Traffic Scheduling in OFDMA-based WiMAX Networks on the PMP Mode

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***Abstract*—Orthogonal Frequency Division Multiple Access (OFDMA) is the basis for several emerging wireless systems, such as 802.16e (WiMAX) and Long Term Evolution (LTE). In special, the diverse requirements of multimedia traffic to be supported by convergent broadband wireless networks are commonly difficult to be satisfied, considering factors such as scarcity of radio resources, variability of wireless channel conditions as well as the exponentially growing number of subscribers. Moreover, a scheduler works aiming to intelligently allocate radio resources to achieve high system performance in terms of efficiency and fairness. In this paper, we consider an OFDMA-based WiMAX network using the point-to-multipoint mode (PMP), where multiple subscribers are served by a centralized service provider (a base station), and PUSC (Partial Usage of Subchannels) channelization, considered mandatory for uplink in the 802.16 standard. Given such network conditions, we propose a scheduling technique, based on an evolution of the technique proposed in [4], that is evaluated through discrete event simulation, considering different traffic conditions and scenarios. Results indicate that the strategy was successfully adapted to the new physical layer specifications, respecting all the quality requirements of each kind of scheduling service.**

***Index Terms*—WiMAX, scheduling, quality of service.**

I. Introduction

In the past few years, several innovative broadband multimedia services have been offered by telecom and Internet providers, imposing severe quality of service constraints on the underlying network technologies. In special, the requirements of multimedia traffic to be supported by convergent broadband wireless networks are commonly difficult to attend when there is an exponential increase in the volume of subscribers. The IEEE 802.16 standard, devoted to wireless metropolitan area networks, was designed to meet the requirements of different contemporary applications, using signaling and bandwidth allocation techniques in order to allow many connections with diverse QoS requirements at one subscriber station. Moreover, the point-to-multipoint (PMP) mode (where the base station allocates resources in a centralized manner) has been considered a preferential option by operators, when compared to mesh mode. This situation, combined with factors such as the scarcity of radio resources and the variability of wireless channel conditions, reinforces the importance of scheduling as a task to be performed by a BS in the PMP mode of a WiMAX network.

We also observe that OFDMA has been a basis in several emerging wireless systems, including WiMAX, IEEE 802.22, DVB-RCT and LTE. Moreover, the WiMAX standard does not define a scheduling algorithm and the channelization based on partial usage of subchannels (PUSC) is considered to be mandatory. In this sense, several strategies of scheduling have been proposed in the past few years, sometimes adopting techniques based on modifications of round robin ([1]-[3]) and commonly considering specific traffic classes. In [4], the authors propose a scheduling algorithm to an OFDM based on a 802.16 network and indicate as a future work its adaptation to an OFDMA based network in the partial usage of subchannels (PUSC). In this paper, we propose a strategy considering that adaptation. Discrete event simulation is carried out for its evaluation using NS-2.

The remainder of the work is organized as follows: in section II, some concepts of WiMAX Networks are presented; in section III, related work is discussed; in section IV, the proposed technique is presented; section V provides the simulations and results and section VI presents some conclusions and mention aspects to be treated in a future work.

II. WiMAX and OFDMA - Basic Concepts

WiMAX (Worldwide Interoperability for Microwave Access) is the name given by a group of industries, grouped under the name of WiMAX Forum, to the IEEE 802.16 standard technology. Standards IEEE 802.16d [5] and IEEE 802.16e [6] define the characteristics of the physical layer (PHY) and link layer (MAC) for local and metropolitan areas wireless broadband networks. The physical layer allows the use of single carrier or multiple carriers (OFDM – orthogonal frequency division multiplexing and OFDMA – orthogonal frequency division multiple access) technologies. When the OFDM physical layer is used, the multiple access to uplink (UL) channel is accomplished through a reservation of period of time, using TDMA (time division multiple access). When the OFDMA physical layer is used, the signals are multiplexed with OFDM and multiple access is accomplished using OFDMA by the reservation of a number of frequencies to each station for a period of time.

