Radio Resource Allocation for Heterogeneous Services in Relay Enhanced OFDMA Systems

M. Shamim Kaiser and Kazi M. Ahmed
Telecommunications, Asian Institute of Technology, Pathumthani, Thailand
Email: M.Shamim.Kaiser@ait.ac.th; kahmed@ait.ac.th

Abstract— **We propose a priority based resource allocation algorithm for heterogeneous services in the relay enhanced OFDMA downlink systems. The aim is to maximize the system throughput while satisfying the quality of service (QoS) requirements of heterogeneous services, comprising real time (RT) and non real time (NRT) services. The base station (BS) allocates resources dynamically to the users in a prioritized manner. The priority parameter depends on the channel condition, QoS requirement and data buffer information. We propose a suboptimal algorithm to reduce the computational complexity. The simulation results are compared with the fixed as well as dynamic resource allocation algorithms proposed in different researches. Our proposed scheme reduces the outage probability of the system and increases the system throughput.**

Index Terms— **Heterogeneous services, OFDMA, resource allocation, fairness, minimum rate constraint (MRC), buffer length.**

I. INTRODUCTION

The next generation wireless systems provide high speed and reliable communications over harsh wireless channel to meet the ever increasing data rate demand of the customers. The inter-symbol interference (ISI) and low transmit power restrict the high data transmission rates. To mitigate these problems, one way is to use relay enhanced Orthogonal Frequency Division Multiplexing (OFDM) system. OFDM splits a high-rate data stream into N number of lower-rate data streams. The duration of each symbol increases for lower rate streams. Thus the relative amount of dispersion decreases. By adding a redundant cyclic prefix (CP) to each symbol, ISI can be omitted completely [1]. On the other hand, the high data rate requirement creates serious power concern. The energy decreases linearly with increasing data transmission rate for a given transmit power. Multi-hop relaying network can reduce the signal degradation at the destination and thereby overcome the transmit power problem [2-3].

OFDMA is a multiuser version of OFDM in which different set of subcarriers are exclusively assigned to different user. Thus the relay-enhanced OFDMA wireless system can meet throughput and coverage requirements for multi-rate services simultaneously. Heterogeneous services are broadly divided into two categories: RT services (Service A), e.g., interactive audio and video, and NRT services (Service B), e.g., email and web applications. Each type of services has its own QoS requirement. Since the radio resources are limited and channel realization of each user on each subcarrier is different, dynamic radio resource (DRR) allocation becomes extremely important.

The problem of assigning available radio resources $(subcarriers\ and\ power)$ to different users has been an area of intense research. Various researchers propose efficient subcarrier, power and rate allocation scheme with/without fairness for the OFDM system [1],[4]. Several papers address the resource allocation problem in cooperative relay based OFDMA system [5]-[7]. Suboptimal algorithms are also proposed in different literatures [1]-[5], [8]. In [8],[9], the problem of power minimizing under the minimum rate constraint for Service A users are studied. Authors have allocated subcarriers with the best channel gain to users under best channel conditions. They allocated less number of subcarriers to users at the cell boundary. Thus, users at the cell boundary and with the worst channel condition fail to maintain minimum data rate requirements. However, the data buffer information of a user is not considered during the subcarrier allocation [4]-[6],[8],[14],[15]. But the buffer condition of each user should be taken into consideration to efficiently utilize the limited resources. These motivates us to consider user priority, data buffer informations, bit-error-rate (BER) and minimum data rate requirements (R_{min}) for allocating resources according to the users request for the proper utilization of the limited radio resources. To the best of our knowledge, resource allocation algorithm considering QoS constraints (BER, R_{min}), data buffer length information and user priority for heterogeneous services has not yet been explored.

In this paper, we investigate a priority based OFDMA downlink resource allocation for heterogeneous services, and formulate an optimization problem as the maximization of system throughput subject to the total power, QoS requirement (BER, R_{min}) and data buffer information. The proposed suboptimal algorithm firstly allocates the resources to Service A, and then to Service B. The sets of Service A as well as Service B users are scheduled according to the priority parameter. This parameter is calculated considering full channel state information(CSI), buffer length information and the QoS constraint.

The remaining of this article is ordered as follows: section II discusses the system model and the problem formulation. Section III develops priority based resource

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Manuscript received May 27, 2009; revised March 08, 2010; accepted March 1, 2010.

doi:10.4304/jcm.5.6.447-454

allocation algorithm. Section IV discusses numerical results. Finally, section V concludes the article.

II. SYSTEM MODEL

We consider a 2-hop downlink OFDMA system as shown in Fig. 1. It consists of a single cell with one base station (BS) communicating simultaneously with k_a number of RT and k_b number of NRT service users. N_a and N_b are the number of subcarriers of RT and NRT service users respectively. It is assumed that the transmitter and the receiver know the instantaneous channel response. We consider a time division transmission in the $S \to R, D$ and $R \to D$ links, where S, R, and D stand for source, relay and destination respectively. In the even time slots, only the R terminal forwards the signal received in the odd time slot from the S terminal. In the BS, the serial data streams for k_a and k_b users are stored in the individual data buffers, the transmitted information is also stored in a data buffer of the selected relay.

An OFDM system converts frequency selective fading into frequency flat fading for each subcarrier. $h^{sd}_{k,n}$, $h^{sr}_{k,n}$ and $h^{rd}_{k,n}$ are the complex channel gains for $S-D, S-R$ and $R-D$ links, σ^2 is the variance of the additive white gaussian noise (AWGN). We consider maximal ratio combining at the receiver that combines the received signal in the two consecutive time slots.

