Dynamic Distributed Resource Allocation in Relay Assisted OFDMA Networks

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***Abstract*—Relay assisted OFDMA networks are promising solutions for provision of high-data-rate services in wide coverage areas. However, the deployment of relays makes the resource allocation a more challenging and complex task. In this paper we study dynamic allocation of power and subchannels in an OFDMA downlink system with regenerative relays which have the capability of buffering the users' data to transmit in a suitable time. We model the network as a multicell scenario with small serving areas and provide a novel framework for resource allocation, in which each of the relays and Base Station (BS) allocate resources based on the queue and channel state information of their own users. We propose a dynamic distributed resource allocation algorithm for this purpose, where BS and relays decide about the allocation of the power and subchannels by passing messages among themselves and based on the local queue and channel state information. Simulation results show significant improvement in terms of system throughput and users' queue stability.**

***Keywords*-OFDMA; regenerative buffering relays; dual decomposition; distributed resource allocation.**

I. INTRODUCTION

Orthogonal frequency division multiple access (OFDMA) is a promising solution for multiple access in high speed wireless networks such as IEEE 802.16 Worldwide Interoperability for Microwave Access (WiMAX), and Long Term Evolution (LTE). Based on this technique, it is possible to provide high spectaral efficiency, multiuser diversity, robustness against multipath fading and flexibility in radio resource allocation. However to make it possible for all the users in a large area to get access to the network, wide coverage is another important objective for next generation of mobile networks. For this purpose, wireless relays have gained significant attention in both industry and research bodies, due to their cost effective and fast deployments. Relays can improve the transmission link between Base Station (BS) and users which are far from BS or have blockage between BS and themselves.

Resource allocation and scheduling are important issues in wireless networks due to increasing demand of users for data traffic and the scarcity of radio resources [1]. It becomes even more challenging and crucial in relay assisted OFDMA networks[2]. Recently there has been remarkable work done in this field [3][4][5][6]. In [3], authors studied the capacity of relay assisted OFDMA networks for both amplify-and-forward (AF) and decode-and-forward (DF) schemes. Adaptive scheduling algorithms have been studied in [4] and, based on a Time Division Duplexing (TDD) frame structure, Greedy Polling (GP) and Partial Proportional Fair (PPF) algorithms have been proposed. In [5] authors assumed that the frequency band is partitioned between users connected directly to BS and users connected through relays. They studied the cross layer scheduling for the relayed users in an AF relay network, as an optimization problem with the objective of maximizing the received goodput and proposed a distributed algorithm for it. Most of the works in this area use two common assumptions. First one is 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. The other common assumption is that relays are "prompt" and the relaying is performed in two consecutive transmission epochs [4]. In other words, time slots are assumed to be divided into two subslots where in the first one, BS transmits to the relays and in the second one, they forward the received data to their users. However having relays with the capability of buffering data and forwarding them in a later time, can provide more flexibility for Radio Resource Management (RRM) as it is possible to keep a user's data in the queue and forward it in a suitable time slot, i.e., when the user's channel gets better or the user gets higher priority. Such a system has been considered in [6], and based on that authors have studied the joint routing and subchannel allocation in a relay assisted OFDMA cellular network. They have considered concurrent transmission for relays where a relay can receive data on some subchannels and at the same time transmit on some others. Assuming equal power allocation and equal number of frequency subchannels being used by either of BS and any of the relays, a centralized algorithm has been proposed. However optimal power allocation is another important factor for efficient utilization of the system resources and providing Quality of Service (QoS) for users in terms of Bit Error Rate (BER) and queue stability [7][8].

In this paper, we consider a relay assissted OFDMA network with buffering capability in relays and availibility of all of the subchannels to all of the BS and Relays. We formulate joint channel and power allocation as an optimization problem and introducing some concepts, we show its similarity to a multicell OFDMA scenario with smaller cells. Moreover, to make the problem tractable, we transform it into a convex optimization problem and using dual decomposition, we propose an iterative Dynamic Distributed Resource Allocation (DDRA) algorithm, where BS and each relay solve their own problem based on their users' Queue and Channel State Information (QCSI) and some global variables exchanged among them. DDRA provides a novel framework for exploiting the system's power and subchannel resources in an effeicient and adaptive way over time, with lower overhead of the CSI feedback and lower computational complexity at the BS compared to optimal centralized scheduling which requires global CSI at the BS.