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Two modes of operation are available in WiMAX: PMP (point-to-multipoint) and mesh (distributed or centralized). The mode of operation adopted by the majority of telecom operators is the PMP (point-to-multipoint), since in this mode the BS has full control over the SSs (subscriber stations) in both directions of communication, as opposed to mesh centralized and distributed mesh modes, which are optional and allow direct communication between SSs [7]. There are two possible technologies for duplexing: time and frequency division, known by the acronym TDD (time division duplex) and FDD (frequency division duplex), respectively. In the TDD mode the DL (Downlink) and UL (Uplink) subframes occur at different instants of time, usually on the same frequency. This work uses the PMP and TDD modes.

IEEE 802.16d [5] standard allows the transmission of multimedia data using scheduling services associated with QoS (Quality of Service) parameters, which are: UGS (unsolicited grant service), rtPS (real-time polling service), nrtPS (nonreal- time polling service) and BE (best effort). In IEEE 802.16e addendum [6], another type has been included: eRTPS (extended real-time polling service). The UGS is designed to support SF (Service Flow) from UL in real time by carrying packets with fixed length and at constant periods, for example, VoIP (Voice over IP) without silence suppression. The rtPS is designed to support SF of real-time UL, carrying packages of variable size and constant periods as, for example, MPEG. The type of scheduling eRTPS, defined in [6], combines characteristics of UGS and rtPS. The service is designed to bear SF of real time UL periodically generating variablesized packets such as VoIP with silence suppression. Type nrtPS is used for applications with tolerance to delay, but they should have a minimum guarantee of bandwidth, such as video on demand. Finally, the BE service has no QoS requirements and is typically used for browsing the web. For all types of scheduling, except for the BE type, MSTR (Maximum Sustained Traffic Rate) and MRTR (Minimum Reserved Traffic Rate) parameters are required.

All these types of traffic and scheduling can coexist on a SS. The UL bandwidth requests can be provided using two mechanisms, the GPC (Grant per Connection), in which the reservation is made for each connection, and GPSS (Grant Per Subscriber Station), in which the reservation is made for SS aggregating the requests of all connections which belong to it. The latter is considered the most efficient one ([8] and [9]) and will be used in this work. Based on solicited requests and on guaranteed requests, the BS should be able to reserve resources for the UL traffic of each SS, according to the agreed service quality. The allocation made is transmitted to SSs through ULMAP messages attached to the DL subframe.

III. Related Work

Considering the lack of definition of a scheduling technique in the 802.16 standard, manufacturers are free to choose an algorithm for this purpose, respecting the classes of service and other features of the standard. Some authors have been devoted to proposing QoS architectures and scheduling techniques for WiMAX networks, such as [8] and [10]. Some authors, such as [2], [3], [9] and [11], proposed algorithms that combine traditional scheduling techniques such as EDF (Earliest Deadline First), DRR (Deficit Round Robin) and WFQ (Weighted Fair Queuing).

These algorithms are quite complex and require many controls. The challenge of allocating resources in a WiMAX network is not only to define the best allocation for a given time, but also to be prepared for constant changes in network configuration and on the demands of users, processing hundreds of frames per second. Some authors, despite meeting most requirements, dedicated only to some types of traffic and do not have comprehensive strategies for the IEEE 802.16 ([12] and [13]). The strategy proposed in [4] meets scheduling services defined in the latest version of the IEEE 802.16 standard, including the new eRTPS class. The technique is simulated on the Network Simulator 2 (NS-2) [14] platform using an OFDM physical layer and link layer adherent to the standardization of WiMAX ([5] and [6]).

In its conclusion, the work [4] says that the algorithm is valid for the physical layers based on SC, OFDM and OFDMA FUSC, but adjustments are necessary for the operation in OFDMA PUSC. It makes the scheduling strategy unsuitable for WiMAX OFDMA, since, the PUSC method is mandatory for the uplink channel.

IV. Proposed Technique

The algorithm proposed in this paper is based on the strategy described in [4], in which the allocation of resources is achieved through a number of slots to ensure an appropriate transmission rate for each scheduling service, using a TDMA OFDM PHY layer. In this type of physical layer specification, all subcarriers are allocated to the transmitter involved. Using an OFDMA FUSC physical layer, each slot is mapped to a subchannel by one OFDMA symbol and all subchannels are allocated to the [6] transmitter. Thus the technique proposed in [4] can be applied directly to the OFDMA FUSC. However, adaptations are necessary to use an OFDMA PUSC physical layer [4]. The physical layer OFDMA PUSC permits the allocation of one or more logical subchannels for a given transmitter. It is necessary to ensure a minimum number of subchannels and OFDMA symbols to meet the requests of SSs and the QoS parameters, notably, the MSTR and MRTR.

