Traffic Scheduling Algorithms for OFDM Based Radio Systems

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Abstract. In this paper, traffic scheduler for OFDM based radio system is studied in detail according to the traffic classes and Round-Robin (RR) series algorithms. The quantum, quanta and weights for the weighted deficit RR (WDRR) in downlink, and the basic quantity, quantity, weights for the weighted RR (WRR) in uplink are derived, respectively. The comprehensive traffic scheduler and algorithms are offered for the OFDM based radio systems.

Keywords: Traffic scheduling · OFDM · RR · DRR · WRR · WDRR

1 Introduction

Traffic scheduling algorithms for OFDM based radio systems, such as WLAN, LTE and WiMAX etc. is of importance in mobile wireless communication systems, and scheduling is also important in 5G networks [1, 2]. In the MAC layer, a very important issue is how to schedule the MAC protocol data units (MPDUs), and then complete to fill the created downlink (DL) and uplink (UL) frames. A large number of traffic scheduling algorithms for wireline networks have been proposed in the literature [3]. However, these algorithms cannot be directly applied to wireless networks because of fundamental differences between these two types of networks. For OFDM based scheduling algorithms, e.g. Round-Robin (RR), WRR (Weighted RR), DRR (Deficit RR), DWRR (Deficit-Weighted RR), and proportional fair (PF) etc. are introduced [3–9], the proportional fair scheduler is of interest in LTE and WiMAX. However, the main drawbacks of the scheduler are that the algorithms assume there are infinite packets to be transmitted at time zero and no packet arrivals, which is not a real-time scheduler. Moreover, the proportional fair scheduling algorithms are complicated to be implemented in practical applications. The criteria for selecting scheduling algorithms for OFDM based radio systems are: QoS requirement and simple to be implemented. Round-Robin scheduler can be unfair if different flows have different packet sizes. The DWRR and WRR are the improved Round-Robin family schedulers which can meet both of the criteria mentioned above. In this paper, the

K. Long et al. (Eds.): 5GWN 2017, LNICST 211, pp. 160–169, 2018.
https://doi.org/10.1007/978-3-319-72823-0_16

explicit values of the weights for the DWRR and WRR are derived for the DL and UL. The basic quantum and quanta for the traffic in the DL, the basic quantity, the quantities of scheduled traffic for the UL are studied and offered. The priority scheduler, the DWRR and WRR scheduling algorithms, and the parameters introduced for using the algorithms have clear physical meanings and also easy to be implemented.

2 Traffic Scheduler for OFDM Based Radio Systems

The scheduler for OFDM based radio systems consists of five classes of traffic in common, namely, UGS (unsolicited grant), ertPS (extended real-time polling), rtPS (real-time polling), nrtPS (non-real-time polling), and BE (best effort) services. UGS can be a CBR (Constant Bit Rate) application, e.g. VoIP (Voice over IP) or video conference. ertPS/rtPS/nrtPS/BE can be, e.g. VoIP (Voice over IP) with VAD (Voice Activity Detection)/video and audio streaming (VAS)/FTP (File Transfer Protocol)/web browsing http applications. The aforementioned traffic classes are for mobile WiMAX, but they can be also applied to WLAN and LTE and other OFDM based radio systems.

The diagram of the scheduler is shown in Fig. 1. We use the priority scheduler for the prioritized traffic. The priority orders of the traffic classes are: (i) MAC management & control messages, (H)ARQ [(hybrid) Automatic Repeat-reQuest)], (N)ACKs [(Non) Acknowledgements] and re-transmission, (ii) UGS, (iii) ertPS, (iv) rtPS, (v) nrtPS, and (vi) BE. We schedule (i) (ii) (iii) traffic when they are available, then the traffic in items (iv)–(vi) classes are scheduled by using DWRR (Deficit Weighted Round-Robin) and WRR (Weighted Round-Robin) algorithms for the DL and UL, respectively. In this paper, we take the joint traffic applications of the rtPS and nrtPS and give the weights and the scheduled traffic. The key reason is that both rtPS and nrtPS traffic have the

