

A Predictive Scheduling Algorithm for the Uplink Traffic in IEEE 802.16 Networks

Marcio A. Teixeira*, Paulo R. Guardieiro**

**Federal Institute of Education, Science and Technology of São Paulo, Salto, SP – Brazil.*

***Faculty of Electrical Engineering, Federal University of Uberlândia, Uberlândia-MG, Brazil.*

marcio.andrey@cefetsp.br, prguardieiro@ufu.br

Abstract— The IEEE 802.16 standard defines MAC and Physical layers for broadband wireless networks called WiMAX, however, it does not define the scheduling algorithm for the uplink and downlink traffic. In this paper, a predictive scheduling algorithm for uplink traffic in IEEE 802.16 networks is proposed. The proposed algorithm uses the cross-layer approach and is applied on the queue of the bandwidth requests messages in the BS. For each bandwidth request, the proposed algorithm calculates a deadline in accordance with the Modulation and Coding Schemes (MCS). Thus, the proposed algorithm reduces the average delay on the access network and uses the resource, in the environment with several burst profiles, in a fair and efficient way. Its evaluation by means of modeling and simulation showed satisfactory results.

Keywords— IEEE 802.16 Networks, Quality of Service, Scheduling, WiMAX.

I. INTRODUCTION

Nowadays, new technologies for wireless access networks are being developed, such as WiMAX (Worldwide Interoperability for Microwave Access) [1], LTE (Long Term Evolution) [2] etc. Therefore, the need to improve the packets scheduling algorithms in accordance with the evolution of these technologies emerges. Most of the proposed scheduling algorithms for wireless networks are based on traditional algorithms and are not completely suitable to the current problems in wireless communications networks.

An example of one current problem in WiMAX and LTE technologies is to scheduler the Subscriber Stations (SS) located in different points away from the Base Station (BS), and send data in different burst profiles, since the standard of these technologies defines the modulation adaptive function in the physical layer [3]. The scheduler must guarantee the Quality of Service (QoS) for each network application and allocate the resource in a fair and efficient way.

In this paper, a new scheduling algorithm for uplink traffic in IEEE 802.16 networks (WiMAX) is proposed. Different from the others scheduling algorithms, the proposed algorithm is applied directly to the bandwidth request queues of the base station and has three fundamental features that make it very efficient in a wireless communication environment. They are: 1) The utilization of the Cross-layer approach: the algorithm uses the information about the Modulation and Codification Schemes (MCS) that

are used in the physical layer, and therefore, calculates the transmission time of the data based on the bandwidth request messages provided by the SS; 2) It is predictive: the algorithm works along with a method that monitors and makes estimative of the delay and the throughput of the UGS, rtPS, nrtPS and BE service classes. The proposed algorithm uses the method information to make the scheduling between the service classes, and aims at the distribution of the existent resources between the several connections in a fair and efficient way; 3) It has a completely dynamic behavior: the scheduling decisions are based on the information from the method procedure, which has an overview of the base station resources and also the QoS parameters, becoming completely dynamic, always trying to maintain the QoS for the real time applications and the minimal resources for the non-real time applications.

The proposed scheduling algorithm has been evaluated by means of modeling and simulation. Experiments were performed considering scenarios with variations in the transmission rate based on the modulation and coding used, and also scenarios where only one type of modulation was used. The proposed algorithm showed satisfactory results in all scenarios.

The remainder of this paper is organized as follows: Section II presents an overview of the IEEE 802.16 standard. Section III describes the proposed scheduling algorithm. Section IV resumes the related works. Section V defines the network scenario and the main parameters used in the simulation. Section VI shows the numerical results. Finally, Section VII does the final considerations of this paper.

II. THE IEEE 802.16 STANDARD

The IEEE 802.16 standard specifies the physical layer (PHY) characteristics and also the medium access control (MAC) layer.

A. The Physical Layer

The physical layer defines the modulation schemes, the synchronization between the transmitter and receiver, the multiplexing schemes among other characteristics whose scope is not part of this paper. The data flows are transmitted in two directions: uplink (from SS to BS) and downlink (from BS to SS). The standard specifies two modes of accessing the physical medium: Frequency Division Duplexing (FDD) and

Time Division Duplexing (TDD) [4]. In our paper, only TDD mode was considered. The IEEE 802.16 also defines the Adaptive Modulation mechanism. Thus, the standard can deliver high throughput at long ranges with a high level of spectral efficiency that is also tolerant of signals reflections [5]. Dynamic adaptive modulation allows the BS to trade off throughput for range [6].

