

A Heuristic Strategy for IEEE 802.16 WiMAX scheduler for Quality of Service

G.S. Paschos, I. Papapanagiotou, C.G. Argyropoulos and S.A. Kotsopoulos
Wireless Telecommunication Laboratory
Electrical and Computer Engineering
University of Patras
Kato Kastritsi, 26500
Greece

Abstract-The advent of Broadband wireless promises quality communications over the wireless channel. The 802.16 standard is expected to arise as the main Broadband Wireless Access (BWA) Technology, providing high-speed data access to subscribers. In this paper, an important part of such a network, the MAC scheduler, is investigated. Although IEEE 802.16 defines specific Quality of Service (QoS) traffic flows, scheduling of heterogeneous applications is left open for research. A heuristic approach is followed to propose a QoS strategy. In the proposed strategy, Call Admission Control (CAC) is implemented for high-priority traffic so as to overcome the problem of starvation of network resources. Moreover different contention minislots allocation strategies, for low-priority traffic, are investigated. The performance of these strategies is simulated via Opnet modeler for several scenarios. Medium Access Control (MAC) delay and throughput rate are used as measures to gauge the efficiency of the protocol for every specific class of service. The quality demands of each class are analyzed and used as input for the heuristic strategy. The results show that effective scheduling can provide high service standards, competitive to other modern cellular networks. The target of the paper is to demonstrate the possibilities for market applications of WiMAX (Worldwide Interoperability for Microwave Access) taking into account the quality of service features and the capability of vendor oriented MAC scheduling.

Keywords: WiMAX, IEEE 802.16, BWA, MAC scheduling.

I. INTRODUCTION

In the last years cellular networks have set up a new era in modern communications and have shown a great capability to solve the last mile problem. On the other hand, Wireless Local Area Networks, such as IEEE 802.11 networks [1], are currently evolving, offering high bandwidth radio communications. The convergence of these has led to the need of Broadband Wireless Access (BWA) and to the standardization of a Wireless MAN air interface, IEEE 802.16 [2]. The IEEE 802.16 Workgroup has up to now defined the *Physical* (PHY) and MAC layers, and continues with IEEE 802.16e [3] to include mobility.

Voice over IP, home entertainment video, triple play and the high evolution of Internet usage have created an exorbitant demand of broadband technologies such as T1 and DSL. On the other hand, it is costly prohibited to create new infrastructures with either fiber optic or copper wires. IEEE 802.16 with the combination of WiMAX Forum can offer a great advantage to Telco, so as to

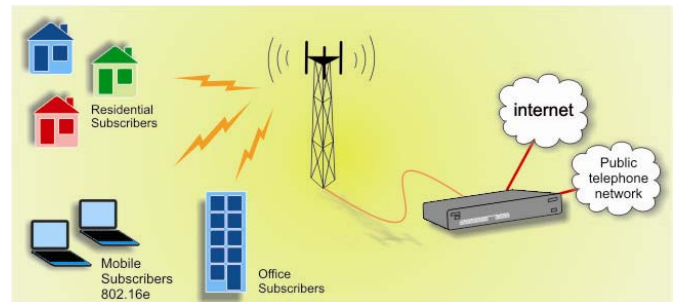


Figure 1. IEEE 802.16 Network architecture for Point to Multipoint (PMP) connection.

provide low cost connections and extensive mobility. Moreover WiMAX has the ability to cover, in Line Of Sight (LOS), a range of 50 km in point to point transmissions with a throughput of almost 72Mbps and in non-line of-sight (NLOS) a range of 6.5km. With such a range and throughput WiMAX technology is capable of delivering backhaul for enterprise campuses, Wi-Fi hotspots and cellular networks. Based on the traffic characteristics of such a network, it is possible to cover the same area as cellular base stations do today or even more. The www.3g.co.uk estimates that economic growth from the selling of WiMAX equipments will increase rapidly in the forthcoming years, as is also shown in figure 2 of [4].