The idea, described in [4], intends to allocate the smallest number of slots possible, seeking to guarantee the agreed QoS. To achieve this objective, authors define some quantities:

- B_i is the bandwidth requirement of the i connection;
- S_i is the slot size, i. e., the number of bytes the i connection can send in one slot;
- *FPS* stands for the number of frames the WiMAX BS sends per one second.

From these parameters, the N_i, number of slots within each frame, is calculated using equation 1. The calculation of N_i enables the reservation of resources by ensuring the bandwidth is in accordance with each class of service.

$$N_i = \left\lceil \frac{B_i}{S_i \times FPS} \right\rceil \tag{1}$$

TABLE I. MODULATION, CODIFICATION AND SIZE OF OFDMA SYMBOL, USED IN THIS WORK

Modulation	Codification	Bytes per symbol
64 QAM	3/4	27
64 QAM	2/3	24
16 QAM	3/4	18
16 QAM	1/2	12
QPSK	3/4	9
QPSK	1/2	6

In order to support the OFDMA physical layer, a scheduling strategy must permit the allocation of symbols by logical subchannels (time domain and frequency, respectively), once they are the basic units for resource reservation of the ULMAP messages ([5], page 153). In [15], a scheduling technique for OFDMA physical layer is proposed. It uses the number of subchannels to reserve resources based on physical parameters such as signal-to-noise ratio. In this work, an adjustment in the general equation of the algorithm seen in [4] was carried out to find not the number of slots, but the number of subchannels in a subframe, named NS_i. The equation 2 was obtained after these changes. The new variables TS and Sb_i refer, respectively, to the number of OFDMA symbols by subframe and to the number of bytes that a connection can send in an OFDMA symbol. The B_i is the bandwidth requirement of each i connection, directly related with the MRTR and MSTR, quality parameters of each connection.

$$NS_i = \left\lceil \frac{B_i}{Sb_i \times FPS \times TS} \right\rceil \tag{2}$$

The adjustment of the other equations followed the same principle. For eRTPS, RTPS, nRTPS and BE connections, the strategy finds NS_i, maximum and minimum, depending on MSTR and MRTR (B_i) values. For UGS connections, NS_i is fixed. Due to lack of space we will not present the details of all the equations.

V. SIMULATIONS AND RESULTS

The WiMAX module for NS-2, developed by NDSL (Networks & Distributed Systems Laboratory) [16], was used to perform the simulations. Some module parameters are kept fixed for all scenarios. The size of the frame, 5ms, remains constant during all simulations, but the DL:UL rate, relation between the number of symbols in DL and UL in a frame, can be changed between scenarios. Other parameters are fundamental to the functioning of the simulation, such as the signal modulation, channel coding and the amount of bytes attributed to an OFDMA symbol. Table I shows the number of bytes that an OFDMA symbol is capable of delivering in accordance with the modulation scheme and coding rate. The other parameters can be found in [16].

A new function (Scheduling Algorithm) was created for the scheduler module to function in accordance with the new equations derived from 2. In [16] there are no QoS parameters to be met. The module has been adapted to allow that the MSTR and MRTR values could be incorporated into SF and checked on each allocation according to the type of connection.

In order to check the correctness of the new technique, we used three simulation scenarios. In all the scenarios, the stations send data to the destination node through the BS. The connection between the recipient node and BS is performed by a channel of 1 Gbps, in order to avoid congestion because of this connection. The module used sends mandatory messages of the WiMAX standard, such as UL-MAP, DL-MAP, UCD, DCD, ranging and registration, and it has been adapted to have the behavior specified in equation 2. Errors are not simulated at physical layer, therefore the possible packet loss must be attributed to the MAC layer. A detailed description of each scenario will be provided in this section.

A. Scenario 1 – Scheduling of BE stations

The network structure for scenario 1 is mounted by distributing 10 BE stations, modulated 64 QAM 3/4, uniformly around the BS. The recipient node of uplink traffic of all SSs is connected to the BS by a 1 Gbps channel with delay of 2ms. Each SS has two connections to the BS, a DL and an UL one. The BE traffic is simulated by an active FTP service at each station. In the transport layer, the TCP protocol is used with packet sizes of 1,500 bytes. The TCP aims to achieve the highest transmission rate possible in the case of 24 Mbps, using a ratio of DL:UL of 3:1, used because the total amount of bandwidth in this configuration is only slightly larger than the maximum in [4] and individual rates are also quite near. To perform the study of the allocation, the FTP service is enabled on each station in different periods of time, according to the Table II.

