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A dynamic joint scheduling and call admission control scheme for IEEE 802.16 networks

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Abstract We propose a dynamic joint scheduling and call admission control (CAC) scheme for service classes defined in IEEE 802.16 standard. Using priority functions, equipped with service weights and service arrival rates, the proposed scheduling scheme differentiates service classes from each other. Based on obtained priority values, we first allocate the achievable bandwidth proportionally. Within individual service classes, we then use appropriate local schedulers to transmit packets accordingly. Moreover, instead of immediate admitting or blocking a new connection request, the proposed CAC scheme computes the average transmission rate that can be allocated to that connection during a time interval. The connection is admitted if its required rate is satisfied while at the same time QoS requirements of ongoing connections are not violated. Our numerical results demonstrate the effectiveness of the proposed schemes compared to the other schemes in the literature.

Keywords IEEE 802.16 · Scheduling · Call admission control · Quality of service

1 Introduction

IEEE 802.16 standard, also known as WiMAX, has been designed to provide wireless broadband access with quality of service (QoS) guarantees in Metropolitan areas [1]. Wireless networks based on this standard can be configured in either single-hop or multi-hop architecture, where there is a base station (BS) that provides Internet access to subscriber stations (SS). These stations, in turn, establish connections between the BS and end-users, through which requested services are provided.

QoS provision in wireless networks requires effective resource allocation schemes. To allocate resources more efficiently, IEEE 802.16 standard employs scheduling-based channel access [2] rather than random-based channel access as proposed in IEEE 802.11 standard. In the scheduling-based method, service priorities are determined based on their bandwidth requests and defined preferences in the standard [3]. Accordingly, network resources such as time, space, frequency, and power are allocated so as to satisfy QoS requirements.

Considering traffic characteristics and service requirements, IEEE 802.16 classifies services of established connections into the following four QoS groups: Unsolicited grant service (UGS) provides real time applications with fixed-size data packets streaming on a periodic basis, e.g. VoIP. Real time polling service (rtPS) provides real time applications with variable-size data packets streaming on a periodic basis, e.g. MPEG video. Non-real time polling service (nrtPS) includes delay tolerant non-real time applications, which require a minimum transmission rate, e.g. FTP.

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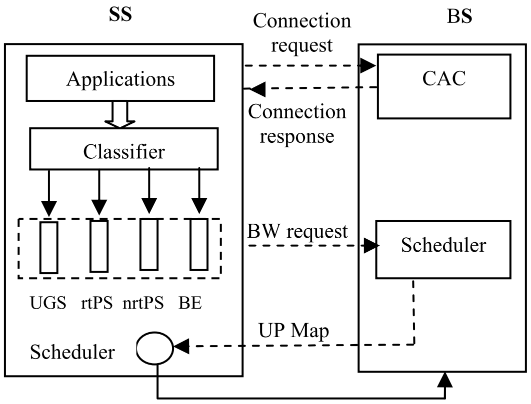

Fig. 1 IEEE 802.16 QoS architecture

Best effort (BE) includes delay tolerant non-real time applications, which do not require any kind of QoS guarantees, e.g. HTTP.

QoS architecture in the uplink direction of IEEE 802.16 standard is shown in Fig. 1. In this architecture, traffic streams in each SS are classified into four service queues. SS notifies the BS of the required bandwidth for service queues. The BS, in turn, schedules the network resources in order to manage the requests from SSs throughout the network. This scheduling is broadcasted in the network by *UL Map* message, which determines the transmission time of each service.

Because of wireless network resource constraints, IEEE 802.16 standard additionally controls newly arrived connections by a call admission control (CAC) mechanism at the BS. Upon generation of a new connection, SS sends a connection request to the CAC in the BS. This mechanism decides on either admitting or blocking the connection and sends back the response to the corresponding SS. In case of admission, CAC ensues not only enough resources are available for newly arrived connection, but also ongoing connections are still provided with guaranteed QoS [4]. Even though IEEE 802.16 has defined the signaling interface of the scheduling and CAC blocks in the QoS architecture in Fig. 1, corresponding algorithms are still open for more research work.

