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ACROSS-LAYER RESOURCE SCHEDULING WITH QOS GUARANTEES USING ADAPTIVE TOKEN BANK FAIR QUEUING ALGORITHM IN WIRELESS NETWORKS

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Abstract

Orthogonal Frequency Division Multiplexing (OFDM) systems are the major cellular platforms for supporting ubiquitous high-speed mobile applications. However, a number of research challenges remain to be tackled. One of the most important challenges is the design of a judicious packet scheduler that will make efficient use of the spectrum bandwidth. Due to the multicarrier nature of the OFDM systems, the applicability and performance of traditional wireless packet scheduling algorithms, which are designed usually for single-carrier systems, are largely unknown. In this paper we present a new scheduler which includes packet scheduling and resource mapping which takes. The proposed algorithm is based on a cross-layer design in that the scheduler is aware of both the channel at the physical layer and the queue state at the data link layer information to achieve proportional fairness while maximizing each user's packet level QoS performance. The performance of the proposed work is compared to that of the round-robin and weighted fair queuing schedulers. It is observed that from the simulation that the proposed scheduling with adaptive parameter selection provides enhanced performance in terms of queuing delay and spectral efficiency. Also we analyze the achieved fairness of the schemes in terms of different fairness indices available in literature.

Keywords: Cross layer design, Packet scheduling, Orthogonal frequency division multiplexing (OFDM), Adaptive token bank fair queuing (ATBFQ).

1. Introduction

The tremendous growth in 1G and 2G wireless networks paved way for development of next generation networks. To meet the growing demands in the number of subscribers, rates required for high speed data transfer and multimedia

Nomenclatures

d	Debt limit
E	A counter
FI	Fairness index
L	Number of bytes of information
p	Token pool size
r	Token generation rate

Greek Symbols

γ_{ij}	SNR of the selected user i in chunk j
λ	Packet arrival rate

Subscripts

i	A user
j	A frame or chunk
max	Maximum

Abbreviations

AMC	Adaptive modulation and coding
ATBFQ	Adaptive token bank fair queuing
MAC	Medium access control
OFDM	Orthogonal frequency division multiplexing
QoS	Quality of service
RLS	Radio link control
RR	Round-roubin
SNR	Signal to noise ratio
TBFQ	Token bank fair queuing
UT	User terminal
WFQ	Weighted fair queuing

applications 3G standards started evolving. Now, the approaching 4G wireless communication services aims to develop an innovative concept in radio access in order to achieve high flexibility and scalability with respect to data rates and radio environments.

The high speed multimedia packet based applications, usually exhibit a large variety of QoS requirements, such as transmission rate, delay and packet dropping ratio, which are difficult to be satisfied in a wireless environment due to the limited radio resource, the time varying channel condition and the resource contention among multiple users. Recently, the orthogonal frequency division multiplexing system has been identified as promising wireless interface solution for 4G systems due to its high capacity to combat channel fading and support for a high data rate (HDR) [1]. Moreover, because it can provide a high degree of flexibility for resource control on different sub carriers, an adaptive packet scheduling for a multiuser OFDM system is widely considered as an important strategy to improve system performance.

Traditionally, the research on packet scheduling has emphasized QoS and fairness issues, and opportunistic scheduling algorithms have focused on exploiting the time varying nature of the wireless channels in order to maximize throughput. This segregation between packet scheduling and radio resource allocation is inefficient. As fairness and throughput are reciprocally related, an intelligent compromise is necessary to obtain the required QoS while exploiting the time varying characteristics of the wireless channel. Therefore, it is important to merge the packet scheduling and the resource allocation to design a cross-layer scheduling scheme [2].

A number of scheduling schemes in the literature analyze physical (PHY) and medium access control (MAC) related design issues by assuming that all users are backlogged, that is, all users in the system have non empty buffers. However, it is shown in [3] that this assumption is not always true, since the number of packets in the buffers can vary significantly, and there is a relatively high probability that the buffers are empty. Consequently, empty queues and partially filled time slots will affect the system performance. Furthermore, these non-queue aware scheduling algorithms lack the capability to provide required fairness among user terminals (UTs). Hence, it becomes necessary to consider queue states in scheduling and resource allocation [4]. The mechanism also facilitates the design of single-frequency networks, where several adjacent transmitters send the same signal simultaneously at the same frequency, as the signals from multiple distant transmitters may be combined constructively rather than interfering as it would typically occur in a single-carrier system [5].