TABLE II. . CONTROL OF TRAFFIC ACTIVATION

SS	0-5s	5-10s	10-15s	15-20s
SS1 - SS3	X	X	X	
SS4 - SS5		X	X	
SS6 - SS8			X	
SS9 - SS10			X	X

The objective of this scenario is to verify if the scheduling strategy is able to allocate resources fairly among the stations with the same characteristics, in this case using the BE class. It is important to emphasize that all stations perform the entry into the network at the beginning of the simulation but only get a logical subchannel with the first bandwidth request. At this point the algorithm checks how many stations are active and divides the subchannels between them. The Fig. 1 contains the transmission rate of each SS to the BS and the sum of traffic out to the destination node in function of time. It is possible to observe that the proposed algorithm distributes the BS resources fairly despite the change in the number of stations. We disagree with the argument presented in [4] for the decline in the total output of BS in the range between 10 and 15s, involving the increase in the size of messages DLMAP and UL-MAP due to a larger number of SSs. In fact, the number of messages increases, but they are sent in the DL subframe and do not interfere in the UL subframe. The total drop rate is observed with a lesser extent in the range between 5 and 10s and more pronounced between 10 and 15s because of the inexact division of the UL subframe between the stations, which does not occur in other intervals.

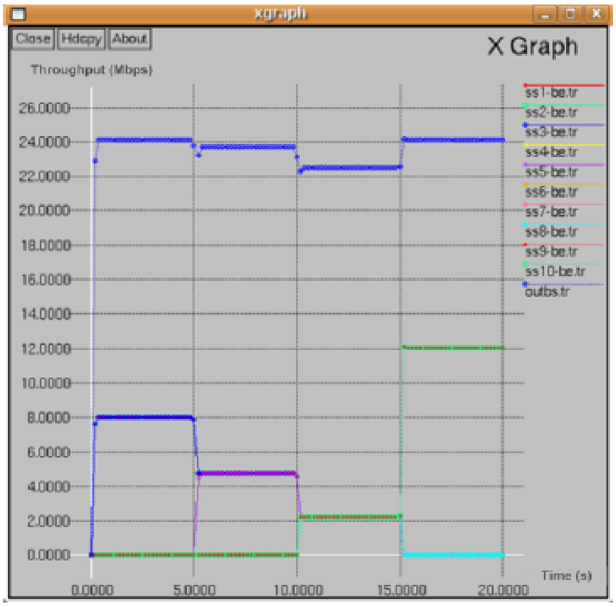

Figure 1. Throughput(Mbps) X time graphic, scenario 1.

B. *Scenario 2 – Scheduling of SSs with diferrent class of service*

In this scenario, seven distinct classes of uplink traffic streams are simulated, as seen in Table III. Each SS has only one active service and sends data to a destination node through the BS according to the type of traffic associated, using a 64 QAM 3/4 coding . In this scenario, all stations transmit data to the BS from the beginning to the end of the simulation.

TABLE III. TYPE OF TRAFFIC AND QOS PARAMETERS

SS	Traffic type	Packet size	Minimum Bandwidth (bps)	Maximum Bandwidth (bps)
SS1	UGS	500	4,000,000	4,000,000
SS2	eRTPS	300	80,000	80,000
SS3	RTPS	1378	2,054,400	4,108,800
SS4	RTPS	1378	2,054,400	4,108,800
SS5	nRTPS	1060	3,524,000	5,200,000
SS6	nRTPS	1060	3,524,000	5,200,000
SS7	BE	200	-	-

Aside from SS5 and SS6, the other data in the table settings are identical to the second scenario simulated in [4]. The higher values (minimum and maximum) are considered for both SSs, since it is the same type of scheduling service, as in the case of SS3 and 4. The traffic generator module, from NDSL, has been adapted to meet the proposed scenario.

