Optimized Dual Uplink and Downlink Resource Allocation for Multiple Class of Service in OFDM Network

Mohamed K. Shehata
Arab Academy for Science, Technology and Maritime Transport / Department of Electronics & Communications Engineering, Cairo, Egypt
Email: mkhshehata@aast.edu

Safa M. Gasser
Arab Academy for Science, Technology and Maritime Transport / Department of Electronics & Communications Engineering, Cairo, Egypt
Email: safagasser@aast.edu

Hesham M. El-Badawy[1]and Mohamed E. Khedr[2]

[1]Network Planning Department, Networks Department
National Telecommunications Institute , Cairo, Egypt
[2]Arab Academy for Science, Technology and Maritime Transport / Department of Electronics & Communications Engineering, Cairo, Egypt
Email: heshamelbadawy @ieee.org and khedr@aast.edu

Abstract—The major challenge in the wireless communication networks is the efficient utilization of the limited resources while maintaining the target quality of service (QoS). In this paper we propose a new algorithm for joint uplink and downlink resource allocation in an OFDM wireless network. In the new algorithm we take both best effort and real traffic classes of service into consideration. The total utility function formulated takes into account both channel quality as well as time delay experienced in both directions. The formulated non-convex problem is solved using dual optimization techniques. The simulation results obtained demonstrate the effectiveness of the proposed joint uplink and downlink allocation scheme.

Index Terms—resource allocation, dual uplink/downlink, OFDM system, uplink, downlink.

I. INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) technique is recognized as one of the leading candidates to provide the wireless signaling for 4G systems. The major challenge in multiuser OFDM is resource allocation. Resource allocation, is the process of best utilizing of the subcarriers and power resource.

There has been a tremendous amount of research in the area of network optimization in OFDM wireless systems. In[1-4] the authors proposed many algorithms considering only downlink resource allocation. An adaptive algorithm is investigated in [1] by assigning set of subcarriers to the user and choosing the number of bits and the power level for each subcarrier in order to minimize the transmitted power. In [2] the authors took fairness into account, as the utility function considered is based on service rate maximization. In [3] the authors proposed an adaptive algorithm for MIMO-OFDM system. The algorithm aimed to minimize the total transmit power while satisfying the user's target rate using convex optimization. The result obtained from the optimization algorithm is suitable for both uplink and downlink, but without any coupling between them.

On the other hand authors in [5] proposed algorithm, taking only the uplink resource allocation into consideration. In [5] Joint subcarrier and power allocation algorithm is considered. In the joint algorithm the subcarrier is allocated to the user with the largest marginal rate; then the user is allocated this power using water filling techniques. The formal algorithm is considered highly complex. As mentioned in [6-8] joint uplink/downlink resource allocation schemes should be considered. The joint scheme ensures optimum utilization in both direction , which affects greatly the overall QoS. In [6] a joint uplink and downlink resource allocation, user level utility function is considered. The utility function is optimized using dual optimization techniques. The authors showed that the overall QoS was greatly affected due to the joint optimization. In [7] the authors considered joint uplink and downlink optimization; by only considering two users and one class of service.

In this paper we propose a new uplink and downlink resource allocation. In the proposed algorithm we consider two classes of service; the best effort traffic for data applications and the real time traffic for time sensitive applications. Utility function takes into account the channel quality and the delay each user faces. Total network utility, which is indicator of the network performance, is the summation of the users utilities. The maximum of the total utility function is obtained by using dual optimization techniques taking into consideration user rate constraints as well as minimum gap between the uplink and the downlink rates. The remainder of the paper is organized as follows, In section II we give a thorough description of the system model. The problem is formulated and solved in Section III. Simulation results follows in Section V. Paper is concluded in section IV.

II. SYSTEM MODEL

The system model considered as a wireless OFDM network with a single cell. The number of active users considered is between 2 to 10 . We consider either best effort traffic for non real time application, or real time traffic for time sensitive application.