There has been a significant research on IEEE 802.16 scheduling. Weighted round-robin (WRR) and earliest deadline first (EDF) schemes are used in [5] and [6], respectively. EDF scheme transmits packets according to their associated deadlines. Proportional fairness (PF) scheme proposed in [7] allocates the whole bandwidth to the user with the highest priority at each time slot. Weighted fair queuing (WFQ) scheme is proposed in [8] for non-real time traffic. To schedule both real time and non-real time traffic simultaneously, modified largest weighted delay first (M-LWDF) scheme is proposed in [9] to guarantee a minimum transmission rate.

CAC in wireless networks has been extensively studied in the literature [4]. A bandwidth allocation and CAC scheme to provide low blocking probability of new connections is proposed in [10]. Authors in [11] aim at handling handoff connections via predicting the trajectory of mobile users in the network. A framework to scale down the bandwidth of ongoing connections in order to admit new connections is proposed in [12]. Despite the similar extensive works, a CAC scheme in IEEE 802.16 networks, however, needs to consider a multi-class service structure consisting of different service queues such as in [13–16]. An analytical model has been proposed in [13] to minimize the blocking probability of each type of service classes in IEEE 802.16 network. Moreover, CAC schemes based on the token bucket principle were proposed in [14] and [15]. Authors in [14] use a bandwidth borrowing and granting mechanism between the ongoing and new connections so as to come up with admission or blocking decisions, whereas authors in [15] simply check for the availability of bandwidth to satisfy QoS requirements of the new connection. Furthermore, a game theoretic approach on CAC and bandwidth allocation was proposed in [16], where the base station and the new connection are players of the game.

In the scheduling part of the literature, there is no consideration on incorporating traffic arrival rate into the scheduling decisions. This issue causes the queue-lengths grow unexpectedly and make the network unstable, which either results in congestion and large delay, or lead to a huge data loss when the buffer sizes are limited. Moreover, CAC schemes in the literature make admission or blocking decisions instantaneously, at the same time of a connection request. Due to the stochastic nature of arrival traffic and time-varying channels, this approach might not be efficient enough. Using this approach, enough resources might be available for a blocked connection in the later time slots. Therefore, making decisions in a time interval rather than just in a time slot could improve the network performance.

In this paper, we propose a dynamic joint scheduling and CAC scheme for providing QoS in the context of IEEE 802.16 standard. We use a two level scheduling. Using a weighted service queuing approach, a global scheduler in the first level computes priority values corresponding to the service queues. The available bandwidth is then allocated proportionally. In the second level, corresponding to each service queue, we use a local scheduler to transmit contained packets via the allocated bandwidth. For CAC, every new connection is temporarily admitted into the network. The impact of this admission on the network performance is evaluated during a time interval so as to come up with the final CAC decision.

This paper is organized as follows. System model is described in Sect. 2. Scheduling and CAC schemes are proposed in Sects. 3 and 4, respectively. In Sect. 5, simulation results are presented, and the paper in concluded in Sect. 6.

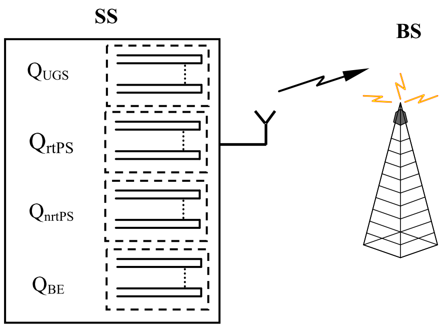

Fig. 2 System model

2 System model

We consider uplink transmission in IEEE 802.16 standard where packets of a set of queues $Q = \{Q_i : i = 1, 2, \dots, N\}$ are transmitted from a SS to a BS, as shown in Fig. 2. Four groups of queues Q_{UGS}, Q_{rtPS}, Q_{nrtPS}, and Q_{BE} are considered to transmit UGS, rtPS, nrtPS and BE traffic, respectively.

