Cross-layer Resource Allocation Algorithm for Downlink OFDM System

Qianjing Guo*, Sung Sue Hwang* ***Regular Members***, Suk Chan Kim°* ***Lifelong Member***

ABSTRACT

In this paper, an adaptive cross-layer resource allocation algorithm for the downlink multi-user OFDM system is proposed. The proposed algorithm does not only concern the wireless characteristics of physical (PHY) layer, but also pays attention to the user's quality of service (QoS) requirement, fairness, and packet queue state information of medium access control (MAC) layer. The algorithm is composed of two parts: one is to decide the priority of the user, and the other is to assign the radio resource according to its priority. Simulation results show that the proposed algorithm has both steady QoS and low computation complexity, even though the mobile users have different receiving signal to noise ratio (SNR).

Key Words: : Cross-layer, Resource Allocation, OFDM, QoS

Ⅰ. Introduction

Orthogonal frequency division multiple access (OFDMA) has emerged as one of the prime multiple-access schemes for wireless broadband networks. OFDM has been selected as the modulation mode for the European digital audio broadcasting (DAB)[1] system and terrestrial digital video broadcasting (DVB-T) system[2] and it is also the standards for several wireless network standards including IEEE 802.16m[3-4].

The cross-layer design of wireless networks has aroused a great interest in the recent years, and there are many particular design approaches using cross-layer emerged in test-beds or in some recent wireless standards. Normally, cross-layer design consists of the specification of the network operation policy that arises from the joint optimization of parameters and processes across the layers in the communication stack, from the PHY layer up to the application layer[5]. In this paper, we discuss the radio resource allocation algorithm through the approaching of cross-layer for OFDM system.

As we know, OFDM system divides the radio resource into both frequency domain and time domain. The entire channel is divided into many orthogonal narrowband sub-carriers to deal with frequency-selective fading and support a high data rate. In order to utilize the time-diversity, the time domain is also divided into a lot of time slots. There is plenty of room to exploit the high degree of flexibility of radio resource management with the two-dimensional radio resource allocation of OFDM system.

Recently, some studies have been reported for the radio resource control and allocation schemes for OFDM systems. A joint subcarrier, power and bit allocation algorithm is proposed using Lagranian Method to minimize the total transmit power in [6]. The further improved allocation schemes are proposed in [7-9]. Moreover, there are also some other resource allocation schemes using cross-layer method[10-11].

In [10], a practical cross-layer resource management is described, which consists of scheduling and resource allocation for the multimedia OFDMA

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system. To provide the appropriate QoS, the scheduler in MAC layer pre-allocate the sub-channel to the users according to the priority, and at PHY layer, resources are allocated again to satisfy the rate requirements. The calculation complexity is considerably high due to the twice resource allocations. Since the scheduling algorithm always assigns the sub-channel to the user with good channel state, when the RT traffic and NRT traffic are in the same priority, the performance of this algorithm will decrease rapidly with the SNR decreasing. In [11], the introduced algorithm needs reallocating subcarriers, bits, and power after initial allocation. However, both of them are not efficient and have high system computation burden.

In this paper, we propose an adaptive cross-layer resource algorithm for downlink multi-user OFDM system. The proposed algorithm does not only concern the wireless characteristics of PHY layer, but also pays attention to the user's QoS requirements, fairness, and packet queue state information of MAC layer. The algorithm consists of two parts: one is to decide the priority of the user, and the other is to assign the radio resource according to its priority. The simulation result shows that the proposed algorithm has lower calculation complexity and more steady performance even though SNR decreased than the above mentioned algorithms.

The remainder of the paper is organized as follows. In section II, system model and problem formulation are described. Section III introduces the cross-layer resource allocation algorithm. In section IV, system performance is analyzed by studying simulation results. The paper is then concluded in Section V.

Ⅱ. System model and problem formulation

This paper considers a typical OFDMA/TDM system where the radio resource is partitioned in both frequency and time domains. For the convenience to be compared with [10], the OFDM system consists only one base station and K mobile stations or users like [10] and this paper focuses only on downlink too.

Figure 1 depicts the OFDMA/TDM system, where the transmission bandwidth is equally divided into N sub-channels, each containing of M subcarriers. Each of the M frequency subcarriers operates as an independent communication channel which means that there are MN subcarriers[11]. If every subcarrier is controlled separately, the control overhead will be considerable high. In order to reduce the control overhead, the M subcarriers can be used as an allocation unit. The time resource is divided into S time slots. In this paper, we assume that the length of the OFDM frame is S. The smallest resource unit through which data is transported is termed as frequency-time-unit. Depending on the application, one or a collection of frequency-time-units can be allocated to a user at a time and each frequency-time-unit can only be assigned to one user within an OFDM frame.