The data rate of the k-th user using n-th subcarrier, i.e., $b_{k,n}$, can be expressed as

$$b_{k,n} = \frac{1}{2}\log_2\left(1+\frac{\Gamma_k P^S_{k,n}|h^{sd}_{k,n}|^2}{\sigma^2}+\Gamma_k\frac{\frac{P^S_{k,n}|h^{sr}_{k,n}|^2}{\sigma^2}\frac{P^R_{k,n}|h^{rd}_{k,n}|^2}{\sigma^2}}{1+\frac{P^S_{k,n}|h^{sr}_{k,n}|^2}{\sigma^2}+\frac{P^R_{k,n}|h^{rd}_{k,n}|^2}{\sigma^2}}\right) \tag{1}$$

$$\Rightarrow b_{k,n} \approx \frac{1}{2}\log_2\left(1+\frac{\Gamma_k P^S_{k,n}|h^{sd}_{k,n}|^2}{\sigma^2}+\frac{\Gamma_k}{\sigma^2}\frac{P^S_{k,n}|h^{sr}_{k,n}|^2 P^R_{k,n}|h^{rd}_{k,n}|^2}{P^S_{k,n}|h^{sr}_{k,n}|^2+P^R_{k,n}|h^{rd}_{k,n}|^2}\right), \tag{2}$$

where Γ_k is the signal to noise gap which can be expressed as

$$\Gamma_k = 1.5/[-\ln 5(BER)_k].$$

$P^S_{k,n}$ and $P^R_{k,n}$ are the source and relay transmit powers. The total power of k-th user using n-th subcarrier is $P_{k,n} = P^S_{k,n} + P^R_{k,n}$. Let $P^S_{k,n} = \varepsilon P_{k,n}$ then $P^R_{k,n} = (1-\varepsilon)P_{k,n}$. Equation (2) can be rewritten as

$$\Rightarrow b_{k,n} = \frac{1}{2}\log_2\left(1+\frac{\Gamma_k P_{k,n}}{\sigma^2}\left(\varepsilon|h^{sd}_{k,n}|^2+\frac{\varepsilon|h^{sr}_{k,n}|^2(1-\varepsilon)|h^{rd}_{k,n}|^2}{\varepsilon|h^{sr}_{k,n}|^2+(1-\varepsilon)|h^{rd}_{k,n}|^2}\right)\right) \tag{3}$$

$$or, b_{k,n} = \frac{1}{2}\log_2\left(1+\frac{\Gamma_k P_{k,n} h^2_{k,n}}{\sigma^2}\right), \tag{4}$$

where

$$h^2_{k,n} = \varepsilon|h^{sd}_{k,n}|^2+\frac{\varepsilon|h^{sr}_{k,n}|^2(1-\varepsilon)|h^{rd}_{k,n}|^2}{\varepsilon|h^{sr}_{k,n}|^2+(1-\varepsilon)|h^{rd}_{k,n}|^2} \tag{5}$$

is the equivalent channel response of the k-th user using n-th subcarrier. The achievable data rate of the k-th RT service user, i.e., b_k, can be expressed as

$$b_k = \sum_{n=0}^{N_a}\rho_{k,n}b_{k,n},$$

where $\rho_{k,n}$ is the subcarrier allocation indicator. It can be given by,

$$\rho_{k,n} = \begin{cases} 1 & \text{if } n\text{-th subcarrier is allocated to } k\text{-th user} \\ 0 & \text{otherwise .} \end{cases}$$

Thus the throughput of the RT service users can be expressed as

$$\sum_{k=0}^{k_a} b_k = \sum_{k=0}^{k_a}\sum_{n=0}^{N_a}\rho_{k,n}b_{k,n}. \tag{6}$$

Similarly, the throughput of the NRT service users can be expressed as

$$\sum_{k=0}^{k_b} b_k = \sum_{k=0}^{k_b}\sum_{n=0}^{N_b}\rho_{k,n}b_{k,n}. \tag{7}$$

The throughput of each RT/NRT user is limited by its buffer occupancy, that is, $b_k \le min[L_k, L_r]$.

where L_k and L_r are the buffer length of the k-th user and r-th relay respectively. In a real system, the data arrival process in the fixed length is random [10]. Thus the behavior of the queue is dynamic.

The total throughput, i.e., $\mathcal{T}$, of the system can be written as

$$\mathcal{T} = \sum_{k=0}^{k_a} b_k + \sum_{k=0}^{k_b} b_k.$$

Thus, the resource allocation problem of the system can be formed as

$$\arg\max_{(\rho_{k,n},P_{k,n})}[\mathcal{T}] = \arg\max_{(\rho_{k,n},P_{k,n})}\left[\sum_{k=0}^{k_a} b_k + \sum_{k=0}^{k_b} b_k\right]. \tag{8}$$

We consider the problem of resource allocation in order to guarantee the QoS of both the RT and NRT services. The throughput of the RT service users are constant, this is due to the minimum data rate requirements of the RT users, i.e., $b_k = R_{k,min}$; for all k, where $R_{k,min}$ is the minimum data rate requirement of the k-th user. The overall system throughput will increase if the throughput of the RT service users increases. The optimization problem of the resource allocation can be written as

$$\begin{aligned} &\text{maximize } \textstyle\sum_{k=0}^{k_b} b_k \\ &\text{subject to } b_k = R_{k,min}\ k \in \{1,2,...,k_a\} \\ &\qquad P_a + P_b \le P \\ &\qquad P_{k,n} > 0; b_k \le min[L_k, L_r]\ \forall k, \end{aligned} \tag{9}$$

where

$$P_a = \sum_{k=0}^{k_a} P_k = \sum_{k=0}^{k_a}\sum_{n=0}^{N_a} P_{k,n},$$

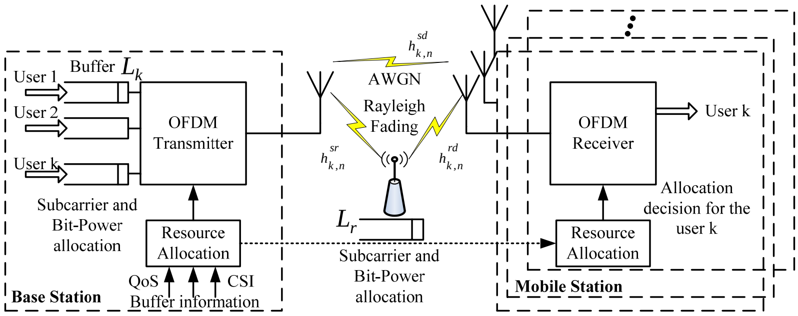

Figure 1. OFDMA downlink system.

$$P_b = \sum_{k=0}^{k_b} P_k = \sum_{k=0}^{k_b} \sum_{n=0}^{N_b} P_{k,n}.$$

P_k is the power of the k-th user, and P is the total power.