In recent years, some schemes have considered integrating packet scheduling and radio resource scheduling into queue and channel aware scheduling algorithms. Stamoulis et al. [6] proposed a weighted fair queuing (WFQ) scheduling scheme, where the largest share of the radio resources is given to the users with the best instantaneous channel conditions in a code-division multiplexing based network. There are chances of starvation that may happen to some users based on the weight assigned to the flow. So it is necessary to find a novel scheduling scheme considering both channel and queue states in to account.

In this paper, we present a scheduler which comprises packet scheduling and resource mapping taking both queue and channel states into account. . In the first level of packet scheduling, users to be served are selected based on Token Bank Fair Queuing [TBFQ] algorithm, considering fairness and delay constraints among users. For our proposed work, the basic TBFQ algorithm is slightly modified by introducing additional parameters like traffic loading and user channel conditions, which adaptively interact with the second level of scheduling (resource mapping). Based on this, the second level of scheduling assigns resources to selected users in an adaptive manner using OFDM (Orthogonal Frequency Division Multiplexing) technique.

The rest of the paper is organized as follows. In section 2, cross-layer system model is described in detail. The Adaptive Token Bank Fair Queuing (ATBFQ) algorithm is discussed in section3. The simulation results and discussion are given in section 4 followed by conclusion in section 5.

2. Cross-Layer System Model

The TBFQ algorithm was initially developed for wireless packet scheduling in the downlink of TDMA systems and was later modified for wireless multimedia services using uplink as well [7, 8]. Its concept was based on the leaky-bucket mechanism which policies flows and conforms them to a certain traffic profile.

Figure 1 shows a traffic flow belonging to user *i*, which is characterized by the following parameters: packet arrival rate (λ_i), token generation rate (r_i), token pool size (p_i) and counter that keeps track of the number of tokens borrowed from or given to the token bank by flow *i* (E_i). Each packet includes *L* bytes of information.

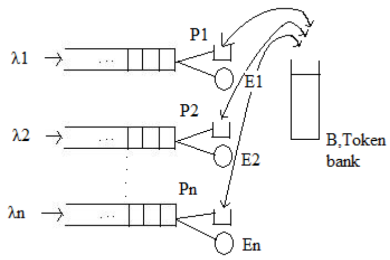

Fig. 1. Traffic Flow Considered.

Each byte of the packet consumes one token. As tokens are generated at rate r_i, the token overflowing from the token pool are added to the token bank, and E_i is incremented by the same amount. When the token pool is depleted and there are still packets to be served, tokens are withdrawn from the back by flow *i*, and E_i is decreased by the same amount. Thus, during periods when the incoming traffic rate of flow *i* is less than its token generation rate, the token pool always has enough tokens to serve arriving packets, and E_i increases and becomes positive and increasing. On the other hand, during periods when the incoming traffic rate of flow *i* is greater than its token generation rate, the token pool is emptied at a faster rate than it can be refilled with tokens. In this case, the connection may borrow tokens from the back. The priority of a connection in borrowing tokens from the bank is determined by the priority index, p_i, is given by

$$p_i = E_i / r_i \tag{1}$$

By assigning priority to the incoming flows in this manner we can ensure that flows belonging to UTs that are suffering from severe interference, and shadowing conditions in particular, will have a higher priority index, since they will contribute to the bank more often.

For multi carrier OFDM systems, traditional TBFQ algorithm is not suitable, which is originally designed for single carrier systems. In order to suit OFDM systems, some additional parameters are required along with TBFQ [9]. The motivation behind this modification is to incorporate the design and performance requirements of the scheduler in 4G networks in to the original scheme. In such networks, the utilization of resources and hence the performance of the network can be enhanced by making use of the multiuser diversity provided by the multiple access scheme being used. In order to make use of the channel feedback, faster scheduling is required. Another requirement is the ability to maintain fairness and provide a minimum acceptable QoS performance to all users.

The cross-layer model considered for design is given in Fig. 2. The basic time-frequency resource unit in OFDM is denoted as a chunk. It consists of a rectangular time-frequency area that comprises a number of subsequent OFDM symbols and a number of adjacent subcarriers. Packets from the traffic flows are exclusively mapped on to these chunks based on QoS requirements obtained from the higher Radio Link Control (RLC) layer along with the channel feedback received from the physical layer. The channel feedback comprises Signal to Noise Ratio (SNR) which is measured in the downlink portion of the frame *j* at the UT's (User Terminal).