This paper assumes that the gain of each sub-channel is contained as a constant during an OFDM frame, and the base station can estimate the channel state information (CSI) at the beginning of a frame. We also assume that the power on each frequency-time-unit is fixed and the transmission rate is variable by using adaptive coding/modulation. It means that the transmission power is equally distributed to all frequency-time-unit. By referring to [10], the problem formulation for cross-layer resource allocation algorithm can be written as follows:

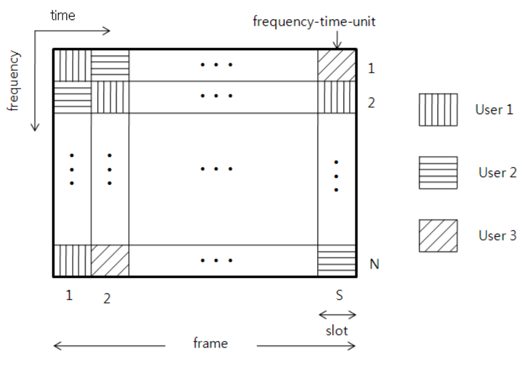

Fig. 1. OFDMA system in frequency-time axis

$$\text{MAX} \sum_{n=1}^{n}\sum_{s=1}^{s}\sum_{k=1}^{k} x_{k,n,s} b_{k,n} \quad (1)$$

$$\text{Subject to} \quad \sum_{s=1}^{s}\sum_{n=1}^{n} x_{k,n,s} b_{k,n} \geq r_{k,} \forall k \quad (2)$$

$$x_{k,n,s} \in 0,1 \sum_{k=1}^{k} x_{k,n,s \leq 1,\, \forall n,s} \quad (3)$$

where $1 \leq k \leq K$, $1 \leq n \leq N$, $1 \leq s \leq S$, represent user index, sub-channel index and slot index of OFDM frame respectively. $x_{k,n,s}=1$ indicates that frequency-time-unit (n, s) is assigned to user k and 0 otherwise.

Define $b_{k,n}$ as the transmission rate for user k on channel per OFDM symbol and r_k as the rate requirement of user k.

$$b_{k,n} = [\log_2(1+\frac{|G_{k,n}|^2}{N_0\Gamma} \bullet \frac{P_{total}}{nm})] \bullet M \quad (4)$$

Where M is the number of subcarriers of each sub-channel and $G_{k,n}$ is the channel gain of user k in channel n. P_{total} is the total transmission power which is equally distributed on all the sub-channels. $\Gamma = -ln(5BER)/1.5$ when MQAM modulation is employed.

If the values are given, this problem is able to be solved as a linear programming. But the calculation complexity order is $O(n^4)$. In order to decrease the calculation complexity, we propose a new suboptimal algorithm in this paper.

Ⅲ. Cross-layer resource allocation algorithm

According to IEEE 802.16, data packets of all users can be classified into four types: the Unsolicited Grant Service, Real Time Polling Service, Non-real Time Polling Service and Best Effort Transmission Service[12]. Usually, we also divide the data packets into two types, one is real-time (RT) traffic data packet, which has a strict delay requirement, with higher priority, and the other one is non-real-time (NRT) traffic data packet with a less delay requirement according to the channel conditions of each user. However, both the RT traffic data packet and NRT traffic data packet cannot bear long delay and the high packet drop rate. Thus, the objective of the proposed resource algorithm is to increase the data rate of the NRT traffic data packet and to decrease the data packet drop rate of NRT traffic data packet at the basis of guaranteeing the QoS of the RT traffic data packet.

In [10], a packet scheduling algorithm in MAC layer and a dynamic resource allocation algorithm in PHY layer are introduced. Most of the packet schedulers give the RT traffic higher priority unconditionally than NRT traffic, since the RT traffic is very delay-sensitive[13-14]. However, the NRT traffic with an excessive delay can also cause user's trouble, such as HTTP or FTP applications.

In order to improve the QoS of NRT services, [10] defines an emergency factor for an RT packet, and gives higher priority to the RT traffic packets which are only under the emergency condition. The RT packet is said to be under the emergency condition, if the emergency factor of this RT packet is higher than a pre-defined value. The emergency factor is defined as the follows:

$$\mu = \frac{waiting\, time\, of\, a\, packet\, in\, MAC\, quene}{delay\, constraint\, of\, a\, packet} \quad (5)$$

An RT packet has the low priority as the same with the NRT packet initially. If the emergency factor of the RT packet is higher than the designated value, its priority will be changed to be a higher value. And the NRT packet always has low priority. Then the scheduler allocates the sub-channels to the user according to its priority in MAC layer. In [10], if two users have the same priority, the sub-channel is allocated to the user with better channel quality. There are two steps for the resource allocation. At first, assign the sub-channels to the users according to the priority and the rate requirement in MAC layer, which is called pre-allocation. And then, allocate the radio resource to the users in order to maximize the system throughput in PHY layer.

