A Novel Fair Mapping Scheme for IEEE 802.16 Downlink Sub-Frame

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Abstract—**A novel fair mapping scheme is proposed in this paper for the IEEE 802.16 downlink sub-frame. The mapping process is critical since it allocates the users' requests into the downlink sub-frame in order to be sent to the mobile stations. One of the most noticeable issues in this area lies on the fairness aspect. Giving that the mapping process defines the order and the way that the users' requests are being serviced, some users may be treated unfairly. In this work this issue is considered and a new mapping scheme is introduced. The proposed scheme encloses fair and more efficient mapping process, compared to the leading scheme, according to the presented simulation results.**

Keywords-IEEE 802.16, fairness, mapping, OFDMA, simulation

I. Introduction

Over the last few years, broadband wireless access (BWA) technologies have attracted a lot of attention in the telecommunication community including researchers, product developers and service providers. The IEEE 802.16 family of standards and its associated industry consortium, Worldwide Interoperability for Microwave Access (WiMAX), has promised to offer high-bandwidth wireless access over long distance [1]. The IEEE 802.16 standards concern the physical (PHY) and medium access control (MAC) layers, providing ubiquitous coverage for metropolitan areas in a variety of ways - from point-to-point communication links to full mobile cellular type access.

The orthogonal frequency division multiple access (OFDMA) scheme has been selected as a potential candidate for many emerging broadband wireless access standards since it efficiently combines discrete multicarrier modulation with frequency division multiple access [2]. In OFDMA, the available spectrum (frequency domain) is divided into orthogonal sub-carriers, which are combined into groups, usually referred as sub-channels.

The network reference model of the WiMAX standard consists of a base station (BS) that is responsible for providing the air interface and a number of Subscriber Stations (SSs) utilized by the end users to access the network. The participants exchange data within specific time periods. Time is partitioned into frame periods of fixed duration, while each frame contains two sub-frames: the downlink (DL) sub-frame, where the BS transmits to SSs, and the uplink (UL) sub-frame, where the SSs transmit to the BS in a Time Division Multiple Access (TDMA) manner. In order to support bi-directional transmissions, the IEEE 802.16 specifies two duplexing techniques: Frequency Division Duplex (FDD), where uplink and downlink transmissions occur simultaneously on separate frequencies and Time Division Duplex (TDD), where uplink and downlink transmissions alternate in the time frame and share the same frequencies [2]. Both FDD and TDD techniques have their own advantages depending on the application. Hence, FDD is typically used in applications that require an equal uplink and downlink bandwidth. In contrast, TDD allows better resource utilization when one direction has heavier traffic load than the other since frame resources can adaptively be divided between the downlink and uplink sub-frames.

WiMAX is a connection-oriented wireless network, in contrast to contention-based IEEE 802.11 networks where stations compete for access to the shared medium. The basic approach in IEEE 802.16 is that the BS controls the access to the medium and allocates resources by scheduling for both the uplink and downlink directions. This type of access control is typically adopted by resources reservation MAC protocols for wireless networks. Typical examples can be found in [3-5]. Specifically, in WiMAX bandwidth is granted to SSs on demand by sending control messages to notify the BS of bandwidth requests. However, the scheduling policy (i.e. an algorithm to allocate slots to each SS) is not defined in the IEEE 802.16 specifications but it is up to each WiMAX implementation.

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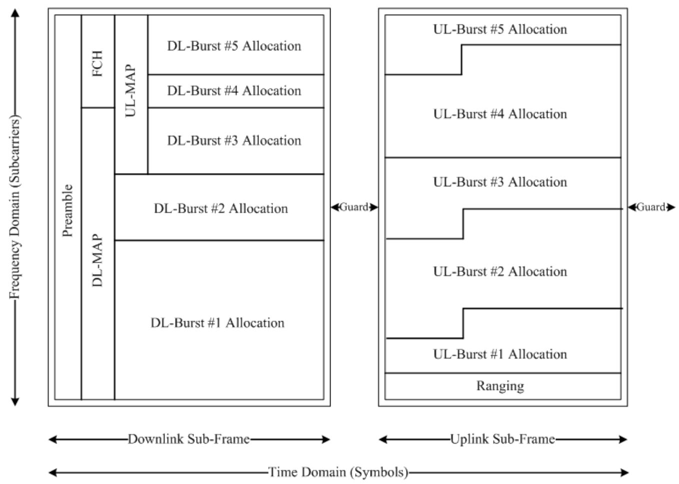