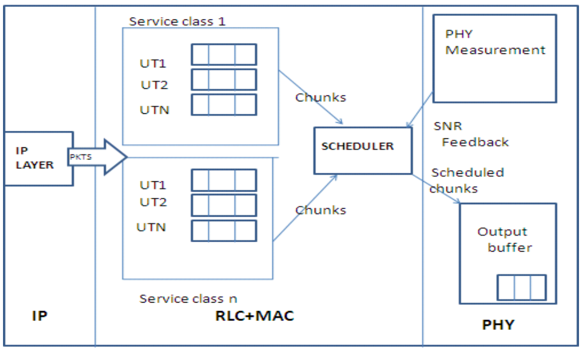

Fig. 2. System Model.

This feedback is then provided to the frame *j*+1 and can be utilized for scheduling purposes at the MAC layer in the downlink of the next frame *j*+2. This adaptive fair queuing using token banking system is based on the principle of leaky bucket mechanism. A debt limit d_i is set as a threshold to limit the amount a UT can borrow from the bank. It also acts as a measure to prevent malicious UTs from borrowing extensively when transmitting at unusually high transmission rates. The packets are then queued in sub queues in a per-flow queuing based on the service classes.

3. Adaptive Token Bank Fair Queuing (ATBFQ) Algorithm

The following steps are executed for implementing the ATBFQ algorithm.

Step 1: At the scheduler, information is retrieved from the higher layer about all active users. An active user is defined as a backlogged queue which has packets waiting to be served.

Step 2: Based on the list of active users, a priority index is calculated using Eq. (1). This step returns the user *i* with the highest priority.

$$i(t_k) = \arg \max_{1 \le i \le N_{act}} (p_i) \tag{2}$$

Step 3: A certain budget is calculated for the priority user, which depends on the value of the token counter and the debt limit d_i , is given by E_i-d_i. E_i keeps track of how much the user has borrowed or given to the bank. The d_i keeps track of how much a user can further borrow from the bank in order to accommodate the burstiness of the traffic over the long term.

Step 4: If the calculated budget is less than the bank size, resources are allocated to the user *i*. This is the second level of scheduling, and deals with allocation of chunk resources to the selected user *i*. Based on the maximum SNR principle. In this principle, the chunk *j* with the best SNR is given to the selected user [10], and can be expressed by

$$j(t_k) = \arg \max_{1 \le j \le N_{chunks}} \{\gamma_{ij}(t_k)\} \tag{3}$$

where γ_{ij} is the SNR of the selected user *i* in chunk *j*. This is the most opportunistic of all scheduling algorithms or time-slotted networks. This means that the Adaptive Modulation and Coding (AMC) policy maximally exploits the frequency diversity of the time-frequency resource, where a chunk is allocated to only one user and a user have multiple chunks in a scheduling instant.

Step 5: The resource mapping is done to determine the amount of bits mapped to the chunks depending on the AMC mode used.

Step 6: Each time chunk resource is allocated, then the token bank, the token counter, and the allocated budget is updated.

The selected user gets to transmit as long as its queue remains backlogged and the allocated budget is less than total bank size and more than the number of bits that can be supported with the lowest AMC mode. If either of the conditions is not satisfied, the user is classified as non-active. A new priority is calculated for new updated active users and steps 1-6 are repeated. This procedure is repeated until there are no chunk resources available or there are no active users.

The parameters for ATBFQ algorithm are initialized with -0.5 MB as debt limit and the token generation rate varies for different type of inputs, which includes rt-ps (real time polling service) , nrt-ps (non real time polling service) and best effort service. The token generation rate should be large enough to handle instantaneous bursty traffic. In simulations, this token generation rate is taken as three times larger than the packet arrival rate. The burst credit for flow i determine the amount of bits selected for user 'i' can receive in a frame adaptively to obtain high spectral efficiency.

4. Simulation Parameters

The ATBFQ algorithm implementation in downlink scenario is studied with the following simulation parameters. The bandwidth is assumed as 15 MHz. the chunk dimension is given as 8 sub carriers by 12 OFDM symbols. The frame duration is given as 691.2 micro seconds. So there are totally 96 chunks present per frame.