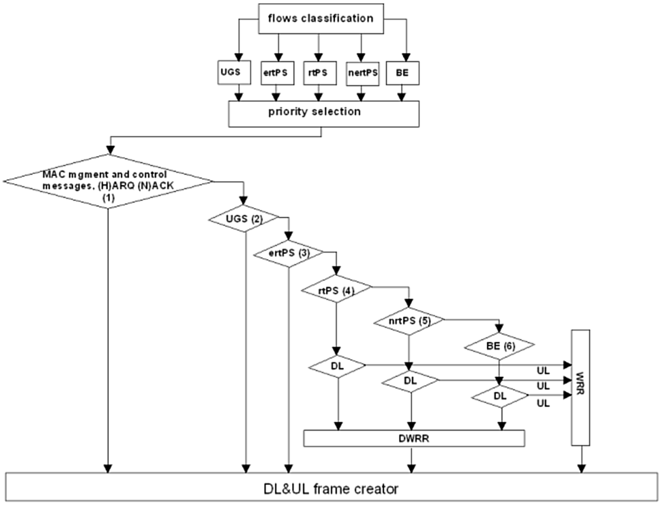


Fig. 1. Traffic scheduler for OFDM based radio systems.

bandwidth requirement. After scheduling items (i)–(iii) traffic, if not enough bandwidth as required in the rtPS and nrtPS traffic, then both should share the available bandwidth. Therefore, when implementing the DWRR and WRR, their weights and the quantity of scheduled traffic are independent. After this step, the rtPS traffic is scheduled first due to its sensitive to delay. The weights for the DWRR and WRR for the DL and UL, the basic quantum, quanta for the DL traffic, and the basic quantity, quantities of scheduled traffic for the UL will be studied in detail in Sects. 3 and 4.

3 The Basic Quantum, Quanta and Weights for the DL Traffic Applications

Assume that the rtPS, nrtPS, and BE traffic classes can have different applications, e.g. rtPS class can have video conference, streaming video, streaming audio, and broad-casting etc. These applications can have different minimum reserved traffic rates $\{MRTR_i\}_{\mathrm{rtPS}}$, and maximum sustained traffic rates $\{MSTR_i\}_{\mathrm{rtPS}}$, where i means a specific application for rtPS class, and $\{\}$ means the assemble of applications. Same as in nrtPS traffic class, the applications (e.g. FTP, web browsing, P2P, large media downloads etc.) can have $\{MRTR_i\}_{\mathrm{nrtPS}}$ and $\{MSTR_i\}_{\mathrm{nrtPS}}$ as well. For the applications (e.g. small scale data transfer, web browsing etc.) in BE class, they're with $\{MSTR_i\}$ but without $\{MRTR_i\}$. In the following discussions, we merge the applications of the rtPS and nrtPS classes and denote their MRTR and MSTR assembles as $\{MRTR_i\}$ and $\{MSTR_i\}$ by removing the traffic classes in the subscripts. Within an application, all the flows (or users) have the same MSTR and MRTR, and the MSTR of an application is greater than its MRTR. The MSTR and MRTR can be the operation and management (O&M) parameters and will be decided by network operators or the agreed parameters between operators and the users.

(a) *Joint traffic applications for rtPS and nrtPS*

DWRR in principle is very similar as DRR, a quantum is needed first to schedule a traffic flow. In this paper, we define a basic quantum and weights for the applications when implementing the DWRR. Using the weights and defined basic quantum, we can get the quanta for the traffic flows included in the applications, and further to implement the DWRR algorithms. For joint applications of rtPS and nrtPS, the basic quantum (in slots) is defined by using both of the MRTR and MSTR of the applications.

$$\begin{aligned} Q_B &= \frac{\sum_i (MSTR_i + MRTR_i)/2 * T_{\mathrm{frame}}}{8 * S} \\ &= \frac{1}{2}\left(\sum_i Q_{i,\min} + \sum_i Q_{i,\max}\right) \end{aligned} \tag{1}$$

where T_{frame} is the frame period in ms, and S is the slot size in bytes, which depends on the modulation and coding schemes (MCSs) and listed in Table 1.

