An Enhanced Maximum C/I Scheduling Method Based on Channel State Prediction in An OFDMA-TDD System

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Abstract – In this paper, we propose a novel downlink packet scheduling algorithm for 802.16e Mobile WiMax OFDMA systems based on channel state prediction. By providing a fast feedback of each user’s channel quality information to the base station, the base station predicts each user’s future channel state and uses this information for prioritized scheduling of downlink transmissions with appropriate rate decisions. The scheduling method is suitable for non-real-time packet transmissions and promises to utilize scarce wireless resource efficiently in an OFDMA system. Simulation results on system throughput, delay and jitter show that the proposed scheduling algorithm achieves a better overall performance than existing scheduling algorithms such as proportional fairness and maximum carrier to interference ratio.

Keywords: OFDMA, TDD, Downlink, Scheduling, Prediction, Adaptive modulation and coding (AMC), MAX C/I

1. INTRODUCTION

With the rapid growth of demand for broadband multimedia applications, orthogonal frequency division multiple access (OFDMA) is becoming an important technology in wireless mobile communications. OFDMA has been specified in many broadband wireless systems, such as IEEE 802.16e wireless metropolitan area network (WMAN) [1]. Not only is OFDMA a modulation scheme, but it is also a multiple access technology. In an OFDMA system, each user is allocated a set of orthogonal subcarriers. In addition to overcoming inter-symbol interference (ISI), an OFDMA system can also mitigate multiple access interference (MAI) by taking advantage of the orthogonality among subcarriers.

Many adaptive resource allocation techniques have been suggested from a viewpoint of OFDMA subcarrier power allocation to further take advantage of frequency diversity [2]–[5]. The goal of this paper is to investigate the OFDMA system from another resource allocation viewpoint, i.e., packet scheduling, which determines the order in which users transmit their packets. Wireless scheduling techniques can further exploit multiuser diversity. In a multiuser wireless system, different users may experience different channel responses over a time varying wireless channel. While some users are experiencing a bad channel, others may be experiencing a good channel. Consequently, if the wireless system can first pick a user with the best channel quality among a group of users to serve, the system capacity can be improved significantly. We call this capacity improvement the multiuser diversity gain. Clearly, for delay-tolerant non-real-time (NRT) data transmissions, wireless scheduling should exploit multiuser diversity for capacity gains.

Many scheduling algorithms have been developed for the single carrier time division multiple access (TDMA) or code division multiple access (CDMA) systems [6]–[10]. The maximum C/I (Max C/I) scheduling scheme allocates the channel to the user that has the best channel condition [6]. This scheduling algorithm can fully exploit multiuser diversity at the expense of fairness among users, as users experiencing sustained periods of bad channel suffer from service starvation. In contrast, round-robin scheduling allocates resource to each user periodically, which maximizes fairness at the expense of overall system throughput as it does not take advantage of multiuser diversity. As a compromise, the proportional fair (PF) scheduling algorithm [7] uses the ratio of the short-term channel response to the long term channel condition of each user to allocate the resource. Exponential rule scheduling [8]–[10] further considers the service delay of each user; a user who has waited for a long period of time will be allocated a channel with a higher priority. These wireless scheduling algorithms have been evaluated only for single carrier wireless systems. To the best of our knowledge, how these scheduling algorithms perform in the OFDMA system is an open issue.

Max C/I scheduling has long been recognized as an effective method to enhance the throughput of single carrier CDMA systems, but it is also known to be unfair to users. In this paper, we proposed an enhanced maximum C/I scheduling algorithm for OFDMA systems, which considers both the throughput and mean delay. Through simulations, we compare the total throughput, mean delay and delay jitter performances of the proposed scheduling algorithm with those of Max C/I and PF.

This paper is organized as follows. Section II describes the system model based on an IEEE 802.16e OFDMA system. In Section III, we present the proposed scheduling algorithm in comparison with Max C/I and PF algorithms. Simulation model
and results are given in Section IV. We give our concluding remarks in Section V.

2. An overview of OFDMA-TDD

OFDMA, also referred to as multi-user-OFDM, is an extension of orthogonal frequency division multiplexing. In current OFDM systems, only a single user can transmit on all of the sub-carriers at any given time, and time division or frequency division multiple access is employed to support multiple users. The major drawback of this static multiple access scheme is the fact that different users see the wireless channel differently, and only one user is selected for packet transmission. In this case, when the channel capacity is larger than the amount of data to be transmitted, the radio resource is not fully utilized.

Figure 1. OFDMA-TDD Structure

Fig.1 illustrates the frame structure of mobile WiMax as an example of OFDMA-TDD system. The frame length is 5 msec and TDD technique is adopted. Uplink and downlink can be partitioned by time slot and the slot partitioning is flexible. Diversity sub-channel and Adaptive Modulation and Coding (AMC) sub-channel exist in both uplink and downlink [1].