The rest of the paper is organized as follows. In Section II, we outline the model for the relay assisted OFDMA system. In Section III, we formulate the resource allocation algorithm design as an optimization problem and solve it by dual decomposition, where distributed closed-form solutions for power and subcarrier allocation are derived. Simulation results for the distributed algorithm are studied in Section IV with conclusion finally presented in Section V.

II. SYSTEM MODEL

We consider a single cell time slotted OFDMA system in downlink (DL) with K users and M relays. Users are uniformly distributed in the cell, K_1 of them being served directly by BS while others receive data through one of the relays. As it is shown in Figure 1, we assume that each user has been assigned to either BS or any of the relays based on a criteria such as average Signal to Nosie Ratio (SNR), distance from the BS and relays, etc.

Relays' locations are fixed and can have different distances from BS, based on the topology of the service area. BS and relays are equipped with buffers, where BS has one for each user but relays have one for each of only the users connected to them. Users' packets arrive at the BS buffer according to their traffic model and are queued until transmission to the directly connected users or to relays serving other users. Relays do not need to transmit the received packets immediately in the next time slot and it is possible to keep them in the buffers and serve them based on the scheduling policy. This gives flexibility to the scheduler to utilize the resources more opportunistically by postponing the transmission until the user gets higher priority or better channel. We use Q_k^B, $k = 1, \dots, K$ to denote the queue size of user k in BS, and $Q_k^{R(k)}$, $k = K_1 + 1, \dots, K$ to denote the queue size of user k in its serving relay, $R(k)$.

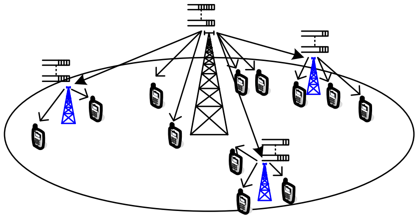

Figure 1. System model

We assume that transmission bandwidth is divided into N subchannels where each subchannel can be used exclusively by BS or relays in one of the groups of the links, i.e., BS-to-users, BS-to-relays and relays-to-users. Any relay has the ability to transmit on some subchannels and at the same time receive data from BS on other ones. The channels in all the links are assumed time variant and frequency selective, but constant during one time slot. We define the gain-to-noise ratio corresponding to the link between BS and user k as follows:

$$e_{kn}^B = \frac{|H_{kn}^B|^2 G_k^B}{\sigma_n^2}, \tag{1}$$

where H_{kn}^B is the small scale fading coefficient between BS and user k in subchanel n, G_k^B is the path loss attenuation between BS and user k and σ_n^2 is the variance of Gaussian noise. $e_{kn}^{R(k)}$ and $e_n^{BR(k)}$ can be defined in a similar way for the links between $R(k)$ and user k and the links between BS and $R(k)$. Assuming that M-ary QAM modulation is used for transmission, the achievable transmission rate can be computed as follows[9]:

$$r_{kn}^B = x_{kn}^B \log_2\left(1 + \frac{p_{kn}^B e_{kn}^B}{\Gamma_k}\right), k = 1, \dots, K_1, \tag{2}$$

where, without loss of generality, the bandwidth of a subchannel has been assumed equal to 1. r_{kn}^B is the achievable transmission rate between BS and user k on subchannel n. x_{kn}^B denotes subchannel allocation indicator which would be one if subchannel n is used by BS to transmit data to user k, $k = 1 ... K_1$, and zero otherwise. p_{kn}^B is the power allocated by BS to user k on subchannel n. Γ_k is the SNR gap due to the limited number of coding and modulation schemes and is related to bit error rate of user k (BER_k), through equation $\Gamma_k = -\frac{\ln(5BER_k)}{1.5}$. In a similar way we can define $x_{kn}^{R(k)}$,$p_{kn}^{R(k)}$ and $r_{kn}^{R(k)}$ for the links of relays-to-users and $x_{kn}^{BR(k)}$, $p_{kn}^{BR(k)}$, and $r_{kn}^{BR(k)}$ for the links of BS-to-relays.