In the first step, if both the RT packet and NRT packet have low priority, the scheduler will assign the sub-channels only according to the CSI. For an instance, a user with good CSI will be allocated one or more sub-channels, but its waiting queuing may be empty or only has very small packet data to be transferred. On the contrary, there may be much packet data waiting to be transferred of the user with bad CSI. But the user with bad CSI cannot be allocated enough radio resource to match the rate requirement in MAC layer. The scheduler allocates the sub-channels according to the QoS, CSI and rate requirement, and in the second step, the resource algorithm will calculate the QoS and CSI again. Of course, the calculation overhead and the calculation complexity are very high.

In order to avoid the re-allocation of the radio resource, this paper proposes a sub-optimal radio resource allocation algorithm to allocate the resource directly in PHY layer according to the users' priority decided by the information from PHY layer and MAC layer. Figure 2 shows the procedure of the cross-layer resource allocation algorithm between MAC layer and PHY layer.

In [10], when the RT packet and NRT packet which are both have the low priority, the user with the best CSI will be allocated the sub-channels first. The users with bad CSI probably will not be able to get the enough radio resource so that they have to wait for a long time. However, the long waiting time cannot be accepted for the RT packets. In order to avoid this shortcoming, the proposed algorithm takes both the CSI and the quantity of data packets waiting to be transferred into account when deciding the priority of

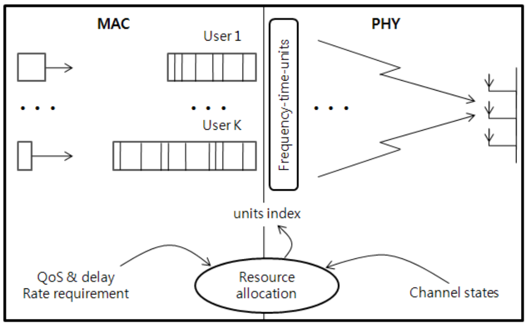

Fig. 2. Procedure of cross-layer resource allocation algorithm

the packets. Here, we define the CSI as the signal-to-noise ratio $SNR_K(t)$, and the quantity of the data packets of user k as $Q_K(t)$.. The priority of the user k is $P_K(t)=\propto SNR_K(t)Q_K(t)$. Where $\propto > 0$ is constant.

In this paper, the proposed cross-layer resource allocation algorithm consists of two steps.

• Step 1. Decide the priority of the user.

1. Give higher priority to the RT packet under the emergency condition.
2. If the emergency factor of the RT packet is lower than the designated value, the priority of both RT packet and NRT packet is decided by $P_K(t)$.

• Step 2. Allocate the frequency-time-units to the users.

1. Assign the radio resource to all the users under the emergency condition. The maximum number of the frequency-time-units to be assigned to one user at a time is $2S$. If the QoS of this user is not matched, the radio resource will be allocated once again according to its priority after all the users under the emergency condition have been assigned the radio resource. Allocator must always keep the rule that the maximum number of the frequency-time-units to be assigned to one user at a time is $2S$. The allocation will be repeated until the QoS of all the users under the emergency condition is satisfied or there are no remaining frequency-time-units to be allocated.
2. If there are frequency-time-units without allocated, assign the radio resource to the users according to the priority decided by $P_k(t)$. The remained processing will be the same with step 1.

Ⅳ. Simulation and Results

For the convenience, we call the algorithm proposed in [10] as Jeong's algorithm. In order to compare with Jeong's algorithm, we have studied the performance of the proposed algorithm by simulating a downlink of a single-cell OFDM system with one base station and multiple users. In order to comare with Jeong's algorithm, this system has 10 slots in each frame and 64 traffic channels in frequency domain, which consist of 10 sub-carriers, and the OFDM frame length is 1 msec. The objective BER is set to 10^{-6}, and we consider path loss, shadowing, and frequency selective Rayleigh fading as channel models. The parameters are the same with the bad city area model in COST207. We also assume that half of the users are dedicated to the RT traffic and the other half of users are dedicated to the NRT traffic. Average data rate of each traffic flow is 400 kbps. The packet sizes of RT and NRT traffic are set to 200 and 1600 bytes, respectively. The packets arrive at the BS at a fixed time point. Through comparing the packet drop rate of RT traffic with different SNR and the total throughput of OFDM system by using of the proposed algorithm and Jeong's algorithm, we can estimate the performance of the two algorithms.