3. System Model and Scheduler Design

3.1 System model

We consider a downlink scheduling model of a single cell in an OFDMA system. The system consists of a base station (BS) and i mobile users. We assume that each user moves with the same speed and the users’ channel information is periodically provided to the BS through uplink channel thus the BS can predict users’ channel state and determine scheduling priority.

The signal processing in the BS is divided into packet scheduler, adaptive modulation, OFDM modulation, channel information data base (DB) and channel prediction module as shown in Fig. 2. When packets are queued, users’ channel information is saved in channel information DB from feedback channel quality information (CQI). The channel prediction module forecasts channel state variation for all users periodically and the scheduler decides which packet will be sent to the corresponding user according to the predicted result.

The wireless channel model considers path loss with shadow fading. It is assumed that each user is dedicated to one or more session belonging to one of traffic classes. Under the assumption that the wireless channel of each user is fixed during a scheduling interval, the channel \( H_i(t) \) between the BS and the \( i \) th user at the \( t \) th scheduling instant may be expressed as [11].

\[
H_i(t) = \sqrt{H_i^p(t)} \cdot H_i^s(t)
\]

where the path loss is given as \( H_i^p(t) = C \cdot \max(r_i(t), r_0)^{-\alpha} \), \( C = 10^{0.36} \) is a constant, \( r_i(t) \) is the distance between the BS and the \( i \) th user, \( r_0 \) is the reference distance, and \( -\alpha \) is the path loss exponent. The log-normal shadow fading is represented as \( H_i^s(t) = 10^{\sigma_s/20} \), where \( X_\xi(t) \) is a zero-mean Gaussian random process with variance \( \sigma_s^2 \).

The signal processing of channel prediction forecasts channel state variation for all users periodically and the scheduler decides which packet will be sent to the corresponding user according to the predicted result.

Figure 2. System model

3.2 Scheduler Design

In this subsection, we first introduce existing representative scheduling algorithms, Proportional Fair (PF) and Max C/I algorithms, and propose a multi-user scheduler at the medium access control (MAC) sub-layer of the data link layer with each user adopting AMC at the physical layer. PF is developed to remedy the fairness problem [13-14]. According to the PF, the selected user of index \( i \) is denoted such that:

\[
i^* = \arg \max_i \left( \frac{R_i(t)}{T_i(t)} \right)^\alpha
\]

where \( R_i(t) \) denotes the average throughput of the \( n \) th subchannel of user \( i \). \( \alpha \) and \( \beta \) are indices used to control the scheduling fairness, which are normally set to \( \alpha = \beta = 1 \). The PF algorithm intends to serve those users seeing very favorable instantaneous radio channel conditions relative to their average
ones, thus taking advantage of the temporal variations of the fast fading channel.

Max C/I uses a simple method which is to serve the user of index \(i\) for every scheduling instance \(t\) with respect to:

\[
I^*_i = \arg \max R_i(t)
\]  

(3)

where \(R_i(t)\) denotes the instantaneous supportable data rate of the user \(i\). This serving principle has obvious benefits in terms of system throughput. However, it does not take into consideration of throughput fairness of users, leaving those users of poor average radio conditions served less frequently [15]. Thus, Max C/I algorithm is not appropriated in wireless scheduler.

Our proposed scheduling algorithm is modified by the Max C/I algorithm with channel state prediction. In order to improve the Max C/I algorithm, we consider packet delay time and data transmission rate as well as channel state prediction for every user. There have been proposed various channel prediction algorithms using Kalman filter[16], Bayesian[17] and time series[18]. They periodically forecast the users’ channel state by reported feedback channel quality information in the BS. However, the prediction accuracy of the algorithms is dependent on the parameter of mobile users’ speed or turning direction, and wireless environment. The algorithms using Kalman filter and Bayesian have shown to give accurate prediction than others but they tend to be overly complex when a large number of users are involved. Time series algorithm is simple compared with others. Thus, we use the time series analysis to predict the future channel state of mobile users. This is defined as the average channel variation of the user \(i\) at time \(t_n\), \(\Delta V_i(t_n)\), which is given by

\[
\Delta V_i(t_n) = \frac{1}{k} \sum_{k=1}^{k} (V_i(t_{k+n}) - V_i(t_{k-n}))
\]  

(4)

where \(k\) is the number of the recent SNR history data in using DB in BS. When the BS receives a new SNR from a mobile user, the oldest history data is deleted in DB and the new SNR data is saved for the next prediction. When \(V_i(t_n)\) is the current SNR of the user \(i\), the predicted SNR of the user \(i\), \(\hat{V}_i(t_{n+1})\), can be obtained by

\[
\hat{V}_i(t_{n+1}) = V_i(t_n) + \Delta V_i(t_n)
\]  