Figure 1. Downlink and uplink TDD sub-frame structure during the period of an IEEE 802.16 frame

In particular, the problem of assigning resources should be seen as a two-dimensional (2D) problem since frames are shown in two dimensions with frequency along the vertical axis and time along the horizontal axis.

The paper is outlined as follows. Section II provides the necessary background by briefly describing the features of the IEEE 802.16 that are specifically relevant to this paper. Section III presents significant related work and section IV describes in detail the proposed fair mapping scheme. Section V explores the performance of the proposed scheme by plotting simulation results. Finally, Section VI concludes the paper.

II. Brief Overview Of The IEEE 802.16

The IEEE 802.16 (WiMAX) standards define a connection-oriented and centrally controlled wireless communication protocol in the context of a uni-directional connection. A typical IEEE 802.16 network consists of a BS and the associated SSs. In order to separate uplink and downlink communication signals, FDD and TDD techniques are specified. Under the TDD technique uplink and downlink share the same frequency but alternate in time by having a downlink sub-frame followed by an uplink sub-frame. Fig. 1 illustrates the UL and DL sub-frames in two dimensions with frequency domain along the vertical axis and time domain along the horizontal axis. The two sub-frames are separated by a TTG (Transmit to Transmit Gap) in order for the BS to switch from transmit to receive mode and by a Receive to Transmit Gap (RTG) in order for the BS to switch from receive to transmit mode. Although, both methods have clear advantages depending on the application, TDD combined with OFDMA is the choice that is currently favored by most implementations because it simplifies the design of the subscriber stations [2]. In this work, we specifically consider TDD since it can allocate dynamically the amount of time slots assigned to each direction providing to operators the significant advantage of defining the ratio between UL versus DL traffic.

Each sub-frame starts with a preamble (for time synchronization) and a Frame Control Header (FCH) followed by the downlink map (DL-MAP) and the uplink map (UL-MAP) control messages that notify the SSs of the start and the duration of their uplink/downlink grants and modulation types. The FCH field defines the duration of MAP messages and usable subcarriers. The DL-MAP and UL-MAP messages indicate the bandwidth allocations and inform the SSs about how the subsequent DL and UL bursts are organized in time and frequency (i.e. describe the mapping of the downlink and uplink physical slots to connections, respectively). The MAP messages are then followed by a downlink transmission period (DL allocations) and an uplink transmission period (UL allocations). Each user can utilize a different burst profile, which is adaptive and can be changed depending on the transmission environment.

III. Related Work On Mapping

In [7] a historical overview of the IEEE 802.16 [6] standards is presented from the first version released in 2001 to the current version together with the futures trends of the protocol. Moreover, work in [7] provides a survey of certain latest developments and technical challenges of IEEE 802.16.

There are some recent proposals for resource allocation schemes and mapping algorithms in order to optimally determine the ratio of downlink and uplink traffic between the BS and SSs. In [8] a different mapping scheme has been introduced by thoroughly scanning the downlink sub-frame in a slot-by-slot basis and accommodating the incoming requests in line one after the other. Nevertheless, the authors do not provide details about how to map the resources to unused spaces if their sizes are over multiple rows. The authors of [9] focused on the study of the impact of the performance of a WiMAX OFDMA base station DL-MAP packing algorithm on the overall system performance and proposed a downlink scheduler that balanced efficiency with execution time. Work in [10] investigated the downlink burst allocation problem in IEEE 802.16 OFDMA system and two channel-aware schemes were proposed for BS to allocate downlink bursts to SSs with high subchannel utilization and network throughput. In [11] the authors explore the impact of improper bandwidth allocation to DL and UL channels on the performance of TCP and develop an adaptive split ratio scheme that adjusts the downlink to uplink capacity ratio according to the current traffic profile. Work in [12] introduced an optimization algorithm capable of reducing the activity of each receiver in the system for decoding its addressed bursts but this approach utilizes an exhaustive search over all possible binary splits of a given rectangle leading to a very quickly growing complexity.

