optimal algorithm in order to solve the problems for BS and RS subframes allocation. In the algorithm, only one link will be active per subchannel. In the first step, the algorithm allocates the resources to the MSs and mobile relay candidates. In this step, demand metrics are calculated for all users and all mobile relay candidates on subchannel n as given in Eq. (1) and (2), respectively. Then, the best BS link that has the maximum demand metric out of all potential links is determined and the queue lenghts at BS and mobile relays are updated. This step is repeated until all subchannels are exhausted or the queue lenghts at BS is zero.

In the second step of the algorithm, BS shares the resources with mobile RSs to transmit to the selected users. The link which has the maximum demand metric belongs to each node (BS and RSs) are determined and then the best link is selected among these links on subchannel n. According to the selected node and serviced user, the queue values are updated. The iteration for this step is also repeated until the queue values at each node reach to zero or the available subchannels are finished. The algorithm is given in detail below:

Step 1-BS Subframe Resource Allocation

- Let $\mathbb{W}$ is the set of demand metrics of all users obtained using Eq. (1) and $\mathbb{W}'$ is the set of demand metrics of mobile relay candidates obtained using Eq. (2). N is the number of subchannels and $\mathbb{S}_m$ is the set of outer users that can communicate to the BS with the help of mobile relay m.
- Update the queue lenghts of each user at BS, $\mathbb{Q}^0 = [Q^0_1, ..., Q^0_K]$ by new arrivals and update the affected queues of the users at relay m, $\mathbb{Q}^m$ by using feedback.
- Initially, $n = 1$,

while $\mathbb{Q}^0 \neq 0$ **do**

∗ Calculate demand metrics for all users and mobile relays by using Eq. (1) and (2), respectively.

ISBN 978-3-8007-3529-7

for $\forall k \in \mathbb{K}$ **do**
$W_{0,k,n} = R_{0,k,n} Q_k^0, \quad W_{0,k,n} \in \mathbb{W}$
end for
for $\forall m \in \mathbb{M}$ **do**
$W'_{0,m,n} = R_{0,m,n} \max_{j \in \mathbb{S}_m} \{(Q_j^0 - Q_j^m)^+\}, \; W'_{0,m,n} \in \mathbb{W}'$
$\ell^m = \underset{j \in \mathbb{S}_m}{\text{argmax}} \{(Q_j^0 - Q_j^m)^+\}$
end for
$*$ Decide the best link index and value at subchannel n
$i^* = \arg\max_i (W^*_{0,i,n}), \; W^*_{0,n} = W^*_{0,i^*,n}$
where $\mathbb{W}^* = \mathbb{W} \bigcup \mathbb{W}', \; W^*_{0,i,n} \in \mathbb{W}^*, \; i \in \mathbb{K} \bigcup \mathbb{M}$
$*$ Update the queues
if $i^* \in \mathbb{M}$ **do**
$k^* = \ell^{i^*}, \; Q^0_{k^*} = Q^0_{k^*} - \min\{Q^0_{k^*}, R_{0,i^*,n}\}$
$Q^{i^*}_{k^*} = Q^{i^*}_{k^*} + \min\{Q^0_{k^*}, R_{0,i^*,n}\}$
else do
$k^* = i^*, \; Q^0_{k^*} = (Q^0_{k^*} - R_{0,k^*,n})^+$
end if
$*$ Increase n by 1 until $n = N$.
end while

Step 2- RS Subframe Resource Allocation

- Let $\tilde{\mathbb{Q}}^m$ is the updated queue of node m after BS subframe where $m = 0, 1, 2, ..., M$ and the case $m = 0$ represents BS node.
- Initially, $n = 1$

while $\sum_{m=0}^{M} \tilde{\mathbb{Q}}^m \neq 0$ **do**
$*$ Find the best demand metric for each node using Eq. (10) and (11), respectively.
for $m = 0$ to M **do**

$$u_{m,n} = \begin{cases} \underset{k \in \mathbb{K}}{\text{argmax}} \{\tilde{W}_{0,k,n}\}, & \text{if } m = 0 \\ \underset{j \in \mathbb{S}_m}{\text{argmax}} \{\tilde{W}_{m,j,n}\}, & o.w. \end{cases}$$