To simulate the UGS class, a constant bit rate (CBR), source of 4Mbps, with 500 bytes packet size sent via UDP was used. Class eRTPS is simulated using an ON / OFF exponential function according to the specifications of Recommendation P.59 ITU-T [17], with active periods (talk spurt) and silence suppression. The active phase follows the parameters of the ITU recommendation G.711 and occurs at a rate of 80Kbps with packets of 300 bytes including the sizes IP/UDP/RTP headers. The RTPS class is simulated by a variable bit rate (VBR) source, considering real video tracing files [18], adapted to the format accepted by the NS-2 encapsulated by the IP/UDP protocols. nRTPS connections are simulated by a FTP over TCP source. This connection will increase the transmission rate to the maximum allowed by the network, in this case 5.2Mbps. BE type station is simulated using a CBR source, UDP protocol and tries to reach a rate of 5 Mbps. For UGS and eRTPS traffic, it is necessary to consider the overhead bytes of the protocols, as well as the PDU and the header sizes, for the correctness of resources allocation.

An important simulation parameter is the DL/UL ratio of the frame. In [4], this rate is 1:1. The result shown in Fig. 2 was obtained with the same rate. Looking at Fig. 2, it is possible to see that the Station SS1, with UGS traffic, has constant transmission rate of 4Mbps. Station SS2 (eRTPS) has a transmission rate of 80Kbps, guaranteed in its active phase. Stations SS3 and SS4 have the minimum transmission rate over 2,054,000 bps and do not exceed 4,108,800 bps. Stations SS5 and 6 reach the maximum rate of 5.2 Mbps. Station SS7 reaches 4.9 Mbps, due to the overhead, which is not computed for traffic type BE. It can be observed that the technique allocates resources so as to guarantee the QoS of users for all types of traffic and also that resources are not over by using a DL/UL ratio of 1:1.

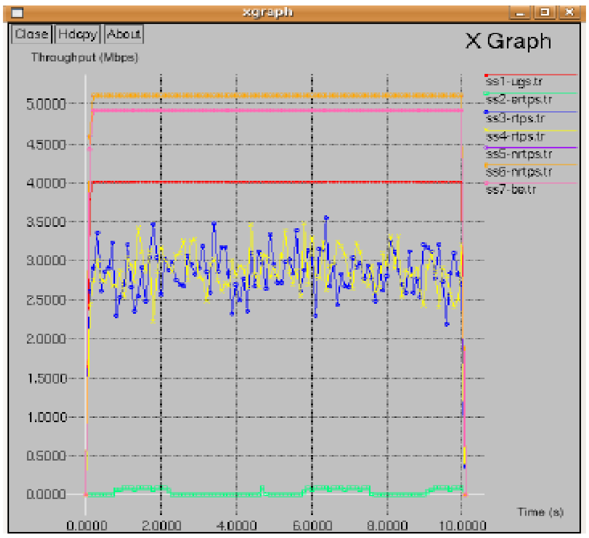

Figure 2. Throughput(Mbps) X time(s) graphic – DL/UL – 1:1,scenario 2.

For the 3:1 rate, the OFDMA network has its uplink resources exhausted. The results are shown in Fig. 3. Looking at Fig. 3, it is noticeable that the stations SS1 and SS2 have their traffic preserved. Stations SS3 and SS4 have the minimum amount of bandwidth above 2.0 Mbps and do not exceed 4.1 Mbps. Stations SS5 and SS6 reach the maximum rate of 5.2 Mbps. Station SS7 no longer reaches the rate of 4.9 Mbps. Its rate depends on how RTPS stations (SS3 and SS4) use the network, as the others have a fixed rate. Therefore, the algorithm reaches the expected behavior. In practice, telecom and cable TV operators which must have a license to provide services using WiMAX technology will probably define other ratios between the frames of DL and UL, as the traffic towards the BS to the SSs will be higher (as 3:2, 2:1 or 3:1, for example).