Finally, authors in [13] and [14] propose two simple heuristic mapping schemes, aiming to keep the mapping operational complexity low by mapping the resource for each subscriber into a downlink burst in a rectangular fashion. All previous works considered the downlink-to-uplink ratio stable or did not take into account the fairness of the proposed schemes and in particular the order and the way that the requests by users are being serviced.

IV. FAIR HORIZON MAPPING SCHEME

Up to now none of the related downlink mapping schemes takes into account the issue of fairness. In this Section the proposed novel fair scheme is described, which has two main targets: (a) to ensure fairness among various subscribers, requesting access and (b) to keep the mapping scheme efficient, without sacrificing the performance for the fairness feature. Regarding the former target, a fairness index is utilized in order to measure the portion of fairness of each subscriber, concerning the satisfaction of their requests in total. More specifically, the fairness index calculates the fraction of the total requested slots that a subscriber asked during its connection session divided by the number of the served slots that the mapping scheme succeeded to offer during the specific session. The fairness index for the subscriber *i* is formulated as:

$$fairness\ index_i = \frac{total\ served\ slots}{total\ \ requested\ slots}$$

The reason for utilizing the fairness index is to identify the order that the requests of subscribers are being processed by the mapping algorithm. In contrast to other mapping schemes the proposed FHM scheme serves downlink requests based on their fairness status, obtained by the fairness index. Hence, the FHM sorts downlink requests in ascending order, considering as main criterion the fairness index and then each ordered request is mapped, initializing the first algorithm phase.

Concurrently, the FHM scheme tries to keep the mapping process as efficient as possible, adopting Horizon-based mapping. The first set of requests that being mapped define Horizons, which constitute pilots for the forthcoming requests. The Horizons are created based on the wasted space that remains in the OFDMA region after the mapping of all requests. In other words, the dimensions of the first set of requests, which define the Horizons, are determined based on the remaining space, are determined based on the leaving space behind, since each request must be treated as a 2D-rectangular in shape, according to the standard restrictions. The mapping process follows a right-to-left direction, covering the base of the OFDMA bin. In this manner two critical issues are addressed: (a) the mapping process complexity is reduced, since the forthcoming requests are mapped more easily and (b) the unused space is decreased, allowing more subscribers to be served. In the case that two or more subscribers attain the same fairness, the largest request gains access.

The first phase is completed when the bin base is covered with requests, defining Horizons. This condition is triggered when the bin width is too small for a request to be mapped. At this point either the requests have been totally mapped or there are remaining requests waiting to be accommodated up to the Horizons. The latter case triggers the second phase of FHM scheme. At least one Horizon has been defined with known width and height, indicating a 2D-rectangular available region upwards of the (initial) mapped request(s). Given these Horizons, FHM tries to allocate rectangular-shaped space to the remaining requests. In this case, the mapping process runs easily, since the remaining requests receive the same width as the Horizon's one. FHM scheme is described in more detail in the following steps:

FHM Algorithm

//First Phase (Horizon definition)

Select the request *A*, having less fairness index

Define its dimensions. Set its width equal to x, where x minimizes the leaving wasted space according to the following equation (W stands for the available bin's width):

$$\underset{x \in [1,W]}{\arg\min}(x \times \lceil A / x \rceil - A)$$

Set its height, denoted as y:

$$y = \lceil A / x \rceil$$

Map the 2D-rectangular at the base of the bin next to the previous requests, beginning from the below right corner.

Calculate the remaining available bin width W.

The formed Horizon has the following dimensions (H stands for the bin's height):

$$Horizon's\ height = H - \lceil A / x \rceil$$

$$Horizon's\ width = x$$

If the remaining bin's width is too small to accommodate the next request $H \times W \leq A$, second phase begins:

//**Second Phase (Remaining requests mapping)**

Select the request *A'*, having less fairness index from the set of the remaining unmapped requests.