B. The MAC Layer

The MAC layer has mechanisms to provide QoS for the downlink and uplink traffic. The packets that cross the MAC layer are classified and associated with a service class. The service class defines a set of QoS parameters, such as delay, throughput, jitter etc. The IEEE 802.16 standard specifies four service classes [6], in which each service class should be treated differently by the BS. A variation at the IEEE 802.16 standard, named IEEE 802.16e [7], was specified and defines a new service class named extended real-time Polling Service (ertPS), but, this service class is not the focus of our work.

The IEEE 802.16 standard does not define the scheduler algorithm for the service classes and also does not define an efficient mechanism for the polling management of BS. The scheduler algorithm aims at making bandwidth allocation between the SSs and determines the transmission order of them, influencing directly the QoS. The scheduling is implemented in the SS and in the BS, however, in our work, it is being addressed the scheduling uplink transmissions in the BS. The polling is a mechanism by which the BS makes the bandwidth allocation so that the SSs can send its bandwidth request messages, before the transmitting data. The Figure 1 shows the polling process used in the uplink transmissions.

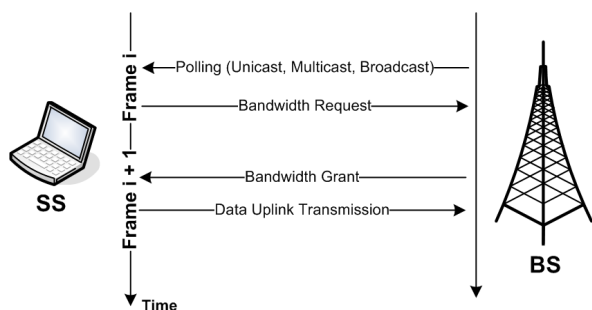


Figure 1. Process polling used in the uplink transmissions.

The BS performs the polling to the SSs periodically. After this, the SSs send its bandwidth requests using the BW-request message (frame i), which can be sent as a stand-alone message in response to a poll from the BS, or it can be piggybacked in data packets. Once the BW-request message is sent, the transmission will occur in the next frame (frame i+1), as it can be seen in Figure 1. The IEEE 802.16 standard defines what service class can use unicast or contention-based polling, but does not define an efficient mechanism to do it. Moreover, it is necessary to consider the overhead existent by the use of polling mechanism, and to

make a balancing of the polling mechanisms, mainly to maximize the throughput at the access network and maintain the constant delay.

III. THE PROPOSED SCHEDULING ALGORITHM

The proposed algorithm is applied directly to the bandwidth request queues of the base station and aims at minimizing the delay for the rtPS service flows and at ensuring minimum bandwidth for rtPS and nrtPs service. The UGS service receives unsolicited bandwidth to avoid excessive delay, as defined at the standard, and has higher transmission priority between the other services. The proposed algorithm and its fundamental features that make it very efficient in a wireless communication environment is described below:

A. Use of the Cross-layer approach

The algorithm uses the information about the MCS that is used in the physical layer, as showed in Figure 2. Thus, it calculates the transmission time of the data based on the bandwidth request messages provided by the SS. The algorithm used to calculate the transmission time is described below:

Algorithm Calculate_transmission_time (bandwidth_lenght)

- 1: verifies the used modulation;
- 2: calculates the amount of symbols used by the modulation;
- 3: calculates the amount of bits to be transmitted (bandwidth_lenght * 8);
- 4: calculates the amount of symbols used to transfer the information;
- 5: transmission time = amount of symbols * duration symbol;
- 6: returns the transmission time;

The transmission time is used to define a deadline for rtPS flows, and therefore, to minimize the delay from the use of several MCS in the access network.