The IEEE 802.16 [1] physical layer operates at both 10-66 GHz and 2-11 GHz (802.16a) with data rates that depend on bandwidth and modulation techniques. The use of OFDM (Orthogonal Frequency Division Multiplexing) makes the standard capable of high speed data connections for both fixed and mobile Service Stations. The IEEE 802.16 MAC protocol defines both *frequency division duplex* (FDD) and *time division duplex* (TDD) for its connections. The architecture comprises two components, a *Base Station* (BS) and a number of *Service Stations* (SS) with two directions of communication. The first one is the *Downlink* (DL) transmission from the BS to the SSs, and is conducted in Point-to-Multipoint access method, whereas the second one is the *Uplink* (UL) direction. The UL channel is common to all nodes and is slotted via TDD method on a demand basis for multimedia data.

Performance evaluations of IEEE 802.16 can be found in references [5], [6] and [7]. Cho et. al. [6] proves also that to maximize throughput, the backoff window size (in slots) must be equal to the number of stations taking part in the

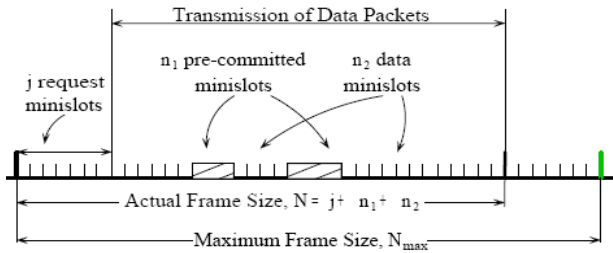


Figure 2. Upstream Frame structure.

network, which is used relatively to our simulation analysis. Whereas in [7] Ramachandran et al. give a similar OPNET model of IEEE 802.16. Though, their results are more close to the Physical layer.

A Scheduling algorithm combined with OPNET simulation can be found in [8], which encompasses only ON-OFF Voice transmission. In [9] a Dynamic Admission Control for UGS traffic flow 802.16 is proposed. Lastly in [10] a great analysis of a QoS Upstream Scheduling algorithm is given, taking into account WFQ for low priority traffic. Another OPNET simulation analysis is provided by Chandrasekaram et al. [11], who simulated DOCSIS MAC protocol which has great similarities with 802.16, in their technical report.

The rest of the paper is organized as follows. In section II WiMAX MAC protocol is explained in detail and in section III a *Quality of Service* (QoS) architecture, in collaboration with the scheduler, is presented. Section IV provides the simulation and the results whereas in the last section the conclusion is discussed.

II. WIMAX MAC PROTOCOL OVERVIEW

The MAC protocol of IEEE 802.16 is connection oriented and each connection is identified by a 16-bit *Connection Identification Number* (CID), which is given to each SS in the initialization process. The transmissions are divided either by TDD or FDD method. In the DL direction, connections are usually multicast, but unicast can also be supported. The SSs use *Time-Division-Multiple-Access* (TDMA) on the uplink and transmit back to the BS in a specific allocated time slots. This means that connections from the SSs to the BS are always unicast. Thus the CID plays an important identification role in the UL channels, so as the BS to be able to identify the SS that sent the MAC PDUs in the DL direction. Differently from other networks the 48-bit MAC address does not play any role in the transmission but serves as an equipment identifier.

IEEE 802.16 is a centrally controlled protocol but can also operate in Mesh mode. In the first case the BS controls the uplink bandwidth allocation and the SSs request transmission opportunities in the uplink channel. In the second case traffic can be routed through SSs and use a distributed scheduling algorithm. One node takes the role of the Mesh BS.

In the centrally controlled method there are two ways to send a transmission opportunity. The first is to transmit in periodic intervals and the second is to contend with the other SSs transmitting request for grants.

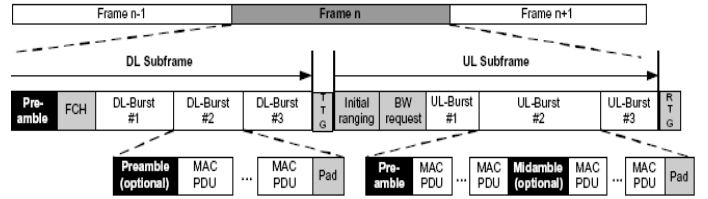


Figure 3. IEEE 802.16 MAC frame in TDD mode.

The BS collects all the requests and therefore has sufficient information about the bandwidth requests. Then the scheduler assigns an appropriate number of data minislots to accommodate the requests, “Fig.2”. The information is passed to the SSs through the MAP message, which describes the way the upstream bandwidth is assigned to each SS. The DL and UL subframes are included in the frame, as shown in “Fig. 3”.