Find the appropriate Horizon x, measuring the least remaining waste space (HW_x stands for Horizon's width):

$$\underset{x}{\arg\min}(HW_X \times \lceil A' / HW_X \rceil MOD A')$$

Map request *A'* into Horizon x, having width equal to the selected Horizon's width and height as follows:

$$height\ of\ A' = \lceil A' / HW_x \rceil$$

Update Horizon's dimensions

Continue the second phase until all requests getting mapped or there is not available Horizon to be attached.

V. Evaluation Results

The proposed scheme is evaluated using a custom simulation environment built in Matlab. A set of simulation experiments have been conducted in which the performance of the FHM scheme is compared to the eOCSA scheme [14]. The eOCSA algorithm has been chosen since it is consider as the leading mapping scheme and combines a lot of notable advantages such as the low complexity, the burst-based mapping logic, and the high efficient performance. The scenarios cover the fairness index of the SSs, the number of unserviced users and the amount of unused space in terms of wasted slots.

TABLE I. Simulation Parameters

Channel Mode	PUSC
Frame Size	10 ms
Preamble Size	1 Symbol
MAP, FCH Sizes	2 Symbols
Downlink Sub-Frame Symbols	27 (2:1 Downlink to Uplink Ratio)
Total Sub-Frame Capacity	810 slots
Frame Iterations	2000

For the following simulation scenarios a set of operational assumptions have been made:

- The partially used sub-channelization (PUSC) mode is adopted. According to this very popular mode for mobile communication environments, the downlink sub-frame defines 30 channels.
- The downlink-to-uplink sub-frame ratio is considered fixed and 2:1.
- The frame size is also fixed and set to 10 ms, allowing 95 symbols to attach to the downlink and the uplink sub-frames.
- Three symbols are destined to control information (Preamble, MAP and FCH fields) and are considered as unavailable (available for control purposes only).
- The request arrivals in the downlink stream are produced using a Poisson distribution. A realistic simulation environment has been defined, in which the connected subscribers produce various traffic demands. In particular, the subscribers are classified into four groups, equally populated, based on their traffic load. The first group produces very light traffic, so the parameter λ of the Poisson distribution is set to 50. The second group creates light traffic with λ equal to 80, the third group produces medium load and the λ parameter is set to 120 and finally the fourth group presents high load and the λ stands equal to 150.
- Each experiment has been conducted for 2,000 frames.

Table 1 summarizes the most important simulation parameters. A bandwidth allocation algorithm is said to be fair if the difference in the serviced requests received by different subscribers is at least bounded. In other words, an allocation algorithm should treat fairly the incoming different downlink requests in order to serve equally all users.

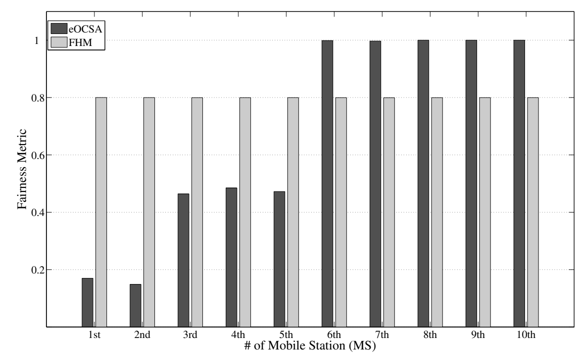

Figure 2. The fainess index for 10 subscribers

Figure 2 measures the *fairness index* for each subscriber, comparing the proposed scheme to the eOCSA scheme. The number of the connected subsribers is 10. The first and the second subscriber belongs to the first group. The next three subscribers produces traffic according to the second group. Sixth, seventh, and eighth subscribers are governed by the third group, while the rest follows the distribution of the last group. It is clear that FHM is fairer than eOCSA. This is because FHM allocated the downlink requests having as main criterion the fairness of each subscriber, independently of the request's bandwidth requirements. One more interesting observation here is the starvation of low load groups that eOCSA infers. For example, eOCSA becomes unfair with light load subscribers, reducing the fairness index below 0.2, fact that means 80% of the 1st and 2nd subscribers' requests remained unserved. At the same time all members of the heavy load groups were served 100%. This inconvenience could lead to mobile services exhibiting low performance and high amount of delays.

