



## Guaranteed QoS in Real-Time Traffic for dynamic Subcarrier Allocation over Multiuser OFDM Systems

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**Abstract-** A dynamic resource allocation algorithm to satisfy the packet delay requirements for real-time services, while maximizing the system capacity in multiuser orthogonal frequency division multiplexing (OFDM) systems is introduced. Our proposed cross-layer algorithm, called Dynamic Subcarrier Allocation algorithm for Real-time Traffic (DSA-RT), consists of two interactive components. In the medium access control (MAC) layer, the users' expected transmission rates in terms of the number of subcarriers per symbol and their corresponding transmission priorities are evaluated. With the above MAC-layer information and the detected subcarriers' channel gains, in the physical (PHY) layer, a modified Kuhn-Munkres algorithm is developed to minimize the system power for a certain subcarrier allocation, then a PHY-layer resource allocation scheme is proposed to optimally allocate the subcarriers under the system signal-to-noise ratio (SNR) and power constraints. In a system where the number of mobile users changes dynamically, our developed MAC-layer access control and removal schemes can guarantee the quality of service (QoS) of the existing users in the system and fully utilize the bandwidth resource. The numerical results show that DSA-RT significantly improves the system performance in terms of the bandwidth efficiency and delay performance for real-time services.

**Keyword-** OFDM, DSA-RT, MAC, PHY, QoS.

### 1. INTRODUCTION

Demands for real-time multimedia applications are increasing rapidly for broadband wireless networks. Orthogonal frequency division multiplexing (OFDM) is considered a promising technique in such systems. In this project, we consider multiuser systems [1] where multiple users are allowed to transmit simultaneously on different subcarriers per OFDM symbol. Mobile users on certain OFDM subchannels may experience deep frequency-selective fading in a multipath propagation environment. Since each user may have a different subchannel impulse response, a poor subchannel for one user may be a good subchannel for another user. Clearly, if a user who suffers from poor subchannel gain can be reassigned to a better subchannel; the total throughput can be increased. This is also known as multiuser diversity. Since the subcarrier gains vary from user to user, to achieve higher system capacity and spectral efficiency, it is better to allocate subcarriers and the corresponding power dynamically according to the instantaneous channel states of all users.

**our proposed algorithm offers the following advantages:**

Based on queuing theory, real-time users' delay requirements can be evaluated in terms of the number of subcarriers required, leading to a more flexible scheduling algorithm which can effectively guarantee the QoS for real-time services in multiuser OFDM systems. With the number of the expected subcarriers and transmission priority information from the MAC layer, the proposed PHY-layer resource allocation scheme aims to maximize the bandwidth usage under the current channel state, system SNR, and power constraints. When the number of mobile users is dynamically changed, the access control and removal schemes can dynamically adjust system flows and provide delay-related guarantee for the active users in the system. The rest of this project is organized as follows. The system model is introduced in Section 2. The detailed description of DSA-RT is presented in Section 3. The simulation results are given in Section 4. Section 5 draws the conclusions.

### 2. SYSTEM MODEL

Figure 1 shows our downlink OFDM system model at a base station (BS). As in previous work [2–5], channel state information (CSI) is assumed to be available at BSs. Assume that the frequency bandwidth is divided into  $N$  subcarriers, and there are  $K$  active users, where  $K$  is changed dynamically and follows a Poisson distribution. BSs are in charge of subcarrier scheduling and resource allocation. We assume a fixed modulation for all subcarriers. The total transmission power is constrained at  $P$  and will be optimally allocated to each subcarrier. Our objective is to maximize the total system throughput, subject to the constraints on the total transmission power, user SNR requirements, and delay constraints. The optimization problem can be expressed as follows:

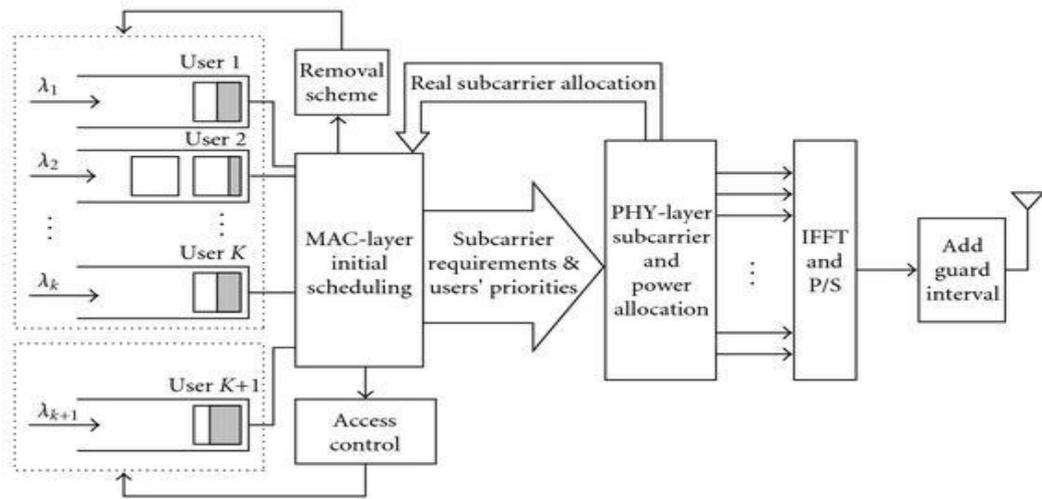


Figure 1. System model

$$\max \sum_{k=1}^K \sum_{n=1}^M bv(k,n), \quad (3)$$

Subject to

- C1:  $\sum_{k=1}^K \sum_{n=1}^M v(k,n) \leq N,$
  - C2:  $\sum_{k=1}^K \sum_{n=1}^M \frac{SNR_k}{h_{k,n}^2} v(k,n) \leq P,$
  - C3:  $v(k_1,n)v(k_2,n) = 0, \quad \forall k_1 \neq k_2 \in [1, K],$
  - C4:  $E[T_k] \leq \tau_k, \quad \forall k \in [1, K],$
- (4)

where  $SNR_k$  represents the SNR requirement of user  $k$ . C1 states that the total subcarriers allocated to all users are less than or equal to  $N$ ; C2 shows that the total transmission power should be less than or equal to the system power limit, while satisfying all users' SNR requirements; C3 means that no more than one user transmits in the same subcarrier; C4 is the average delay requirement of each user. The solution of the above optimization problem (3) is not explicit due to the fact that C4 is not directly related to  $v(k,n)$ . Thus in the following section, we will establish the relationship between them and give the suboptimal subcarrier allocation solution  $v(k,n)$  for each symbol with lower computational complexity. For a bipartite graph  $G(V_1, V_2, E)$ , if the cardinalities of  $V_1$  and  $V_2$ , denoted as  $n_1$  and  $n_2$ , are equal, then this bipartite graph is symmetric. For single objective optimization, it has been proved that the Kuhn-Munkres algorithm can always find the maximum weight matching for a bipartite graph with  $O(n^3)$  computational complexity.

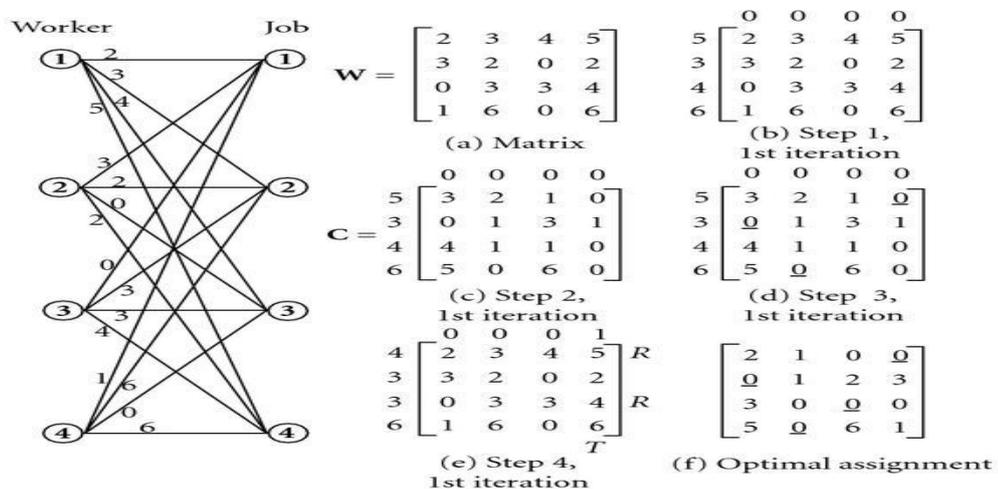


Figure 2. Weighted bipartite matching.