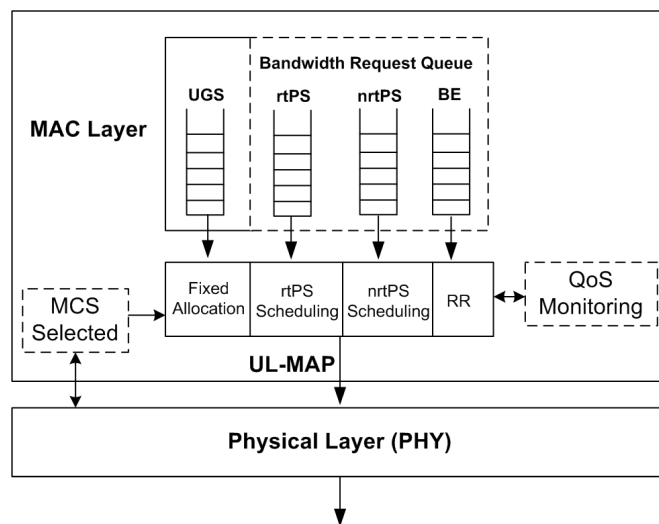


Figure 2. Scheduler architecture for uplink traffic proposed.

B. It is Predictive

The algorithm works along with a method that monitors and makes estimative of the delay for rtPS service class. This method is named **QoSMonitoring()**. Thus, it is possible, for example, to control the periodicity of sending unicast polling to

the rtPS and nrtPS service classes, to maintain the minimal bandwidth, or even increase the throughput of the nrtPS service class, by sending more Unicast polling if the average delay of the rtPS service class is in lower limits than the predefined values. The same can be done for the UGS and rtPS service classes. The pseudo-cod of the method **QoSMonitoring()** is showed as follows:

QoSMonitoring()

```

1: estimate_delay = (estimate_delay * 0.9) + (sample_delay * 0.1);
2: if (estimate_delay < rtPS_threshold) then
3:   {
4:     if (There is bandwidth)
5:       Polling_Unicast_nrtPS++;
6:   }
7: else
8:   polling_Unicast_nrtPS--;
9:   polling_contention_base;

```

The method **QoSMonitoring()** is executed in the BS making the estimative of the average delay for rtPS service class. Through this estimative, it is possible to make a balancing of the Unicast polling for the rtPS and nrtPS service classes. It is defined a threshold for the rtPS service class (line 2) and, if the estimated delay is less than the threshold, it is possible to increase the frequency of unicast polling for the nrtPS service. Thus, it is made a control of the overhead existent by the use of the polling mechanisms. The Figure 3 shows an example of the sample delay and of the estimate delay vs. simulation time obtained from the **QoSMonitoring()** method.

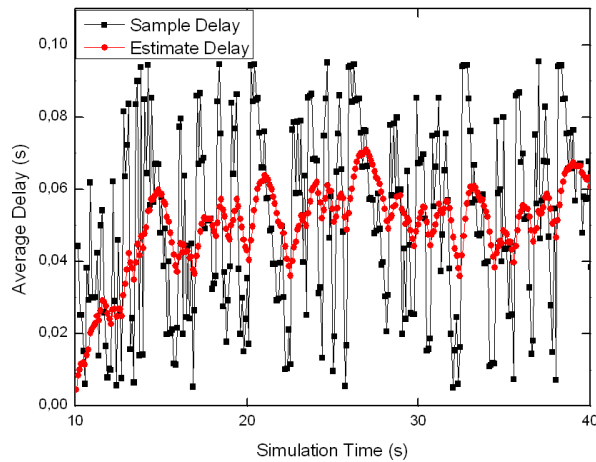


Figure 3. Estimate delay obtained from the **QoSMonitoring** method.

The IEEE 802.16 standard specifies which service classes must receive unicast polling, but it does not define the frequency of this mechanism. Actually, the optimal way to request the bandwidth for a given QoS requirement is still in open research area [8]. The **QoSMonitoring()** is responsible for controlling the periodicity of the unicast polling. So, the proposed scheduling algorithm interacts with the BS polling mechanisms to control the polling frequency for the rtPS and the nrtPS services.