III. CROSS LAYER SCHEDULING AND RESOURCE ALLOCATION

In this section, we formulate the cross layer scheduling and resource allocation and then using some definitions and modifications, we propose a new perspective with simplified convex optimization problem.

A. Problem Formulation

In each time slot, the resource allocation policy aims at efficient use of the system resources, i.e., power and subchannles, while considering the QoS for the users, in terms of BER and queue stability. For this purpose, a weight is considered for each of the users on their links and the objective is to maximize the weighted throughput over the links. The cross layer scheduling and resource allocation can be formulated as the following optimization problem:

$$P:\max_{\boldsymbol{p},\boldsymbol{x}} \sum_{k=1}^{K_1}\sum_{n=1}^{N} w_k^B r_{kn}^B + \sum_{k=K_1+1}^{K}\sum_{n=1}^{N} w_k^{BR(k)} r_{kn}^{BR(k)} + \sum_{k=K_1+1}^{K}\sum_{n=1}^{N} w_k^{R(k)} r_{kn}^{R(k)}, \tag{3a}$$

$$\text{s.t. } C1: \sum_{n=1}^{N}\Big(\sum_{k=1}^{K_1} p_{kn}^B + \sum_{k=K_1+1}^{K}\big(p_{kn}^{BR(k)} + p_{kn}^{R(k)}\big)\Big) \le P_t, \tag{3b}$$

$$C2: \sum_{k=1}^{K_1} x_{kn}^B + \sum_{k=K_1+1}^{K}\big(x_{kn}^{BR(k)} + x_{kn}^{R(k)}\big) \le 1, \forall n, \tag{3c}$$

$$C3: x_{kn}^B, x_{kn}^{BR(k)}, x_{kn}^{R(k)} \in \{0,1\}, \forall k,n, \tag{3d}$$

$$C4: p_{kn}^B, p_{kn}^{BR(k)}, p_{kn}^{R(k)} \ge 0, \forall k,n \tag{3e}$$

where w_k^B, $w_k^{BR(k)}$, and $w_k^{R(k)}$ are the weights of the users over the links of BS-to-users, BS-to-relays and relays-to-users. Constraint $C1$ is the total power constraint for the BS and the relays. The problem (3a) is a complex combinatorial optimization problem, which needs an exhaustive search to find the optimal solution. In order to make the problem tractable, we relax the subchannel assignment variables $x_{kn}^B, x_{kn}^{BR(k)}, x_{kn}^{R(k)}$ to be real value between zero and one, instead of a Boolean, i.e., $0 \le x_{kn}^B, x_{kn}^{BR(k)}, x_{kn}^{R(k)} \le 1$, which is known as time or tone sharing. Furthermore, we consider the buffers of users $k = K_1, \ldots, K$ in their relays, as virtual users that are directly connected to BS. In other words, we interpret the links between BS and relays as the direct links between BS and some virtual users. As shown in Figure 2, this perspective helps us to divide the serving area (single cell) into smaller areas (multi cells) served by $M+1$ nodes, where node 1 is BS with K users and has the complicated RRM capability and act as a central controller while nodes $m, m = 2, \ldots, M+1$, are the relays with their own users, totally $K - K_1$ users, and acts as antennas distributed in the serving area and connected wirelessly to the controller. We denote the set of users of node m with $\mathcal{U}_m$; in particular $\mathcal{U}_1 = 1...K$. Each node has the buffers of its own users and transmits data independently; however in the beginning of each slot they all communicate with a central controller in node 1 to decide about their shares of power and subchannels in order not to make interference to other nodes.