In the UL contention period collisions might occur, when two or more SSs place their request PDUs in the same minislot. Moreover the SSs cannot listen directly to the upstream, and thus the correct request will be acknowledged in the next MAP message. The transmission of the collided requests will be repeated until the successful reception by the BS. To avoid such collisions, IEEE 802.16 makes use of a binary exponential backoff algorithm, similar to the CSMA-CD of Ethernet. Due to this type of contention, the protocol cannot guarantee access delay. IEEE 802.16 takes care of real time applications (VoIP, Video on demand) assigning unsolicited bandwidth grants and polling. The use of polling is essential because these applications should receive service on isochronous basis. Moreover QoS guarantees are made possible through a QoS differentiation provided by different types of service flows that might operate in such a broadband wireless network.

Bandwidth allocation in IEEE 802.16 can be made in two ways. Either by *grant per connection* (GPC) or by *grant per Service Station* (GPSS). In the first case each grant is associated with a specific connection. Thus whenever several connections of an SS are polled or granted transmission opportunities, multiple entries are set in UL-MAP message. The main disadvantage of this approach is that it creates additional overhead. On the other approach GPSS, the SS is given a single grant for all its connections. Then the local scheduler in the SS decides how to allocate the transmission opportunities to each connection. In doing this the SS must respect the QoS requirements of its connections. In both modes the bandwidth requests are issued per connection.

III. QoS STRATEGY FOR THE WIMAX SCHEDULER

WiMAX scheduler is expected to occupy many laboratories and R&D departments of several Telecommunication providers in the near future. This section has as a goal to provide a complete description of the possible features that every Telco could control to enhance the performance of its WiMAX devices.

The standard provides four features to enhance its support for QoS: Fragmentation, Concatenation,

Contention and Piggyback. In addition, for differentiation among the data streams, IEEE 802.16 provides four scheduling service flows which represent the data handling mechanisms supported by the MAC scheduler for data transport on each type of connection. The standard offers details of the SSs request upstream minislot functionality and the expected behavior of the BS upstream scheduler.

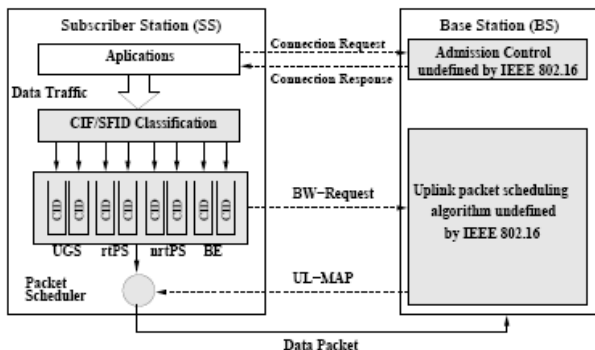


Figure 4. QoS architecture in 802.16.

Scheduling Service flows

Unsolicited Grant Service Flows (UGS): This service flow is designed to support Real time data streams, where fixed data packets are generated on periodic basis, such as TDM voice and T1/E1. QoS for these applications is provided through unsolicited data grants which are issued at periodic intervals. The advantage of this service flow is that it eliminates the overhead and latency of the SS to send request for transmission. In UGS, the SS is prohibited from using any contention and piggyback requests, and the BS does not provide any unicast request opportunities. To ensure the ability of the UGS service flow to support delay prone applications, four key service parameters are included: Unsolicited Grant Size, Grants per Interval, Nominal Grant Interval and Tolerated Grant Jitter.

Real-Time Polling Service Flows (rtPS): This service flow is designed to support similar data streams to UGS case, but with variable size data packets, such as MPEG video and VoIP with Silence suppression. This flow type offers periodic unicast request opportunities, which meet the flow's real-time needs and allow the SS to specify the size of the desired grants. As in UGS contention and piggyback request are prohibited to be sent. In this service flow the key parameters are Nominal Polling Interval, Tolerated Poll Jitter and Minimum Reserved Traffic Rate.