Table 1. Slot sizes for different MCSs in WiMAX

Modulation	QPSK	QPSK	16QAM	16QAM	64QAM	64QAM	64QAM
Coding rate	1/2	3/4	1/2	3/4	1/2	2/3	3/4
Slot size/Bytes	6	9	12	18	18	24	27

In (1), MSTR is in Kbps. The basic quantum is defined for a frame, and the traffic is scheduled frame by frame. $Q_{i,\min}$ and $Q_{i,\max}$ are the minimum and maximum quanta for application i and can be calculated as follows

$$Q_{i,\min} = \frac{MRTR_i * T_{\text{frame}}}{8 * S} \tag{2}$$

$$Q_{i,\max} = \frac{MSTR_i * T_{\text{frame}}}{8 * S} \tag{3}$$

The weights of DWRR can be defined and calculated as

$$W_i = \frac{MSTR_i}{\sum_i MSTR_i} \tag{4}$$

In (4), the weights have been normalized. The larger the MSTR, the larger the weight for an application. The weight defined in (4) is fair regarding of each application. We define the quantum for application i as

$$Q_i = Q_B \cdot W_i \tag{5}$$

From (1), it's seen that if the application types and the corresponding MSTRs and MRTRs are pre-decided, the basic quantum Q_B is fixed. The quantum for a specific application i is defined and calculated as a product of the basic quantum and its weight, which means that when an application with a larger weight, then it can have larger quantum. Q_i shown in (5) generally is larger than $Q_{i,\min}$, but less than $Q_{i,\max}$, namely $Q_{i,\min} \leq Q_i \leq Q_{i,\max}$. Let's start prove this inequality. From (1), when using $Q_{i,\max}$ instead of $Q_{i,\min}$

$$\begin{aligned} Q_B &= \frac{1}{2}\left(\sum_i Q_{i,\min} + \sum_i Q_{i,\max}\right) \\ &\leq \frac{1}{2}\left(\sum_i Q_{i,\max} + \sum_i Q_{i,\max}\right) = \sum_i Q_{i,\max} \end{aligned} \tag{6}$$

From (4), (5) and (6), we can get

$$\begin{aligned} Q_i =& Q_B \cdot W_i \leq \sum_i Q_{i,\max} \cdot \frac{MSTR_i}{\sum_i MSTR_i} \\ =& \frac{\sum_i MSTR_i \cdot T_{\text{frame}}}{8 * S} \cdot \frac{MSTR_i}{\sum_i MSTR_i} \\ =& \frac{MSTR_i \cdot T_{\text{frame}}}{8 * S} \\ =& Q_{i,\max} \end{aligned} \tag{7}$$

which means that $Q_i \leq Q_{i,\max}$. In (1), when using $Q_{i,\min}$ instead of $Q_{i,\max}$, we can get

$$\begin{aligned} Q_B =& \frac{1}{2}\left(\sum_i Q_{i,\min} + \sum_i Q_{i,\max}\right) \\ \geq & \frac{1}{2}\left(\sum_i Q_{i,\min} + \sum_i Q_{i,\max}\right) = \sum_i Q_{i,\min} \end{aligned} \tag{8}$$

From (4), (5) and (8), we can have

$$\begin{aligned} Q_i =& Q_B \cdot W_i \geq \sum_i Q_{i,\min} \cdot \frac{MSTR_i}{\sum_i MSTR_i} \\ =& \frac{\sum_i MRTR_i \cdot T_{\text{frame}}}{8 * S} \cdot \frac{MSTR_i}{\sum_i MSTR_i} = C \end{aligned} \tag{9}$$

Because of $MRTR_i \leq MSTR_i$, and $\frac{\sum_i MRTR_i}{\sum_i MSTR_i} \leq 1$, from (9), we can get

$$\begin{aligned} C \leq & \frac{\sum_i MRTR_i}{\sum_i MSTR_i} \frac{MRTR_i \cdot T_{\text{frame}}}{8 * S} \\ \leq & \frac{MRTR_i \cdot T_{\text{frame}}}{8 * S} = Q_{i,\min} \end{aligned} \tag{10}$$

From (9) and (10), $Q_i \geq C$ and $Q_{i,\min} \geq C$, which means that Q_i can be either larger or smaller than $Q_{i,\min}$. However, if the weight in (4) can also be defined by the MRTR (We expected that this can be happen due to when an application with larger MSTR, then it's with larger MRTR as well, so the weights can be kept as constant), then

$$W_i = \frac{MRTR_i}{\sum_i MRTR_i} = \frac{MSTR_i}{\sum_i MSTR_i} \tag{11}$$

In such a case, from (5), (8), and (11)

$$\begin{aligned} Q_i = Q_B \cdot W_i &\geq \sum_i Q_{i,\min} \cdot \frac{MRTR_i}{\sum_i MRTR_i} \\ &= \frac{\sum_i MRTR_i \cdot T_{\text{frame}}}{8 * S} \cdot \frac{MRTR_i}{\sum_i MRTR_i} \\ &= \frac{MRTR_i \cdot T_{\text{frame}}}{8 * S} = Q_{i,\min} \end{aligned} \tag{12}$$

