

# *Design of an Effective QoS-aware Mapping Scheme Using Persistent Allocation Probing*

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**Abstract**—Mobile Worldwide Interoperability for Microwave Access (WiMAX) constitutes an attractive trademark for supporting wireless access to Intranets and the Internet. Scheduling and mapping processes are of paramount importance since they dramatically affect the network performance. This work endeavors to provide a robust mapping scheme for the downlink sub-frame with respect to various Quality of Service (QoS) constraints. Each downlink request creates rectangular regions, called Horizons, and the mapping technique applies a persistent probing of the Horizons recorded. The evaluation experiments conducted indicate that the scheme designed beneficially affects the system performance.

**Keywords**—IEEE 802.16, mapping, OFDMA, QoS, WiMAX

## I. INTRODUCTION

The IEEE 802.16-2009 standard [1] designated the Mobile Worldwide Interoperability for Microwave Access (WiMAX) as an attractive wireless system, capable of supporting effective access and mesh networking. The system employs a flexible multiplexing technique, based on Orthogonal Frequency Division Medium Access (OFDMA), whereby the bandwidth exploitation is realized by allocating resources in both frequency and time domains. In fact, Media Access Control (MAC) requests are delivered from the MAC layer to the OFDMA allocation mechanism in order to receive PHYsical (PHY) system resources. Hence, multiple subscribers have concurrently access to the system resources in units of slots, which are the smallest quanta of PHY layer resource that can be allocated to a single subscriber in the time and frequency domain [2].

In the context of an access wireless network the Base Station (BS) plays the main role of the connection point between multiple Mobile Stations (MSs). The MSs are fully controlled by the BS, which is the gateway to other Intranets or to the Internet. Accordingly, each MS aims at

communicating with the BS to send and receive information data via the gateway.

Undoubtedly, the efficiency of a Mobile WiMAX access network lies in the effectiveness of the two-way communication between the BS and the MSs. Typically, the BS is responsible for establishing, preserving, and maintaining a viable full-duplex communication, delivering data to MSs (downlink direction) and receiving data from MSs (uplink direction) on a frame-by-frame basis. At the beginning of each frame, the BS is aware of the uplink and downlink requests of each connected MS. Therefore, an effective allocation program has to be designed in accordance to the MAC request properties, the available allocation resources, and the OFDMA rules and constraints. In the light of the aforementioned aspects, the efficiency of a Mobile WiMAX access network is directly depends on the allocation process effectiveness on handling the MAC requests, known also as mapping process.

In a Time Division Duplexing (TDD)-based frame the downlink sub-frame comes first and the uplink sub-frame follows. The standard does not impose strict techniques or algorithms dealing with the downlink or uplink mapping processes. However each downlink request (or a set of requests that share common PHY characteristics referred to as a burst) must follow the rectangular shape. This constraint implies that MAC request(s) should be accommodated in a two dimensional rectangular shape, having one dimension associated with frequency (height) and the other associated with time (width), independently of the original number of slots that have been initially allocated. It is clear that this allocation rule hinders the mapping process in the downlink sub-frame and may lead to deficiencies.

Although many mapping techniques can be found in the literature, most of them present either static allocation techniques or inflexibly designed methods. Furthermore, the most of the presented works seem to neglect the QoS provisioning, considering equal priorities for all requests. On

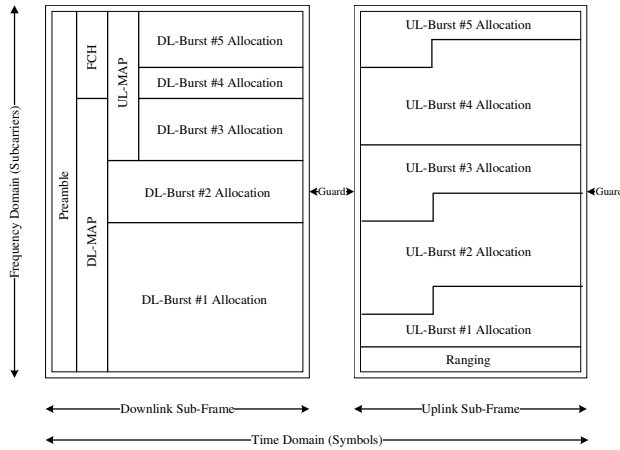


Figure 1. Frame structure of the Mobile WiMAX System.

the contrary, this paper tackles this issue by proposing a novel QoS-aware effective mapping algorithm for the downlink sub-frame. The method introduced is called PERSistent Allocation (PERA) and aims at effectively exploiting the available allocation OFDMA capabilities, improving the performance of the mapping process in terms of bandwidth utilization and system service ratio. The basic idea behind the PERA scheme is to significantly reduce the wasted bandwidth derived by the allocation process, by exploiting every empty space created by previous accommodations. In this manner, the PERA persistently tries to exploit any available residual allocation area within the OFDMA downlink allocation space. Concurrently, the effective bandwidth exploitation is accompanied with adequate QoS provisioning.

