Computer Communications 37 (2014) 92–105

Contents lists available at ScienceDirect

Computer Communications

journal homepage: www.elsevier.com/locate/comcom

Efficient resource allocation for emerging OFDMA wireless networks ☆

Juan Ignacio del Castillo Waters, Francisco M. Delicado Martínez *, Jose Miguel Villalón Millán

Albacete Research Institute of Informatics (I3A), University of Castilla-La Mancha (UCLM), 02071 Albacete, Spain

ARTICLE INFO

Article history:
Received 6 September 2012
Received in revised form 28 March 2013
Accepted 11 September 2013
Available online 3 October 2013

Keywords:
IEEE 802.16
WiMAX
Resource allocation
2d Burst mapping

ABSTRACT

In the context of IEEE 802.16e networks, physical transmission relies on Orthogonal Frequency Division Multiple Access (OFDMA). This mechanism defines resource allocation as a bi-dimensional mapping of spectral resources. Although in the IEEE 802.16e standard the Medium Access Control (MAC) and physical (PHY) layers are well defined, the problem of resource allocation still remains an open issue, encouraging competition between companies to develop new commercial products. As this component is crucial to guaranteeing maximum performance and Quality of Service (QoS) fulfillment, it is critical to define efficient algorithms to solve the problem. Usually, the allocation problem is divided into two sub-problems: the scheduler problem, which decides the amount of resources that must be granted to each connection or user, and the mapping problem, which defines how the granted resources are allocated in the bi-dimensional matrix of spectral resources. Several factors have to be taken into account by the mapping algorithms, such as efficiency, QoS, power consumption and algorithmic complexity. In this work we define an adaptive algorithm to solve the OFDMA mapping problem in IEEE 802.16e networks. The performance of our proposal is extensively evaluated against other state-of-the-art proposals, by means of a simulation tool.

1. Introduction

Emerging Broadband Wireless Access (BWA) systems are expected to support a high number of simultaneous users and high spectral efficiencies, providing mobility and Quality of Service (QoS) support. The transmission medium itself turns these into very challenging goals. In order to achieve them, several forthcoming technologies such as Worldwide Interoperability for Microwave Access (WiMAX) [1] and Long Term Evolution (LTE) [2] are defining Orthogonal Frequency Division Multiple Access (OFDMA) as their prevailing physical communication profile.

WiMAX technology aims to provide link-level and system-level solutions for deploying fixed and mobile Wireless Metropolitan Area Networks (WMANs). The goal of the IEEE 802.16e standard is to provide wireless access over long distances in a variety of ways: from point-to-multipoint (PMP) to full mobile cellular access (Fig. 1). In a WiMAX network the Base Station (BS) performs most of the system decisions, both at the physical (PHY) level and at the Medium Access Control (MAC) level, being in charge of establishing logical connections between Subscriber Stations (SSs) or Mobile Stations (MSs) and itself, and of allocating available resources as efficiently as possible.

For the physical layer, the standard specifies the use of the OFDMA technique, a multicarrier modulation technique which arose as the multiuser version of Orthogonal Frequency Division Multiplexing (OFDM). OFDMA combines multicarrier modulation with frequency division multiple access. The available frequency spectrum is divided into subsets of orthogonal subcarriers or tones which will be dynamically allocated to users over time. The advantages of the use of OFDMA are the flexibility in subcarrier allocation and the minimization of user interference due to orthogonality. This flexibility provides a way of boosting system performance at the cost of increasing the challenge of resource allocation. Higher data rates, longer transmission distances and better mobility support are the main advantages of using this technology [3].

In current OFDMA systems such as IEEE 802.16e the individual subcarriers are grouped into larger units called subchannels. These subchannels are then grouped into bursts. All the subcarriers within a burst share the same Modulation and Coding Scheme (MCS), which is adapted on a frame basis. This adaptive process allows the BS to adjust the bandwidth of each SS depending on its current channel quality state feedback. The problem arises when those bursts must be mapped into the 2d time–frequency matrix that represents the available resources of each frame, a problem known as OFDMA resource allocation or the mapping problem.

This work focuses on the mapping problem, selecting a specific BWA technology: IEEE 802.16e networks. An efficient allocation mechanism must be defined in order to maximize data throughput and user allocation flexibility, thus improving the QoS of the

☆ Expanded version of a talk that will be presented at the 10th International Conference on Networking (Valencia, Spain, May 2011).

* Corresponding author.
E-mail address: Francisco.Delicado@uclm.es (F.M. Delicado Martínez).

0140-3664/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.comcom.2013.09.012

deployed network. We analyze the factors affecting the resource allocation process, and propose a specific mechanism to map downlink (DL) traffic into the DL-OFDMA subframe. To test the performance of our proposal we compare it with several existing algorithms by means of extensive simulation.

The paper is organized as follows. In Section 2, the OFDMA resource allocation problem is stated, in the context of the QoS architecture of IEEE 802.16e networks, and several factors that affect the performance and flexibility of a resource allocation algorithm are described. After that, we restate several existing proposals in Section 3. Section 4 provides a full description of a novel resource allocation algorithm, which is aimed at satisfying several of the stated goals. A performance evaluation of these is carried out in Section 5. Finally, conclusions are drawn and future work is outlined in Section 6.