A. Uplink Model

In the uplink channel we consider SC^U subcarriers to be allocated to M users. If the channel bandwidth is given by B. If the channel gain is $|h_{ij}^2|$ and $P_{ij}^U(t)$ is the uplink allocated power by user i to subcarrier j, then the signal to noise ratio is defined as follows [9];

$$SNR_{ij}^U(t)) = \frac{|h_{ij}^2|}{N_0 B/SC^U} \tag{1}$$

We consider $w_{ij}^U(t)$ as the subcarrier weight, which is set to 1 if subcarrier j is allocated to user i otherwise set to 0. Then, the uplink rate equation as in [7] is defined by

$$R_i^U(t) = \sum_{j=1}^{SC^U} w_{ij}^U(t) \ \log_2(1 + \frac{P_{ij}^U(t)}{w_{ij}^U(t)} SNR_{ij}^U(t)) \tag{2}$$

For simplicity a free space model is considered. Where the power received for the user p_r is computed as follows [10];

$$p_r = p_t + G_R + G_T - L_p \tag{3}$$

Where p_t, $G_R$and G_T represents power transmitter, receiver gain and the transmitter gain respectively .While the path loss L_p is computed as in [10].

The set of constraints considered as follows;

1) The power consumed by the subcarriers allocated to user i must not exceed the maximum power allocated to each user.

$$\sum_{j=1}^{SC^U} P_{ij}^U(t) \ \leq P_{max,i}^U \tag{4}$$

2) For a given subcarrier j the sum of weights $w_{ij}^U(t)$ must not exceed unity.

$$\sum_{i=1}^{M} w_{ij}^U(t) \ \leq 1 \tag{5}$$

Consider τ_i^U(t) to be the delay time of a packet in the uplink direction, while τ_{av}^u(t) is the average delay time for all the transmitting users. Thus, the normalized indicator for the delay user i faces in the uplink direction is defined as given in [10] as

$$\theta_i^u(t) = \frac{\tau_i^U(t) \ - \ \tau_{av}^U(t)}{\tau_{av}^U(t)} \tag{6}$$

As in [11] we define the utility function for user i using best effort traffic as;

$$U_{BE,i}^U(t) = R_i^U(t) e^{\theta_i^U(t)} \tag{7}$$

While that for real traffic is also defined as;

$$U_{RT,i}^U(t) = R_i^U(t) \frac{\tau_i^U(t)}{T_s + 1} e^{\theta_i^U(t)} \tag{8}$$

Where T_s is the duration of the time slot.

B. *Downlink Model*

In the downlink channel we consider SC^D subcarriers to be allocated to M users. If the channel bandwidth is given by B. If the channel gain is $|h_{ijj}^2|$ and $P_{ijj}^D(t)$ is the downlink allocated power to subcarrier jj of user i, then the signal to noise ratio is defined as in [8] as follows;

$$\mathrm{SNR}_{ij}^D(t)) = \frac{|h_{ijj}^2|}{N_0 B/SC^D} \tag{9}$$

We consider $w_{ijj}^D(t)$ as the subcarrier weight, which is set to 1 if subcarrier jj is allocated to user i otherwise set to 0. Then, the downlink rate equation as in [7] is defined by

$$R_i^D(t) = \sum_{jj=1}^{SC^D} w_{ijj}^D(t) \ \log_2(1 + \frac{P_{ijj}^D(t)}{w_{ijj}^D(t)} \mathrm{SNR}_{ijj}^D(t)) \tag{10}$$

The set of constraints considered as follows;

1) The power consumed by all the subcarriers allocated to M users must not exceed the maximum power of the base station.

$$\sum_{j=1}^{SC^U} P_{ij}^U(t) \ \leq P_{\max,i}^U \tag{11}$$

2) For a given subcarrier jj the sum of weights $w_{ijj}^D(t)$ must not exceed unity.

$$\sum_{i=1}^{M} w_{ijj}^D(t) \ \leq 1 \tag{12}$$

Consider $\tau_i^D(t)$ to be the time spend by a packet in the downlink direction, while $\tau_{av}^D(t)$ is the average delay time for all the users. Thus, the normalized indicator for the delay user i faces in the downlink direction is defined as given in [10] as

$$\theta_i^D(t) = \frac{\tau_i^D(t) \ - \ \tau_{av}^D(t)}{\tau_{av}^D(t)} \tag{13}$$

As in [11] we define the utility function for user i using best effort traffic as;

$$U_{BE,i}^D(t) = R_i^D(t) e^{\theta_i^D(t)} \tag{14}$$

While that for real traffic as;

$$U_{RT,i}^D(t) = R_i^D(t) \frac{\tau_i^D(t)}{T_s + 1} e^{\theta_i^D(t)} \tag{15}$$

Where T_s is the duration of the time slot.