This is a non-linear optimization problem. It is difficult to solve directly and the complexity of this problem is very high. Thus the optimization problem in Equation (9) can be transformed into two suboptimal problems as

Problem I: Service A

$$\begin{aligned} &\text{minimize } \textstyle\sum_{k=0}^{k_a} \sum_{n=0}^{N_a} P_{k,n} \\ &\text{subject to } b_k = R_{k,min} \\ &\qquad P_{k,n} > 0; b_k \leq min[L_k, L_r]. \end{aligned} \quad (10)$$

Problem II Service B

$$\begin{aligned} &\text{maximize } \textstyle\sum_{k=0}^{k_b} b_k \\ &\text{subject to } P_a + P_b = P \\ &\qquad P_{k,n} > 0; b_k \leq min[L_k, L_r]. \end{aligned} \quad (11)$$

The outage probability of a k-th user using n-subcarrier i.e., P_{otg}, can be obtained from exponential channel gain distribution, i.e., ${\sigma^{ij}_{k,n}}^{-2}$, of the channel coefficient $|h^{ij}_{k,n}|^2$ [11]

$$\begin{aligned} P_{otg} &= Pr\{C_{k,n} < R_{k,min}\} \\ &= \left(\frac{{\sigma^{sr}_{k,n}}^2 + {\sigma^{rd}_{k,n}}^2}{2{\sigma^{sd}_{k,n}}^2 {\sigma^{sr}_{k,n}}^2 {\sigma^{rd}_{k,n}}^2} \right) \left(\frac{2^{2R_{k,min}} - 1}{1/\sigma^2} \right). \end{aligned}$$

III. RESOURCE ALLOCATION

We allocate less number of subcarriers with high SNR to the user's at the cell edge to achieve the minimum data transmission rate. Because the user at the cell edge suffers high path loss. In order to ensure the minimum QoS to all RT and NRT service users at the cell edge, a scheduling parameter must be set. The QoS requirements of the different users are different. The priority parameter, i.e., $W_k(q)$, is given as

$$W_k(q) = \left[R_{k,min} \times \frac{R_k(q)}{R_k(q-1)} \right]^{1-\alpha} \times {h_{k,n}}^{\alpha}, \quad (12)$$

where $R_{k,min}$ is the minimum rate constraint of k-th user,

$R_k(q-1)$ is the average rate at the end of $(q-1)$th frame of k-th user, and

$$R_k(q) = \min[Q_k(q), L_k(q), L_r(q)],$$

where $Q_k(q)$ is the number of bits which should be sent out at the q-th frame to satisfy the users demand,

$L_k(q)$ and $L_r(q)$ are the data buffer length of the k-th user and r-th relay at the q-th frame respectively, and α is the priority selection factor,

$$\alpha = \begin{cases} 0 & \text{if } b_k < R_{k,min} \\ 1 & \text{if } b_k \geq R_{k,min}. \end{cases} \quad (13)$$

A. Resource Allocation for the RT User

In this subsection, we discuss the resource allocation algorithm for the RT service users. In the optimization problem I, we minimize the resource usage while maintaining the target data rate requirement of the RT service users. As the number of subcarriers and allocated power are correlated, we can minimize the allocated power to each RT service user by assigning more subcarriers. The resource usage, i.e., η_k , of the k-th RT user can be written as

$$\eta_k = \left(\frac{\sum_{n=1}^{N_a} P_{k,n}}{P_a} \times \frac{\sum_{n=1}^{N_a} \rho_{k,n}}{N_a} \right), \quad (14)$$

where the first and second terms are the normalized power and subcarrier usages of the k-th user respectively. The optimization problem for minimizing the resource usage of the RT users can be expressed as

$$\begin{aligned} &arg \min \textstyle\sum_{n=1}^{k_a} \eta_k \\ &= arg \min \textstyle\sum_{n=1}^{k_a} \left(\frac{\sum_{n=1}^{N_a} P_{k,n}}{P_a} \times \frac{\sum_{n=1}^{N_a} \rho_{k,n}}{N_a} \right) \\ &\text{subject to } b_k = R_{k,min}; b_k \leq min[L_k, L_r]. \end{aligned} \quad (15)$$

The optimization problem in Equation (15) is difficult to solve, because we have to select minimum resource usage $(power, subcarriers)$ for each RT user corresponding to all RT users. Thus, we propose suboptimal approach to solve this problem. In the proposed algorithm, there are k_a number of iterations. At each iteration, we select one RT service user, estimate the number of subcarriers and then allocated power that minimizes the resource usage of the selected RT service user. User with better channel condition requires fewer subcarriers and less power to achieve the target data rate. The number of best subcarriers is used as the representative of channel condition of each user. The set of best subcarriers, i.e., ψ_k, for the k-th RT user can be written as

$$\psi_k = \{\arg\max_k(h_{k,n})\}. \tag{16}$$

The cardinality, i.e., n_k, of $|\psi_k|$ is $n_k = |\psi_k|$. The selected user corresponds to

$$k = \arg\max_k(W_k(q)). \tag{17}$$

The maximum number of available subcarriers for the k-th user is n_k and the corresponding channel gains are $h_{k,n}$, where $n \in \{1, 2, ..., n_k\}$. It is assumed that m_k number of subcarriers from n_k satisfy the target data rate requirement of k-th user. The resource usage for the k-th user can be written as

$$\eta_k = \left(\frac{\sum_{n=1}^{m_k} P_{k,n}}{P_a} \times \frac{m_k}{N_a}\right). \tag{18}$$