The rest of the paper is organized as follows. Section II briefly presents OFDMA basics and Section III describes related mapping techniques proposed in research literature. Section IV presents the proposed PERA scheme and Section V evaluates its performance. Finally, Section V concludes this paper.

## II. OFDMA BASICS

As previously mentioned, the Mobile WiMAX frame length is fixed and periodically repeated in time. Each frame is divided into a downlink sub-frame and an uplink sub-frame separated by transmit/receive transition gaps (TTGs) and receive/transmit transition gaps (RTGs) to prevent collisions. Figure 1 illustrates the mobile WiMAX TDD frame structure. The downlink sub-frame includes a preamble that indicates the start of a frame, broadcasting control information such as a frame control header (FCH), MAP messages, and downlink bursts for normal data transmission. The uplink sub-frame includes control channels such as a ranging channel for performing frequency and power measurements as well as MSs' bandwidth requests.

## III. RELATED MAPPING TECHNIQUES

There are many research efforts in generating mapping programs for the downlink direction. Because of the shape

restriction, the downlink mapping topic has gained more attention than the uplink one. One of the simplest approaches is introduced in [3], wherein the simple packing algorithm (SPA) involves a top to bottom and left to right slot allocation, accommodating symbols (rows) and sub-channels (columns) for each request in a first in first out (FIFO) way, until the requested number of slots is met. Even though this approach is simple, large number of idle slots is produced due to rectangular constraint. The scheme in [4], presents binary-tree full search tree, but the final result indicates complex operation, limited to eight users. Other schemes [5-6] apply heuristic methods such as bucket defining and a combination of horizontal and vertical mapping after an initial request sorting. AHBM algorithm [7] initially sorts the downlink requests in descending order and then defines allocation drivers in order to facilitate the accommodation process. Large requests are accommodated first, leaving minimum remaining idle space, while driver regions are formed in a right to left and bottom to top manner. Notwithstanding, the AHBM scheme neglects the QoS provisioning issue, assuming equal priority for all requests. The same shortcoming arises in the work in [8], where the fairness issue is explicitly examined. Finally, our extension in [9] takes into account only the deadline of sensitive requests, without dealing with the service class issue.

## IV. PERSISTENT ALLOCATION SCHEME

### A. Contributions

Most proposed mapping schemes are inflexibly designed, defining static allocations, and neglecting the QoS adaptation. In generating the mapping program in the downlink sub-frame, there are three major contributions in this paper. First, an efficient mapping algorithm is proposed. Second, the QoS provisioning issue is addressed by elegantly dealing requests in accordance with their priority. Finally, the service classes per MS are respected and handled adequately giving guarantees to the MSs contracts.

### B. Main Operation

The main operation of the mapping algorithm is based on the observation that each request's accommodation redefines allocation rectangular areas. Considering that the allocation method follows a right to left and bottom to top manner each accommodation redefines two, one or none areas formed into rectangular shape. In order to facilitate the mapping process, we consider that each request is placed either next to the allocation space edge or next to another adjacent request. Furthermore, each request is sited either above the allocation space base or above another adjacent request. In this manner, the placement may create two rectangular shapes, one above the request, having width equal to request's width, and one next to the placement, having width equal to the area's width before the placement minus the request width.

Each rectangular area created upon request's accommodation is called Horizon. PERA maintains a list of all available Horizons, considering that the initial Horizon is the whole allocation bin. For each available Horizon, the mapping algorithm calculates its footprint. Thereafter, the

algorithm examines only the Horizons that have footprint larger or equal to the request being accommodated. The main criterion of selecting the suitable Horizon and determining the rectangular dimensions of the rectangular region of the allocation space for each request is the wasted space that each request produces upon its accommodation. PERA selects the appropriate dimensions of the rectangular, prior to the accommodation procedure, based on the idle (wasted) space that each request leaves behind.