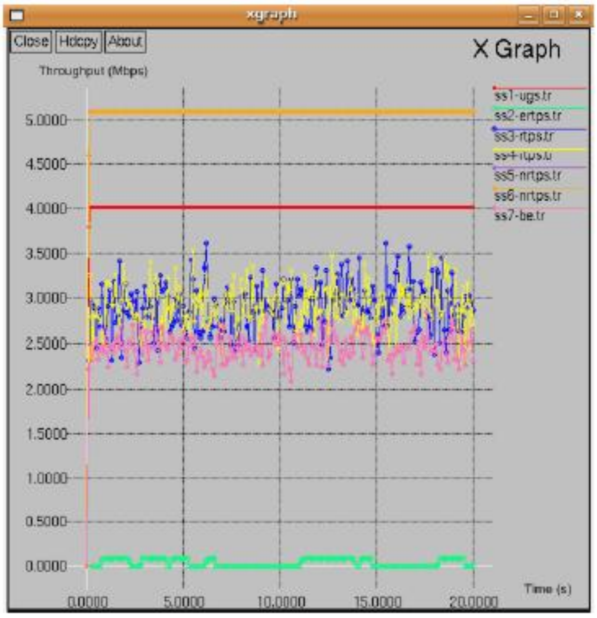

Figure 3. Throughput(Mbps) X time(s) graphic – DL/UL – 3:1,scenario 2.

The second part of the scenario is the measurement of jitter from station SS1. In [4], values are found just above 2 ms, without the use of the process to change the order in which the slots are transmitted. Fig. 4 presents the measurement of jitter achieved by this work. Jitter varies from tenths of a millisecond to 4 ms throughout the simulation period. Between packets of the same subframe, the delay variation is very small, but between different subframes it can get to up to 4 ms. That is, what leads to higher jitter is the time the BS deals with the frames, which is related to the size of the frames.

At this point, it is important to mention that the larger the size of the frame used in the network, the greater the increase of jitter [4]. Although not explicit in [4], it is possible to estimate the size of the frame used by the parameters of the article and the equations of the IEEE 802.16 OFDM. Considering the values of G (guard interval) eligible, 1/4, 1/8, 1/16 or 1/32, we find the possible values for T_s (time of a symbol): 40, 36, 34 and 33 µs. With this we can estimate that the frame used in [4], is between 2.6 and 3.2 ms. It allows BS to handle up to twice the number of frames of the module used in this work. Thus the result found in this work is justifiable in relation to the result obtained in [4].

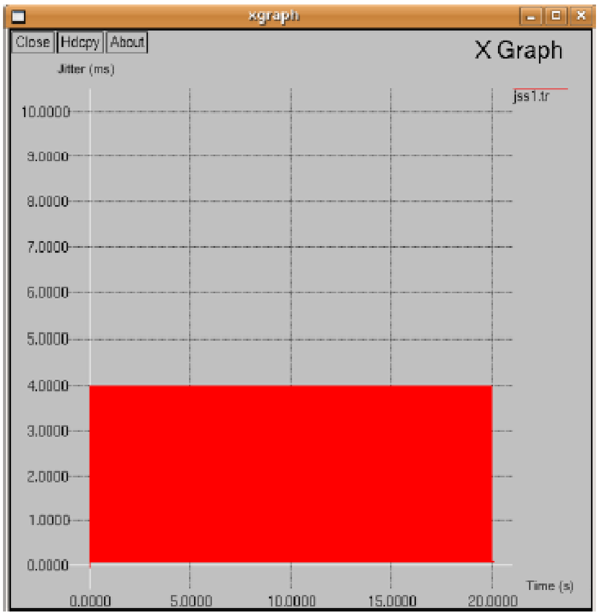

Figure 4. Jitter(ms) X time(s) graphic, scenario 2.

C. *Scenario 3 – Scheduling SSs with diferrent signal modulation and codification*

The third scenario consists of five stations with UGS scheduling type and one of BE type. The objective of this scenario is to verify if the proposed scheduling strategy has the expected behavior when there are variations of the modulation/codification of the signal from a more to a less robust one or vice versa. To do so, modulation and codification of five UGS SSs are varied over the time, keeping the station BE with QPSK 1/2 modulation and codification.