If we minimize $\sum_{n=1}^{m_k} P_{k,n}$, then η_k will be minimized. For the k-th user the optimal power allocation problem is formulated as

$$\begin{aligned}&\text{minimize } \textstyle\sum_{n=0}^{m_k} P_{k,n}\\ &\text{subject to } b_k = R_{k,min}\\ &P_{k,n} > 0; b_k \leq min[L_k, L_r].\end{aligned} \tag{19}$$

Using the Lagrange multiplier and Karush-Kuhn-Tucker conditions [2],[8], we can get the solution of the above optimization problem. By taking the derivatives of L and after some algebraic manipulation, we can get the following solution,

$$P_{k,n} = \frac{\sigma^2}{\Gamma_k}\left[\left(\frac{2^{2R_{k,min}}}{\prod_{n=1}^{m_k}|h_{k,n}|^2}\right)^{\frac{1}{m_k}} - \frac{1}{|h_{k,n}|^2}\right]^+, \tag{20}$$

where $(x)^+$ stands for $\max(0, x)$. The supported rate of the k-th RT user can be written as

$$b_k = \sum_{n=1}^{m_k} \rho_{k,n} \frac{1}{2} \log_2 \left(\frac{2^{2R_{k,min}}|h_{k,n}|^{2m_k}}{\prod_{n=1}^{m_k}|h_{k,n}|^2}\right)^{\frac{1}{m_k}}. \tag{21}$$

The derivation of this solution is given in the Appendix A.

We repeat the same process for the rest $(k_a - 1)$ RT service users. Note that, allocated subcarrier and the selected user must be excluded in the next iteration.

Fig. 2 shows the flow chart of the resource allocation algorithm for the RT service users. The proposed algorithm sorted the users in the descend order according to the priority parameter, then a set of best subcarriers are allocated to user with the highest priority sothat the required QoS has been met. Before the next iteration the allocated subcarriers are subtracted from the total number of subcarriers.

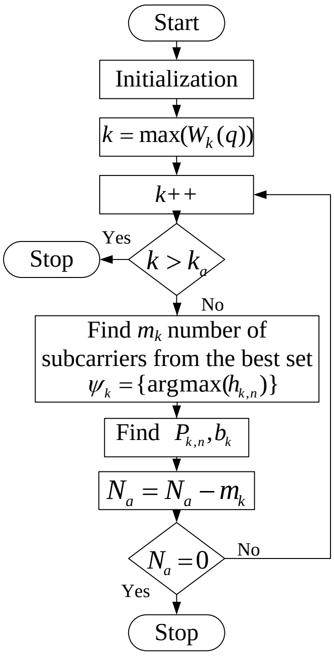

Figure 2. Flow chart of the resource allocation algorithm for the RT service users.

B. Resource Allocation for the NRT User

In this section, we discuss the resource allocation for the NRT service users. After allocating resources to the RT users, the remaining resources are

$$(Power, Subcarriers) = (P_b, N_b) = (P - P_a, N - N_a),$$

where P is the total power and N is the total number of downlink subcarriers.

The subcarrier and power allocation optimization problem for the NRT service users can be rewritten as

$$\begin{aligned}&\text{minimize } -\textstyle\sum_{k=0}^{k_b} b_k\\ &\text{subject to } P_a + P_b = P\\ &P_{k,n} > 0; b_k \leq min[L_k, L_r].\end{aligned} \tag{22}$$

The above optimization problem is also difficult to solve. Thus we propose suboptimal algorithm to allocate subcarriers and power to each NRT user.

For any k-th NRT user, the optimal power allocation problem is formulated as

$$\begin{aligned}&\text{minimize } -\textstyle\sum_{n=0}^{n_k} \rho_{k,n} b_{k,n}\\ &\text{subject to } \textstyle\sum_{n=0}^{n_k} P_{k,n} = P_k\\ &P_{k,n} > 0; b_k \leq min[L_k, L_r].\end{aligned} \tag{23}$$

where n_k is the total number of allocated subcarriers to the k-th NRT service users.

Using the Lagrange multiplier and Karush-Kuhn-Tucker conditions [2],[8], we get the solution of the above optimization problem. By taking the derivatives of L and after some algebraic manipulation, we can get the following solution

$$P_{k,n} = \left[\frac{1}{n_k}\left(P_k + \sum_{n=0}^{n_k} \frac{\sigma^2}{\Gamma_k|h_{k,n}|^2}\right) - \frac{\sigma^2}{\Gamma_k|h_{k,n}|^2}\right]^+. \tag{24}$$

The supported rate of the k-th NRT user can be written as

$$b_k = \sum_{n=0}^{n_k} \rho_{k,n} \frac{1}{2} \log_2 \left[\frac{1}{n_k} \left(P_k + \sum_{n=0}^{n_k} \frac{\sigma^2}{\Gamma_k |h_{k,n}|^2} \right) \frac{\Gamma_k |h_{k,n}|^2}{\sigma^2} \right]. \tag{25}$$

The derivation of this solution is presented in the Appendix B.

The proposed suboptimal algorithm is described below:

Estimation of the number of required subcarriers per user: Numbers of subcarriers assigned to each NRT service user is directly proportional to its minimum data rate [12]. We estimate the number of subcarriers as $m_k = \phi_k \lfloor N_b \rfloor$. These subcarriers are initially assigned to each user in order to satisfy their minimum rate constraint. ϕ_k is the proportional constant which depends on the k-th user data rate. The numbers of unallocated subcarriers can be calculated as

$$N^* = N_b - \sum_{k=1}^{k_b} m_k. \tag{26}$$

Allocation of subcarrier for the worst users: We sort the users based on $k = \arg\max_k(W_k(q))$ (here the value of $\alpha = 0$) and allocate the subcarriers with best channel gain, i. e., $m_k = \arg\max_k(h_{k,n})$.