(5)

This time series algorithm predicts the channel state for all users in the future. Then, the system decides the time when the users’ channel modulation coding change and we use this method in the proposed scheduling algorithm. Max C/I assign resource for the users which have good SNR (high channel level). In the proposed scheme, there are several channel levels (C level) according to data transmission rate, and each level has sub_level 1, 2 and 3. Sub_level 3 has higher priority than sub_level 1 as shown in Fig. 3. When the SNR of mobile users increases from sub_level 2 to sub_level 1 in N C level, the users will have N+1 C level soon. In this case, they have lower priority because the user will be serviced higher data rate than now such as (a) in Fig. 3. On the contrary, if the SNR of users decreases to sub_level 3 from sub_level 2, the users will have N-1 C level soon, they have higher priority because the user will be serviced lower data rate than now such as (b). The key idea is that users get the highest priority before decreasing the transmission rate. On the other hand, users in sub_level 1 get the lowest priority before increasing the transmission rate. The proposed scheduling algorithm follows the three-step scheduling policy.

**Scheduling Policy:**

**Step 1)** Channel state prediction results

A. The users, whose predicted SNR is moving to sub_level 1 from sub_level 2, have resource allocation with the lowest priority.

B. The users, whose predicted SNR is moving to sub_level 3 from sub_level 2, have resource allocation with the highest priority.

C. The users, whose predicted SNR is staying in sub_level 2, have resource allocation with the interim priority.

**Step 2)** Data transmission rate

If some users have the same sub_level, the scheduler assigns resource according to their data transmit rate.

**Step 3)** Packet delay

If some users have the same sub_level and data transmit rate, the scheduler assigns resource according to their packet delay. The longer users have packet delay, the higher users have priority of resource allocation.

Fig. 4 describes the priority order by the scheduling policy.
4. Performance Evaluation

4.1 Simulation Model

We evaluate the performance of the proposed scheme in an OFDMA-TDD system using computer simulation. We consider a single cell with a 1 km radius and the cell uses an omnidirectional antenna. Mobile stations are uniformly distributed in the cell and move with the same velocity. We also consider the AMC which is classified with five levels of downlink interval usage code (DIUC) stages according to SNR. We assume that a frame length is 5 msec and one sub-channel is considered in simulation. The sub-channel consists of 8 sub-carriers and 12 symbols for downlink traffics so the number of total slots is 96. The simulation parameters for the system model and modulation scheme are shown in Table 1 and 2 respectively.

Table 1. A summary of system parameters.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>System</td>
<td>OFDMA</td>
</tr>
<tr>
<td>Frame period</td>
<td>5ms</td>
</tr>
<tr>
<td>Number of sub-channels</td>
<td>8</td>
</tr>
<tr>
<td>Number of downlink symbol per frame</td>
<td>12</td>
</tr>
<tr>
<td>Total number of downlink slots per frame</td>
<td>96</td>
</tr>
</tbody>
</table>

Table 2. A summary of modulation schemes

<table>
<thead>
<tr>
<th>DIUC</th>
<th>Per-slot Encoding Size</th>
<th>Total Downlink Bandwidth (with 96 slots)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>16 bytes</td>
<td>2.457 Mbps</td>
</tr>
<tr>
<td>2</td>
<td>24 bytes</td>
<td>3.686 Mbps</td>
</tr>
<tr>
<td>3</td>
<td>32 bytes</td>
<td>4.915 Mbps</td>
</tr>
<tr>
<td>4</td>
<td>40 bytes</td>
<td>6.144 Mbps</td>
</tr>
<tr>
<td>5</td>
<td>48 bytes</td>
<td>7.372 Mbps</td>
</tr>
</tbody>
</table>

The BS has also infinite queue size for data traffic and wireless channel state of each user is fixed during a scheduling interval. We consider path loss and shadow fading as channel models which was introduced in 2.2. The system in the BS predicts channel state every frame and uses three recent channel history data for the forecast. Every user is continuously keeps on communicating with the BS during the simulation to track the number of users. During a simulation run, web traffic model occur data for NRT traffic, which is a web traffic model generated of main object, embedded file number, reading time and so on. Main object has the information of letters and web page, and embedded files may be pictures [19]. Fig.5 shows the members of the web traffic modeling and its parameters are in table 3. However, we ignore ARQ scheme in order to focus on scheduling scheme.

In order to consider mobile users, we also use a mobility model. There are several models for capturing user mobility, such as the fluid model, the Markov model, and user tracking models [20]. Among the various models, we used Gauss-Markov model for simulation, in which users move randomly in a cell and the variation of the direction of the mobiles is based on Gaussian probability density function. This mobility model tends to show that users move on a straight line with a small variation of directions which is suitable for metropolitan environment. Fig. 6 shows an example of a user trace using Gauss-Markov mobility model for 1000 seconds. The user moves 10km/h in a cell and turns direction every 100 msec with in 0~5˚ of turning direction angle on both sides randomly.