The algorithmic form of the core mapping process of PERA is outlined in Algorithm1. The algorithm receives the set of downlink requests along with the initial set of Horizons, which contains the initial allocation bin, and produces the mapping program by providing the lists of accommodated and unmapped requests. It should be noted that the algorithm operates in a right to left and bottom to top manner. Hence, the initial coordination point (0,0) is set to be the lower left corner of the initial allocation bin. The algorithm begins by selecting the appropriate request to be mapped based on the QoS criteria specified, as will be explained in sub-section IV.C. In the case of QoS specifications absence, the algorithm continuously selects the most demanding request in order to prioritize large requests which may fail to find available allocation space if handled in a later time. The *For* loop (lines 3-5) probes the most appropriate Horizon that is capable of accommodating the current request based on the wasted portion of slots left behind. If a suitable Horizon found, then the algorithm proceeds to the request rectangular region formation (line 7) and redefines the Horizons emerged. There are three cases, as previously mentioned in Lemma 1: a) a new Horizon is formed (lines 8-9) and the selected Horizon is reformed (line 10) b) the Horizon selected is reformed (lines 11-12), and the selected Horizon is entirely occupied by the request and therefore is deleted.

#### Algorithm1: Persistent Horizon Mapping

**Input:** The allocation bin height, denoted by  $H$   
The allocation bin width, denoted by  $W$   
The set of downlink requests  $R = \{Req^1, Req^2, \dots\}$   
The initial set of Horizons  
 $Ho = \{Ho^1 = [Ho_{height}^1, Ho_{width}^1, Ho_x^1, Ho_y^1]\}$ , where  
 $Ho_{height}^1 = H, Ho_{width}^1 = W, Ho_x^1 = 0, Ho_y^1 = 0$   
**Output:** The set of accommodated requests  $RA$   
The set of unmapped requests  $RU$

1. **Do**
2. Select the request  $Req$  from the set  $R$ , requiring  $Req_{slots}$  slots, on the QoS criteria. If no QoS criteria exist, select the request  $Req$  that has the largest  $Req_{slots}$
3. **For** each Horizon  $h \in Ho$ ,  
where  $Ho_{width}^h \times Ho_{height}^h \geq Req_{slots}$
4. Find the Horizon  $q \in Ho$  that supports the minimum  $Req_{width}$ :  

$$Req_{width} \in [1, Ho_{width}^q] \left( Req_{width} \times \left\lceil \frac{Req_{slots}}{Req_{width}} \right\rceil - Req_{slots} \right)$$
5. **End\_For**
6. **If** Horizon  $q$  found

7. Define the request rectangular specifications:  
 $Req_{height} = \left\lceil \frac{Req_{slots}}{Req_{width}} \right\rceil$   
 $Req_x = Ho_x^q + (Ho_{width}^q - Req_{width})$   
 $Req_y = Ho_y^q$
8. **If**  $Req_{width} < Ho_{width}^q$  AND  $Req_{height} < Ho_{height}^q$
9. Insert new Horizon  $q'$  into  $Ho$ :  
 $Ho_{width}^{q'} = Req_{width}$   
 $Ho_{height}^{q'} = Ho_{height}^q - Req_{height}$   
 $Ho_y^{q'} = Req_y + Req_{height}$   
 $Ho_x^{q'} = Req_x$
10. Redefine Horizon  $q$ :  
 $Ho_{width}^q = Ho_{width}^q - Req_{width}$
11. **Else\_If**  $Req_{width} == Ho_{width}^q$  AND  
 $Req_{height} < Ho_{height}^q$
12. Redefine Horizon  $q$ :  
 $Ho_{height}^q = Ho_{height}^q - Req_{height}$   
 $Ho_y^q = Ho_y^q + Req_{height}$
13. **Else\_If**  $Req_{width} == Ho_{width}^q$  AND  
 $Req_{height} == Ho_{height}^q$
14. Remove Horizon  $q$  from  $Ho$
15. **End\_If**
16. Remove  $Req$  from the  $R$  and insert it into the  $RA$  set
17. **Else**
18. Remove  $Req$  from the  $R$  and insert it into the  $RU$  set
19. **End\_If**
20. Select the next request ( $Req$ )
21. **While** ( $R \neq \emptyset$ )

#### C. QoS-aware Mapping

QoS provisioning is one of the essential features in IEEE 802.16 standards. In downlink transmissions a BS has sufficient information to perform scheduling, hence the mapping process is aware of the QoS specifications of each MS. For proper allocation of bandwidth, five services are defined to support different types of data flows: a) Unsolicited grant service (UGS) is designed to support real-time constant bit rate (CBR) traffic such as VoIP; b) Real-time polling service (rtPS) is designed to support variable bit rate (VBR) traffic such as MPEG video, c) Non-real-time polling service (nrtPS) is for delay-tolerant data service with a minimum data rate, such as FTP, d) extended rtPS supports real-time service flows that generate variable size data packets on a periodic basis, and e) Best effort (BE) service does not specify any service related requirements. The PERA scheme creates five service classes sets based on the above categorization and inserts the downlink requests into these classes. Then the members of each set are sorted with respect to request time deadlines and the algorithm defines the request service order set. Algorithm2 describes the operation.