Fig. 3 depicts the *fairness index* considering a scenario with 20 subscribers. Subscribers are assigned to traffic group proportional to the case of 10. Again, the FHM scheme seems to be fairer than the leading mapping scheme. Regarding the eOCSA scheme the violation of the fairness issue increases as the number of the connected subscribers increase, leading light load users to starvation. The portion of the served requests of some subscribers remains lower than 15%, while the high load subscribers monopolize the available bandwidth.

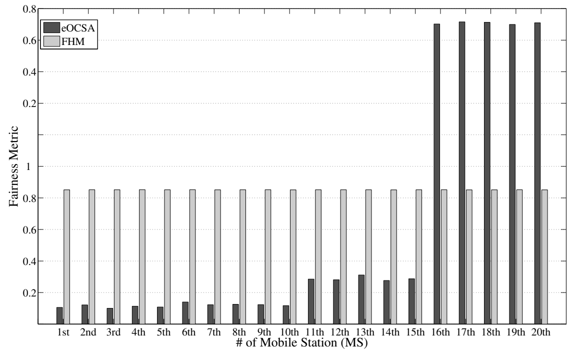

Figure 3. The fairness index for 20 subscribers

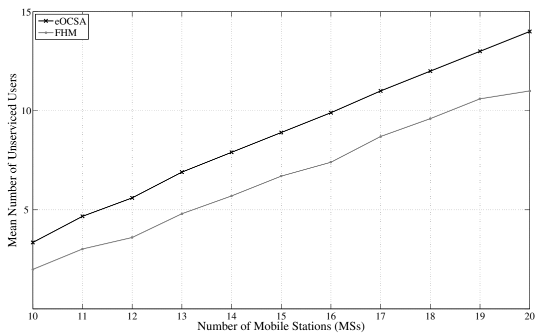

Figure 4. The mean number of unserviced users

Figure 4 shows an interesting result: even though the suggested mapping scheme ensures fairness it moves a step forward, by improving the performance of the mapping process, in terms of unserviced users. Specifically, the FHM algorithm succeeds to increase the number of users being served by the mobile network infrastructure compared to the eOCSA scheme. This stands because the FHM algorithm brings forward the Horizon-based mapping process, allowing more slots to be mapped. Hence, the FHM retains fairness and concurrently achieves to serve more subscribers than other mapping schemes. Previous results are sustained also by Fig. 5, which examines the number of unused slots per frame. Results of figures 4 and 5 are combined to indicate that the proposed scheme outperforms the eOCSA one not only in the fairness issue but in the general performance of the mapping procedure. This is may attributed to the fact that FHM treats the incoming downlink requests more efficient than eOCSA, in terms of idle slots remaining during the dimensions definition. In this manner, the rectangular-shaped requests accommodate more space in the downlink sub-frame allocation bin, allowing more subscribers to be served per frame fairly.

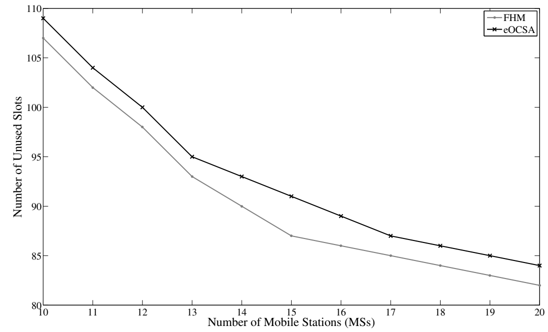

Figure 5. The mean number of unused slots

VI. CONCLUSION

A novel fair mapping scheme has been proposed in this paper. The suggested scheme achieves two critical targets. It ensures that all subscribers are treated fairly, independently of their load and at the same time inducts efficient mapping process by adopting Horizon-based mapping. This combination offers fair and efficient mapping compared to the leading mapping scheme, allowing more subscribers to be served fairly.

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