The scheduling decisions are based on the deadline for the

BW-requests and also the information from the monitoring method, which has an overview of the base station resources and also the QoS parameters, becoming completely dynamic, always trying to maintain the QoS for the real time applications. The proposed scheduling algorithm is showed as follows:

Proposed Scheduling Algorithm

```

1: Verifies the bandwidth messages request at the BS queue;
2: for each request i at the BS queue do
3:   if (request[i] = rtPS) then
4:     BW[i] += request[i].length;
5:     if (connections_numbers > 1) then
6:       deadline[i] = Calculates_deadline (request[i].length);
7:       if (deadline[i] < deadline[i+1]) then
8:         tmp = deadline[i+1];
9:         deadline[i+1] = deadline[i];
10:        deadline[i] = tmp;
11:      UL-MAP = request order by transmission time;
13:      if (BW[i] < MinimumReservedTrafficRate) then
14:        Adjust_periodicity_polling(request[i].CID);
15:        QoSMonitoring();
16:      if (request[i] = nrtPS) then
17:        BW[i] += request[i].length;
18:        if (BW[i] < MinimumReservedTrafficRate) then
19:          QoSMonitoring();
20:
21: Calculates_deadline(requested_length)
22: Deadline= Calculate_Transmission_time(requested_length) + queuing
    delay;
23: return deadline;
24:
25: Adjust_periodicity_polling(Connection_CID);
26: if ((BW_UGS + BW_rtPS) < BW_total) then;
27:   Periodicity_Unicast_rtPS++;
28: else
29:   Periodicity_Unicast_rtPS = current;

```

The rtPS service is designed to support real-time flows that generate variable-size data packets on a periodic basis. Therefore, the scheduling algorithm should guarantee a limit value for the delay and a minimum bandwidth to provide QoS. The algorithm verifies the amount of bandwidth for each connection (line 4) and calculates the deadline for each bandwidth request message (line 6) based on the length of the bandwidth requested more the queuing delay. After this, it is made a list of rtPS connections arranged by the lowest deadline. The information in the list of rtPS connections defines the transmission order of the rtPS connections, and this information is included in the UL-MAP message. The UL-MAP message is sent to the SSs by the downlink channel in each frame.

The nrtPS scheduling algorithm is simpler than rtPS scheduling algorithm, because this service class does not have temporal restriction, verifying only the minimum bandwidth for nrtPS service (line 16). In each frame, the BS executes the scheduling algorithm and verifies if the minimum bandwidth of the rtPS and nrtPS services is within the predefined limits. If so, the BS maintains the initial configuration. However, if not, the BS will execute the **Adjust_periodicity_nrtPS_polling()** method and the **QoSMonitoring()** method, aiming at keeping the minimum bandwidth. The minimum bandwidth is defined by the *MinimumReservedTrafficRate* variable, which expresses

the minimal data rate value in bit per second (bps). If the minimal bandwidth of the nrtPS service is degraded because of the increased number of UGS or rtPS connections, the BS will increase the periodicity of the unicast polling for the nrtPS service, whether there is resource for this, or will reduce the grant opportunities of BE service.

IV. RELATED WORKS

It was defined in [9] an adaptive bandwidth distribution algorithm for the aggregate scheduler in a two level hierarchical scheduler. Based on the backlogged traffic, the spectral efficiency in terms of modulation efficiency and the QoS requirements, the proposed algorithm defined in [9] adaptively allocates bandwidth to each service class, however, it was not defined the type of polling mechanisms used, which is a fundamental issue. In our work, the bandwidth is allocated based on the bandwidth request messages sent by SS, and is made a control of the unicast polling mechanism to guarantee minimal bandwidth to rtPS and nrtPS service classes.

It is proposed in [10] a scheduling algorithm for the rtPS service. This algorithm identifies the SS which has low quality of transmission, and depending on this, the SS is removed temporarily from the scheduler list. In our proposal, a scheduling list of SSs is made based on the lowest transmission time, giving to all SSs opportunity for transmission.

The scheduling algorithm proposed in [11] for IEEE 802.16 networks implements the combination of the priority scheduling algorithm with the EDF and WFQ policy. Our paper presents a simpler solution when compared with the proposal described in [11].

It was defined in [12] a packet-based scheduling strategy for an IEEE 802.16 with adaptive coding and modulation. Results were obtained by means of modeling and simulation but, were used only three types of modulation/coding scheme. The proposed scheduling algorithm defined in our work use the MCS defined by the standard.