#### Algorithm2: QoS-aware Mapping

**Input:** The request service class  
The request deadlines  
**Output:** The request service order set  $SO$

1. **For** each frame
2. Insert all requests to service classes sets:  
 $R_{UGS}, R_{rtPS}, R_{ErtPS}, R_{nrtPS},$  and  $R_{BE}$
3. Sort each service class set with respect to time deadlines.
4. Starting from the first service class set ( $R_{UGS}$ ) to the last one ( $R_{BE}$ ) fill the request service order set  $SO$ .
5. Apply the Persistent Horizon Mapping to the set  $SO$
6. **End\_For**

## V. PERFORMANCE EVALUATION & RESULTS

### A. Evaluation Background

The performance of the PERA scheme is evaluated in a robust simulation environment implemented in Matlab. In the first set of experiments the efficiency of the PERA scheme is comparatively inspected to similar mapping schemes. Specifically, the mapping performance of the following algorithms are investigated: the eOCSA scheme [6], the pure AHBM scheme [7], having deactivated the prediction module, and the PERA scheme. The performance metrics investigated are the average number of unmapped MSs per frame and the mean number of idle slots produced within a frame.

In the second set of experiments the QoS provisioning capabilities of the scheme proposed are examined. Specifically, it is considered that each incoming request belongs to a service class. Each request belongs to one of the five well-known Mobile WiMAX service classes with probability equal to 30%, 15%, 5%, 20%, and 30% for  $R_{UGS}, R_{rtPS}, R_{ErtPS}, R_{nrtPS},$  and  $R_{BE}$  set of classes respectively. Moreover, it is assumed that each request, originated from the first three ‘sensitive’ service classes, expires after a period of time. This deadline is expressed in number of frames and is randomly defined within  $[0, 10]$ . Consequently, the second scenario examines the proposed scheme’s behavior when dealing with QoS-aware subscribers by investigating the average request waiting time of each class as well as the packet drop ratio experienced by each class.

The simulation environment is designed in accordance with the following IEEE 802.16e network parameters: The well-known Partially Used Sub-Channelization (PUSC) mode is adopted. According to this technique, the downlink sub-frame defines 30 different channels. The frame length is set to be 10 ms. Accordingly, three symbols are reserved for control (one symbol for Preamble, and two symbols for MAP and FCH fields) and are excluded from allocating downlink requests. The downlink-to-uplink ratio is set equal to 2:1, allowing 27 symbols to be utilized for the downlink sub-frame. Hence, a set of 810 ( $30 \times 27$ ) slots are destined to downlink sub-frame allocation needs.

A self-similar traffic model is employed in order to generate realistic downlink traffic requests from the scheduler to the mapper. Forty Pareto-distributed ON/OFF periods are cycled producing the traffic requests of each source with shape parameter  $\alpha_{ON} = 1.6$  and  $\alpha_{OFF} = 1.4$ . The scheduler forwards Ethernet frames to the mapper, while the (MAC) buffer capacity is set equal to 10 MB.

TABLE I  
WIRELESS CHANNEL PARAMETERS

Probability	Modulation/Coding	Bits per slot
5%	Outage	0
45%	QPSK-1/2	48
25%	QPSK-3/4	72
15%	16QAM-1/2	96
10%	16QAM-3/4	144

The impact of wireless channel condition is also taken into account. The number of bits per slot a MS receives depends on the chosen modulation and coding scheme, which in turn depends on its radio channel condition. In this manner, for each frame, MSs’ requests in bytes are associated to slots based on specific probabilities [10]. Table I summarizes the wireless channel parameters.

### B. Evaluation Results

For all the experiments that follow it is assumed that each connected MS may request one burst per frame. The burst constitutes a compound of various subscribers’ data packets that share common physical properties. A burst length may varies from 1 to  $6 \times H \times W$  slots resulting in 1600 Bytes under QPSK-1/2 status (minimum operational channel conditions). The mean (downlink) arrival rate per MS is set to 5 Mbps per MS.

Figures 2 and 3 are associated with the first scenario, where the average number of unmapped MSs (Fig. 2) and the average number of idle slots (Fig. 3) evaluate the performance of the three mapping algorithms. It should be noted that in the context of the first scenario, the PERA scheme is explicitly evaluated in terms of mapping efficiency, without taking into account QoS constraints.

