A Study on Performance of Proportional Fairness Scheduling on IEEE 802.16e OFDMA

Nararat RUANGCHAIJATUPON†[1] and Yusheng JI†‡[2]

† The Graduate University for Advanced Studies 2-1-2 Hitotsubashi, Chiyada-ku, Tokyo, 101-8430 Japan
‡ National Institute of Informatics 2-1-2 Hitotsubashi, Chiyoda-ku, Tokyo, 101-8430 Japan
E-mail: [1]nararat@nii.ac.jp, [2]kei@nii.ac.jp

Abstract Proportional Fairness (PF) scheduling has been proposed to be the scheduling rule for the next generation wireless network. It has been extensively studied, modified, and suggested to be used in many wireless networks, including IEEE 802.16e OFDMA. However, less attention has been paid on how to define users' average data rate, the denominator in the PF ratio. We focused our study on the procedure to derive the average data rate of the mobile terminal, as well as proposed the alternative approach to calculate the average rate. We made simulations and showed that our proposed method gives better delay and throughput performances in IEEE 802.16e OFDMA network model.

Keyword Proportional Fairness, Scheduling, QoS, IEEE 802.16e, WiMAX, OFDMA

1. Introduction

Nowadays, wireless networks have been gaining more popularity as they are easy to setup without a cost of cabling and land rental for wiring. In users' point of view, wireless networks also offer a convenient way to get connected. However, questions about Quality of Service (QoS) have been raised according to the nature of the undulated wireless channels and the increasing of bandwidth-demand applications.

Scheduling is one of the methods to answer the wireless network QoS questions. By the scheduling rules on how to select users to be allowed to transmit, how much data they can transmit, and when they can start to transmit, specified QoS can be achieved. Accompanied with the scheduling rule is the question of how to utilize network resources efficiently, i.e. to maximize network throughput with limited bandwidth constraint. At the same time, fairness is another concern. In wireless environment, different users are affected from path loss, fading, and shadowing differently. To be fair, two users, who may see channels differently, should have equal chance to receive service.

Proportional Fairness (PF) scheduling rule has been proposed for wireless networks and believed to be able to provide both throughput maximization and users' fairness. According to the algorithm, the user who has the highest $R_k(t)/T_k(t)$ is picked up for transmission. Note that $R_k(t)$ and $T_k(t)$ are user k's instantaneous data rate and average data rate at time t respectively. PF scheduler is likely to select a user who sees better channel, i.e. higher instantaneous rate. Therefore, it tends to maximize system throughput. Nevertheless, users who already got service will have higher average data rate and they will get less chance to be picked up, according to the formula. Hence, fairness is exercised.

PF was introduced to be used in wireless networks by Jalali, Padovani, and Pankaj of Qualcomm [1]. They assumed infinite backlogged queues in a CDMA-HDR network where adaptive modulation and TDM are performed. They suggested using Exponential Moving Average (EMA) to calculate user's average data rate. The equation is shown as follows.

$$T_k(t+1) = (1-\frac{1}{t_c})T_k(t) + \frac{1}{t_c}R_k(t+1) \qquad (1)$$

The value of t_c is recommended to be related to user's starvation time and a temporary drop in channel condition. However, this recommendation can not solve the starvation problem as it is pointed out by Ji et al. [2] and Qiu and Huang [3]. As a result, both papers recommend the concept of a starvation time counter.

This leads us to query how to acquire user's average data rate in PF algorithm. It can play an important role that affects user selection, and then on user's QoS. We also consider the situation where finite backlogged queue is assumed. Then, we suggest the approach to calculate user's average data rate and simulate our algorithm in the IEEE 802.16e OFDMA network model.

The rest of this paper is organized as follows. How PF is adopted in OFDMA network is explained in section 2. Section 3 illustrates our proposed methodology. Section 4 shows the simulation results and comparisons. We make a conclusion in section 5.

2. Proportional Fairness in OFDMA

In order to cope with wireless fading characteristic, OFDMA is selected for several wireless network standards, including IEEE 802.16e OFDMA. In this access method, frequency band is divided into carriers. A number of carriers are grouped into one subchannel to deal with effects of fading. A transmission unit defined by the standard is a frame. Hence, an OFDMA frame consists of a block of downlink OFDMA subchannels and then a block of uplink OFDMA subchannels. The scheduling algorithm must specify a mobile terminal that will transmit in each subchannel during each frame duration. IEEE 802.16e also employs adaptive coding and modulation, in which a mobile terminal changes its coding and modulation scheme according to SINR. As a result, each mobile terminal will know its instantaneous data rate, according to its adapted coding and modulation rate, for each subchannel. We assume that the mobile terminal reports the instantaneous data rates to the central scheduler residing in the base station on every frame period using dedicated uplink bandwidth.