V. MODELING AND SIMULATION

The proposed scheduling algorithm has been implemented and evaluated by means of simulation experiments with the simulation tool ns-2 [13], along with the module that implements the WiMAX Module developed by [14]. This module contains the UGS, rtPS and BE service classes, but does not have the nrtPS service class. Thus, in addition to implementing the proposed scheduling algorithm, it was necessary to implement: the nrtPS service, the procedures for the bandwidth allocation, the unicast and contention based polling. The Figure 4 shows the simulation scenario.

The simulation scenario consists of a BS and several SSs distributed around the BS in a random mode. The SSs used the modulation schemes in accordance with the signal-to-noise ratio (SNR) values, as defined in Table I. The values of the SNR in Table I were obtained in [10]. According to the choice of modulation/coding and the bandwidth value, it is

possible to determine the transmission rate. The Table I shows examples of transmission rate in accordance with the bandwidth of 5 and 7 MHz based on modulation/coding scheme.

The simulation aims at studying the properties of the proposed scheduling algorithm and analysing their characteristics in a network that has a variety of burst profiles. The Table II shows the main parameters used in the simulation.

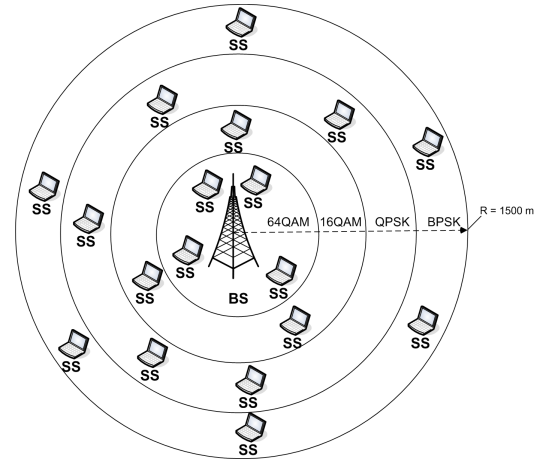


Figure 4. The simulation Scenario.

Table 1. Modulation Levels, Coding Scheme and Transmission rate.

Modulation	Codificati on rate	SNR(dB)	Capacity of Transmission (Mbps)	
			5 MHz	7 MHz
BPSK	$\frac{1}{2}$	3.0	1,71	2,40
	$\frac{3}{4}$	6.0	3,42	4,80
16QAM	$\frac{1}{2}$	8.5	5,17	7,20
	$\frac{3}{4}$	11.5	6,85	9,60
64QAM	$\frac{1}{2}$	15.0	10,28	14,4
	$\frac{3}{4}$	19.0	13,71	19,2
	$\frac{3}{4}$	21.0	15,42	21,6

Table 2. Main parameters used in the simulation.

Parameters	Values
Frequency band	5 MHz
Duplexing	TDD
Propagation Model	Two Ray Ground
Antenna	Omnidirecional
Frame duration	20 ms
Cyclic Prefix (CP)	0.25
Downlink bandwidth	6.16 Mbps
Uplink bandwidth	9.25 Mbps
Simulation time	60 s
Coverage radius	1500 m

The types of traffic used in the simulation were: voice, video, Web and FTP, which were mapped, respectively, by the service classes: UGS, rtPS, BE and nrtPS. The voice traffic was generated by means of an on/off source. During the "on" periods, packets of 66 bytes were generated every 20 ms, following the exponential distribution. The video traffic was obtained by a traffic source that generates, regularly, packets in different sizes, simulating the MPEG traffic. The web traffic

was modeled by a hybrid Lognormal/Pareto distribution. The body of the distribution corresponding to an area of 0,88 is modeled as a Lognormal distribution with a mean of 7247 bytes, and the tail is modeled as a Pareto distribution with a mean of 10558 bytes [15]. The FTP traffic was generated using a source with exponential distribution and average packets size of 512 Kbytes.

VI. NUMERICAL RESULTS

A. Experiment 1

The first experiment verifies the performance of the proposed algorithm in an environment with several transmissions using one MCS and several MCS. Thus, it is possible to analyse if the deadline defined in our work for the bandwidth request messages is efficient in both environments. The simulated network includes one BS and 20 SSs with one rtPS connection by SS. The MCS was used in accordance with the distance of the SS from BS, in random form. The transmission rate varies between 200 and 800 kbps, and the number of active SS varies from 5 to 20. The Figure 5 shows the average delay, where the MCS used was 64QAM. The Figure 6 shows the same experiment but using the MCS defined in Table I.