We use the following notations for each user:

$$e_{kn}^m = \begin{cases} e_{kn}^B, & m=1, k=1,\ldots,K_1 \\ e_n^{BR(k)}, & m=1, k=K_1+1,\ldots,K \\ e_{kn}^{R(k)}, & m=2,\ldots,M+1, k=K_1+1,\ldots,K, k \in \mathcal{U}_m \end{cases}$$

w_k^m, x_{kn}^m and p_{kn}^m can be defined in a similar way. We define $\mathcal{D} = \{(\boldsymbol{p},\boldsymbol{x}) | 0 \le p_{kn}^m \le P_t, x_{kn}^m \in [0,1]\}$ as the domain of the problem. Due to tone sharing, SNR will be equal to $\frac{p_{kn}^m e_{kn}^m}{x_{kn}^m}$; this SNR is because of viewing p_{kn}^m as the energy per time slot that node m uses for user k on subchannel n [10]. As a result the rates will be computed by $r_{kn}^m = x_{kn}^m \log_2(1 + \frac{p_{kn}^m e_{kn}^m}{x_{kn}^m \Gamma_k})$. Assuming that the system is stabilizable, similar to [11], it can be proved that queue stability can be provided by defining the weights of users as follows:

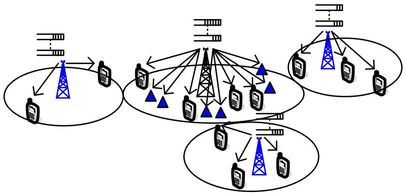

Figure 2. Similarity of the model to multicell network

$$w_k^m = \begin{cases} Q_k^B, & m=1, k=1,\ldots,K \\ Q_k^{R(k)}, & m=2,\ldots,M+1, k=K_1+1,\ldots,K, k \in \mathcal{U}_m \end{cases} \tag{4}$$

Considering these weights for queue stability provision, makes it possible for BS and relays to utilize only local QCSI for resource allocation algorithm provided in the subsequent subections. Using the framework mentioned above, resource allocation problem can be represented as follows:

$$\max_{\boldsymbol{p},\boldsymbol{x}\ \in \mathcal{D}} \sum_{m=1}^{M+1}\sum_{k\in\mathcal{U}_m}\sum_{n=1}^{N} w_k^m x_{kn}^m \log_2\Big(1 + \frac{p_{kn}^m e_{kn}^m}{x_{kn}^m \Gamma_k}\Big), \tag{5a}$$

$$\text{s.t.} \quad C1: \sum_{n=1}^{N}\sum_{m=1}^{M+1}\sum_{k\in\mathcal{U}_m} p_{kn}^m \le P_t, \tag{5b}$$

$$C2: \sum_{m=1}^{M+1}\sum_{k\in\mathcal{U}_m} x_{kn}^m \le 1, \forall n \tag{5c}$$

It is worth to note that the ordinary OFDMA networks can be considered as a special case of this formulation where M=0; in that case the virtual users will become the real users directly connected to BS.

Problem 5 is convex and the strong duality holds [10] (This can be verified by defining $\tilde{p}_{kn}^m = \frac{p_{kn}^m}{x_{kn}^m}$ and substituting in the objective and constraints). Therefore, using dual decomposition, an iterative algorithm can be designed to solve the problem.

B. Dual Problem Formulation

In this subsection, we formulate the dual problem for the resource allocation optimization problem. For this, we first obtain the Lagrangian function of primal problem. After rearranging the terms, the Lagrangian can be written as:

$$\begin{aligned}\mathcal{L}(\boldsymbol{p},\boldsymbol{x},\mu,\boldsymbol{\delta}) &= \sum_{m=1}^{M+1}\sum_{k\in\mathcal{U}_m}\sum_{n=1}^{N} w_k^m x_{kn}^m \log_2(1+\frac{p_{kn}^m e_{kn}^m}{x_{kn}^m \Gamma_k}) \\ &- \sum_{m=1}^{M+1}\sum_{k\in\mathcal{U}_m}\sum_{n=1}^{N} \mu p_{kn}^m \\ &- \sum_{m=1}^{M+1}\sum_{k\in\mathcal{U}_m}\sum_{n=1}^{N} \delta_n x_{kn}^m \\ &+ \mu P_t + \sum_{n=1}^{N}\delta_n \qquad (6)\end{aligned}$$

where μ is the Lagrangian multiplier associated with total power constraint and $\boldsymbol{\delta}$ is the Lagrangian multiplier vector for the subchannel allocation constraints. The dual problem is given by:

$$\min_{\boldsymbol{\mu},\boldsymbol{\delta}\geq 0} \ \max_{\boldsymbol{p},\boldsymbol{x}\in\mathcal{D}} \mathcal{L}(\boldsymbol{p},\boldsymbol{x},\mu,\boldsymbol{\delta}) \qquad (7)$$