$\tilde{W}_{m,n} = \tilde{W}_{m,u_{m,n},n}$
end for
$*$ Decide the transmitting node and related serviced user,
$\hat{m} = \underset{m}{\text{argmax}} \{\tilde{W}_{m,n}\}, \qquad \kappa = u_{\hat{m},n}$
$*$ Update the queue values
$\tilde{Q}^{\hat{m}}_{\kappa} = (\tilde{Q}^{\hat{m}}_{\kappa} - R_{\hat{m},\kappa,n})^+$
$*$ Increase n by 1 until $n = N$.
end while

IV. Simulation Results

In this study, we consider a single cell network topology with a BS located in the center and surrounded by MSs as shown in Figure (3a). The cell radius is chosen as $R = 500m$ and the users which are far from the $2R/3$ in the cell is labeled as the cell-edge users. The percentage of cell-edge users is chosen as 10%. The coverage area radius is chosen $R/2$ to find the relay candidates for the cell-edge users. Independent Poisson packet arrival process is assumed at BS queues with an average arrival rate $336kbps$ per user. All users have the same traffic pattern. In the simulations, we have used 3GPP-LTE parameters as summarized in Table I.

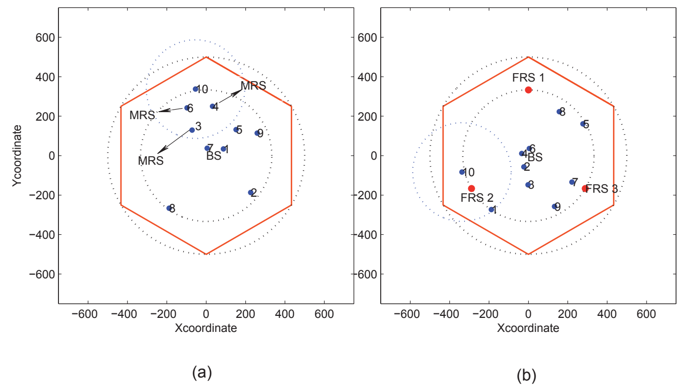

Fig. 3: (a) Mobile Relay Topology (b) Fixed Relay Topology.

In this paper, we have compared the proposed mobile relay-enhanced queue aware resource allocation algorithm with the fixed relay enhanced and two other non-relaying schemes. The first scheme is the queue aware RQ scheduler that use no relays. The subchannels are allocated to the user which has the maximum product of rate and queue values. Other non-relaying scheme is the Max-SNR scheduler that allocates the subchannels to the maximum Signal to Noise Ratio (SNR) valued user of only those with buffered data. In the fixed relay case, we have located 3 fix relays at equal angles and equal distance to the BS as seen in Figure (3b). The distance of each fixed relay from the BS is chosen as $(2R/3)$. The path loss, shadowing and multipath channel parameters for all links except the BS-RS link, which has $4dB$ lognormal shadowing and experience Rician fading with a Rician factor of $10dB$, is the same with mobile relay scenario and given in Table I.

TABLE I: Simulation Parameters

Parameter	Value
Frequency	$2GHz$
Bandwidth	$20MHz$
Thermal Noise Density	$-134.89dBm/Hz$
nTX $\times$ nRX antennas	1×1
eNodeB TX power	$46dBm$
Fixed relay TX power	$37dBm$
UE as relay TX power	$24dBm$
Cell radius	$500m$
Frame Duration	$10ms$
Simulation Duration	$1sec$
Pathloss model	BS $\rightarrow$ MS, BS $\rightarrow$ RS and RS $\rightarrow$ MS $128.1 + 37.6log10(d)$
Shadowing model	Lognormal distribution, $\mu = 0, \sigma = 10(dB)$
Multipath model	Extended Pedesterian A (EPA)