The Kuhn-Munkres algorithm is based on the procedure of the Hungarian algorithm [9]. Matrix  $W = [w_{ij}]$  has elements  $w_{ij}$ , which represent the earnings of assigning worker  $i$  to job  $j$  as shown in Figure 2 (a).

For a bipartite graph  $G(V_1, V_2, E)$ , if the cardinalities of  $V_1$  and  $V_2$ , denoted as  $n_1$  and  $n_2$ , are not equal, then this bipartite graph is asymmetric. In our modified Kuhn-Munkres algorithm, we enhance an asymmetric graph to a symmetric one, and then solve the optimization problem as in the symmetric case. Firstly, suppose that the resource on both  $V_1$  and  $V_2$  cannot be reused,

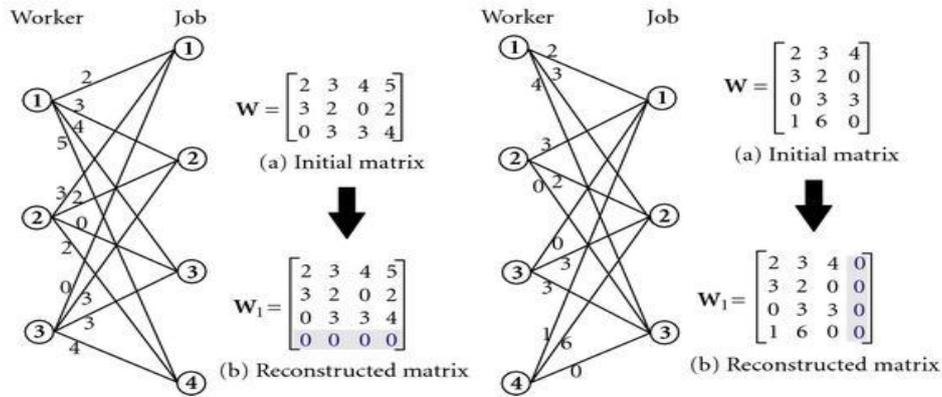


Figure 3. Asymmetric bipartite matching without resource reallocation.

we append  $|n_1 - n_2|$  all-zero rows or columns to the weight matrix to construct a square matrix, and then transform the problem to a symmetric bipartite matching, as shown in Figure 3.

Secondly, for some special cases in which the redundant resource may be reused, the modified Kuhn-Munkres algorithm reproduces the corresponding columns or rows till the matrix is transformed to a square matrix. If necessary, all-zero columns or rows will be added. If  $n_1 > n_2$  and the elements in  $V_2$  is reusable, Figure 4 shows the case where the remaining elements in  $V_1$  may reuse the elements in  $V_2$  with the same probability. If  $n_1 < n_2$ , given the number of required elements in  $V_2$  by the elements in  $V_1$ , namely,  $q_1, q_2, \dots, q_{n_1}$ , then the square matrix may be constructed by reproducing the rows in demand, as shown in Figure 5.

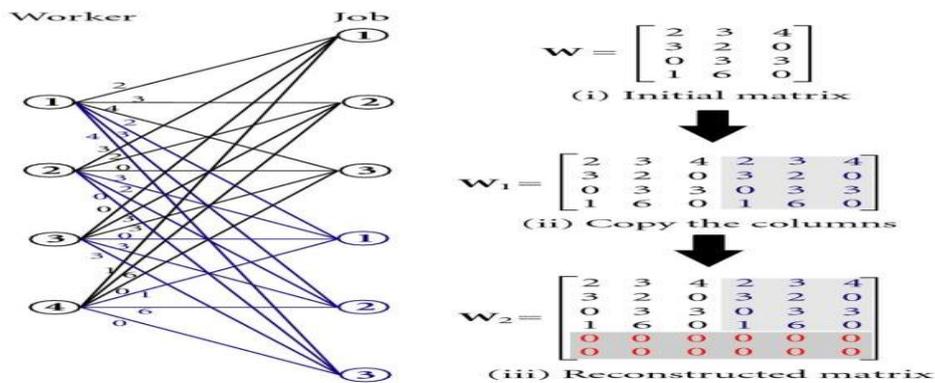


Figure 4. Asymmetric bipartite matching with resource reallocation ( $n_1 > n_2$ ).