2. IEEE 802.16e and the resource allocation problem

In this section we describe the resource allocation problem, also commonly known as the 2d mapping problem. In Section 2.1 we briefly describe the QoS architecture of an IEEE 802.16e BS, where resource allocation is one of the main components. In Section 2.2 we describe the mapping problem with its associated restrictions in some depth. In Section 2.3 we state several goals that should be fulfilled by any resource allocation algorithm. existing proposals are described.

2.1. Description of the WiMAX QoS architecture

Point-to-multipoint IEEE 802.16e networks are expected to be deployed in a cellular architecture, and are composed of two different types of nodes: the BS and the SSs/MSs. As briefly stated in Section 1, the BS is responsible for performing most of the system decisions. From the perspective of QoS, these decisions include: Call Admission Control (CAC), scheduling and resource allocation.

CAC determines whether a new connection is accepted into the system or not, based on the available capacity. The goal of this process is to assure that new connections will not impair the QoS requirements of the existing ones.

When the CAC allows a user or application to establish a connection with the network, the traffic generated must be properly prioritized according to a certain scheduling policy. This policy should be able to guarantee that the QoS requisites of each connection are actually being fulfilled.

With the parameters declared by the CAC for each connection, the scheduler decides the bandwidth to be assigned to each traffic frame to frame, trying to meet the QoS requirements of this.

In the case of the OFDMA physical profile, and after the scheduler has prioritized the incoming traffic, an additional process is needed: resource allocation. In this physical mode, network traffic must be logically mapped into a time–frequency matrix before its actual transmission through the wireless medium. After this step is performed, some traffic may remain unmapped (traffic that does not fit in the matrix), so it must be returned to the scheduler for its transmission in a later frame.

Two different architectures for packet forwarding from the scheduler to the resource allocator can be considered: online and offline modes [4]. In the case of the online architecture, packets are forwarded to the resource allocator one at a time, and are allocated in order of arrival. Therefore goals such as frame use optimization are very difficult to achieve with online approaches, because the allocator ignores the total of packets to be allocated in a frame when the allocation algorithm starts. On the other hand, with the offline architecture, packets to be allocated in a frame are delivered from the scheduler at the beginning of the frame, so the allocator

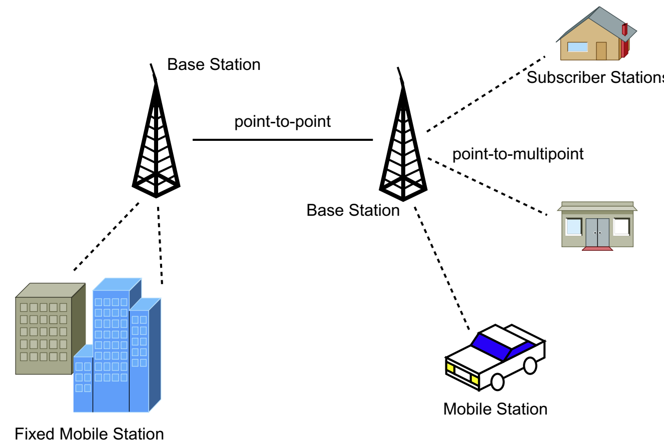

Fig. 1. Deployment of WiMAX networks.

knows the total of resources requested and can select the packets that optimize the use of the frame. The problem of the offline architecture is that the allocator action could potentially lead to a change in the order established by the scheduler, in order to optimize the bandwidth, and thus to an impairment in QoS. This can happen if the prioritization established by the scheduler is not fully respected by the resource allocation process.

2.2. IEEE 802.16e's allocation problem

The structure of a WiMAX frame is defined by the standard [1]. In the case of the DL-subframe it is usually represented as shown in Fig. 2: an OFDMA matrix with the x-axis being time (symbols) and the y-axis being frequency (subchannels). After an initial preamble, which is needed to allow the synchronization of the SSs, the BS broadcasts the DL-MAP message (in column-wise order). The remaining space in the subframe is then used for data allocation. There is a mandatory restriction in the IEEE 802.16e standard on DL resource allocation; this is that in DL the data must be allocated in *Data Regions*. According to the standard a Data Region is a two-dimensional allocation of a group of contiguous subchannels, in a group of contiguous OFDMA symbols, which may be visualized as rectangular regions. Each of these regions is called a burst. In order to select an appropriated Data Region distribution in the DL subframe a resource allocation mechanism is required. The position and size of each burst is specified through an Information Element (IE) in the DL-MAP. This implies that, the greater the number of bursts, the greater the size of the DL-MAP will be. As the DL-MAP

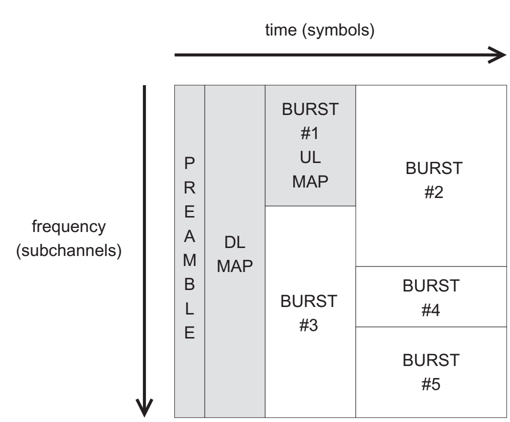

Fig. 2. IEEE 802.16e DL subframe structure.