Non Real-Time Polling Service Flows (nrtPS): nrtPS is designed to support non-real-time service flows that require variable size data grants on a regular basis, but using more spaced intervals than rtPS. This service flow can support bandwidth to data streams under heavily saturation condition, due to its polling feature. The BS provides SS the opportunity to request bandwidth using unicast and contention period. In addition piggyback request opportunities are also available. The key service parameters are: Nominal Polling Interval, Minimum Reserved Traffic Rate and Traffic Priority (a range 0-7).

Best Effort Service Flows (BE): BE supports any other traffic without significant quality constrains such as HTTP. All available mechanisms of the protocol for transmission requests are available. This service flow uses only contention request opportunities and unicast request opportunities. The key service parameters are: Minimum Reserved Traffic Rate and Traffic Priority (a range 0-7).

TABLE I

Service Flow	Definition	Applications
UGS	Real time data streams with fixed size data packets issued at periodic intervals	T1/E1, VoIP without silence suppression.
rtPS	Real time data streams with variable size data packets issued at periodic intervals	MPEG video, VoIP with Silence suppression
nrtPS	Delay Tolerant data streams with variable size data packets issued at periodic intervals	FTP, Telnet
BE	Delay Tolerant data streams, background traffic or any other application without significant QoS constrains	HTTP, E-mail

QoS Features

The scheduler is in charge of controlling the common uplink bandwidth as well as distributing resources to flows for maintain quality. The QoS features provided by the scheduler are expected to be the only ammendements to the protocol allowed, and therefore the most possible to be custom-tailored by the client Telco according to each needs.

Piggybacking is used as a request for additional bandwidth sent together with a data transmission. The key advantage of this approach is that piggybacking obviates contention. Concatenation is used in the MAC protocol to send more than a frame during a transmission opportunity so as to reduce packet overhead. In the following we investigate concatenation combined with fragmentation and prove that both give an improvement to throughput and provide a better use of resources. The third feature that can be sometimes managed is the backoff window of the exponential backoff algorithm part of the contention period of the BE service flow. We investigate the performance of the network by differentiating the values of the Backoff Window.

The last but not least parameter which can be modified, from the interface of each WiMAX device, by the Telecommunication providers, is the Traffic Priorities of the BE service flow. Each Telco can provide an alternative to low bandwidth DSL lines by specifying the Traffic Priority to each client. It is proved by simulation that higher Traffic Priorities can provide better delay performance and thus accomplish the specified Service Level Agreements (SLAs) of each connection.

IV. SIMULATION AND RESULTS

In order to create our simulation environment we incorporated OPNET modeler and the DOCSIS module. DOCSIS MAC layer is similar to the IEEE 802.16, and the appropriate changes were made to provide a model that closely resembles to [2]. In the following simulation

scenarios exponential distribution of packet interarrival time and packet size was used so as to accomplish a more realistic networking environment. The downstream channel was set up to 50Mbps all of which was successfully captured by the load.

Scenario 1: Backoff Start

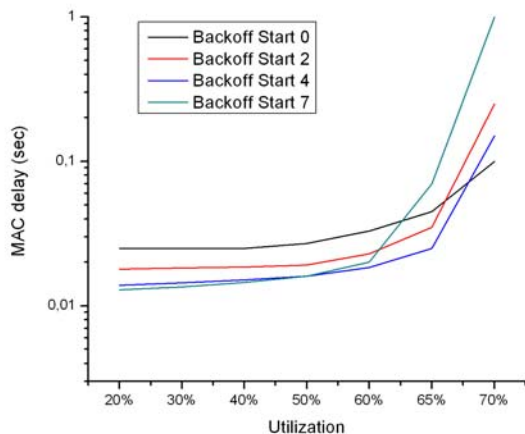


Figure 5. Overall MAC delay in logarithmic scale with Backoff Start differentiation, piggyback, concatenation and fragmentation enabled. (Packet Generation by 10 SSs)

In figure 5 it is shown that for low loads of traffic, the MAC delay of the ones that have higher Backoff Start Value is less. This in fact happens due to reduction of collision probability when increasing the backoff start value. But for values of 4, 7 and higher there is not much difference. This result in higher values of the contention period whereas the collision probability is decreasing and therefore the delay due to collisions is less. It is also observed that in higher values of backoff start, the saturation comes in lower utilization. In reality this is true, high values are less adaptive to higher loads, as each station differs its transmission by a greater number of minislots, and may not be included in the next MAP, and thus wait for more than one MAP. Therefore it is proved that each Telco, in cooperation with its vendor, may adjust the value of backoff start according to the load of BE traffic and SLAs. Lastly we mention that the effect of Backoff Start values would be clearer if we had fragmentation and concatenation disabled. Though with both of them enable the scenario is much more realistic.