Time and frequency correlated Rayleigh fading channel is used to generate the fading channel coefficients. The channel feedback comprises SNR which is measured in the downlink portion of the frame j at the user terminals. This feedback is then provided to the base station in the uplink duration of the frame j+1 and can be utilized for scheduling purposes at the MAC layer in the downlink portion of the next frame j+2.

Table 1. Transmission Modes Specified for AMC and corresponding Chunk Throughput.

AMC Mode	Coding Rate	SNR (dB)	Chunk Throughput (bits)
BPSK	1/2	0 to 1.2311	48
QPSK	1/2	1.231 to 4.242	96
QPSK	3/4	4.242 to 6.686	144
16 QAM	1/2	6.686 to 10.33	192
16 QAM	3/4	10.33 to 14.08	288
64 QAM	2/3	14.08 to 15.6	384
64 QAM	5/6	15.6 and above	432

The Adaptive modulation with concatenated Reed Solomon and Convolutional codes is used for adaptive transmission schemes. A better adaptation algorithm is used to provide a better tradeoff between throughput and overall bit error rate by choosing a more suitable scheme for each sub band. The average value of the SNR of the sub carriers in the sub band is used for adaptive modulation schemes. The switching algorithm used for the adaptive modulation schemes is based on the transmission parameters given in Table 1 as specified in IEEE 802.11/15/16 [11].

5. Results and Discussion

The performance results are compared with Round-Robin (RR) and Weighted Fair Queuing (WFQ) algorithms in terms of fairness, spectral efficiency (b/s/Hz) and delay (ms). In RR scheduling, all the users have equal chances of getting the service. For delay sensitive applications, RR algorithm is not suitable because the flows suffer severe starvation due to the lack of immediate service.

In WFQ algorithm, the chances of getting service are based on the weight assigned to the user. Obviously more weights are assigned to the delay sensitive applications. In this algorithm also starvation cannot be avoided for non-delay sensitive applications.

Fairness index is one of the performances metric to evaluate the proposed cross-layer scheduling. If a system allocates resources to n contending user terminals such that the i^{th} user receives an allocation x_i, then the fairness index is given by

$$FI = \left(\sum_{i=1}^{n} x_i\right)^2 \Big/ n\sum_{i=1}^{n} x_i^2 \quad (4)$$

where $x_i \geq 0$. This index measures the quality of user terminal allocation i. for our work, the allocation metric x is defined as the ratio of the user terminal throughput and queue size. The fairness index obtained for the RR, WFQ and the proposed cross-layer scheduling with ATBFQ algorithm is given in Table 2.

Table 2. Fairness Achieved.

Algorithm	*FI*
RR	0.35
WFQ	0.6
ATBFQ	0.8

Table 3. Performance Measures.

Algorithm	Spectral Efficiency (b/s/Hz)	Delay (ms)
RR	3	190
WFQ	3.65	110
ATBFQ	4	42

The spectral efficiency and delay measures from the simulation of the three algorithms are listed in Table 3. Based on the results obtained, it can be said that the proposed scheduling is having better performance than the other two algorithms.

In this simulation, adaptive mode transmission data will be transmitted constantly during AMC even though the channel is in deep fades. If the channel quality is very bad, a robust modulation mode will be used and when the channel quality is good, a spectrally efficient modulation will be used. The result shown in Table 3 is obtained when the average SNR is above 15 dB or when M_n-ary QAM modulation mode is selected.

6. Conclusions

In this paper, the performance of the ATBFQ scheduling algorithm with adaptive parameter selection is presented. It is a queue and channel-aware scheduling algorithm which attempts to maintain fairness among all users. The performance of the ATBFQ algorithm is compared with reference to Round-Robin and Weighted Fair Queuing scheduling schemes. Being an opportunistic scheduling belonging to the proportional fair class, WFQ aims to maximize throughput while trying to maintain fairness. However, the users in this scheme, suffering from poor channel conditions, are more severely affected. Also, due to the bursty traffic, such users experience higher queuing delay, results in a more packet dropping. But ATBFQ is a credit-based scheme which aims to accommodate the burstiness of users by assigning them more resources in the short term, provided that long term fairness is maintained. The observed results indicate the superiority of ATBFQ algorithm.

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