Allocation of N^* subcarriers to increase the throughput: The unallocated N^* subcarriers allocated in this step. We select the users based on $k = \arg\max_k(W_k(q))$ (here the value of $\alpha = 1$) and allocate a subcarrier with best channel gain, i. e., $n = \arg\max_k(h_{k,n})$.

Power allocation: Allocate equal power to each user and then use waterfilling power allocation on the basis of known power and subcarriers of each user.

Fig. 3 shows the flow chart of the resource allocation algorithm for the NRT service users

IV. SIMULATION AND RESULTS

We consider a single cell with a cell-radius of 1000 m. BS is placed at the center of the cell whereas the fixed infrastructure relays are placed 700 m away from BS. Table I shows the simulation parameters. We generate N=8 users (N_a=3 and N_b=5) randomly in the cell. The total transmit power of each link is 30 dBm. Depending on the value of ε the source and relay powers are distributed. Each subcarrier experiences a 3-Rayleigh multipath fading with rms delay spread of 300 ns. We assume the path loss model of IEEE 802.11 with relay [13] and define the average SNR as $1/\sigma^2$. In the fixed allocation A and B we allocate 20 and 10 subcarriers respectively.

Fig. 4 shows the throughput analysis of the NRT users. Our algorithm can maintain almost same data rate as of the algorithm in [8] and it outperforms the fixed allocation. The slight difference in performance is due to the allocation of best carriers to the worst users in our case while algorithm in [8] allocates best carriers to the best users. It is also observed from Fig. 4 that dynamic resource allocation is better than the fixed allocation. For low value of SNR, the throughput of the fixed allocation A performs better then fixed allocation B whereas fixed allocation B performs better than fixed allocation A for the high SNR. It is due to the allocation of more subcarriers in the low SNR region and allocation of more power in the high SNR region.

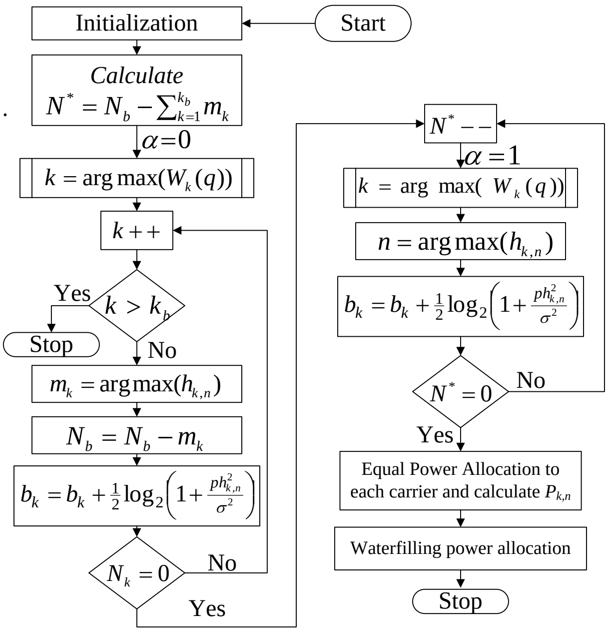

Figure 3. Flow chart of the resource allocation algorithm for the NRT service users.

Fig. 5 presents the outage probability analysis of the RT service users. We compare our proposed algorithm with the adaptive resource allocation proposed in [8] and fixed allocation A and B. The proposed algorithm outperforms in all aspects. It is observed that the outage probability is reduced if more subcarriers are allocated to the users.

Fig. 6 shows the performance of the proposed algorithm and resource allocation proposed in [8]. When buffer information is considered, the data rate of the algorithm in [8] degrades and becomes equal to our proposed algorithm.

Fig. 7 shows the impact of the minimum rate constraint on the individual user's data rate. We consider the best channel user, worst channel user and average channel user for comparison. In case of the proposed algorithm the data rate of the worst channel user improves whereas the data rate of the best channel user decreases with the increase of MRC. On the other hand, the data rate of the worst channel user decreases whereas the data rate of the best channel user increases with the increase of MRC in case of algorithm in [8].

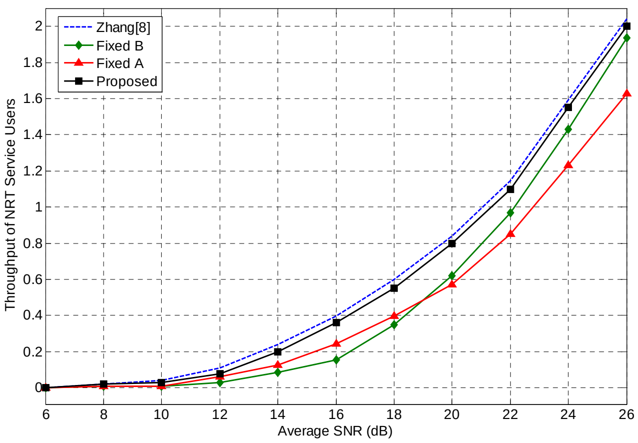

Figure 4. Throughput of the NRT users.

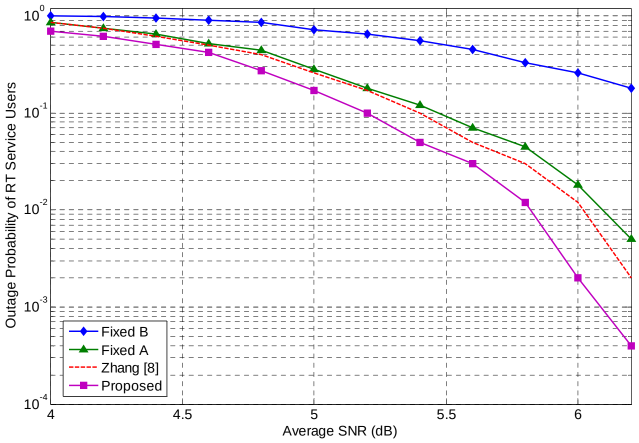

Figure 5. Outage Probability of the RT users.