C. *Uplink/Downlink Coupling*

In this subsection we introduce the coupling assumed that links both the uplink and downlink. This coupling makes the problem formulation untraditional as it avoids dealing with the uplink and downlink channels independently, thus, increases the overall QoS of the OFDM system. For a given user i the difference between uplink rate and downlink rate follows the following equation

$$R_i^D(t) - R_i^U(t) \leq \Omega \tag{16}$$

Where Ω is a parameter set by the network operator on a service-level basis. While the total network utility function is defined as follows;

$$U(t) = \sum_{i=1}^{M} U_i^U + U_i^D - \left(R_i^D(t) - R_i^U(t)\right) \tag{17}$$

III. PROBLEM FORMULATION

To formulate our problem we consider N number of users with best effort class of service and $M - N$ number of users with real time class of service. Thus the total utility function is rewritten as follows;

$$\max_{W^U P^U W^D P^D} \sum_{i=1}^{N} U_i^U + U_i^D - \left(R_i^D(t) - R_i^U(t)\right) + \sum_{i=M-N}^{M} U_i^U + U_i^D - \left(R_i^D(t) - R_i^U(t)\right) \tag{18}$$

Subject to

$$\mathrm{R_i^D} \geq \mathrm{R_{min}^D}, \quad \mathrm{R_i^D} \geq \mathrm{R_{min}^D} \tag{19}$$

The previously discussed constraints in (4), (5), (11), (12) and (16) is also considered.
The optimization problem is a non convex problem. Thus, dual optimization techniques are utilized with the aid of Lagrange multipliers. The Lagrangian corresponding to the formulated objective function is rewritten

$$\mathcal{L}(.) = \mathcal{L}(.)_{BE} + \mathcal{L}(.)_{RT} \tag{20}$$

Where $\mathcal{L}(.)_{BE}$ is given by [7]

$$\begin{aligned}
\mathcal{L}(.)_{BE} = \sum_{i=1}^{N} & \left(\left(e^{\theta_i^U(t)} \alpha_{i,BE}^{u} + \lambda_{i,BE} - \mu_{i,BE} \right) \sum_{j=1}^{SC^U} w_{ij}^{U}(t)\ \log_2\left(1 + \frac{P_{ij}^{U}(t)}{w_{ij}^{U}(t)} SNR_{ij}^{U}(t)\right) \right) \\
& - \sum_{i=1}^{N} \varepsilon_{i,BE}^{U} \left(\sum_{j=1}^{SC^U} P_{ij}^{U}(t) \right) \\
& + \sum_{i=1}^{N} \left(\left(e^{\theta_i^D(t)} + \alpha_{i,BE}^{D} + \mu_{i,BE} - \lambda_{i,BE} \right) \sum_{jj=1}^{SC^D} w_{ijj}^{D}(t)\ \log_2\left(1 + \frac{P_{ijj}^{D}(t)}{w_{ijj}^{D}(t)} SNR_{ijj}^{D}(t)\right) \right) \\
& - \sum_{i=1}^{N} \varepsilon_{i,BE}^{D} \left(\sum_{jj=1}^{SC^D} P_{ijj}^{D}(t) \right) \\
& - \sum_{i=1}^{N} \left(\Omega_i + \alpha_{i,BE}^{u} R_{min}^{U} + \alpha_{i,BE}^{D} R_{min}^{D} - \varepsilon_{i,BE}^{U} P_{max}^{U} - \varepsilon_{i,BE}^{D} P_{max,BS} - \lambda_{i,BE}\Omega_i - \mu_{i,BE}\Omega_i \right)
\end{aligned} \tag{21}$$

Where $\varepsilon_{i,BE}^{U}$, $\varepsilon_{i,BE}^{D}$, $\alpha_{i,BE}^{D}$, $\alpha_{i,BE}^{u}$, $\lambda_{i,BE}$ and $\mu_{i,BE}$ are Lagrange Multipliers.
Similarly an expressions for the real-time traffic can be written as