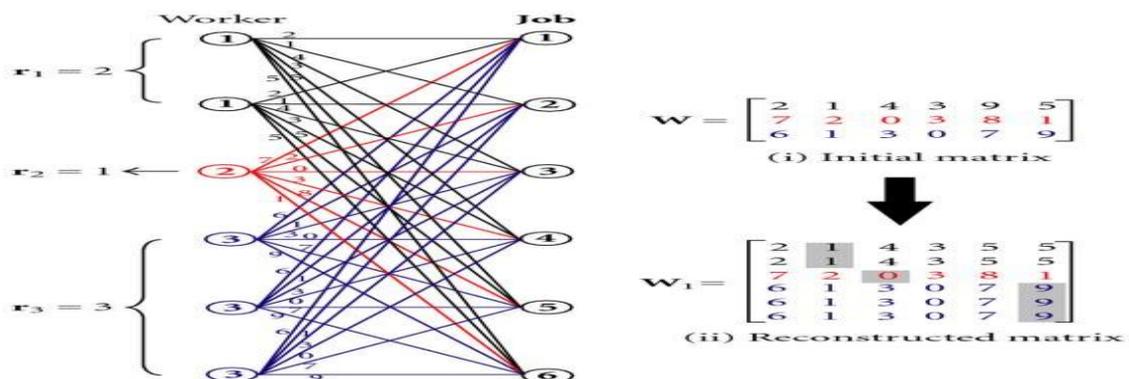


Figure 5. Asymmetric bipartite matching with resource reallocation ( $n_1 < n_2$ ).

$$p_k(t) = \sum_{i=1}^{i=q_k} \frac{\text{SNR}_k}{h_{k,n}^2}, \quad (13)$$

Therefore, for user  $k$ , the required transmission power in time slot  $t$  is given by

where  $h_{k,n}$  is the detected subchannel gain of user  $k$  on subchannel  $i$ . Then the total system required power can be

$$P(t) = \sum_{k=1}^K p_k(t) = \sum_{k=1}^K \sum_{i=1}^{i=q_k} \frac{\text{SNR}_k}{h_{k,n}^2}, \quad (14)$$

expressed as

With the above problem formulation, the minimization of the system power  $P(t)$  as required in the second step of the PHY-layer allocation scheme may be converted to a bipartite matching problem. The edge weight for user  $k$  on subcarrier  $n$  is  $\text{SNR}_k / h_{k,n}^2$ . Therefore, similar to the case illustrated in Figure 5, the modified Kuhn-Munkres algorithm may be applied to give an optimal solution to the minimization of the system power.

### 3. ACCESS CONTROL AND REMOVAL SCHEME

In real networks, the number of active users changes dynamically. Without access control, the bandwidth may be inadequate. In addition, particularly for real-time traffic, without a removal scheme, not only may the QoS of the users newly granted access not be guaranteed but also the previously granted access users will suffer from QoS degradation. Therefore, the MAC-layer access control and removal schemes are introduced in our DSA-RT algorithm.

As analyzed in the previous subsection, a new user's QoS requirements should be considered when  $P > P_{\min}$  and

$$N' = \sum_{k=1}^K \sum_{n=1}^N v(k,n) \leq N, \quad (15)$$

### 4. Implementation Of DSA-RT

Thanks to the cooperation of the above schemes, for each OFDM symbol, our algorithm DSA-RT can give the suboptimal solution  $v(k,n)$  of the optimization problem addressed in Section 2. The computational delay is not expected to be a problem. The number of operations required by the algorithm is approximately  $O(N^3)$ , which translates to a computational delay of a small fraction of a symbol time with the support of current chips. In addition, if we want to lower the computational delay, multiple symbols can be combined as one scheduling unit, but this will affect the scheduling efficiency. It is a tradeoff. The flow chart of the implementation of our algorithm is shown in Figure 6.