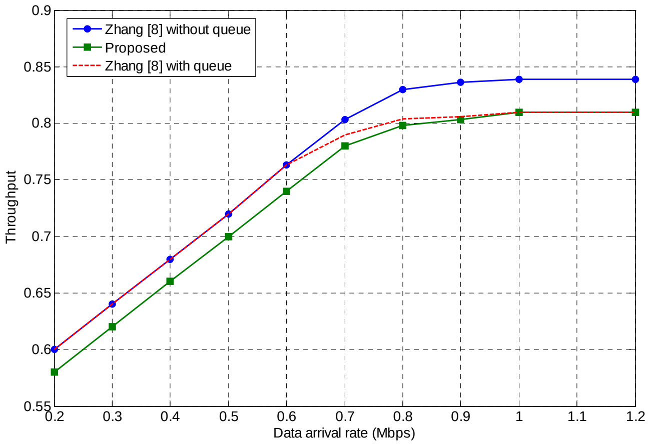

Figure 6. Impact of the arrival rate on the throughput.

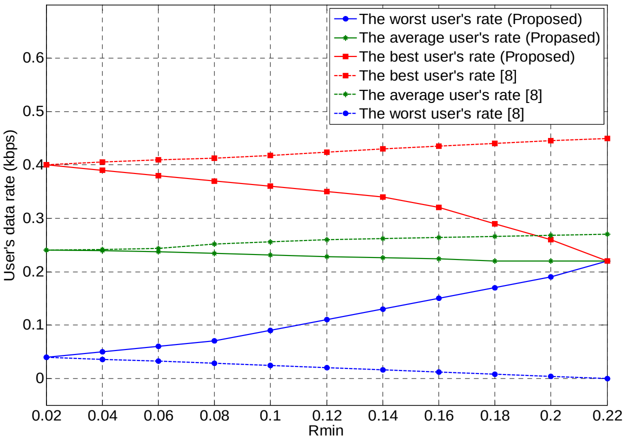

Figure 7. Data rate as a function of MRC.

V. COMPLEXITY ANALYSIS

In this section, we analyze the complexity of the proposed algorithm. $K = k_a + k_b$ is the total number of users and $N = N_a + N_b$ is the total number of subcarriers, where k_a and k_b are the RT and NRT users, and N_a and N_b are the number of subcarriers allocated to the RT and NRT users respectively. In case of resource allocation to the RT user, initialization requires a constant timing step, and sorting of the users according to the priority parameter requires $k_a \log_2 k_a$ operations. The loop in the flow chart, as shown in Fig 2, requires $k_a m_k \log_2 m_k + constant$ operations. Finding the value of $P_{k,n}$, b_k and subtraction of the used subcarriers from the N_a require constant time. In case of resource allocation to the NRT users, the algorithm requires constant time to initialize all variables and calculate N^*. The sorting of the users according to the priority parameter requires $k_b \log_2 k_b$ operations. The allocation of $\sum_{k=1}^{k_b} m_k$ subcarriers to the users require $k_b m_k \log_2 m_k$ operations while the allocation of the residue subcarrier requires N^* operations. Calculation of data rate and subtraction of the used subcarriers require some constant time. The asymptotic complexity of the proposed algorithm is $O(KN \log_2 N)$ whereas the asymptotic complexity of the optimal search is $O(K^N)$.

VI. CONCLUSION

In this paper, we propose a suboptimal priority based resource allocation algorithm for the multiservice 2-hop OFDMA systems. The simulation results are compared with the fixed and dynamic resource allocation algorithms proposed in different researches. The proposed scheme performs better then the fixed allocation. The outage probability of the system is reduced and achieved almost the same throughput as compare to algorithm in [8]. The complexity analysis shows that the complexity of the proposed suboptimal algorithm is greatly reduced compared to the optimal algorithm. Our work can be extended considering the partial CSI instead of full CSI and overlay cognitive radio system.

REFERENCES

[1] S. Zukang, J. G. Andrews, and B. L. Evans, “Adaptive Resource Allocation in Multiuser OFDM Systems With Proportional Rate Constraints,” in *IEEE Transactions on Wireless Communications* , vol. 4(6), pp. 2726-2737, Nov. 2005.

TABLE I.
SIMULATION PARAMETERS

Parameters	Value
System	OFDMA downlink
Channel Model	3-Rayleigh-multipath+AWGN
Number of subcarriers	64
K_a, K_b	3, 5
Path loss exponent	3.5
Frame length	$2ms$
Simulation loop	10000
MRC of RT	2.0
MRC of NRT	0.2
BER requirement of RT	10^{-5}
BER requirement of NRT	10^{-3}

[2] J. Shi and A. Hu, “Radio Resource Allocation Algorithm for the Uplink OFDMA System ,” in *IEEE International Conference on Communications Workshops ’08 (ICC Workshops ’08)*, pp. 11-15, 19-23 May 2008

[3] J. N. Laneman, D. N. C. Tse, and G. W. Wornell, “Cooperative Diversity In Wireless Networks: Efficient Protocols And Outage Behavior,” in *IEEE Transactions on Information Theory*, , vol. 50(12), pp. 3062-3080, Dec. 2004

[4] Y-H. Lu, T. Lua, C.-C. Yin, and G.-X. Yue, “Adaptive radio resource allocation for multiple traffic OFDMA broadband wireless access system,” in *Journal of China Universities of Posts and Telecommunications* , pp. 1-6, December 2006.

[5] R. Kwak and J .M. Cioffi,, “ Resource-Allocation for OFDMA Multi-Hop Relaying Downlink Systems,” in *IEEE Global Telecommunications Conference, 2007. (GLOBECOM ’07)*, pp. 3225-3229, 26-30 Nov. 2007.

[6] C. S. Bae and D.-H. Cho,, “ Fairness-Aware Adaptive Resource Allocation Scheme in Multihop OFDMA Systems,” in *IEEE Communications Letters* pp. 134-136, Feb. 2007.