Proportional fairness rule can be used in OFDMA by treating individual subchannel independently [4]. Let $R_k(t,n)$ denote the supportable data rate for user k in subchannel n at time t. For each subchannel, the user with the largest $R_k(t,n)/T_k(t)$ is selected for transmission. The user's average data rate is update as

$$T_k(t+1) = (1-\frac{1}{t_c})T_k(t) + \frac{1}{t_c}\sum_{n\in\Omega_k(t)} R_k(t,n) \qquad (2)$$

for $k = 1, 2, ..., K$ and $\Omega_k(t)$ is the set of subchannels in which user k is scheduled to transmitted at time slot t.

3. The Proposed Method

We propose to use our modification of Simple Moving Averaging (SMA) to calculate user's average data rate for proportional fairness formula. First, we explain the SMA method without modification. Suppose we have a user's instantaneous rate as a data point, SMA simply distributes weight to each data point uniformly by summing up all the data and dividing by the number of data points. We adapt SMA method to use in proportional fairness scheduling. We propose that the average data rate must be re-calculated every frame period by using simple moving average method whenever the user has data in its queue. The number of frame while the user queue is not empty is used as the divider. We also consider the situation when a user's queue has no data. In that case, we suggest that the average data rate of that user should remain the same value. Furthermore, the number of frame while the queue is not empty, as well as the sum of data rate, should be reset to their default values.

We state here again the summary of our proposed method to calculate user's average data rate, the denominator in proportional fairness scheduling.

- When the user's queue has data, the user's average data rate must be re-calculated every frame period by using simple moving average method.
- When the user's queue has no data, the user's average data rate is set to the latest value and remains unchanged until the queue has data again.

The implementation of our proposed SMA method adds slightly more complexity to the proportional fairness algorithms. For each user, we need 3 more variables. One is a variable to record the added up instantaneous data rate. It will be reset to zero when a user has no data to transmit. The second variable is for counting the number of frame in which the user's queue is not empty. This variable will be reset to 1 whenever the queue becomes empty again. The reason why the default value of this variable is 1 is because we want to give weight to the retained average rate. The third variable is used to retain the user average data rate when that user has no data in the queue. This variable will keep the last average data rate before the user queue becomes empty.

Let $U_k(t,n)$ be the variable to keep the added up instantaneous data rate of user k in subchannel n at time t, $V_k(t)$ record the number of frame while user k has data in the queue, and W_k be the variable to retain the average data rate. The following figure illustrates how the user average data rate ($T_k(t)$) is updated.

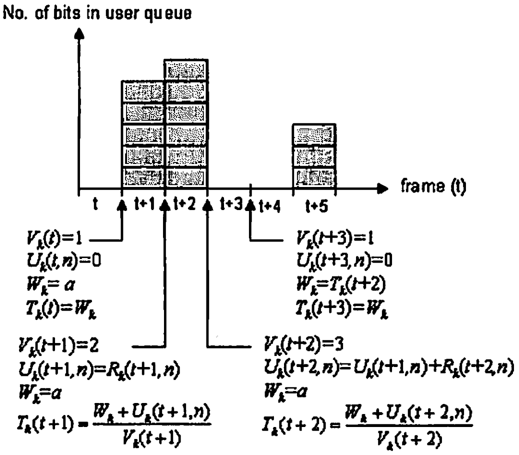

Figure 1. Average data rate calculation

From figure 1, at frame t, user k has no data. $U_k(t,n)$ equals to zero, $V_k(t)$ equals to one, and W_k retains the previous average data rate, which is assumed to be a. As a result, the average data rate ($T_k(t)$) also equals to W_k or a. At frame t+1, user's queue has data. The frame counter ($V_k(t+1)$) starts to increase, as well as $U_k(t+1,n)$, which keeps the summation of data points. The average data rate ($T_k(t+1)$) is the results of simple moving averaging of the retained rate and the summation of instantaneous data rate while the queue is not empty. The averaging algorithm continues as shown in Fig. 1 at frame t+2. When the user queue becomes empty, the frame counter and the added up data rate are reset to their default values while the average data rate keeps the latest value. The illustration is shown in Fig. 1 at frame t+3.