Scenario 2: Traffic Priorities

IEEE 802.16 specifies that Traffic Priorities can be used for rtPS and BE service flows, in a range of 0-7 scale (0 is the higher and 7 the lower). According to the Traffic Priority our scheduler is responsible for allocating transmission opportunities in priority order offering differentiation among MAC delay of each station.

Clients with SLAs who request non delay-prone applications to be passed by BE can be prioritizing according to the Traffic Priority feature. After 60% of load, the queue is building up and the delay increases to

very high values. We believe this QoS feature will take a hand in WiMAX networks as it might be open by vendors.

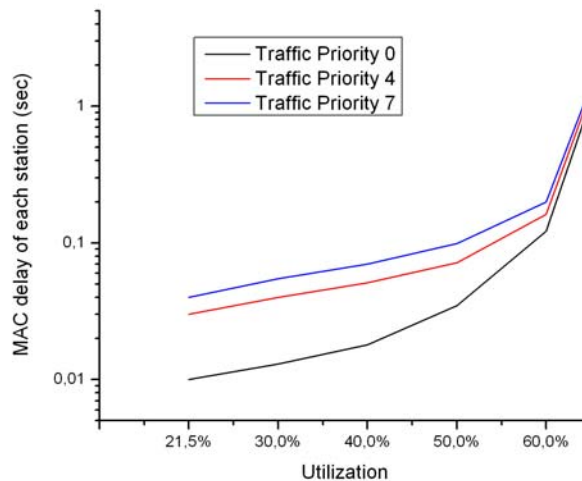


Figure 6. MAC delay in logarithmic scale of each station with different Traffic Priorities with piggyback enabled.

Scenario 3: Fragmentation and Concatenation

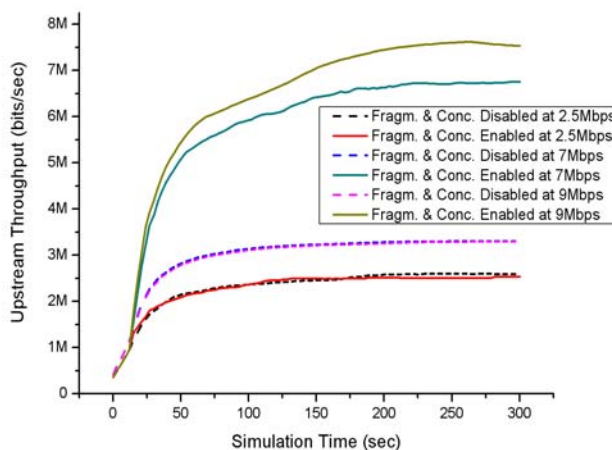


Figure 7. Upstream Throughput at 10Mbps Upstream Bandwidth with and without Fragmentation and Concatenation (Packet Generation by 4 SSs)

Concatenation plays the role to combine multiple upstream packets into one packet so as to reduce extra packet overhead. This is clearly shown in “Fig.7” where after 3.3Mbps, the upstream throughput is not increasing unless fragmentation and concatenation are enabled. The reason that both of them are enabled is because if concatenation is enabled and fragmentation disabled, the packets would be too large to be transmitted in a single MAP. Thus for high loads, fragm. and conc. should be used as they provide better utilization with lesser access delays. A similar performance could be observed in a delay graph. In the above we must also mention that 15% of total bandwidth was used for UGS service flow. This is done so as to have a more realistic performance.