We consider a single-carrier and time-slotted transmission, where channel state information remains unchanged during each time slot but varies randomly and independently across time slots. Transmission data of individual service queues are arranged into a transmission symbol at each time slot. The channel is considered to be a Rayleigh fading channel where the received signal to noise ratio (SNR), γ, follows an exponential distribution as

$$f(\gamma) = \frac{1}{\bar{\gamma}} \exp\left(-\frac{\gamma}{\bar{\gamma}}\right) \tag{1}$$

where $\bar{\gamma}$ is the average SNR. Accordingly, channel capacity at time slot t is given by the Shannon formula [17] as

$$C(t) = \log_2(1 + \gamma(t)) \text{ bps/Hz}. \tag{2}$$

3 Scheduling scheme

In this section, we propose the scheduling algorithm. Due to the high priority of UGS class in IEEE 802.16 standard, we always reserve a predetermined amount of bandwidth, C_{UGS}, to be allocated to this class. Moreover, we assume that handling hand-off connections from the other SSs requires $C_{\text{hand-off}}$. Therefore, we manage the bandwidth $C'(t) = C(t) - C_{\text{UGS}} - C_{\text{hand-off}}$ to be allocated to rtPS, nrtPS and BE services at every time slot t via the following two-level scheduling scheme.

3.1 Level one

First, using a weighted service queuing (WSQ) approach, each service queue is assigned a predetermined priority weight, i.e., w_{rtPS}, w_{nrtPS}, and w_{BE}. In accordance with the standard, we consider the priority weights as

$$w_{\text{rtPS}} > w_{\text{nrtPS}} > w_{\text{BE}} \tag{3}$$

which shows the highest priority for rtPS and the lowest one for BE. To determine the fraction of bandwidth to be allocated to each service class $s \in \{\text{rtPS}, \text{nrtPS}, \text{BE}\}$, we use priority functions as

$$p_s(t) = \frac{w_s(l_s(t) + 1)\bar{\lambda}_s(t)}{\bar{r}_s(t)} \quad \text{for all } s \tag{4}$$

at time slot t. In (4), w_s is the priority weight as in (3) and $l_s(t)$ is the packet dropping probability. Moreover, $\bar{\lambda}_s(t)$ and $\bar{r}_s(t)$ denote the average arrival and departure rates of class s up to time t, respectively. Having $\lambda_s(t)$ and $r_s(t)$, arrival and departure rates at time t, we use exponential moving average expressions to derive average rates at time $t + 1$ as

$$\bar{\lambda}_s(t+1) = (1 - 1/T_c)\bar{\lambda}_s(t) + (1/T_c)\lambda_s(t), \tag{5}$$

$$\bar{r}_s(t+1) = (1 - 1/T_c)\bar{r}_s(t) + (1/T_c)r_s(t) \tag{6}$$

where T_c is the number of time slots over which rates are averaged. Incorporating the average arrival rates into the scheduling decisions is the key point in WSQ so that service queues remain stable.

We adopt the assumption that service queues are backlogged, i.e., there are always enough data packets in the queues to transmit. Therefore, the amount of the bandwidth allocated to each queue is the same as its departure rate. Given the priority values obtained in (4), the bandwidth to be allocated to each service class is obtained as

$$r_s(t) = \frac{p_s(t)}{\sum_i p_i(t)} C'(t) \quad \text{for all } s \tag{7}$$

where $i \in \{\text{rtPS}, \text{nrtPS}, \text{BE}\}$. As shown, the allocated bandwidth to each service queue is proportional to its priority value.

3.2 Level two

Given $r_{\text{rtPS}}(t)$, $r_{\text{nrtPS}}(t)$ and $r_{\text{BE}}(t)$ obtained in level one, we secondly use local schedulers to transmit packets in individual service classes separately. These schedulers are based on the assumption that each packet in a service queue is associated with a *deadline time* and a *weight* in rtPS and nrtPS classes, respectively. These parameters are utilized by the local schedulers. For rtPS, nrtPS, and BE classes, we respectively use EDF, WFQ, and first input first output (FIFO) scheduling schemes. EDF first sorts packets in rtPS service class with respect to their associated time deadlines and then transmits them accordingly, i.e., packets with the earliest deadlines are transmitted first. On the other hand, WFQ

Algorithm 1 WSQ scheduling scheme

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Compute priority values as in (4).
Compute $r_s(t)$, $s \in$ {rtPS, nrtps, BE}, as in (7).
Use EDF scheme to transmit $r_{\mathrm{rtPS}}(t)$ packets from all $Q_i \in Q_{\mathrm{rtPS}}$.
Use WFQ scheme to transmit $r_{\mathrm{nrtPS}}(t)$ packets from all $Q_i \in Q_{\mathrm{nrtPS}}$.
Use FIFO scheme to transmit $r_{\mathrm{BE}}(t)$ packets from all $Q_i \in Q_{\mathrm{BE}}$.
Update each queue length as $Q_i(t) = Q_i(t-1) + \lambda_i(t) - r_i(t)$ for all $i$.
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Algorithm 2 CAC scheme