In general, our proposed average data rate calculation can be formulated as the following equation.

$$T_k(t+1) = \frac{W_k + \sum_{n\in\Omega_k(t)} U_k(t+1,n)}{V_k(t+1)} \tag{3}$$

W_k retains the latest average data rate of the user whenever the user's queue is empty.

When a user's queue size is zero, the average data rate of the user will not change, unlike what is proposed by [1]. However, this user will not be considered when the scheduler performs user selection, as said by PF selection procedure [1]. The reason why we retain the average data rate of the user with empty queue is that if the average data rate is re-calculated when the user has no data, it will bias this user whenever the queue becomes active again. Let's consider if we update the average data rate of a user who has no data to send using the exponential moving average method in equation (2). As this user will be ignored in the selection procedure, the second term of the right hand side of the equation will be zero. Hence, the average data rate of this user will continually decrease. Whenever this user has data again, it gets favor from the proportional fairness scheduler because of the decreased average data rate.

In our method, when user has no data to send, the average data rate will remain the same value. According to equation (3), as W_k is unchanged, $V_k(t)$ is one, and the summation term is zero, the average rate calculated will equal to W_k. Furthermore, when the user's queue is not empty and this user is selected to transmit, the average data rate will be increased, according to equation (3). Thus, the proportional fairness priority index ($R_k(t,n)/T_k(t)$) is likely to be decreased in the next frame, releasing the chance to the other users. For a user with non-empty queue who is not selected, the average data rate continually decreases because of the increasing frame counter; the divider in equation (3), as well as a summation of data rate is zero. As a result, this user's PF priority index has a tendency to increase.

4. Simulation Results

We prove our proposed method by simulation and compare the results with the results from the exponential moving average method. We use OPNET modeler tool and create our simulation model based on IEEE 802.16e OFDMA standard. The model consists of one base station serving a number of mobile stations. The original locations of mobile stations are uniformly distributed around a cell radius of 0.5 kilometers, in which mobile stations keep moving with uniformly distributed velocity of [3, 100] kilometers per hour in a random direction [5]. The path loss model and log-normal shadowing follow a 3GPP TR 25.848 technical report [6]. Furthermore, the adaptive coding and modulation scheme follows IEEE C802.16d-03/78r1 OFDMA PHY performance and coverage simulations [7].

In our model, we employ proportional fairness scheduling for downlink data. As stated previously, our model is created based on the assumption that a mobile station reports its instantaneous data rate to the central scheduler residing in a base station on every frame duration using dedicated uplink allocation. Moreover, we assume that during one frame duration, a mobile terminal which is selected to transmit in the defined subchannel will occupy the allocated subchannel for the whole frame duration. A mobile station is considered as one user who has traffic sent to with the traffic rate of 1 Mbps in a long term average. We examine two cases; when data to all mobile stations has constant traffic rate, and when the data has variable traffic rate.

We assign a frame period of 5 milliseconds and run simulations for 300 seconds. As we implement the scheduling for traffic in downlink direction, downlink queue delay and downlink throughput are collected every frame period. For exponential moving average method, we also vary the value of t_c from 10 to 100 to explore the effects of t_c on an OFDMA network. Furthermore, the number of users is varied from 12 to 48 users. The higher number of users means the higher system input load. We plot complementary cumulative distribution function (CCDF) of queue delay of two traffic patterns; constant rate traffic and variable rate traffic. The plots of constant rate traffic with EMA and SMA methods are shown in Fig. 2 and Fig. 3. The plots of variable rate traffic with EMA and SMA methods are shown in Fig. 4 and Fig. 5.

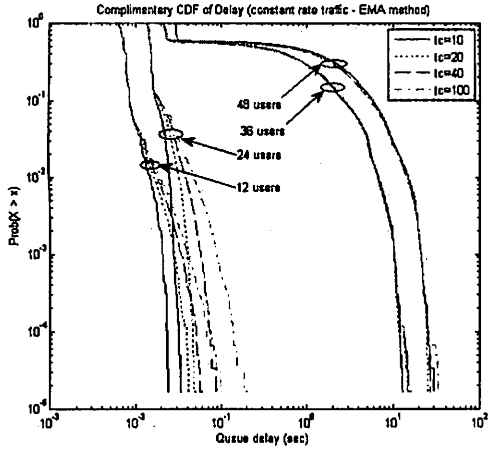

Figure 2. Complementary CDF of queue delay - constant rate traffic with EMA method case