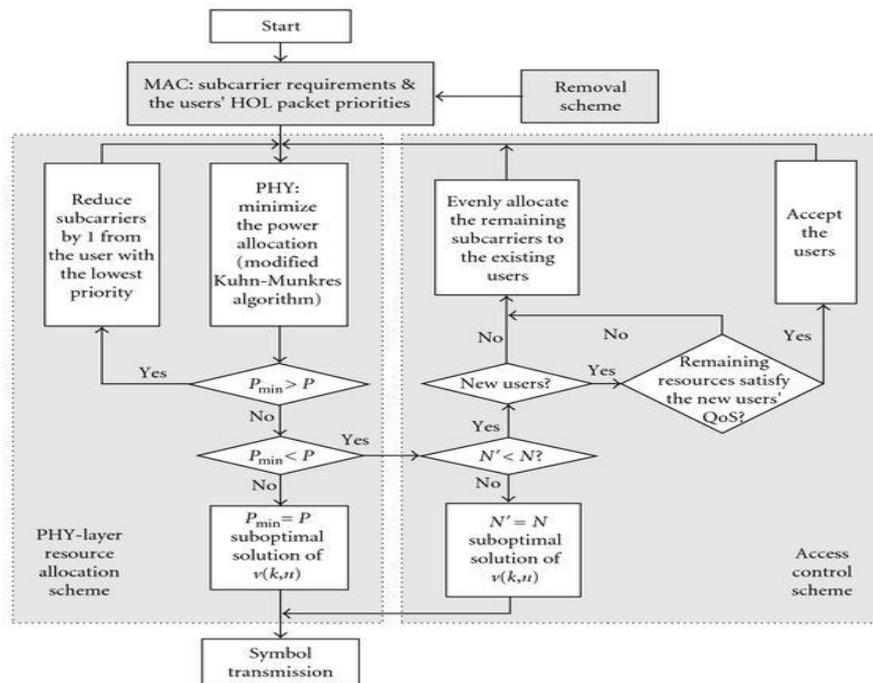


Figure 6. Flow chart of DSA-RT.

### 5. Simulation Results

In this section, the performance of the proposed DSA-RT scheduling algorithm is investigated and compared with CSD-RR, FEDD, and M-LWDF [2-4]. We consider QPSK modulation in multiuser OFDM downlink systems. However, other modulations are supported with different SNR constraints. The IFFT size is 128, and the OFDM symbol duration is equal to 200 microseconds [14]. We consider the quasistatic flat fading channel with multipath [15]. Assume that the users arrive as a Poisson process with parameter  $\lambda$ , and their active times in the system follow the exponential distribution with mean 10 seconds. In this section, we assume that all users have the same type of real-time traffic. During each user's active time, the packet arrivals follow the Poisson distribution. The packets have a fixed length of 1000 bytes, and the mean traffic rate is 1 Mbps. The delay bound is set to be 50 milliseconds. In simulations, we consider one type of real-

time traffic, so we fixed the packet length. However, if multiple types of real-time traffics are supported, a variable length is acceptable in our algorithm. In our simulations, we vary the user arrival rates  $\lambda$  from 0.01 to 0.1 and compare the delay and dropping rate performance of some packet scheduling algorithms and our proposed DSA-RT algorithm. All simulations are in Mat lab 7.3. The simulation time of each experiment is 100 seconds and we repeat it 100 times. The average delay is the mean of the delay of all packets not dropped. For each successfully delivered packet, the delay is calculated as the difference between the departure and arrival times. In DSA-RT, packets which have been dropped will not re-enter the system. The delay comparisons of DAS-RT and three other packet scheduling algorithms. It is obvious that our algorithm distinctly improves the delay performance, particularly when the traffic density is high. Accordingly, the dropping rates of our algorithm at any user arrival rate are also much lower than the other three algorithms. DSA-RT is developed to schedule at the subcarrier level and tries to provide delay guarantees for the real-time traffics. Therefore, it has the best delay and dropping rate performance. Based on the consideration of channel state, CSD-RR has better performance than M-LWDF and FEDD. By considering the system capacity and queuing, the throughput performance of M-LWDF is optimal, but the delay performance still needs to be improved. FEDD gives the packet with the earliest deadline of the highest transmission priority. However, with the bandwidth and channel state constraints, the transmission still has a high probability to fail within its deadline. Therefore, it has the poorest performance.