Similar to the method in [10], the dual problem can be solved by a centralized iterative algorithm in BS. In this case, since the BS has the information of the previous transmissions, it would have QSI of all the relays, but it will need to ask for the CSI for the links between relays and their users on all the subchannels which will lead to an overhead in the order of O$((K-K_1)N)$. Alternatively, as in [5], using dual decomposition and concept of pricing, we propose an iterative distributed algorithm where in each iteration, BS and relays, solve their own problem based on the global variables and their local QCSI.

In the following subsection, we solve the dual problem in (7) by decomposing it into two parts: the first part is the local subproblem to be solved by each of the serving nodes, BS and relays, and the second part is the main dual problem to be solved by BS.

C. Dynamic Distributed Resource Allocation - DDRA

By dual decomposition, the dual problem is decomposed into a main global problem and $M+1$ local problems which can be solved iteratively. In each iteration, using the dual variables, which are global for all the nodes, BS and relays solve their local subproblem based on their QCSI. Then relays report their results to the BS and BS updates the dual variables and broadcasts them to relays. In this way, dual variables act as prices that BS adjusts to control the demands. The local subproblem in each node is given by:

$$\max_{\boldsymbol{p},\boldsymbol{x}\in\mathcal{D}} \mathcal{L}_m(\boldsymbol{p},\boldsymbol{x},\mu,\boldsymbol{\delta}), \qquad \text{with}$$

$$\begin{aligned}\mathcal{L}_m(\boldsymbol{p},\boldsymbol{x},\mu,\boldsymbol{\delta}) &= \sum_{k\in\mathcal{U}_m}\sum_{n=1}^{N} w_k^m x_{kn}^m \log_2(1+\frac{p_{kn}^m e_{kn}^m}{x_{kn}^m \Gamma_k}) \\ &- \sum_{k\in\mathcal{U}_m}\sum_{n=1}^{N} \mu p_{kn}^m \\ &- \sum_{k\in\mathcal{U}_m}\sum_{n=1}^{N} \delta_n x_{kn}^m \qquad (8)\end{aligned}$$

where the lagrange multipliers μ and $\boldsymbol{\delta}$ are provided by the BS. Using the Karush-Kuhn-Tucker conditions we have:

$$\frac{\partial \mathcal{L}_m}{\partial p_{kn}^m} = \frac{w_k^m x_{kn}^m e_{kn}^m}{x_{kn}^m \Gamma_k + p_{kn}^m e_{kn}^m} - \mu = 0 \qquad (9)$$

As a result, power allocation for subchannel n is obtained by:

$$\begin{aligned}&p_{kn}^{m\,*}(\boldsymbol{x},\mu,\boldsymbol{\delta}) = x_{kn}^m \tilde{p}_{kn}^m(\mu), \qquad \text{with} \\ &\tilde{p}_{kn}^m\,(\mu) = \min\Big(P_t, \big(\frac{w_k^m}{\mu} + \frac{\ln(5BER_k)}{1.5\ e_{kn}^m}\big)^+\Big) \qquad (10)\end{aligned}$$

where $(a)^+$=max$(a,0)$. After substituting $p_{kn}^{m\,*}$ into (8), we have:

$$\mathcal{L}_m\ \ (\boldsymbol{x},\mu,\boldsymbol{\delta}) = \sum_{k\in\mathcal{U}_m}\sum_{n=1}^{N} x_{kn}^m V_{kn}^m \qquad (11)$$

$$\text{with}\quad V_{kn}^m \ = w_k^m \log_2(1+\frac{\tilde{p}_{kn}^m e_{kn}^m}{\Gamma_k}) - \Big(\mu\tilde{p}_{kn}^m + \delta_n\Big)$$

Defining $V_n^{m*} = \max_{k\in\mathcal{U}_m}\{V_{kn}^m\}$, (11) will be maximized if subchannel assignment variables are computed as follows:

$$x_{kn}^{m\,*}(\mu,\boldsymbol{\delta}) = \begin{cases} 1, & V_{kn}^m = (V_n^{m*})^+, \\ 0, & V_{kn}^m < (V_n^{m*})^+, \end{cases} \qquad (12)$$