$$\begin{aligned}
\mathcal{L}(.)_{RT} = \sum_{i=M-N}^{M} & \left(\left(e^{\theta_i^U(t)} \alpha_{i,RT}^{u} + \lambda_{i,RT} - \mu_{i,BE} \right) \sum_{j=1}^{SC^U} w_{ij}^{U}(t)\ \log_2\left(1 + \frac{P_{ij}^{U}(t)}{w_{ij}^{U}(t)} SNR_{ij}^{U}(t)\right) \right) \\
& - \sum_{i=M-N}^{M} \varepsilon_{i,RT}^{U} \left(\sum_{j=1}^{SC^U} P_{ij}^{U}(t) \right) \\
& + \sum_{i=M-N}^{M} \left(\left(e^{\theta_i^D(t)} + \alpha_{i,RT}^{D} + \mu_{i,RT} - \lambda_{i,RT} \right) \sum_{jj=1}^{SC^D} w_{ijj}^{D}(t)\ \log_2\left(1 + \frac{P_{ijj}^{D}(t)}{w_{ijj}^{D}(t)} SNR_{ijj}^{D}(t)\right) \right) \\
& - \sum_{i=M-N}^{M} \varepsilon_{i,RT}^{D} \left(\sum_{jj=1}^{SC^D} P_{ijj}^{D}(t) \right) \\
& - \sum_{i=M-N}^{M} \left(\Omega_i + \alpha_{i,RT}^{u} R_{min}^{U} + \alpha_{i,RT}^{D} R_{min}^{D} - \varepsilon_{i,RT}^{U} P_{max}^{U} - \varepsilon_{i,RT}^{D} P_{max,BS} - \lambda_{i,RT}\Omega_i - \mu_{i,RT}\Omega_i \right)
\end{aligned} \tag{22}$$

Where $\varepsilon_{i,RT}^{U}$, $\varepsilon_{i,RT}^{D}$, $\alpha_{i,RT}^{D}$, $\alpha_{i,RT}^{u}$, $\lambda_{i,RT}$ and $\mu_{i,RT}$ are Lagrange Multipliers.
Thus The dual problem can be formulated as

$$D(.) = \max\ (\mathcal{L}(.)_{BE} + \mathcal{L}(.)_{RT}) \tag{23}$$

The maximum of $\mathcal{L}(.)_{BE}$ is obtained by ignoring the constants in equation (21) and taking $w_{ij}^{U}(t)$ as a common factor as following;

$$\underset{P^U W^U}{max\mathcal{L}(.)_{BE}} = \sum_{i=1}^{N}\sum_{j=1}^{\mathrm{SC^U}} \mathrm{w_{ij}^U(t)}\left(\left(\log_2\left(1+\frac{\mathrm{P_{ij}^U(t)}}{\mathrm{w_{ij}^U(t)}}\mathrm{SNR_{ij}^U(t)}\right)\left(\mathrm{e}^{\theta_i^U\mathrm{(t)}}\alpha_{\mathrm{i,BE}}^{\mathrm{u}}+\lambda_{\mathrm{i,BE}}-\mu_{\mathrm{i,BE}}\right)\right) - \left(\mathcal{E}_{\mathrm{i,BE}}^{\mathrm{U}}\frac{\mathrm{P_{ij}^U(t)}}{\mathrm{w_{ij}^U(t)}}\right)\right) \tag{24}$$

$$\underset{P^D W^D}{max\mathcal{L}(.)_{BE}} = \underset{P^D W^D}{max\mathcal{L}(.)_{BE}} \sum_{i=1}^{N}\sum_{jj=1}^{\mathrm{SC^D}} \mathrm{w_{ijj}^D(t)}\left(\left(\log_2\left(1+\frac{\mathrm{P_{ijj}^D(t)}}{\mathrm{w_{ijj}^D(t)}}\mathrm{SNR_{ijj}^D(t)}\right)\left(\mathrm{e}^{\theta_i^P\mathrm{(t)}}+\alpha_{\mathrm{i,BE}}^{\mathrm{D}}+\mu_{\mathrm{i,BE}}-\lambda_{\mathrm{i,BE}}\right)\right) - \left(\mathcal{E}_{\mathrm{i,BE}}^{\mathrm{D}}\frac{\mathrm{P_{ijj}^D(t)}}{\mathrm{w_{ijj}^D(t)}}\right)\right) \tag{25}$$