Table 3. The parameters of Web traffic model

<table>
<thead>
<tr>
<th>Component</th>
<th>Distribution</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Object size</td>
<td>Truncated</td>
<td>Mean: 10710 bytes Min: 100 bytes Max: 2Mbytes</td>
</tr>
<tr>
<td>Embedded Object size</td>
<td>Truncated</td>
<td>Mean: 7758 bytes Min: 50 bytes Max: 2Mbytes</td>
</tr>
<tr>
<td>Number of embedded objects/page</td>
<td>Truncated</td>
<td>Mean: 5.64 Max: 53</td>
</tr>
<tr>
<td>Reading time</td>
<td>Exponential</td>
<td>Mean: 30 seconds</td>
</tr>
<tr>
<td>Parsing time</td>
<td>Exponential</td>
<td>Mean: 0.13 seconds</td>
</tr>
</tbody>
</table>

In the simulation, the total throughput and mean delay are calculated by total transmitted data for each minute and queueing
delay before every packet is transmitted during simulation time. To compare the jitter performance, we adopt a jitter index (6) according to [20]

\[ j = \left( d_1 - d_i - \ldots d_n \right) / \sum d_i \]  

(6)

where \( d_i \) is the mean delay of each user and \( \sum d_i \) is the sum of total delay time.

4.2 Simulation Results

In this subsection we compare the performances of the system throughput, mean delay and jitter with PF, Max C/I and proposed scheduling algorithm. We simulate the users' velocity both 4km/h and 40km/h. When the velocity of mobile users is 4km/h, the users choose the turning direction angle in 0~5˚ on both sides randomly. But the users' velocity is 40km/h, the users move straight way so we use the turning direction angle in 0~15˚ on both sides.

Figure 7. Total Throughput

In Fig. 7, the total throughput of the proposed scheme is compared with that of PF and max C/I. The throughput of max C/I show the highest result because the priority of resource assignment is ordered for users according to the best channel state. On the other hand, as PF considers the fairness for resource assignment, PF is saturated with over 300 users. The reason is that PF considers the fairness for resource assignment. The result of the proposed scheme is saturated lower than max C/I. The reason is that the proposed scheme also considers fairness in every channel level. The proposed scheme and max C/I have similar throughput performance both 4km/h and 40km/h but 40km/h of throughput is higher than 4km/h in case of PF. It means that users, who have fast velocity, could stay outside shorter than users, who have low velocity, in a cell.

In Fig. 8, the results of mean delay are compared. Until the number of users in 40km/h reaches 300, PF and the proposed scheme show similar results, and the delay of max C/I are higher than others. However, the mean delay of PF increases significantly when the number of users is over 300 because PF is an algorithm considering the fairness for each user so the buffer size for each user gets bigger as the number of users increases. In this case, we also need to check the result of jitter value for PF when the number of users is over 300 in Fig. 9. The mean delay of the proposed scheme is better than others on the whole because the proposed scheme also considers assigning resource to users fairly.

In Fig. 9, the results of mean jitter are compared. When the number of users is 250, the mean delay of PF and the proposed scheme are almost the same as shown in Fig. 8 but the mean jitter of the proposed scheme is better than those of other algorithms. Furthermore, the mean jitter of the proposed scheme is half of that of PF when the number of user is 300.

Figure 8. Mean Delay

Figure 9. Mean Jitter

5. Conclusions and Future Directions

In this paper, we have proposed a packet scheduling algorithm based on channel state prediction for downlink transmissions, which utilizes scarce wireless resource efficiently in an OFDMA-TDD system. Through simulations, we have shown that the proposed scheme given a better overall performance in terms of throughput, delay and jitter in comparison with Max C/I and PF.
scheduling. Even though the throughput of the proposed scheme is lower than that of Max C/I, the mean delay and jitter performances are better. Furthermore, the throughput, delay and jitter performances of the proposed scheme are better than those of PF under both mobility scenarios considered.

However, our proposed scheme relies on perfect CQI and prediction of users’ channel states. If the received CQI is delayed time or predicted channel state iswrong, the proposed scheme is unable to work properly. Thus, a timely and error-free CQI feedback mechanism and accurate prediction algorithms need to be developed in further research.

We have proposed an enhanced opportunistic scheduling for NRT traffic in this paper, but it is also necessary to consider scheduling for real-time traffic that requires quality of service (QoS) guarantees. It is of interest to further study the extension of our proposed scheme to support multimedia traffic with QoS guarantees, by taking into account of QoS requirements of different traffic classes in the scheduler.

6. REFERENCES