TABLE IV. CONTROL OF USED MODULATION AND CODIFICATION

SS	0-5s	5-10s	10-15s	15-20s
SS1	64QAM 3/4	16QAM 1/2	16QAM 1/2	QPSK 3/4
SS2	64QAM 2/3	16QAM 1/2	16QAM 1/2	QPSK 3/4
SS3	16QAM 3/4	16QAM 1/2	16QAM 1/2	QPSK 3/4
SS4	QPSK 3/4	QPSK 3/4	16QAM 1/2	QPSK 3/4
SS5	QPSK 3/4	QPSK 3/4	16QAM 1/2	QPSK 3/4
SS6	QPSK 1/2	QPSK 1/2	QPSK 1/2	QPSK 1/2

To simulate the UGS traffic type, a constant data flow is used at a rate of 1 Mbps with UDP protocol and to simulate BE station a FTP application is used sending data to the destination node. The QoS parameters for the UGS SSs are maximum and minimum transmission rates of 1Mbps, while the SS BE has no requirement for quality. The inclusion of SS with class BE service is designed to verify that the scheduler allocates the remaining resources to this station, according to the variation of modulation and codification rates. Table IV defines the variation of the modulation and codification rates of the stations on each time interval.

Fig. 5 contains the graph of the transmission rate of each SS obtained in this work in function of time. It is possible to see that the expected behavior is achieved. The transmission rate of UGS stations is maintained constant throughout the simulation period, even with the variations of modulation and codification over the time. It is verifiable that the BE station has its highest rate of transmission in the range between 0 and 5s (period in which the BS uses the least number of subchannels because of the utilization of the least robust modulation, 64 QAM 3/4) and the smallest in the range between 15 and 20s (the period in which the BS uses the largest number of subchannels due to the more robust modulation, QPSK 3/4).

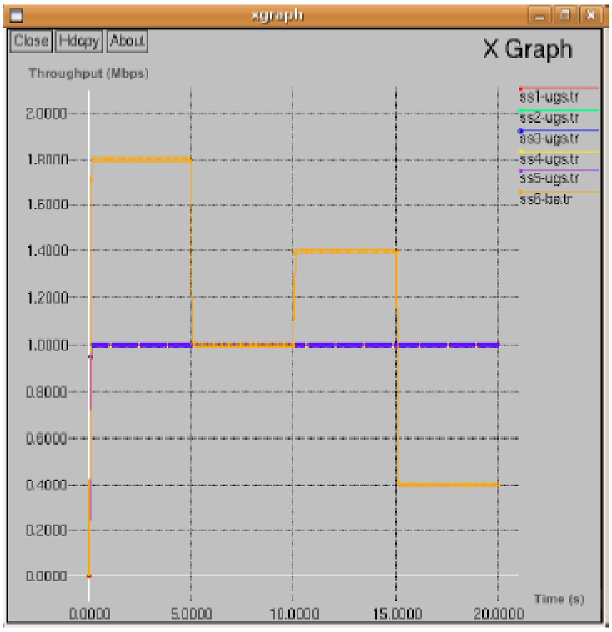

Figure 5. Throughput(Mbps) X time(s) , scenario 3.

In [4], there are some fluctuations in the transmission rate of the BE station, in contrast to the result shown in Fig. 5. It occurs because the remaining resources, after guaranteed UGS traffic, are used for the BE station, but also for periods of bandwidth request. In the WiMAX module used in this simulation, the opportunities for bandwidth request are reserved, with the guarantee of 12 OFDMA symbols, in each frame, for this purpose. This procedure is in accordance with the latest standard, IEEE 802.16e [6]. Therefore, the resource allocation for BE station is free of greater or lesser numbers of bandwidth requests, avoiding fluctuations in the transmission rate.

VI. Conclusion and Future Works

This article presented a MAC scheduling strategy compliant with IEEE 802.16 to support the physical layer WirelessMAN - OFDMA using PUSC subchannels distribution, guaranteeing QoS for all traffic types. The WiMAX network scenarios were simulated using the NDSL module for NS-2 with the necessary adaptations. In these scenarios, it was possible to observe the correction of the strategy. The network resources were divided equally between the stations of the same type of traffic. The stations of different types of traffic had their QoS parameters observed at the expense of stations of BE type, for example. Finally, it was verified that the proposed technique is able to adapt to different transmission profiles existing in a WiMAX network, supporting their changes over time.

In future studies, we intend to adapt the simulator to enable the application of mobility models, verifying the behavior of scheduling algorithms in such situations. Another possible extension is the use of optimization techniques, as the ones proposed in [19], defining the minimum number of possible subchannels for different network configurations.

References

[1] C. Cicconetti, L. Lenzini, E. Mingozzi, and C. Eklund, "Quality of service support in IEEE 802.16 networks," *IEEE Networks*, vol. 20, no. 2, pp. 50-55, Mar.-April 2006.