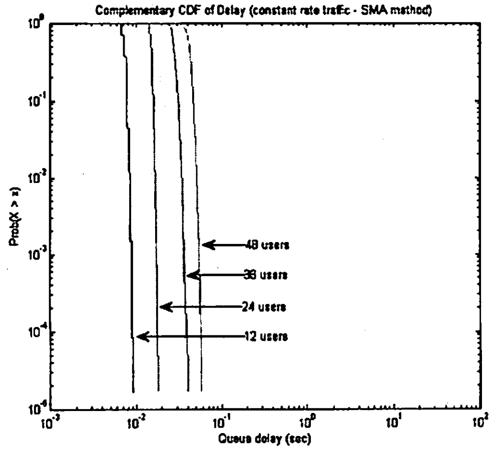

Figure 3. Complementary CDF of queue delay - constant rate traffic with SMA method case

Fig. 2 and 3 show the delay results of constant rate traffic case. Fig. 2 is the result from EMA method with t_c equals to 10, 20, 40, and 100 respectively while Fig. 3 shows the result from our SMA method. Comparing Fig. 2 and Fig. 3, our proposed simple moving average method gives lower and nearly constant delay. In this case, for 12 and 24 users, the delays of SMA and EMA method are comparable. Only small portion of data face higher delay by EMA method. Moreover, larger value of t_c produces longer delay, which is known for PF. For higher number of users, i.e. 36 and 48 users, EMA gives lower delay for probability of 0.5. The other half faces much longer delay and the value of t_c does not produce any dominant differences. On the other hand, SMA provides lower and nearly constant delay with very high probability, i.e. approximately 1.0, in the constant rate traffic case.

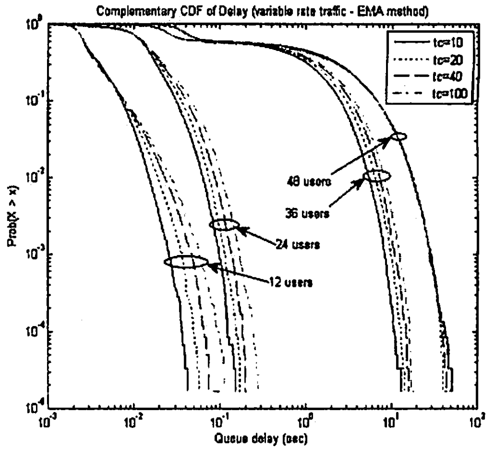

Figure 4. Complementary CDF of queue delay - variable rate traffic with EMA method case

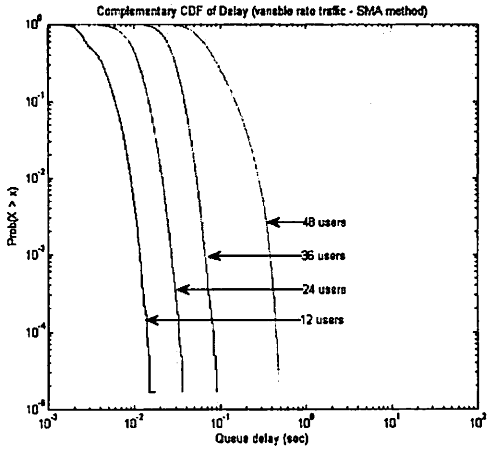

Figure 5. Complementary CDF of queue delay - variable rate traffic with SMA method case

In case of variable rate traffics are sent to mobile users, the plots are shown in Fig. 4 and Fig. 5. The plots confirm better delay performance of our simple moving averaging. Both of them show the similar trend as Fig. 2 and Fig. 3 do. When system input load is low such as 12 – 24 users, SMA gives slightly lower delay compared with EMA. When the number of users increases to 36 – 48, SMA outperforms EMA with much higher probability. Note that for exponential moving average method in variable rate traffic case, effect of t_c over queue delay is noticeable. This effect weakens when a network has more users.

For throughput performance, we collect all users' throughput and calculate average throughput per user. The plots are shown in Fig. 6 and Fig. 7. Fig. 6 shows the average throughput per user versus the number of users, in constant rate traffic case. Fig. 7 shows the average throughput per user versus the number of users in the case of variable rate traffic.