Figure 3 shows the packet drop rate of RT traffic with different SNR. Here, we assume that there are 1/3 users working with SNR of 5dB, 1/3 users working with 10dB, and the other 1/3 users working with 15dB. From simulation results, we can find that Jeong's algorithm can get almost zero packet drop rate of RT traffic with high SNR, such as 15dB or 10dB, but when the SNR is low and the number of users is larger than 36, the packet drop rate of RT traffic increases rapidly. However, by using the proposed algorithm, the packet drop rate of RT traffic is always smaller than 0.2 and it changes slowly with the number of users increasing.

Figure 4 shows that the two algorithms' throughput of RT traffic and NRT traffic according to the number of users. The throughput of RT traffic of the two algorithms increases almost linearly with the number of users increasing, but the throughput of NRT traffic trends to steady when the number of users is larger than 32. Anyway, the total throughput of OFDM system through the proposed algorithm is almost same with that through Joeng's algorithm.

Figure 5 shows the calculation complexity of the two algorithms according to the number of the users. Here the calculation time only dedicates the time it takes by the computer simulation. Even though it is

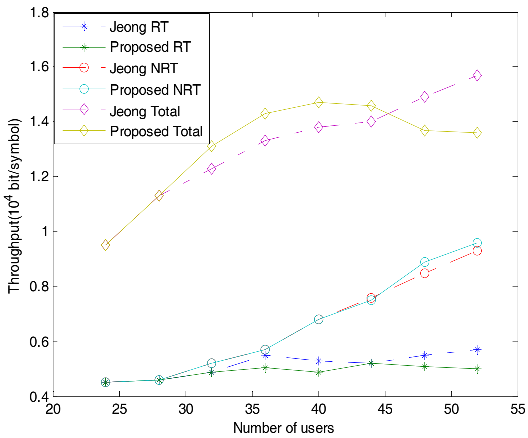

Fig. 4. Throughput according to the number of users

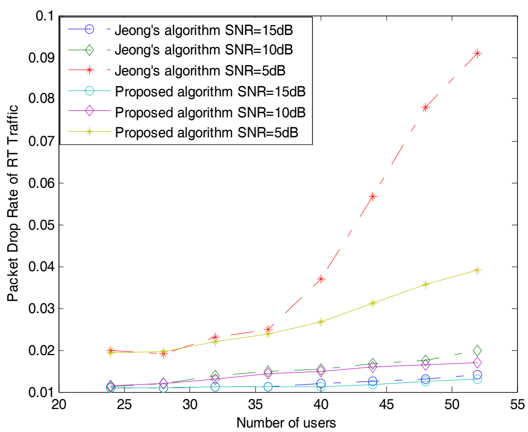

Fig. 3. Packet drop rate of RT traffic according to the number of users

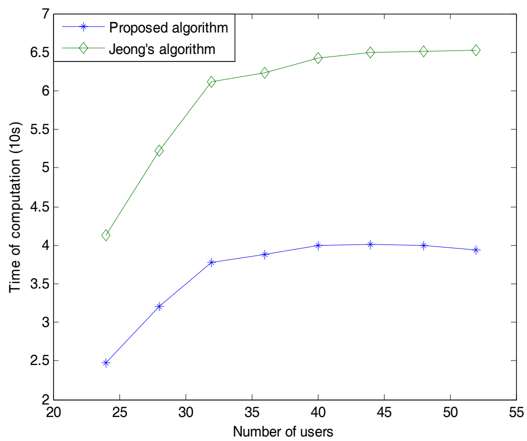

Fig. 5. Calculation complexity according to the number of users

not the allocation time of the OFDM system in practice, we can also evaluate the performance of the two algorithms. From the above simulation results, we can find that the performance of the proposed algorithm is better than that of Jeong's algorithm in the calculation complexity.

Ⅴ. Conclusion

In this paper, a sub-optimal cross-layer resource allocation algorithm for multi-user OFDM system is proposed. The algorithm directly allocates the radio resource in PHY layer according to the priority of the users decided in MAC layer. Simulation results show that the proposed algorithm works well even in the bad channel state and the computation complexity decreases much than the former reported algorithms.

For the further study, we will do more simulations to build a more stable and robust cross-layer resource allocation algorithm for multi-user OFDM system.

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