It means that $Q_i \geq Q_{i,\min}$, then the inequality of $Q_{i,\min} \leq Q_i \leq Q_{i,\max}$ keeps. The equal sign can be taken when $Q_{i,\min} = Q_{i,\max}$ by assuming that the MRTR is equal to the MSTR. From the results of the above discussions, we can get the following conclusions:

① The inequality $Q_{i,\min} \leq Q_i \leq Q_{i,\max}$ is true when the weight can be defined and calculated by Eq. (11).
② In this paper, we define the weight by Eq. (4), then the quantum Q_i can be either larger or smaller than $Q_{i,\min}$.

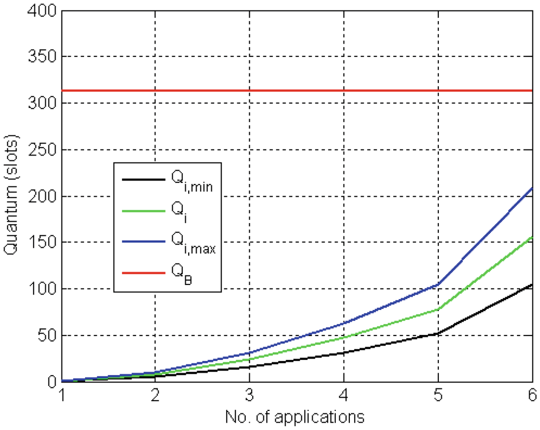
In conclusion ②, when $Q_i \leq Q_{i,\min}$, we should assign the quantum Q_i as $Q_{i,\min}$ so that it can guarantee the requirement of the minimum reserved traffic rate of the application. The general quantum can be expressed as follows when taking into consideration of (5)

$$Q_i = \begin{cases} Q_B \cdot W_i, & Q_{i\min} < Q_B \cdot W_i \\ Q_{i\min}, & \text{otherwise} \end{cases} \tag{13}$$

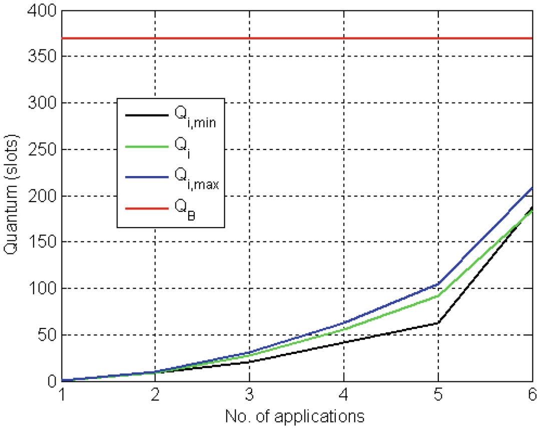
(b) *Demonstration examples*

For joint applications of the rtPS and nrtPS traffic classes, assume the {MSTR} are within 10 Kbps–2 Mbps, and we have six applications with {MSTR} = {10 100 300 600 1000 2000} in Kbps. The frame period is 5 ms, and the QPSK(1/2) MCS is applied with slot size of 6 bytes.

Example 1: Let MRTR = {5 50 150 300 500 1000}. For each application, the MRTR is taken as the half of its MSTR. The purpose is that the same weights can be remained by using either the MSTRs or the MRTRs defined in (11). The results are shown in Fig. 2(a) which shows that $Q_{i,\min} < Q_i < Q_{i,\max}$. The basic quantum Q_B in this case is about 313 slots (1878 bytes).



(a)



(b)

Fig. 2. Quanta relationships among $Q_{i,\min}$, Q_i and $Q_{i,\max}$. (a) The same weights can be defined by either the MSTRs or the MRTRs as in (11). (b) The weights are defined only by the MSTRs as in (4).

Example 2: Let MRTR = {5 80 200 400 600 1800}. For every application, the MRTR is taken randomly a smaller value than the corresponding MSTR. The results are shown in Fig. 2(b). It shows that Q_i is less than $Q_{i,\max}$. However, it cannot always keep that $Q_{i,\min}$ is less than Q_i. The basic quantum Q_B is about 370 slots (2220 bytes).