In some time slots, more than one users might have $V_{kn}^m = (V_n^{m*})^+$. This happens mostly for the virtual users of BS that represent the links belonging to the same group, i.e., between BS and a particular relay, as these links have the same channel condition over a subchannel. In such cases, subchannel is allocated to the user that has larger queue size or better channel condition. According to (4), (10) and (12), queue sizes of users, their channel conditions and required BER will affect their share of power and subchennals.

D. Solution of Main Dual Problem at BS

Based on the information of the powers and channel allocation variables reported by relays and using subgradient method, BS will update the dual variables through the following iterations:

$$\begin{aligned}\mu(t+1) &= \Big[\mu(t) - \xi_1(t)\Big(P_t - \sum_{m=1}^{M+1}\sum_{k\in\mathcal{U}_m}\sum_{n=1}^{N} p_{kn}^m\Big)\Big]^+, \\ \delta_n(t+1) &= \Big[\delta_n(t) - \xi_2(t)\Big(1 - \sum_{m=1}^{M+1}\sum_{k\in\mathcal{U}_m}\sum_{n=1}^{N} x_{kn}^m\Big)\Big]^+, \forall n \\ & \qquad (13)\end{aligned}$$

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In this algorithm, the overhead of messages reported by relays will be in the order of $O(NM)$ multiplied by the number of iterations, which would be considerably lower than that of centralized algorithm in the networks with high number of users. Number of iterations can be optimized to reach fast convergence, by choosing suitable step sizes and initial values [5].

IV. NUMERICAL RESULTS

To evaluate the system performance, we have considered a system with M=3 and N=20 and have conducted extensive Matlab simulations over 1000 time slots. Simulation parameters are shown in table I. For the links from BS or relay to users, Rayleigh channel model is used, while the links from BS to relays, are modeled with Rician channel with κ factor equal to 6 dB. Results are presented in terms of system throughput as well as average and maximum queue sizes in the system. For baseline, we have used the PPF method proposed in [4] in which power is equally allocated over subchannels and relays are prompt, i.e., they transmit in a time subslot immediately after the reception subslot. We have adjusted PPF for our scenario by considering the availability of data in the queues of users in BS; we call it Queue Aware PPF (QAPPF), as it computes the achievable rates of users based on their queue size and channel conditions. Figure 3 shows the average system throughput in each time slot, with two values of systme total power. It is observed that DDRA is able to utilize the wireless resources more efficiently, compared to QAPPF. The reason is that although both of them share the system power and subchannels for the users directly connected to BS and users connected through relays, in DDRA BS and relays allocate power and subchannels adaptively and also have flexibility over time to transmit to users and as a result they are able to get higher benefit from resources and from time diversity. Also it is observed that as the number of users increases, DDRA is able to utilize the multiuser diversity and get more gain. This is also displayed in Figure 4, by the Cumulative Distribution Function (CDF) of throughputs in each time slot, in the case of 10 users. The jumps in the diagram of DDRA are because of the fact that it utilizes resources efficiently and is able to empty the queues sometimes. Then when a new packet is arrived in a time slot in one of the queues, it is transmitted completely. It is clear frrom Figure 4 that DDRA is able to provide higher bit rates with higher probability.

Table I
SIMULATION PARAMETERS

Parameter Name	Setting
Cell Radius	1000m
Min UE-BS distance	50m
BS Antenna Height	15m
Relay Antenna Height	5m
User Antenna Height	1.5m
Relay Distance from BS	2/3 cell radius
Pathloss Model	From [12]
Subchannel Bandwidth	15 kHz
Time Slot Duration	1ms
BER Requirement	1e-6
Traffic Model/Packet Size	Poisson/1Kb
Packet Interarrival Time	30ms

Figure 5 demonstrates the average queue size in the system over time, with 10 users. While DDRA keeps queues stable, QAPPF is not able to reach this goal and therefore queue sizes increase unboundedly. We also show the CDF of maximum queue sizes in a system with 10 users in Figure 6. QAPPF results in higher probability for large queue sizes in the system, which would cause higher probability of buffer overflow. On the other hand, DDRA is able to keep queue sizes in smaller ranges and guarantee system stability. This is due to the fact that according to (4) DDRA gives higher weights to the users with larger queue sizes and using (10) and (12), it is able to allocate resources adaptively based on queue size, channel condition and required BER of the users. As the results confirm, DDRA is a throughput optimal algorithm, meaning that it is able to keep the queue sizes bounded if it is feasible at all [11].