Scenario 4: Piggyback

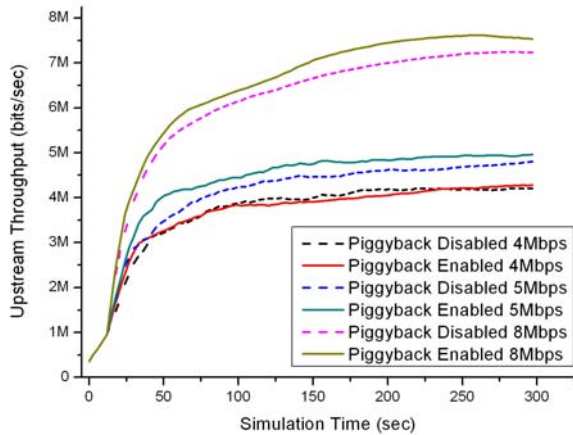


Figure 8. Upstream Throughput at 10Mbps Upstream Bandwidth with and without Piggyback (Packet Generation by 4 SSs)

From the above figure it is seen that piggyback in low traffic does not offer great difference in upstream throughput. For high loads the difference seems to be larger as more frequent contentions happen when the feature is disabled. On the other hand when it is enabled more requests are being piggybacked in each data transmission. So higher loads can occur when the piggyback feature is enabled. 15% of the total load was occupied by the UGS service flow in this case as well.

Scenario 5: Call Admission Control

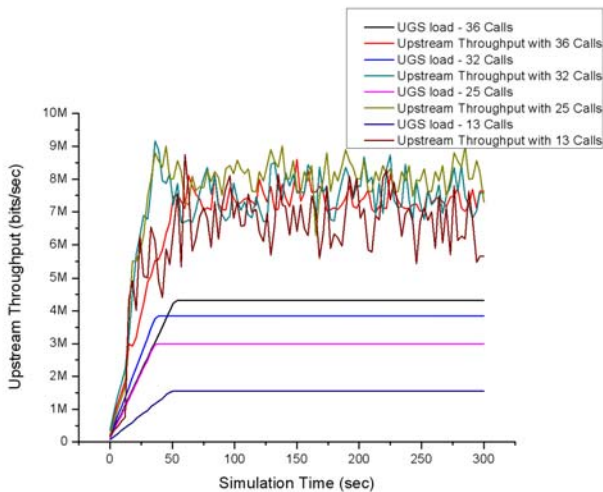


Figure 9. Upstream Throughput at 10Mbps Upstream Bandwidth with CAC (Packet Generation by 4 SSs with G.711 Voice Codec)

In this scenario a Call Admission Control (CAC) strategy is implemented. The simulation scenarios were done for 15%, (13 calls), 30% (25 calls), 40% (32 calls) and 50% (36 calls) UGS traffic. After that value new calls were not admitted to the network. Grants of the UGS traffic flow are generated in constant intervals. After saturation, UGS does not perform well because too many grants cannot be admitted in only one MAP. Thus a number of grants are served in the next MAP. Our

admission control has the role to protect the UGS service from overflow. The overall upper limit of throughput of all the service flows is the same in all cases.

V. CONCLUSIONS

In this paper various QoS attributes based on the scheduler of IEEE 802.16 are elaborated, showing after simulations the performance of such networks, which in fact tend to overcome the already existing BWA and cellular networks. Differentiation of specific QoS features can provide an augmentation to the provided resources, according to the needs of each Telco. Moreover a CAC is implemented in the UGS service flow. It is generally agreed that the deployment of such WiMAX networks will flourish the forthcoming years and thus more studies on WiMAX will appear. Similar case studies require a close cooperation between the vendor and Telco, and could be an excellent study for R&D departments.

As a future work, we intend to evaluate the behavior of IEEE 802.16 under full saturation condition and provide a mathematical analysis combined with extensive OPNET simulations. Similar simulations will be combined with market products so as to create a full study of WiMAX and IEEE 802.16 standard. Yet, low cost WiMAX interfaces are due to arrive within 2007.