In the simulations, we let only cell-edge users to use relays in order to increase the data rate of these users. Figure 4 shows the cell-edge users' data rate as a function of number of users. As expected, relay enhanced scenarios outperform the non-relaying scenarios since if the direct link of the cell-edge users' is not enough to communicate, they have a chance to communicate over a relay. Among all schemes, Max-SNR scheduler has the minimum data rate when compared to other three queue-awareness schemes. The proposed mobile-relay

ISBN 978-3-8007-3529-7

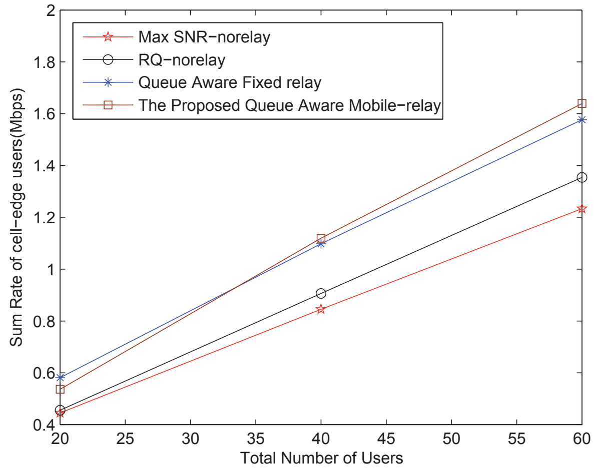

Fig. 4: Sum rate of cell edge users vs number of users.

enhanced scheme outperforms the fixed relay scheme over 40 users and the difference is getting slightly higher with the increased number of users. This can be interpreted as not only the number of users but also the number of mobile relays is increasing in the cell so there are more choice to select a mobile relay that can optimize the system performance. The results reveal the advantage of mobile relay enhanced networks that not victimize the cell-edge users because of their locations to the BS by increasing the data rate.

In queue-aware communication schemes, not only the data rate but also the the waiting time in the queue is important. Therefore, the average delay of different schemes is compared in Figure 5. It is observed in this figure that the proposed mobile-relay enhanced scheme has the lowest delay compared to non-relaying schemes. Moreover, the proposed scheme outperforms the fixed relay scheme for the higher number of users.

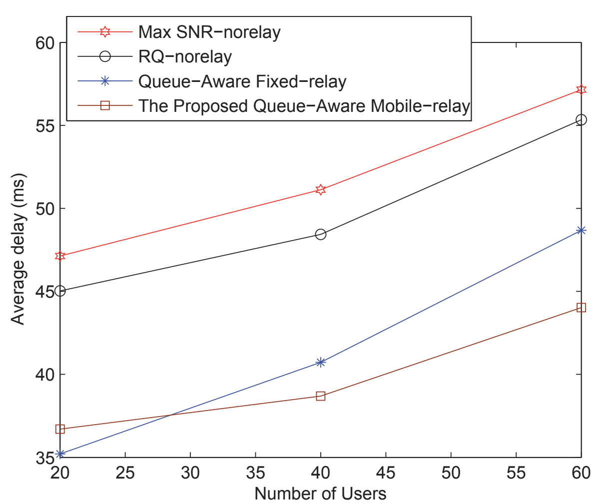

Fig. 5: Average delay vs number of users.

V. Conclusion

In this paper, we have developed a queue aware resource allocation algorithm for the OFDMA-based mobile relay-enhanced networks. By using queue lenghts of the users, the system resources are not wasted and traffic diversity is exploited, which means that when some users have no data to send at an allocation instant, more resources can be allocated to the other users to provide a better and fairer service to them. The simulation results showed us that the proposed mobile relaying scheme increased the data rate of the cell-edge users and decreased the delay time of the queues without the need for fixed relay stations which is expensive and cost inefficient to plan, optimize and maintenance.

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ISBN 978-3-8007-3529-7