(c) *Traffic applications for BE class*

For BE applications, there are no $\{MRTR_i\}$ QoS parameters, the basic quantum can be calculated by the $\{MSTR_i\}$. The basic quantum in (1) now is changed as

$$Q_B = \frac{\sum_i MSTR_i * T_{\text{frame}}}{8 * S} \tag{14}$$

Using (14) and the weights defined in (4). Then the quantum for application i is

$$\begin{aligned} Q_i = Q_B \cdot W_i &= \frac{\sum_i MSTR_i * T_{\text{frame}}}{8 * S} * \frac{MSTR_i}{\sum_i MSTR_i} \\ &= \frac{MSTR_i * T_{\text{frame}}}{8 * S} = Q_{i,\max} \end{aligned} \tag{15}$$

which means that the flows (or users) within an application, e.g. web browsing, will contend the available bandwidth. Once the contention is successful, then the traffic can be scheduled based on its MSTR. BE traffic has no QoS requirement and the MSTR is the only parameter available for scheduling the traffic. Figure 3 shows the flowchart of how the quanta and weights are defined and calculated in Sect. 3 as a summary.

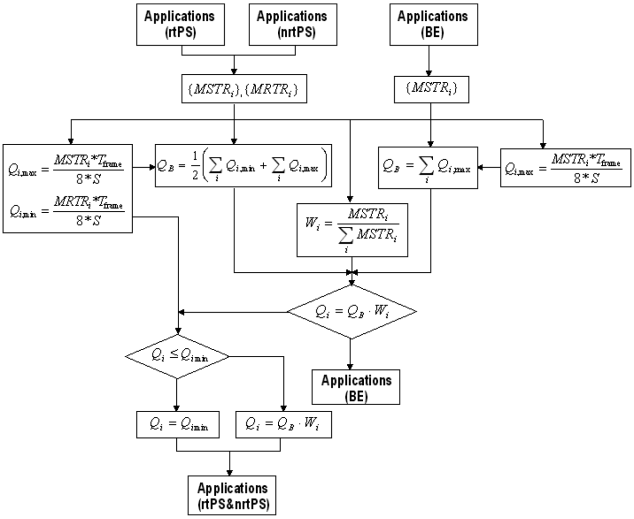


Fig. 3. The quanta and weights for the DL traffic applications using DWRR

4 Basic Quantity, Quantity of Scheduled Traffic and Weights for the UL Traffic

For the UL scheduling, the priority orders of the traffic classes are the same as in the DL. The difference is that in the UL we use WRR to schedule rtPS, nrtPS and BR traffic. For a specific application in the DL, the quantum Q_i and weight W_i are needed when implementing DWRR. While implementing the WRR algorithms in the UL, we need to know the weight and also the scheduled quantity of traffic for an application in a frame. For the WRR scheduling algorithm, it has no quantum concept, however we can use the scheduled quantity of traffic X instead of quantum Q in Sect. 3, then all the equations for the DL scheduling can be applied to the UL case. The specific replacements are as follows: we use the basic scheduled traffic X_B to replace of the basic quantum Q_B, use scheduled traffic X_i to replace the quantum Q_i, use the minimum and maximum scheduled traffic $X_{i,\min}$ and $X_{i,\max}$ for application i to replace the minimum and maximum quanta $Q_{i,\min}$ and $Q_{i,\max}$, respectively. Then we can get the corresponding formulas for scheduling the UL traffic as well for WRR.

5 Conclusion

The priority scheduler in this paper clearly shows that what kind of traffic class should be scheduled first for OFDM based radio systems. It can meet the QoS requirements both in throughput and delay. The DWRR and WRR algorithms are used further to schedule the rtPS, nrtPS and BE traffic in the DL and UL, respectively. DWRR and WRR have very clear physical meanings, they are straight forward algorithms to be implemented and are also very efficient scheduling algorithms. Moreover, we developed the basic quantum, quanta and weights for the applications in the DL by using WDRR as well as the basic quantity, the quantity of scheduled traffic, and the weights for the UL by using WRR for OFDM based system, such as mobile WiMAX.

Acknowledgement. This work is supported by the Department of Science and Technology, State Grid, China.

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