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An efficient analytical model for the dimensioning of WiMAX networks supporting multi-profile best effort traffic

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ABSTRACT

This paper tackles the challenging task of developing a simple and accurate analytical model for performance evaluation of WiMAX networks. The need for accurate and fast-computing tools is of primary importance to face complex and exhaustive dimensioning issues for this promising access technology. In this paper, we present a generic Markovian model developed for three usual scheduling policies (slot sharing fairness, throughput fairness and opportunistic scheduling) that provides closed-form expressions for all the required performance parameters instantaneously. We also present and evaluate the performance of a fourth policy, called throttling policy, that limits the maximum user throughput and makes use of the Maximum Sustained Traffic Rate (MSTR) parameter foreseen by the standard. At last, we extend these studies to multi-profile traffic patterns. The proposed models are compared in depth with realistic simulations that show their accuracy and robustness regarding the different modeling assumptions. Finally, the speed of our analytical tools allows us to carry on dimensioning studies that require several thousands of evaluations, which would not be tractable with any simulation tool.

1. Introduction

Candidate for 4G, Worldwide Interoperability for Microwave Access (WiMAX) is a broadband wireless access technology which is based on IEEE standard 802.16. The first operative version of IEEE 802.16 is 802.16-2004 (fixed/nomadic WiMAX) [2]. It was followed by a ratification of amendment IEEE 802.16e (mobile WiMAX) in 2005 [3]. A new standard, 802.16m, is currently under definition to provide even higher efficiency. In addition, the consortium WiMAX Forum was found to specify profiles (technology options are chosen among those proposed by the IEEE standard), define an end-to-end architecture (IEEE does not go beyond physical and MAC layer), and certify products (through inter-operability tests).

A number of services such as voice, video and web are to be offered by WiMAX networks. Considering the web services, the users may generate traffic of different profiles (characterized by the volume of data generated and reading time). They may also have to respect a QoS parameter associated with best effort service in the standard: the *Maximum Sustained Traffic Rate* (MSTR). As defined in [3] (section 11.13.6), this parameter is not a guaranteed rate but an upper bound on the throughput achieved by a mobile.

Some WiMAX networks are already deployed but most operators are still under trial phases. As deployment is coming, the need arises for manufacturers and operators to have fast and efficient tools for network design and performance evaluation able to account for these possibilities. Literature on WiMAX performance evaluation is constituted of two sets of papers: (i) packet-level simulations that precisely implement system details and scheduling schemes; (ii) analytical models and optimization algorithms that derive performance metrics at user-level.

In the former set, [19,12,12] are interesting because they investigate different QoS support mechanisms proposed in the standard. In addition, studies of the performance of multi-profile internet traffic have been proposed in both [25,23]. Authors of [25] evaluated the throughput performance in a WiMAX cell while considering the number of users, the modulation schemes they may use and the data rate they require, using system level simulations. They also introduced a notion similar to MSTR: the *Mean Information Rate* (MIR) and observed the impact of different MIR values on the traffic performance. In [23], a measurement based procedure has been adopted to evaluate the performance of fixed WiMAX network in presence of multi-profile best effort traffic.

Among the latter set of papers, [26] provided an analytical model for studying the random access scheme of IEEE 802.16d. Niyato and Hossain [21] formulated the bandwidth allocation of multiple services with different QoS requirements by using linear programming. They also proposed performance analysis, first at connection level, then, at packet level. In the former case, variations of the radio channel are however not taken into account. In the latter

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case, the computation of performance measures rely on multi-dimensional Markovian model that requires numerical resolutions. Finally, authors of [27] presented the mathematical expressions to calculate the blocking probabilities of a mixed WiMAX-WiFi system. They considered users who generate voice/data traffic and focused on the admission control aspect of the network.

Not specific to WiMAX systems, generic analytical models for performance evaluation of cellular networks with varying channel conditions have been proposed in [11,10,20]. The models presented in these articles are mostly based on multi-class processor-sharing queues with each class corresponding to users having similar radio conditions and subsequently equal data rates. The variability of radio channel conditions at flow level is taken into account by integrating propagation models, mobility models or spatial distribution of users in a cell. These papers implicitly consider that users can only switch class between two successive data transfers. However, as highlighted in the next section, in WiMAX systems, radio conditions and thus data rates of a particular user can change frequently during a data transfer. In addition, capacity of a WiMAX cell may vary as a result of varying radio conditions of users.

In this paper, we develop a novel and generic analytical model that takes into account frame structure, precise slot sharing-based scheduling and channel quality variation of WiMAX systems. Unlike existing models [11,10,20], our model is adapted to WiMAX systems' assumptions and is generic enough to integrate any appropriate scheduling policy. Moreover, our approach makes it possible to consider the so-called "outage" situation. A user experiences an outage, if at a given time radio conditions are so bad that it cannot transfer any data and is thus not scheduled.