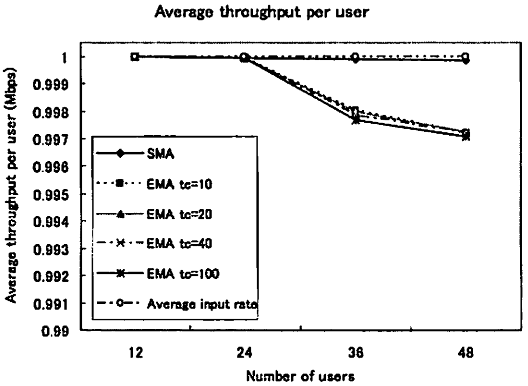

Figure 6. Average throughput per user versus number of users - constant rate traffic case

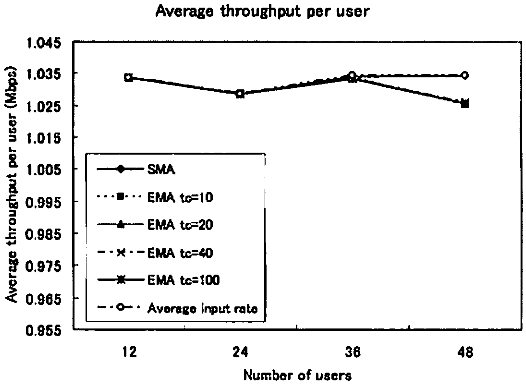

Figure 7. Average throughput per user versus number of users - variable rate traffic case

In Fig. 6, the average input rate per user is always 1 Mbps. Throughput per user provided by SMA method is slightly decreasing with the increasing number of users. Unlike SMA, throughput per user by using PF with EMA method reduces sharply when number of users increases over 24. Furthermore, EMA with higher value of t_c achieves lower throughput per user in an OFDMA wireless network model.

Similar tendency happens to variable rate traffic case except that the average input rate per user is fluctuating around 1 Mbps, as shown in Fig. 7. Proportional fairness scheduling with our proposed simple moving averaging provide very high user's throughput. We can see in Fig. 7 that the SMA line almost overlaps the input line. When EMA is used in PF priority index calculation, average throughput per user decreases when system input load increases. In this case, varying the value of t_c does not produce significant differences.

5. Conclusion

In this paper, we show our study on proportional fairness scheduler in IEEE 802.16e OFDMA wireless networks, where PF rule is used for downlink data scheduling. We pay attention on how user's average data rate is calculated, as well as when finite backlog queue is assumed. We proposed the method to calculate average rate based on simple moving averaging and make a comparison with the exponential moving average method previously proposed for PF. The simulation results prove that our proposed method performs better than the EMA method in both delay and throughput aspects. Our simulation results also shows the effects when different values of t_c are set in EMA method.

References

[1] A. Jalali, R. Padovani, and R. Pankaj, "Data throughput of CDMA-HDR a high efficiency-high data rate personal communication wireless system, " proc. IEEE 51st Vehicular Technology Conference, vol. 3, pp. 1854-1858, Tokyo, Japan, Spring 2000.

[2] Y. Ji, Y. Zhang, Y. Wang, and P. Zhang, "Average rate updating mechanism in proportional fair scheduler for HDR, " proc. IEEE Global Communication Conference, vol. 6, pp. 3464-3466, Dallas, Texas, USA, November 2004.

[3] J. Qiu, and T. Tiancong, "Packet scheduling scheme in the next generation high-speed wireless packet networks, " proc. IEEE International Conference on Wireless And Mobile Computing, Networking And Communications, vol. 2, pp. 224-227, August 2005.

[4] J. Andrews, A. Ghosh, and R. Muhamed, Fundamentals of WiMAX: understanding broadband wireless networking, Prentice Hall, 2007.

[5] D. H. Kim, C. G. Kang, P. J. Song, Y. S. Shin, and B. J. Lee, "Wireless packet scheduling for integrated services of real-time and non-real-time applications in mobile broadband wireless access system, " proc. IEEE 62nd Vehicular Technology Conference, vol. 4, pp. 2591-2596, Dallas, Texas, USA, September 2005.

[6] 3GPP, "Physical layer aspects of UTRA high speed downlink packet access (release 2000), " 3G TR25.848 V4.0.0, March, 2001.

[7] IEEE 802.16 Broadband Wireless Access Working Group, "Coverage/Capacity simulations for OFMDA PHY in with ITU-T channel model, " IEEE C802.16d-03/78r1, November, 2003.