Maximization of equation (24) is done with respect to $\mathrm{w_{ijj}^D(t)}$ and $\frac{\mathrm{P_{ijj}^D(t)}}{\mathrm{w_{ijj}^D(t)}}$ .Thus the derivative of $\left(\log_2\left(1+\frac{\mathrm{P_{ijj}^D(t)}}{\mathrm{w_{ijj}^D(t)}}\mathrm{SNR_{ijj}^D(t)}\right)\left(\mathrm{e}^{\theta_i^P\mathrm{(t)}}+\alpha_{\mathrm{i,BE}}^{\mathrm{D}}+\mu_{\mathrm{i,BE}}-\lambda_{\mathrm{i,BE}}\right)\right)-\left(\mathcal{E}_{\mathrm{i,BE}}^{\mathrm{D}}\frac{\mathrm{P_{ijj}^D(t)}}{\mathrm{w_{ijj}^D(t)}}\right)$ with respect to $\frac{\mathrm{P_{ijj}^D(t)}}{\mathrm{w_{ijj}^D(t)}}$ is obtained and equated to zero, to obtain;

$$\left(\frac{\mathrm{P_{ij}^U(t)}}{\mathrm{w_{ij}^U(t)}}\right)_{max} = \frac{\left(\mathrm{e}^{\theta_i^U\mathrm{(t)}}\alpha_{\mathrm{i,BE}}^{\mathrm{u}}+\lambda_{\mathrm{i,BE}}-\mu_{\mathrm{i,BE}}\right)}{\mathcal{E}_{\mathrm{i,BE}}^{\mathrm{U}}\ln(2)} - \frac{1}{\mathrm{SNR_{ij}^U(t)}} \tag{26}$$

Applying the same manner on equation (25) we obtain;

$$\left(\frac{\mathrm{P_{ijj}^D(t)}}{\mathrm{w_{ijj}^D(t)}}\right)_{max} = \frac{\left(\mathrm{e}^{\theta_i^P\mathrm{(t)}}+\alpha_{\mathrm{i,BE}}^{\mathrm{D}}+\mu_{\mathrm{i,BE}}-\lambda_{\mathrm{i,BE}}\right)}{\mathcal{E}_{\mathrm{i,BE}}^{\mathrm{D}}\ln(2)} - \frac{1}{\mathrm{SNR_{ijj}^D(t)}} \tag{27}$$

Thus, the optimum weights allocated to each subcarrier is;

$$\mathrm{w_{ij}^{*U}(t)} = \underset{\mathrm{w_{ij}^U(t)}}{max}\sum_{i=1}^{N}\sum_{j=1}^{\mathrm{SC^U}} \mathrm{w_{ij}^U(t)}\left(\left(\log_2\left(1+\left(\frac{\mathrm{P_{ij}^U(t)}}{\mathrm{w_{ij}^U(t)}}\right)_{max}\mathrm{SNR_{ij}^U(t)}\right)\left(\mathrm{e}^{\theta_i^U\mathrm{(t)}}\alpha_{\mathrm{i,BE}}^{\mathrm{u}}+\lambda_{\mathrm{i,BE}}-\mu_{\mathrm{i,BE}}\right)\right) - \left(\mathcal{E}_{\mathrm{i,BE}}^{\mathrm{U}}\left(\frac{\mathrm{P_{ij}^U(t)}}{\mathrm{w_{ij}^U(t)}}\right)_{max}\right)\right) \tag{28}$$

Similar expression is obtained for the weight in the downlink

$$\mathrm{w_{ijj}^{*D}(t)} = \underset{\mathrm{w_{ijj}^D(t)}}{max}\sum_{i=1}^{N}\sum_{jj=1}^{\mathrm{SC^D}} \mathrm{w_{ijj}^D(t)}\left(\left(\log_2\left(1+\left(\frac{\mathrm{P_{ijj}^D(t)}}{\mathrm{w_{ijj}^D(t)}}\right)_{max}\mathrm{SNR_{ijj}^D(t)}\right)\left(\mathrm{e}^{\theta_i^P\mathrm{(t)}}+\alpha_{\mathrm{i,BE}}^{\mathrm{D}}+\mu_{\mathrm{i,BE}}-\lambda_{\mathrm{i,BE}}\right)\right) - \left(\mathcal{E}_{\mathrm{i,BE}}^{\mathrm{D}}\left(\frac{\mathrm{P_{ijj}^D(t)}}{\mathrm{w_{ijj}^D(t)}}\right)_{max}\right)\right) \tag{29}$$