We first consider three *full-capacity* policies which aim at sharing the whole resource, i.e., all slots of each frame, among the active users: *slot sharing fairness*, *instantaneous throughput fairness*, and *opportunistic*. Then, we consider a *throttling* scheduling policy which limits the attained throughput of each user to a given value. This policy allows us to take into account the aforementioned MSTR in our model. For each policy, we develop closed-form expressions for all performance metrics. We also provide extensions of our model to take into account multi-profile web traffic in mobile WiMAX networks.

The rest of paper is organized as follows. System description including specific WiMAX network details concerning our analytical model is provided in Section 2. Section 3 presents the generic analytical model and the assumptions it stands on. The model is adapted to the three full-capacity scheduling policies in Section 4 and to the throttling policy in Section 5. Section 6 details the multi-profile traffic extensions for both kinds of scheduling policy. Validation and robustness of model are discussed in Section 7. Lastly, Section 8 gives an example of WiMAX dimensioning process using our model.

2. WiMAX system description

In this section, we briefly present the WiMAX system details needed to understand the proposed analytical model. Although the analysis is also valid for fixed WiMAX, we focus on mobile WiMAX, which is based on standard IEEE 802.16e and SOFDMA (Scalable Orthogonal Frequency Division Multiple Access) physical layer. In particular, the WiMAX frame structure, the notion of radio resources (slots), the access technique, and the different Modulation and Coding Schemes (MCS) are presented. Finally we also introduce the different scheduling policies considered in this work.

2.1. WiMAX standard

The PHY layer of WiMAX is based on OFDMA. OFDM splits the available spectrum into a number of parallel orthogonal narrow-band subcarriers, grouped into multiple subchannels. Radio resources are thus available in terms of OFDM symbols (time domain) and subchannels (frequency domain) providing a time-frequency multiple access technique [18].

In IEEE 802.16e, possible system bandwidths are 20, 10, 5 and 1.25 MHz with associated FFT (Fast Fourier Transform) sizes of 2048, 1024, 512 and 128 respectively [1]. The total number of subchannels depends on the subcarrier permutation, i.e., the way subcarriers are grouped together. Two main methods mentioned in [1] are: distributed and adjacent subcarrier permutations. Full usage of subchannels (FUSC) and Partial usage of subchannels (PUSC) are examples of distributed permutations, they take advantage of channel diversity among subchannels. Adaptive modulation and coding (AMC) is a type of adjacent permutation, it allows an opportunistic use of the channel.

IEEE 802.16e has specified time division duplex (TDD) as duplexing technique. The ratio of downlink (DL) to uplink (UL) has been left open in the standard. WiMAX Forum has specified a duration of TDD frame of 5 ms [3]. An example of a WiMAX TDD frame is shown in Fig. 1. It has a two directional structure with horizontal and vertical axes showing the time and frequency domain respectively. A slot is the smallest unit of resource in a frame which occupies space both in time and frequency domain. A burst is a set of slots using the same MCS. The total number of slots in the frame depends on the subcarrier permutation method. For numerical applications, we focus on PUSC, although our model is valid for any permutation scheme. Note however that a slot always carries 48 subcarriers whatever the type of used subcarrier permutation. In the DL sub-frame, a first part contains a Preamble, a Frame Control Header (FCH), a UL_MAP and a DL_MAP. The preamble is used for synchronization. The FCH provides length and encoding of two MAP messages and information about usable subchannels. Finally, in the MAP messages reside the data mapping for users. Their sizes depend on the number of scheduled users in the frame.

One of the important features of IEEE 802.16e is link adaptation: using different MCS enables a dynamic adaptation of the transmission to the radio conditions. As the number of data subcarriers per slot is the same for all permutation schemes, the number of bits carried by a slot for a given MCS is constant. The choice of the right MCS is done for each mobile wishing to transmit (i.e., active mobile) according to its signal to interference plus noise ratio (SINR). However, note that when the SINR is too low, no data can be transmitted without error. This situation is called *outage*.

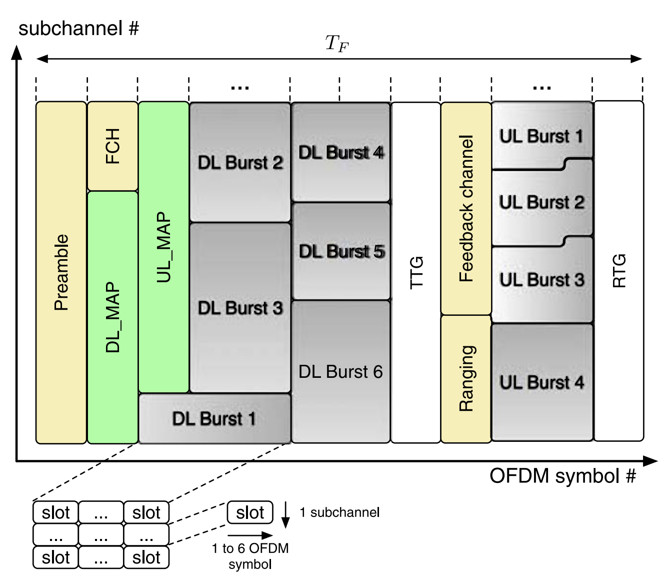

Fig. 1. TDD frame structure.