[2] H. Safa, H. Artail, M. Karam., R. Soudan, and S. Khayat, "New scheduling architecture for IEEE 802.16 wireless metropolitan area networks," in *Proc. IEEE/ACS International Conference on Computer System and Applications*, 2007, pp. 203-210.

[3] W. Lilei and X. Huimin, "A new management strategy of service flow in IEEE 802.16 system," in *Proc. IEEE Conf. Industrial Electronic and Applications*, 2008, pp. 1716-1719.

[4] A. Sayenko, O. Alanen, J. Karhula, and T. Hämäläinen, "Ensuring the qos requirements in 802.16 scheduling," in *MSWiM '06: Proceedings of the 9th ACM international symposium on Modeling Analysis and Simulation of Wireless and Mobile Systems*, 2006, pp. 108–117.

[5] Air Interface for Fixed Broadband Wireless Access Systems, IEEE Standard for Local and Metropolitan Area Networks Part 16: IEEE Std 802.16-2004 (Revision of IEEE Std 802.16-2001) (2004) 1–857.

[6] Air Interface for Fixed and Mobile Broadband Wireless Access Systems. IEEE Standard for Local and Metropolitan Area Networks Part 16: IEEE Std 802.16e-2005 (Amendment and Corrigendum to IEEE Std 802.16-2004) (2006) 1–822.

[7] S. Xergias, N. Passas, and A. Salkintzis, "Centralized resource allocation for multimedia traffic in ieee 802.16 mesh networks," *Proceedings of the IEEE* , vol. 96, no. 1, pp. 54-63, 2008.

[8] K. Wongthavarawat and A. Ganz, "IEEE 802.16 based last mile broadband wireless military networks with quality of service support," in *Proc. IEEE Military Communications Conference*, vol. 2, 2003, pp. 779–784.

[9] K. Vinay, N. Sreenivasulu, D. Jayaram, *et al.*, "Performance evaluation of end-to-end delay by hybrid scheduling algorithm for QoS in IEEE 802.16 network," in *Proc. IEEE IFIP International Conference on Wireless and Optical Communications Networks*, 2006, pp. 5.

[10] G. Chu, D. Wang, and S. Mei, "A QoS architecture for the MAC protocol of IEEE 802.16 BWA system," in *Proc. IEEE International Conference on Communications, Circuits and Systems and West Sino Expositions*, vol. 1, 2002, pp. 435-439.

[11] J. Chen, W. Jiao, and H. Wang, "A service flow management strategy for IEEE 802.16 broadband wireless access systems in TDD mode," in *Proc. IEEE International Conference on Communications*, vol. 5, 2005, pp. 3422-3426.

[12] H. Lee, T. Kwon, and D. H. Cho, "An enhanced uplink scheduling algorithm based on voice activity for VoIP services in IEEE 802.16 d/e system," *IEEE Communications Letters*, vol. 9, no. 8, pp. 691-693, 2005..

[13] S. Kim and I. Yeom, "TCP-aware uplink scheduling for IEEE 802.16," *Communications Letters*, IEEE, vol. 11, no. 2, pp. 146-148, 2007.

[14] K. Fall and K. Vardhan. The network simulator (ns-2). [Online]. Available: http://www.isi.edu/nsnam/ns.

[15] X. Zhu, J. Huo, X. Xu, C. Xu, and W. Ding, "QoS-guaranteed scheduling and resource allocation algorithm for IEEE 802.16 OFDMA system," in *Proc. IEEE International Conference on Communications*, 2008, pp. 3463–3468.

[16] J. Chen, C. C. Wang, F. C. D. Tsai, *et al.*, "The design and implementation of WiMAX module for ns-2 simulator," in *Proc. From the 2006 Workshop on ns-2: The IP Network Simulator*, *ACM*, 2006, pp. 5.
[17] Helsinki. (1993). Artificial conversational speech. *ITU recommendation P.59*. [Online]. Available: http://www.itu.int
[18] Arizona State University (2009). Video Trace Research Group. [Online]. Available: http://trace.eas.asu.edu
[19] C. E. C. Vieira, P. Gondim, C. A. Rodrigues, *et al*., "A new technique to the channel assignment problem in mobile communication networks," in *Proc. IEEE 19th International Symposium on Personal, Indoor and Mobile Radio Communications*, 2008, pp. 1-5.

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