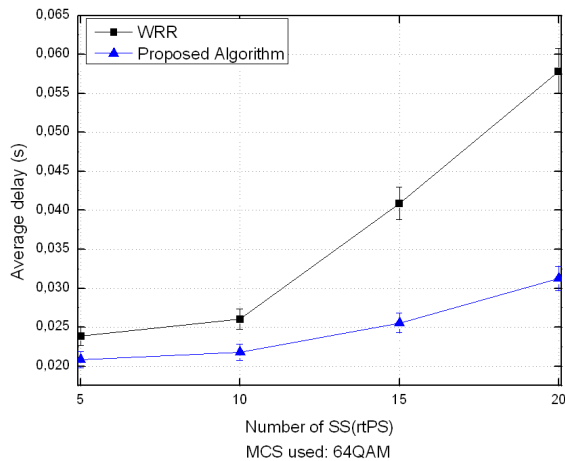


Figure 5. Average delay vs. Numbers of SSs with rtPS connections.

This experiment was performed with the Weight Round Robin (WRR) scheduling algorithm and also the proposed algorithm. As it can be seen in Figure 5 and 6, the proposed algorithm was more efficient in both environments. The use of the deadline defined in our work really reduces the average delay, being appropriate in both environments, especially when several MCS is used, that is one of the major open issues in the access networks which use adaptive modulation. The same did not occur with WRR scheduling policy. It is possible to see that the increase of average delay is more significant when the scheduling WRR policy was used. This happened because the WRR uses a circular list to define the transmission order without considering the time restrictions of the applications.

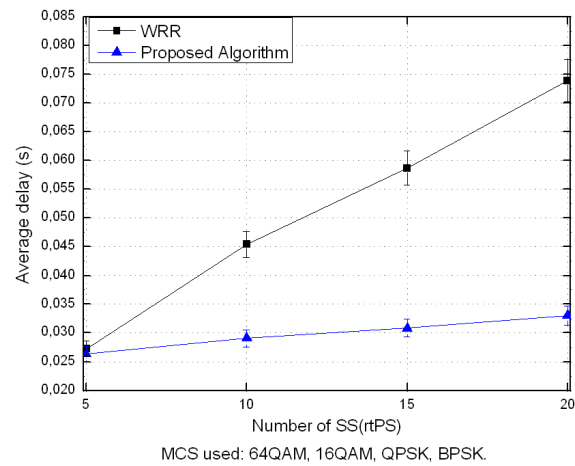


Figure 6. Average delay vs. Numbers of SSs with rtPS connections.

B. Experiment 2

The second experiment aims at evaluating the performance of the proposed algorithm in overload conditions. The link was saturated at approximately 85%. The simulated network and the transmission rate was the same of the experiment 1, and were used the MCS defined in Table 1. The Figure 7 shows the behavior of the average delay according to the overload.

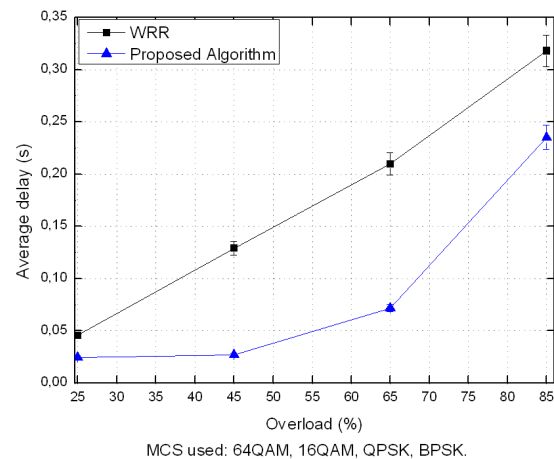


Figure 7. Average delay vs. Overload.

It is possible to see in Figure 7 that the average delay increased in accordance with the overload, what was expected, but the proposed algorithm made a better distribution of the resource, minimizing the delay in approximately 45%.