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Upon arrival of a new connection NC at time slot $t$:
01. Set $r_{\mathrm{NC}}(t-1) = 0$.
02. for $t' = t$ to $t + T$
03.     Obtain $r_{\mathrm{rtPS}}(t')$, $r_{\mathrm{nrtPS}}(t')$ and $r_{\mathrm{BE}}(t')$ from the scheduling algorithm.
04:     $\Delta r_{\mathrm{rtPS}}(t') = r_{\mathrm{rtPS}}(t') - r^{\mathrm{TH}}_{\mathrm{rtPS}}$.
05:     $\Delta r_{\mathrm{nrtPS}}(t') = r_{\mathrm{nrtPS}}(t') - r^{\mathrm{TH}}_{\mathrm{nrtPS}}$.
06:     $\Delta r_{\mathrm{BE}}(t') = r_{\mathrm{BE}}(t') - r^{\mathrm{TH}}_{\mathrm{BE}}$.
07:     $r_{\mathrm{NC}}(t') = (1 - 1/T) r_{\mathrm{NC}}(t'-1) + (1/T)(\Delta r_{\mathrm{rtPS}}(t') + \Delta r_{\mathrm{nrtPS}}(t') + \Delta r_{\mathrm{BE}}(t'))$.
08. end for
09. if $(r_{\mathrm{NC}}(t') \geq r^{\mathrm{TH}}_{\mathrm{NC}})$
10.     accept NC.
11. otherwise
12.     Block NC.
13: end
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sorts packets in ntrPS class with respect to their associated weights and transmits high weight packets first. Moreover, FIFO scheme does not consider any priority among the packets. Given the aforementioned comments, we propose WSQ scheduling scheme in Algorithm 1.

4 CAC scheme

CAC schemes in the literature make admitting or blocking decisions instantaneously, at the time of the connection request. Due to the variable nature of traffic and channel state information in wireless networks, these decisions are not efficient enough. For instance, a blocked connection in the current time slot might be admitted in the next time slots due to the possibility of channel quality improvement. Moreover, immediate rate allocation to an admitted connection changes the rate of ongoing connections abruptly. This issue makes the network unstable, which requires more signaling overhead such as TCP protocol to resume the network.

Based on the CAC categories in [4], we propose a reactive (measurement-based) CAC scheme in cooperation with the proposed scheduling scheme. At the beginning of each time slot, we use the proposed WSQ scheduling to allocate the available bandwidth, $C'(t)$, to the ongoing connections. We assume that rtPS, nrtPS, and BE services should at least be provided with predetermined departure rates $r^{\mathrm{TH}}_{\mathrm{rtPS}}$, $r^{\mathrm{TH}}_{\mathrm{nrtPS}}$, and $r^{\mathrm{TH}}_{\mathrm{BE}}$, respectively. Upon arrival of a new connection request, NC with a threshold rate $r^{\mathrm{TH}}_{\mathrm{NC}}$, we compute the average bandwidth that can be allocated to it for a period of T time slots via exponential moving average. This connection is admitted if the threshold rate $r^{\mathrm{TH}}_{\mathrm{NC}}$ is satisfied in average during this period, otherwise blocked. The proposed CAC scheme is presented in Algorithm 2.

In this algorithm, $r_{\mathrm{NC}}(t')$ is the average departure rate allocated to connection NC up to time slot t'. Also $r_{\mathrm{rtPS}}(t')$, $r_{\mathrm{nrtPS}}(t')$, and $r_{\mathrm{BE}}(t')$ are the allocated rates at time slot t' to rtPS, nrtPS, and BE services, respectively. The extra bandwidths from ongoing connections, which can be allocated to NC at time slot t', are computed in lines 4–6. In line 7, $r^{\mathrm{TH}}_{\mathrm{NC}}$ is updated using an exponential moving average, where $(\Delta r_{\mathrm{rtPS}}(t') + \Delta r_{\mathrm{nrtPS}}(t') + \Delta r_{\mathrm{BE}}(t'))$ is the aggregate extra bandwidth. The new connection NC would be admitted if the required threshold rate $r_{\mathrm{NC}}(t')$ can be provided in average after T time slots, otherwise NC would be blocked.