REFERENCES

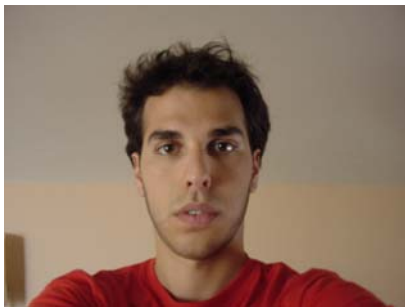
- [1] IEEE Std. IEEE 802.11-1999 - Local and metropolitan area networks Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications, 1999.
- [2] IEEE Std. 802.16-2004 (Revision of IEEE Std. 802.16-2001): IEEE Standard for Local and Metropolitan Area Networks Part 16: Air Interface for Fixed Broadband Wireless Access Systems, Mar. 17, 2004.
- [3] IEEE Std. 802.16/D5-2004, Part 16: Air Interface for Fixed and Mobile Broadband Wireless Access Systems - Amendment for Physical and Medium Access Control Layers for Combined Fixed and Mobile Operation in Licensed Bands, Nov. 2004.
- [4] Steven J. Vaughan-Nichols, "Achieving Broadband Wireless Access with WiMax" *IEEE Computer Society Magazine*, vol. 37 Issue 6, pp 10-13, June 2004.
- [5] C. Hoymann, "Analysis and performance evaluation of the OFDM-based metropolitan area network IEEE 802.16", *In Computer Networks, Selected Papers from the European Wireless 2004 Conference*, Vol. 49, No. 3, p.p. 341-363, The Hague, Netherlands Oct. 2005.
- [6] D.H. Cho, J.H. Song, M.S. Kim, and K.J. Han "Performance Analysis of the IEEE 802.16 Wireless Metropolitan Area Network," *Proceedings of the First International Conference on Distributed Frameworks for Multimedia Applications (DFMA '05)*, pp. 130-137, 2005.
- [7] S. Ramachandran, C.W. Bostian and S.F. Midkiff, "Performance Evaluation of IEEE 802.16 Broadband Wireless Access", *Proceedings of OPNETWORK 2002*, Aug 2002.
- [8] H. Lee, T. Kwon, and D.H. Cho, "An Efficient Uplink Scheduling Algorithm for VoIP Services in IEEE 802.16d/e System", *IEEE comm. Letters*, Vol. 9, No. 8, Aug. 2005.
- [9] H. Wang, W. Li and D.P. Agrawal, "Dynamic Admission Control and QoS for 802.16 Wireless MAN", *Wireless Telecommunication Symposium 2005*, pp. 60-66, April 2005.
- [10] M. Hawa and D.W. Petr, "Quality of Service in Cable and Broadband Wireless Access Systems", *Tenth Int. Workshop on Quality of Service*, pp. 247-255, May 2002.
- [11] G. Chandrasekaram, M. Hawa and D. Petr, "Preliminary Performance Evaluation of QoS in DOCSIS 1.1", *Technical Report, in University of Kansas*, Jan. 2003
- [12] Cable Television Laboratories, Data-Over-Cable Service Interface Specifications - Radio Frequency Interface Specification v1.1, July 1999.



Georgios S. Paschos was born in Athens, Greece, in 1978. He received his Diploma in electrical and computer engineering, Polytechnic School of Aristotle University of Thessaloniki (2002). He is currently in the process of defending his Ph.D. thesis in telecommunications in the School of Electrical Engineering and Computer Science in the University of Patras, Greece. His main interests are wireless networks, quality of service, and network management.



Ioannis Papapanagiotou is pursuing his undergraduate diploma in the Electrical and Computer Engineering School of University of Patras Greece, and he is currently in his last year of studies. His main interests include Quality of Service in Wireless Local and Metropolitan Area Networks and performance evaluation.



Christos G. Argyropoulos has been studying in the Electrical and Computer Engineering School of University of Patras, Greece, since 2002. His interests include Wireless Metropolitan Area Networks (WMANs) and Broadband technologies.



Stavros A. Kotsopoulos was born in Argos Argolidos, (Greece), in the year 1952. He received his B.S. degree in physics in the year 1975 from the University of Thessaloniki, and in the year 1984 got his Diploma in electrical and computer engineering from the University of Patras. He did his postgraduate studies in the University of Bradford in the United Kingdom, and he is an MPhil and Ph.D. holder since 1978 and 1985, respectively. Currently he is member of the academic staff of the Department of Electrical and Computer Engineering of the University of Patras and holds the position of Associate Professor. Since 2004, he has been the Director of the Wireless Telecommunications Laboratory and has been developing his professional life teaching and doing research in the scientific area of telecommunications, with interest in mobile communications, interference, satellite communications, telematics applications, communication services, and antennae design. Moreover he is the (co)author of the book *Mobile Telephony*. His research activity is documented by more than 160 publications in scientific journals and proceedings of international conferences. Associate Professor Kotsopoulos has been the leader of several international and many national research projects. Finally, he is a member of the Greek Physicists Society and a member of the Technical Chamber of Greece.