C. Experiment 3

The aim of experiment 3 is to investigate the behavior of rtPS and UGS services with the increase of the UGS traffic load. For this purpose, the simulated scenario includes one BS, 10 SS with one rtPS connections by SS, 20 SSs with one UGS connection by SS that varies from 5 to 20 SSs active, 10 SS with one nrtPS connection by SS and 10 SS with one BE connection by SS. It was defined a threshold of 100 ms for the rtPS delay. The Figure 8 shows the delay of the rtPS and of the UGS services. The delay of the rtPS service presented an oscillation as the number of UGS connection increased. Moreover, the delay values remained less than the threshold.

The delay of the UGS service was not affected by the load increase. This happened because the scheduler is able to provide data grants at fixed intervals as required by this service.

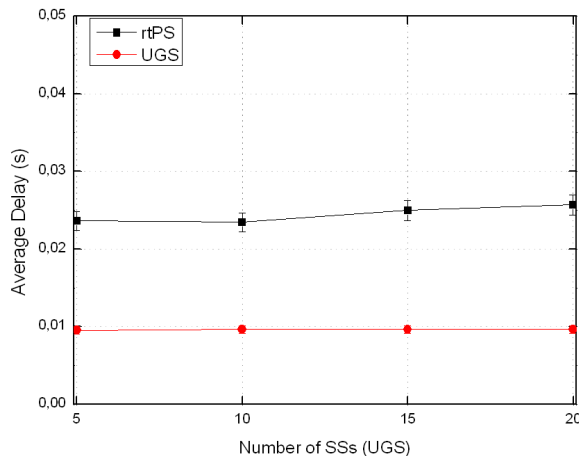


Figure 8. Average delay vs. number of SSs with UGS connections.

D. Experiment 4

The experiment 4 analyses how the proposed scheduler distributes the resources for the non-real time applications. In this case, it is verified whether the increase of the nrtPS traffic load influences or not the BE service. The simulate scenario has one BS and 15 SS with one BE connection by SS and which varies between 5 and 20 SSs with one nrtPS connection by SS. It was used in this experiment 5 SS with one UGS connection by SS, and 5 SS with one rtPS connection by SS as background traffic. The Figure 9 shows the throughput of the nrtPS and of the BE connections.

The BE service had higher throughput than nrtPS when the number of active SS with nrtPS connection was small, since the scheduler allocates the resource (slots) not used by SS with higher priority (for example, UGS, rtPS and nrtPS). When the number of SSs with nrtPS connections increases, the scheduler distributes the existent resources between nrtPS connections, and the throughput of BE decreases, since each BE connection receives fewer resources (slots).

VII. CONCLUSIONS

In this paper, a predictive scheduling algorithm for uplink traffic in IEEE 802.16 networks was proposed. The proposed solution based on the cross-layer approach in which a deadline to the bandwidth requests messages in accordance with the transmission time and the MCS used by the BS is defined. Moreover, it is defined a method that monitors the average delay for the multimedia applications in order to guarantee the QoS. The results of simulation showed the efficiency of the proposed scheduling. The scheduler uses the deadline defined in our work to make the scheduling, minimizing the average delay according to the MCS used in the physical layer and the information of the monitoring method.

As future work, the proposed scheduling algorithm will be extended and tested in the LTE networks, once this technology defines the modulation adaptive.

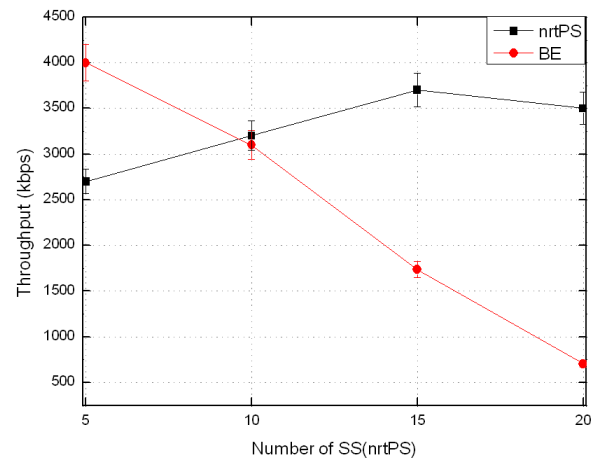


Figure 9. Throughput of nrtPS and BE connections.

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