Even though the proposed scheme incurs delay in CAC decision making, it considers the achievable bandwidth in the time-varying channel so as to come up with more accurate decisions. The value of T is a trade-off between delay and the desired stability. As the network dynamic increases, the value of T should be increased to make more stable decisions.

5 Numerical results

We consider uplink transmission from a SS to a BS in a single-hop network. Transmission channel is assumed to be a Rayleigh fading channel with 10 dB SNR in average. Arrival rates to service queues, maintained in the SS, follow a Poisson distribution with mean 900 packets per time slot. Packets of each service are maintained in a separate buffer of 7000 packets. In the following, we evaluate the performance of the proposed WSQ and CAC schemes in Sects. 5.1 and 5.2, respectively.

5.1 WSQ performance evaluation

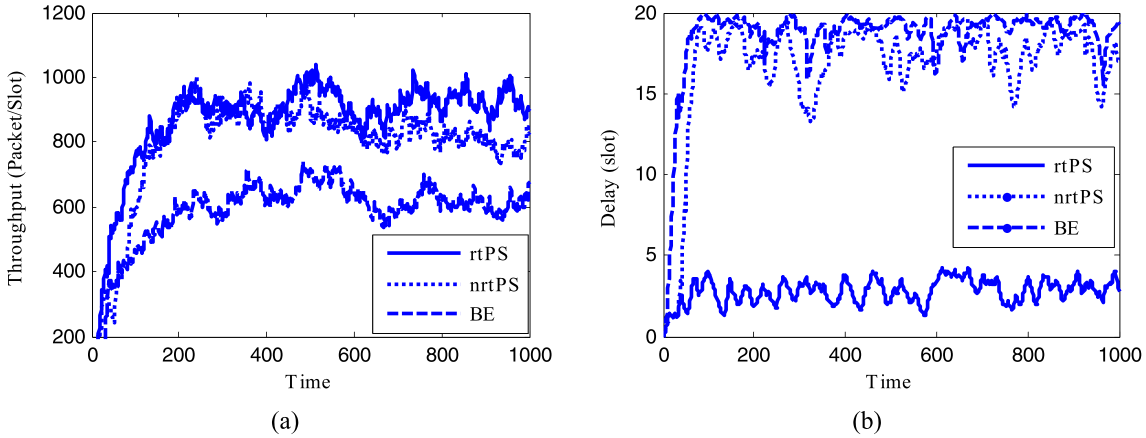
We perform the simulation for 1000 realizations of the fading channel. Throughput and delay performance of WSQ scheduling for different service classes over the simulation time are depicted in Figs. 3a and 3b, respectively.

As shown, rtPS and BE classes have been allocated the highest and the lowest throughputs, respectively, in accordance with the priority weights in (3). Delay of rtPS service is much smaller than those in the other classes. This is due to the fact that EDF scheduling in rtPS class transmits packets before their deadlines approach. Furthermore, while nrtPS throughput is much higher than that of BE, their delay performance is comparable. The reason is that WFQ scheduling in nrtPS class serves the packets based on the associated weights rather than arrival times in BE class.

In the following, we compare WSQ with MLWDF and round robin (RR) scheduling schemes. MLWDF is a well-known joint channel-aware and queue-aware scheduling scheme proposed in [9] to support both real time and non-real time traffic. This algorithm allocates the whole bandwidth, at each time slot, to the queue with the maximum priority value. On the other hand, RR allocates the available bandwidth to network services equally without considering any priority. The average throughput of service classes are shown in Fig. 4a for WSQ, MLWDF and RR scheduling schemes. WSQ throughputs are in accordance with Fig. 3a. RR serves service classes equally which results in the same throughput for all of them. Throughput performance in MLWDF follows our observation in [18] that the channel in this scheme is mostly allocated to nrtPS and BE classes, i.e., non-real time traffic, because of high queue lengths. Following the result in Fig. 4a, delay performance in Fig. 4b shows that WSQ provides rtPS class with lower delay than those of MLWDF and RR schemes.