Finally the optimum power in both uplink and downlink is obtained by multiplying (26) by (28) and (27) by (29) as following;

$$\mathrm{P_{ij}^{*U}(t)}=\mathrm{w_{ij}^{*U}(t)}\left(\frac{\mathrm{P_{ij}^U(t)}}{\mathrm{w_{ij}^U(t)}}\right)_{max} \tag{30}$$

$$\mathrm{P}_{\mathrm{ijj}}^{*\mathrm{D}}(\mathrm{t})=\mathrm{w}_{\mathrm{ijj}}^{*\mathrm{D}}(\mathrm{t})\left(\frac{\mathrm{P}_{\mathrm{ijj}}^{\mathrm{D}}(\mathrm{t})}{\mathrm{w}_{\mathrm{ijj}}^{\mathrm{D}}(\mathrm{t})}\right)_{max} \tag{31}$$

An iterative sub-gradient approach as in [12] is followed to obtain the multipliers in (21).
The previous formulation is redone taking into consideration real time traffic.

V. SIMULATION RESULTS

A. System Parameters

The simulation model consists of a single cell, and number of users ranging from 2 to 10. The users are randomly located within the range of $1Km$ radius of the cell. We consider an OFDM system with 5MHz in the uplink and downlink divided into $SC^U = SC^D$ =10 subcarriers. The maximum allowable delay in uplink and downlink is set to 50msec while the slot duration is fixed to 10msec. The minimum target rate considered for both directions is chosen to be 1MHz while the gap allowable between the uplink and downlink per user is chosen to be $\Omega = 0.5$MHz. The noise variance considered $\sigma^2 = 1$. The maximum power a user and the BTS can transmit is $\mathrm{P}_{\mathrm{max,i}}^{\mathrm{U}} = 1$W and $\mathrm{P}_{\mathrm{max,BS}} = 30$W respectively.

B. Results and Analysis

Fig.1 shows the rate achieved by each user. Users from 1 to 5 are using best effort traffic while the other 5 users are using real time traffic. First we notice the symmetry between the uplink rate and downlink rate for each user as the difference between the uplink rate and downlink rate for each user is very small. This indicates that the constraint in equation (16) is satisfied for all users. The proposed algorithm maintain the required QoS as all the users satisfy the minimum allowable rate considered. It is noticed that the real time traffic rate is higher than the best effort traffic rate, which is normal to maintain the QoS of the real time class of service.

In Fig.2 the problem was solved for different number of users and at each time slot the uplink rate and downlink rate of each user are obtained. The figure shows the average gap between the uplink rate and downlink rate for each scenario. It is noticed that the gap decreases with increasing the number of users. We notice that as the number of users increases the rate of each user decreases consequently, the uplink and downlink gap also decrease. It can be concluded from Fig.2 that, even though there is a big difference in the transmitted power in the uplink and the downlink, the difference in rate is very small. Thus, we deduce that the rate in both directions becomes independent on the link budget equation, and it depends on the Lagrange multipliers values.

Fig.3 shows the simulation results for three different systems ; System I has two class of service best effort and real time, System II has best effort only, System III has real time only. For system I we notice that the average rate among the different time slots of user 2 is higher than user 1. Thus, we conclude that there was a rate distribution fairness, depending on the class of service of each user.