[7] Y. G. Ding et al., “ Power Allocation For Non-Regenerative OFDM Relaying Channels ,” in *International Conference on Wireless Communications, Networking and Mobile Computing*, , vol. 1, pp. 185-188, 23-26 Sept. 2005.

[8] X. Zhang, S. Chen and W. Wang, “Multiuser Radio Resource Allocation for Multiservice Transmission in OFDMA Based Cooperative Relay Networks ,” *EURASIP Journal on Wireless Communications and Networking*, 2009

[9] W. Wang, K. C. Hwang, K. B. Lee and B. Saewoong,, “Resource Allocation For Heterogeneous Services In Multiuser OFDM Systems,” in *IEEE Global Telecommunications Conference, (IEEE GLOBECOM)*, vol. 6, pp. 3478-3481, 2004.

[10] C. Sarr and I. G. Lassous, “Estimating Average End-to-End Delay in IEEE 802.11 Multihop Wireless Networks,” in *Rapport de Recherche: Theme COM*, July 2007.

[11] K. J. R Liu, A. K. Sadek, W. Su, A. Kwasinski, “Cooperative Communications and Networking,” *Cambridge University Press, UK* , 2009

[12] I. C. Wong, Z. Shen, B. L .Evans, J. G. Andrews, “A low complexity algorithm for proportional resource allocation in OFDMA systems,” in *Workshop on Signal Processing Systems, 2004(SIPS 2004)*, pp. 1-6, 13-15 Oct. 2004

[13] G. Senarath et al., “Multihop Relay System Evaluation Methodology: Channel Model and Performace Matric,” *IEEE802.16j-06*, 2007

[14] J. Yang, D. Gunduz, D. R. Brown and E. Erkip, “Adaptive Resource Allocation in OFDMA Relay Aided Cooperative Cellular Netwroks,” *42nd Annual Conference on Information Science and Systems (CISS)*, 2008

[15] L. You, M. Song, J. Song, Q. Miao and Y. Zhang, “Resource Allocation for Cooperative Relaying,” *IEEEVTC Spring*, 2008

M. Shamim Kaiser is currently a Ph.D. candidate in Telecommunications field of study from Asian Institute of Technology, Thailand.He received his MS and BS degrees in Applied Physics,Electronics and Communication Engineering from University of Dhaka, Dhaka, Bangladesh in 2004, and 2002 respectively.

His current research interests include cooperative-cognitive radio networks, resource allocation, cross layer optimization, Applications of bio inspired systems in 4G wireless system

Mr. Kaiser is a student member of the IEICE Communication Society and member of IEEE Communication Society and Life member of Bangladesh Electronic Society.

Kazi M. Ahmed received his the Ph.D. degree from the University of Newcastle, NSW, Australia and M.Sc. Engg degree in Electrical Engineering from the Institute of Communications, Leningrad, USSR, in 1983 and 1978, respectively.

Currently, he is a Professor of Telecommunications in the School of Engineering and Technology, Asian Institute of Technology, Pathumthani, Thailand. His current research interests include digital signal processing, antenna array processing, tropospheric and ionospheric propagation studies for Microwave, very high frequency-ultrahigh frequency (VHF-UHF) communications, and satellite communications.

Mr. Ahmed is a member of IEEE Communication Society, IEICE Communication Society.

APPENDIX

A. Derivation of solution of Equations (20) and (21)

Using Equation (4) and (19), we can set up the Lagrangian function as

$$\begin{aligned} L = -\sum_{n=0}^{m_k} P_{k,n} + \\ \frac{\mu}{2}\left[\sum_{n=0}^{N_a} \rho_{k,n} \log_2\left(1+\frac{\Gamma_k P_{k,n}|h_{k,n}|^2}{\sigma^2}\right) - \log_2 2^{2R_{k,min}}\right] \\ + \lambda P_{k,n}. \end{aligned} \tag{27}$$

The derivation of the Lagrangian with respect to $P_{k,n}$ is given by

$$\frac{\partial L}{\partial P_{k,n}} = -1 + \mu \frac{\frac{\Gamma_k |h_{k,n}|^2}{\sigma^2}}{2\ln_2\left(1+\frac{\Gamma_k P_{k,n}|h_{k,n}|^2}{\sigma^2}\right)} + \lambda. \tag{28}$$

Setting Equation (28) to zero, we get,

$$\lambda = 1 - \mu \frac{\frac{\Gamma_k |h_{k,n}|^2}{\sigma^2}}{2\ln_2\left(1+\frac{\Gamma_k P_{k,n}|h_{k,n}|^2}{\sigma^2}\right)}. \tag{29}$$

From the KKT conditions, we know that $\lambda \geq 0$, and $\lambda P_{k,n} = 0$ but $P_{k,n} > 0$. Thus we get

$$\mu = \frac{\frac{\Gamma_k |h_{k,n}|^2}{\sigma^2}}{2\ln_2\left(1+\frac{\Gamma_k P_{k,n}|h_{k,n}|^2}{\sigma^2}\right)}. \tag{30}$$

From the equation (30), we can obtain,

$$\frac{\frac{\Gamma_k |h_{k,n}|^2}{\sigma^2}}{1+\frac{\Gamma_k P_{k,n}|h_{k,n}|^2}{\sigma^2}} = \frac{\frac{\Gamma_k |h_{k,o}|^2}{\sigma^2}}{2^{2R_{k,min}}},$$

where $n \neq o$ and $n, o \in \{1, 2, ..., m_k\}$.

$$\Rightarrow \frac{1+\frac{\Gamma_k P_{k,n}|h_{k,n}|^2}{\sigma^2}}{\frac{\Gamma_k|h_{k,n}|^2}{\sigma^2}} = \frac{2^{2R_{k,min}}}{\frac{\Gamma_k|h_{k,o}|^2}{\sigma^2}}$$

$$\Rightarrow P_{k,n} + \frac{1}{\frac{\Gamma_k|h_{k,n}|^2}{\sigma^2}} = \frac{2^{2R_{k,min}}}{\frac{\Gamma_k|h_{k,o}|^2}{\sigma^2}}. \qquad (31)$$