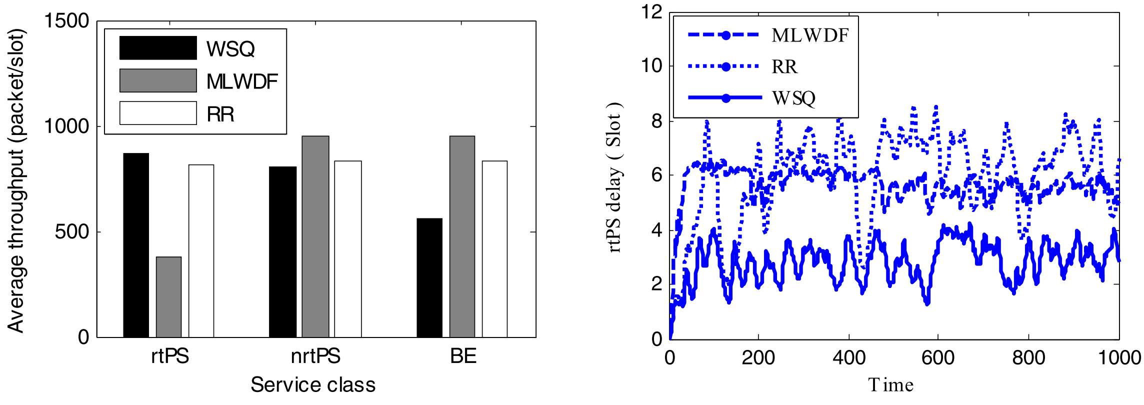
5.2 CAC performance evaluation

The set up in Sect. 5.1 is also used in this subsection to evaluate the performance of the proposed CAC scheme. The scheme parameters are set as $r^{\mathrm{TH}}_{\mathrm{nrtPS}} = 900$ and $r^{\mathrm{TH}}_{\mathrm{BE}} = 500$. In case of rtPS, we evaluate $r^{\mathrm{TH}}_{\mathrm{rtPS}}$ at each time slot such that delay of this class would be less than 5 time slots. Time duration T, the number of time slots over which the allocated bandwidth to a new connection is averaged, is set to 10 time slots based on our observations to get smooth results in our case. Beginning the simulation with 3 service classes, we assume that inter arrival time of new connections follows an exponential distribution with mean 50 time slots. Moreover, the service type of every new connection is considered to be either BE or rtPS or nrtPS with equal probabilities. In what follows, we compare the performance of our proposed CAC scheme with those of token-bucket-based CAC mechanisms in [13–15] in terms of throughput for nrtPS and BE classes and delay for rtPS class. In contrast to the proposed CAC scheme, these mechanisms make the CAC decision at the same time of connection request. In all of these schemes, scheduling of ongoing connections is carried out by WSQ scheme. Figures 5a and 5b illustrate the average throughput of nrtPS and BE classes, respectively, and Fig. 6a is the average delay of rtPS class. Moreover, the connection blocking probability in all classes is also depicted in Fig. 6b.



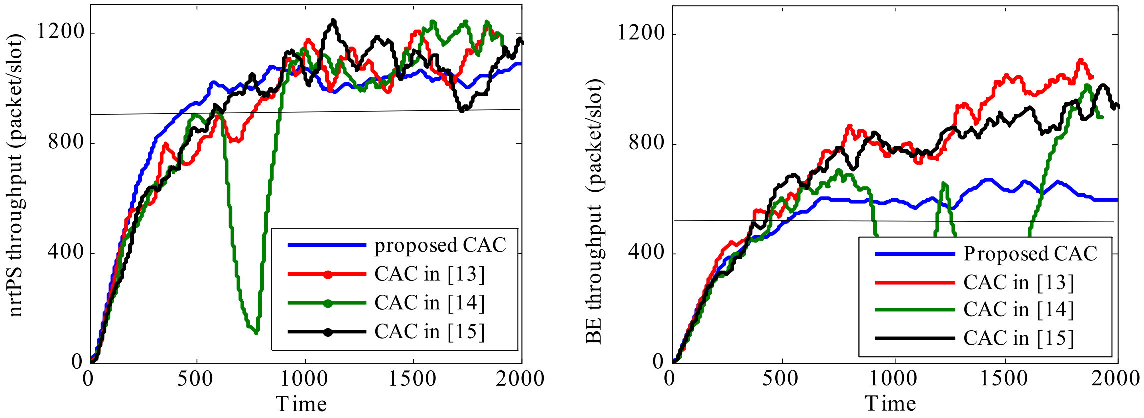
(a) (b)