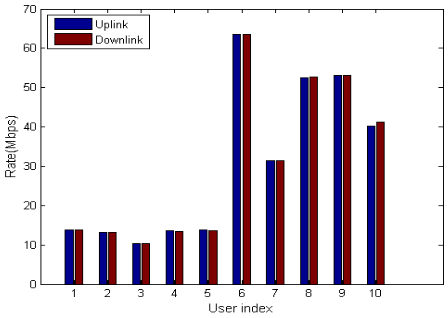

Figure 1. Users rates using the proposed algorithm

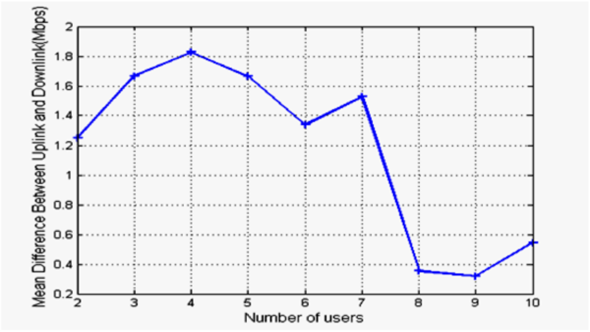

Figure 2. Downlink and Uplink gap for different number of users

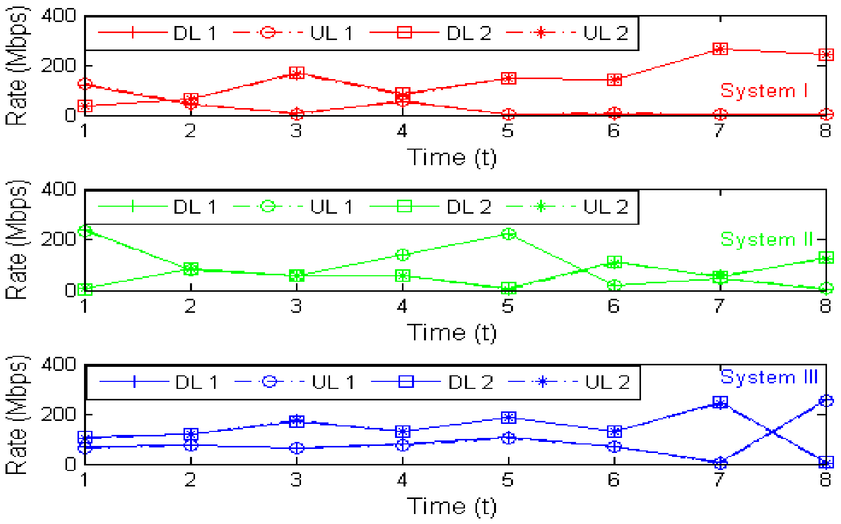

Figure 3. Achieved users rates for different systems

IV. CONCLUSION

In this paper we proposed a new joint uplink and downlink resource allocation algorithm. The algorithm has the advantage of optimizing uplink and downlink jointly, by minimizing the achievable rate difference between them. compared to the results presented in the literature, it was observed from the simulation results that a higher rate was obtained while still maintaining a minimum gap between both the uplink and downlink rates. In addition, the results highlights the fairness occurring in the system when two classes of services were considered. Our future work is summarized in considering more practical channel models as well as multi-cell network.

REFERENCES

[1] Wong, C., R. Cheng, K. Lataief & R. Murch (1999). Multiuser OFDM with adaptive sub-carrier, bit, and power allocation. *IEEE JSAC* 17, 1747-1758.

[2] Song, G. & Y. Li (2003) . Adaptive subcarrier and power allocation in OFDM based on maximizing utility. IEEE VTC 2, 905–909.

[3] Ho, W. & Y. Liang (2009). Optimal Resource Allocation for Multiuser MO-OFDM Systems With User Rate Constraints. *Vehicular Technology, IEEE Transactions* 58, 1190-1203.

[4] Sadr, S., A. Anpalagan & K. Raahemifar (2009). Radio Resource Allocation Algorithms for the Downlink of Multiuser OFDM Communication Systems. *Communications Surveys & Tutorials, IEEE* 11, 92-106.

[5] Kim, K., H. Kim, Y. Han, and S. Kim (2004). Iterative and greedy resource allocation in an uplink OFDMA system. *IEEE PIMRC* 4, 2377-2381.

[6] Kim, S., & J. Lee (2009). Joint Resource Allocation for Uplink and Downlink in Wireless Networks: A Case Study with User-Level Utility Functions. *IEEE VTC*, 1-5.

[7] El-Hajj, A. & Z. Dawy (2011). On Optimized Joint Uplink/Downlink Resource Allocation in OFDMA Networks. IEEE ISCC, 248-253.

[8] Zorba, N., E. Yaacoub & A. El-Hajj, Z. Dawy (2013). A Modified Joint Uplink-Downlink Opportunistic Scheduling for Quality of Service Guarantees. *Communication Workshops (ICC) IEEE*, 1000-1004

[9] El-Mayet, R., H. El-Badawy & S. El-Ramly (2012). Modeling and Analysis for Effective Capacity of a Cross-Layer Optimized Wireless Networks. *World Academy of Science, Engineering and Technology* 6, 221-227.

[10] Andrea Goldsmith (2005). Wireless Communications. Cambridge: Cambridge University Press.

[11] Katoozian, M., K. Navaie & H. Yanikomeroglu (2008). Optimal Utility-Based Resource Allocation for OFDM Networks with Multiple Types of Traffic. *IEEE VTC*, 2223-2227.

[12] Fathi, M. & E. Karipidis (2012). Distributed Resource Optimization in Multi-cell OFDMA Networks. *WCNC IEEE*, 1316-1320.