Taking $\log_2$ on the both side, Equation (31) can be simplified as

$$P_{k,n} = \frac{\sigma^2}{\Gamma_k}\left[\left(\frac{2^{2R_{k,min}}}{\prod_{n=1}^{m_k}|h_{k,n}|^2}\right)^{\frac{1}{m_k}} - \frac{1}{|h_{k,n}|^2}\right]^+. \qquad (32)$$

The corresponding supported data rate can be written as

$$b_k = \sum_{n=0}^{m_k}\rho_{k,n}\frac{1}{2}\log_2\left(1+\frac{\Gamma_k P_{k,n}|h_{k,n}|^2}{\sigma^2}\right). \qquad (33)$$

Using Equations (32) and (33), we have

$$b_k = \sum_{n=0}^{m_k}\rho_{k,n}\frac{1}{2}\log_2\left(\left(\frac{2^{2R_{k,min}}}{\prod_{n=1}^{m_k}|h_{k,n}|^2}\right)^{\frac{1}{m_k}}|h_{k,n}|^2\right). \qquad (34)$$

Thus, the supported rate of the k-th RT user can be written as

$$b_k = \sum_{n=1}^{m_k}\rho_{k,n}\frac{1}{2}\log_2\left(\frac{2^{2R_{k,min}}|h_{k,n}|^{2m_k}}{\prod_{n=1}^{m_k}|h_{k,n}|^2}\right)^{\frac{1}{m_k}}. \qquad (35)$$

B. Derivation of solution of Equations (24) and (25)

Using Equations (4) and (21), we can set up the Lagrangian function as

$$L = \frac{1}{2}\log_2\left(1+\frac{\Gamma_k P_{k,n}|h_{k,n}|^2}{\sigma^2}\right) + \lambda P_{k,n} - \mu\left(\sum_{n=0}^{n_k}P_{k,n} - P_k\right).$$

The derivation of the Lagrangian with respect to $P_{k,n}$ is given by

$$\frac{\partial L}{\partial P_{k,n}} = \frac{\frac{\Gamma_k|h_{k,n}|^2}{\sigma^2}}{2\ln_2\left(1+\frac{\Gamma_k P_{k,n}|h_{k,n}|^2}{\sigma^2}\right)} + \lambda - \mu. \qquad (36)$$

Setting Equation (36) to zero, we get,

$$\lambda = \mu - \frac{\frac{\Gamma_k|h_{k,n}|^2}{\sigma^2}}{2\ln_2\left(1+\frac{\Gamma_k P_{k,n}|h_{k,n}|^2}{\sigma^2}\right)}. \qquad (37)$$

From the KKT condition, we know that $\lambda \geq 0$. Thus we get from Equation (37)

$$\mu \geq \frac{\frac{\Gamma_k|h_{k,n}|^2}{\sigma^2}}{2\ln_2\left(1+\frac{\Gamma_k P_{k,n}|h_{k,n}|^2}{\sigma^2}\right)}. \qquad (38)$$

Another KKT condition is that $\lambda P_{k,n} = 0$, that is,

$$\left(\mu - \frac{\frac{\Gamma_k|h_{k,n}|^2}{\sigma^2}}{2\ln_2\left(1+\frac{\Gamma_k P_{k,n}|h_{k,n}|^2}{\sigma^2}\right)}\right)P_{k,n} = 0. \qquad (39)$$

But $P_{k,n} > 0$ Thus, Equation (39) can be reduced to

$$\mu = \frac{\frac{\Gamma_k|h_{k,n}|^2}{\sigma^2}}{2\ln_2\left(1+\frac{\Gamma_k P_{k,n}|h_{k,n}|^2}{\sigma^2}\right)}. \qquad (40)$$

From the Equation (40), we can write

$$\frac{\frac{\Gamma_k|h_{k,n}|^2}{\sigma^2}}{2\ln_2\left(1+\frac{\Gamma_k P_{k,n}|h_{k,n}|^2}{\sigma^2}\right)} = \frac{\frac{\Gamma_k|h_{k,o}|^2}{\sigma^2}}{2\ln_2\left(1+\frac{\Gamma_k P_{k,o}|h_{k,o}|^2}{\sigma^2}\right)}, \qquad (41)$$

where $n, o \in \{1, 2, ..., n_k\}$ and $n \neq o$, Equation (41) can be rewritten as

$$P_{k,n} = P_{k,o} + \frac{\frac{\sigma^2}{\Gamma_k|h_{k,n}|^2} - \frac{\sigma^2}{\Gamma_k|h_{k,o}|^2}}{\frac{\sigma^2}{\Gamma_k|h_{k,n}|^2}\frac{\sigma^2}{\Gamma_k|h_{k,o}|^2}}. \qquad (42)$$

Since $P_k = \sum_{n=0}^{n_k}P_{k,n}$ and $P_{k,n} > 0$, then

$$P_{k,n} = \left[\frac{1}{n_k}\left(P_k + \sum_{n=0}^{n_k}\frac{\sigma^2}{\Gamma_k|h_{k,n}|^2}\right) - \frac{\sigma^2}{\Gamma_k|h_{k,n}|^2}\right]^+. \qquad (43)$$

The supported rate of the k-th NRT user can be written as

$$b_k = \sum_{n=0}^{n_k}\rho_{k,n}\frac{1}{2}\log_2\left(1+\frac{\Gamma_k P_{k,n}|h_{k,n}|^2}{\sigma^2}\right). \qquad (44)$$

Using Equations (43) and (44), the supported rate of the k-th NRT user can be written as

$$b_k = \sum_{n=0}^{n_k}\rho_{k,n}\frac{1}{2}\log_2\left[\frac{1}{n_k}\left(P_k + \sum_{n=0}^{n_k}\frac{\sigma^2}{\Gamma_k|h_{k,n}|^2}\right)\frac{\Gamma_k|h_{k,n}|^2}{\sigma^2}\right]. \qquad (45)$$