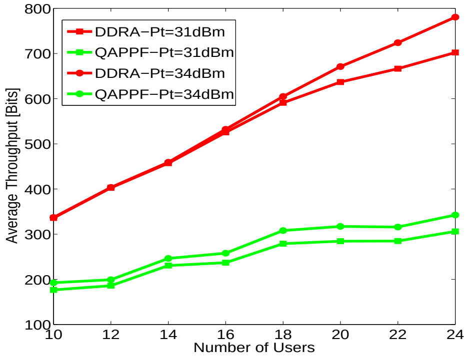

Figure 3. System Average Throughput

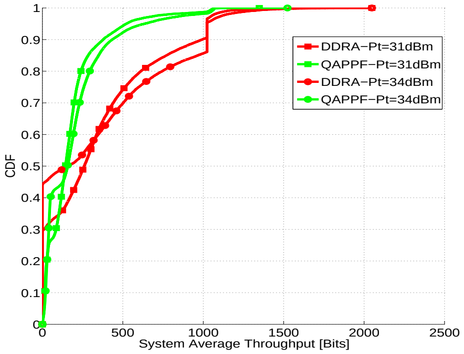

Figure 4. Distribution of System Average Throughput, K=10

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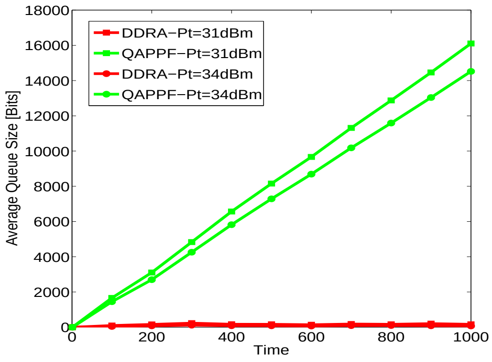

Figure 5. System Average Queue Size Over Time, K=10

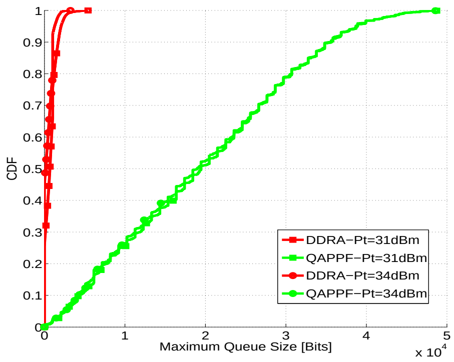

Figure 6. Distribution of System Maximum Queue Size, K=10

V. CONCLUSION AND FUTURE WORK

In this paper we provided a novel framework for joint power and subchannel allocation in a relay assisted OFDMA network, with the assumption that relays are able to buffer data and transmit in a later time. Defining the links between BS and relays as virtual users, a new perspective was provided and similarity of the system to a multicell network was shown. We formulated the resource allocation problem as a convex optimization problem and using dual decomposition, we proposed an iterative Dynamic Distributed Resource Allocation (DDRA) algorithm, in which each of the BS and relays solve their own problem based on some global variables and their local information about queue and channel states of their users. The closed form equations derived for power and subchannel allocation, reveals the adaptive characteristic of our resource allocation algorithm based on queue size, channel condition and required BER of the users. The propsed perspective and algorithm, is highly scalable which is of great appeal for deployment and radio resource management of relay assisted OFDMA networks. Numerical results confirm the throughput optimality of DDRA and show significant improvement in the system performance in terms of average throughput and queue stability. As the future work, we will consider separate power constraints for BS and relays and will extend DDRA for a scenario with both delay-sensitive and delay-tolerant services.

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