Fig. 2 depicts the system service ratio in terms of unmapped MSs as the number of connected MSs increases. Obviously, as more MSs are connected to the access network more downlink requests need accommodation. Accordingly, all algorithms begin to present deficiencies when the number of connected MSs reaches to 10. However, the proposed PERA scheme seems to keep the losses at a minimum level, resulting in network performance improvements. Furthermore, PERA presents the lowest number of idle slots, as shown in Fig. 3, resulting, thus, to a more efficient utilization of network resources. This may be attributed to

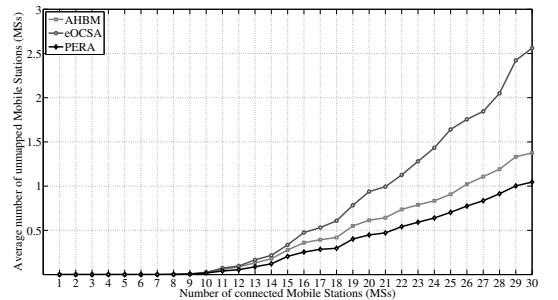


Figure 2. Average number of unmapped MSs.

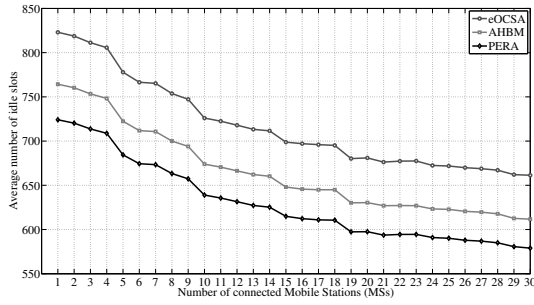


Figure 3. Average number of idle slots.

the designed accommodation strategy, which is based on the concept of persistent Horizon mapping. Overall, the designed mapping technique is more efficient than the other methods as a result of the mapping strategy that efficiently organizes the available allocation space in Horizons and effectively exploits them to accommodate as more requests as possible.

Figure 4 outlines the average packet delay per service class in secs. Clearly, the QoS provisioning is guaranteed since the obtained results show a relative differentiation between the various traffic classes in accordance to the initial assumption of the classes' categorization. More specifically, the presented average delay is proportional to the priority given to each traffic class. Consequently, the PERA scheme achieves QoS differentiation in terms of packet delay according to the predefined traffic classes of Mobile WiMAX network. Packet drop ratio results are illustrated in Figure 5. According to the initial assumption only the first three traffic classes generate 'sensitive' packets. As expected, the ErtPS service class presents the most extended losses, since the ErtPS class experiences lower priority than the rtPS and UGS classes. Once more, the obtained results are proportional to the traffic classes adopted. Under any circumstances, the PERA scheme succeeds to provide QoS differentiation allowing the most 'sensitive' traffic flows to be favored in order to guarantee the subscribers' contracts.

## VI. CONCLUSIONS

Modern wireless access networks have to provide efficient, effective, and QoS-aware service provisioning. In this work, a novel QoS-aware mapping strategy is proposed to address the deficiencies occurred by the QoS constraints violation and the bandwidth exploitation underutilization.

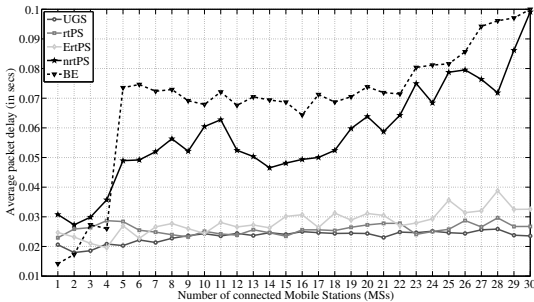


Figure 4. Average packet delay per service class.

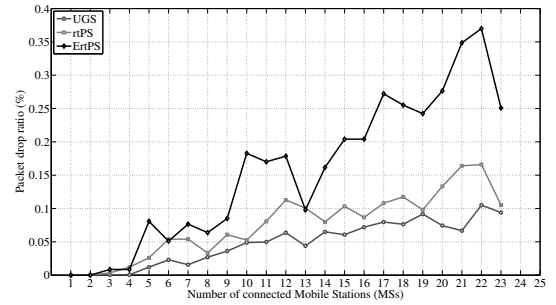


Figure 5. Packet drop ratio of the UGS, rtPS, and ErtPS classes.

The introduced PERA scheme aims at providing effective downlink request accommodation by productively organizing the allocation space into separate Horizons structures. Concurrently, the applied persistent mapping technique extends the potential of incoming requests to find available allocation space. Finally, the PERA scheme provides QoS-aware treatment of the incoming requests by relatively handling the downlink data packets in accordance to their service class and time constraints.

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