## 6. CONCLUSIONS

In this project, DSA-RT aims to satisfy the packet delay requirements of real-time traffics in multiuser OFDM system, while maximizing the system bandwidth efficiency. This algorithm consists of two cooperative components. At the MAC layer, based on queuing theory and the modified LWDF algorithm, active users expected transmission rates in terms of the number of subcarriers per symbol and their corresponding transmission priorities are deduced. With different subcarrier states, based on our modified Kuhn-Munkres algorithm, a PHY-layer resource allocation scheme is developed to satisfy the users' requirements under the system SNR and power constraints. When considering a system where the number of active users changes dynamically, the access control and removal scheme can fully utilize the bandwidth resource and guarantee the QoS of the existing users in the system. Finally, compared with other widely used scheduling algorithms, simulation results show that our proposed algorithm significantly improves the system performance for real-time users in multiuser OFDM systems.

## References

- [1] 1)E Lawrey, Multiuser OFDM. Proceedings of the International Symposium on Signal Processing and Its Applications (ISSPA '99), August 1999, Brisbane, Australia, 761–764
- [2] 2)P Bhagwat, A Krishna, S Tripathi, Enhancing throughput over wireless LAN's using channel state dependent packet scheduling. Proceedings of 17th Annual Joint Conference of the IEEE Computer and Communications Societe (INFOCOM '98), March 1998, San Francisco, Calif, USA, 1103–1111
- [3] 3)S Shakkottai, R Srikant, Scheduling real-time traffic with deadlines over a wireless channel. *Wireless Networks* 8(1), 13–26 (2002).
- [4] 4)M Andrews, K Kumaran, K Ramanan, A Stolyar, P Whiting, R Vijayakumar, Providing quality of service over a shared wireless link. *IEEE Communications Magazine* 39(2), 150–153 (2001).
- [5] 5)YJ Zhang, SC Liew, Link-adaptive largest-weighted-throughput packet scheduling for real-time traffics in wireless OFDM networks. Proceedings of IEEE Global Telecommunications Conference (GLOBECOM '05), November–December 2005, St. Louis, Mo, USA 5, 2490–2494
- [6] 6)YYW Cheong, CY Tsui, RS Cheng, KB Letaief, A realtime sub-carrier allocation scheme for multiple access downlink OFDM transmission. Proceedings of the 49th IEEE Vehicular Technology Conference (VTC '99), September 1999, Amsterdam, The Netherlands 2, 1124–1128
- [7] 7)Z Diao, D Shen, VOK Li, CPLD-PGPS scheduler in wireless OFDM systems. *IEEE Transactions on Wireless Communications* 5(10), 2923–2931 (2006)
- [8] 8)J Munkres, Algorithms for the assignment and transportation problems. *Journal of the Society for Industrial and Applied Mathematics* 5(1), 32–38 (1957).
- [9] 9)HW Kuhn, The Hungarian method for the assignment problem. *Naval Research Logistic Quarterly* 2, 83–97 (1955).
- [10] 10)J Zhu, B Bing, Y Li, J Xu, An adaptive subchannel allocation algorithm for OFDM-based wireless home networks. Proceedings of the 1st IEEE Consumer Communications and Networking Conference, (CCNC '04), January 2004, Las Vegas, Nev, USA, 352–356
- [11] 11)D Bertsekas, R Gallager, *Data Networks*, 2nd edn. (Prentice-Hall, Englewood Cliffs, NJ, USA, 1992)
- [12] 12)DB West, *Introduction to Graph Theory* (Prentice-Hall, Englewood Cliffs, NJ, USA, 2001)
- [13] 13)E Kwon, S-G Kim, J Lee, Overload control with removal algorithm for real-time flows in wireless networks. Proceedings of the IEEE 63rd Vehicular Technology Conference (VTC '06), May 2006, Melbourne, Australia 3, 1127–1131
- [14] 14)J Cai, X Shen, JW Mark, Downlink resource management for packet transmission in OFDM wireless communication systems. Proceedings of IEEE Global Telecommunications Conference (GLOBECOM '03), December 2003, San Francisco, Calif, USA 6, 2999–3003
- 15)C Xiao, YR Zheng, NC Beaulieu, Second-order statistical properties of the WSS Jakes' fading channel simulator. *IEEE Transactions on Communications* 50(6), 888–891 (2002).