Fig. 3 (**a**) Throughput, and (**b**) delay of WSQ scheduling



(a) (b)

Fig. 4 (**a**) Average throughput and (**b**) rtPS delay in WSQ, MLWDF, and RR scheduling schemes



(a) (b)

Fig. 5 Average throughput performance of (**a**) nrtPS class and (**b**) BE class

Because of immediate response to connection requests, the benchmark CAC schemes demonstrate back and forth in the allocated rate to ongoing connections, as in Fig. 5. However, the proposed CAC avoids the oscillation by some computations prior to the final CAC decision, as in Algorithm 2. Due to the more strict QoS requirements in rtPS class, the proposed CAC scheme also provides the lowest delay for this class in Fig. 6b, in the expense of low bandwidth for BE class in Fig. 5b.

The connection blocking probability is generally an informative criterion in the comparison of CAC schemes. As shown in Fig. 6b, this performance in the proposed CAC scheme significantly outperforms those schemes in [13] and [15], and remarkably is comparable with that in [14]. Despite of low blocking probability in [14], however, this scheme does not demonstrate an admissible performance because QoS requirements in this scheme are sometimes violated, as shown in Figs. 5 and 6b.

Low connection blocking probability of our proposed CAC scheme along with its ability to satisfy the QoS requirements in a multi-class service structure makes it appropriate for the application in IEEE 802.16 networks.

6 Conclusion

The cooperation between the scheduling and CAC in IEEE 802.16 standard improves the network performance. The degree of quality of service in IEEE 802.16 networks can be improved by providing different service classes with appropriate schedulers. Considering this differentiation, WSQ provides rtPS and nrtPS service classes with target delay and throughput requirements, respectively. Moreover, taking connection arrival rates into account in determining the allocated bandwidths avoids the network to be unstable. In addition, making CAC decisions after a period of time slots from the connection request time could results in fewer oscillations in the connection service rates and low connection blocking probability. As the service requirements become

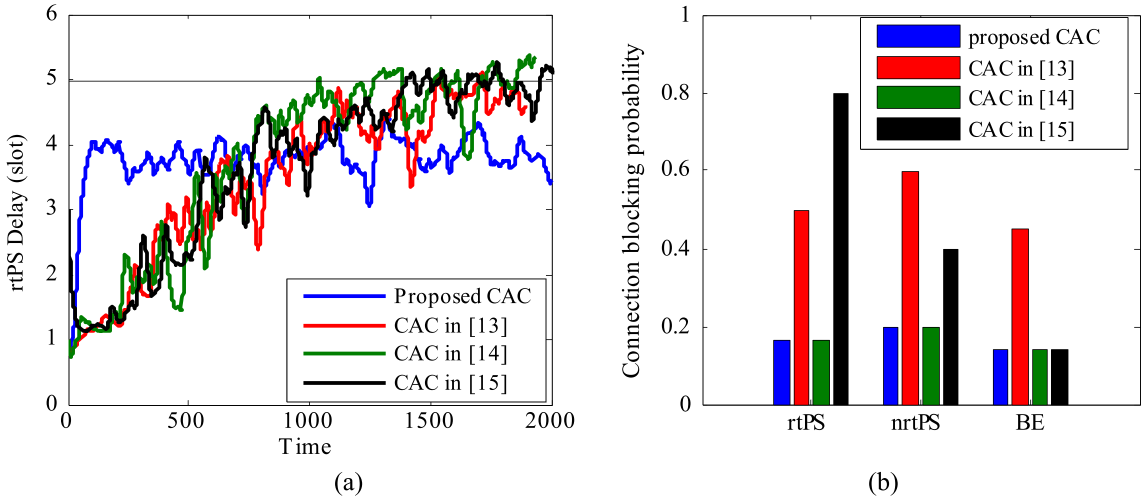


Fig. 6 (**a**) Average delay of rtPS class and (**b**) connection blocking probability

more restrictive, the number of admitted connections would be decreased.

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