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A performance study of uplink scheduling algorithms in point-to-multipoint WiMAX networks

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ABSTRACT

The IEEE 802.16 standard defines the specifications for medium access control (MAC) and physical (PHY) layers of WiMAX networks. A critical part of the MAC layer specification is packet scheduling, which resolves contention for bandwidth and determines the transmission order of users. Evaluating the performance packet scheduling algorithms is of utmost importance towards realizing large-scale WiMAX deployment. In this paper, we conduct a comprehensive performance study of scheduling algorithms in point-to-multipoint mode of OFDM-based WiMAX networks. We first make a classification of WiMAX scheduling algorithms, then simulate a representative number of algorithms in each class taking into account that vital characteristics of the IEEE 802.16 MAC layer and OFDM physical layer. We evaluate the algorithms with respect to their abilities to support multiple classes of service, providing quality of service (QoS) guarantees, fairness amongst service classes and bandwidth utilization. To the best of our knowledge, no such comprehensive performance study has been reported in the literature. Simulation results indicate that none of the current algorithms is capable of effectively supporting all WiMAX classes of service. We demonstrate that an efficient, fair and robust scheduler for WiMAX is still an open research area. We conclude our study by making recommendations that can be used by WiMax protocol designers.

1. Introduction

The vast increase in contemporary applications with varying QoS requirements creates a demand for a unified service and/or networking platform that can simultaneously support such applications. To this end, the IEEE 802.16-2004 standard [1] specifies a service framework of four scheduling class services, unsolicited grant service (UGS), real-time polling service (rtPS), non-real time polling service (nrtPS) and best effort (BE). These classes are considerably diverse with respect to bandwidth request/grant mechanism and QoS requirements. For example, to support UGS flows, the base station (BS) is required to allocate fixed size data grants, based on a fixed data rate requested by subscriber stations (SSs) of the UGS class. The IEEE 802.16e-2005 [2] standard introduces an additional scheduling service, extended real-time polling service (ertPS), which builds on the efficiency of both UGS and rtPS. Just like the UGS class, the BS is allowed to provide unicast grants to the ertPS SSs, but the size of the grants can vary, enabling a more efficient usage of available bandwidth.

Although the IEEE 802.16-2004 standard specifies a service framework and its associated bandwidth request/grant mechanisms over single-carrier or multiple-carrier physical layer technologies such as OFDM and OFDMA, it does not specify the scheduling algorithm to allocate the OFDM or OFDMA frame symbols that enforce QoS requirements of all traffic classes. Accordingly, there have been several proposals of scheduling algorithms, some based on legacy algorithms [3–9]. Others are designed specifically for WiMAX and some are tailored to WiMAX standard specifications [10–14], WiMAX specific algorithms are centered on the major characteristics of the MAC layer, as specified by the IEEE 802.16-2004 standard.

Despite the numerous scheduling algorithms proposed for WiMAX networks, there is no comprehensive study that provides a unified platform for comparing such algorithms. The aim of this work is to allow a thorough understanding of the relative performance of representative uplink scheduling schemes and subsequently utilize the results to address their scarcity in designing more efficient schemes. We focus our work on implementing representative algorithms for the uplink traffic in OFDM WiMAX physical layer using network simulator 2 (NS-2). Another major contribution of this work is evaluating the algorithms using traffic models specifically designed for WiMAX to represent its diverse

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applications [19], incorporating the mandatory and some optional parameters of all the traffic classes as specified in the IEEE 802.16-2004 standard. The traffic model has also been implemented in NS-2. It is our intention to add our contributions to the NS-2 public code base, which may assist future evaluations and make it easier to implement variations of the evaluated scheduling schemes. The findings of this work are beneficial both for academia and industry. For instance, our analysis indicates that none of the current algorithms is capable of providing efficient, fair, and robust scheduler to support all the WiMAX classes. As well, the analysis and conclusions from this study can be used in understanding the strengths and weaknesses of current scheduling algorithms and thus designing efficient scheduling algorithms that addresses some or all of these weaknesses. The study is also beneficial to WiMAX BSs and SSs manufacturers, vendors and operators in that it provides a baseline to choose appropriate scheduling algorithms depending on the traffic profiles in their network.

The rest of the paper is organized as follows. In Section 2, a survey of scheduling algorithms for the uplink traffic in WiMAX is provided. This section also includes justification of selecting representative algorithms for our simulation study. Section 3 describes the simulation framework that includes the simulation parameters, traffic model, and the performance metrics used to evaluate the algorithms and the results and discussion of the experiments. In Section 4, we summarize the results, provide suggestions for improvement and discuss some future research directions.

2. Scheduling algorithms in PMP WiMAX networks

Packet scheduling is the process of resolving contention for bandwidth. A scheduling algorithm has to determine the allocation of bandwidth among the users and their transmission order. One of the most important tasks of a scheduling scheme is to satisfy the quality of service (QoS) requirements of its users while efficiently utilizing the available bandwidth. For the uplink traffic, the scheduling algorithm has to work in tandem with call admission control (CAC) to satisfy the QoS requirements. The CAC algorithm ensures that a connection is accepted into the network only if its QoS requirements can be satisfied as well as the performance of existing connections in the network is not deteriorated.

In our survey, several scheduling algorithms are assessed with respect to the characteristics of the IEEE 802.16 MAC layer and OFDM physical layer. We classify the proposals into three categories; homogenous algorithms, hybrid algorithms and opportunistic algorithms. Homogenous and hybrid categories consist of legacy algorithms with the hybrid category employing multiple legacy schemes in an attempt to satisfy the QoS requirements of the multi-class traffic in WiMAX networks. The opportunistic category refers to algorithms that exploit variations in channel conditions in WiMAX networks whilst incorporating the QoS requirements in their scheduling design. Representative schemes in each of these categories will be discussed next.

2.1. Homogeneous algorithms

Weighted Round Robin (WRR) and Deficit Round Robin (DRR) algorithms are evaluated in a WiMAX network in reference [3]. WRR is evaluated for the uplink traffic while DRR is evaluated for the downlink traffic. In WRR, weight to each SS can be assigned to reflect their relative priority. Priority of the SSs can also be incorporated in the DRR algorithm. DRR allows provision of different quanta for each SS. A higher quantum can be assigned to higher priority SSs. Ruangchaijatupon et al. [4] evaluate the performance of Earliest Deadline First (EDF) algorithm. EDF is a work conserving algorithm originally proposed for real-time applications in wide area networks [5]. The algorithm assigns deadline to each packet and allocates bandwidth to the SS that has a queued packet with the earliest deadline. Weighted fair queuing (WFQ) is also evaluated and compared with EDF in reference [4].

Tsai et al. [6] propose an uplink scheduling algorithm and a token bucket based Call Admission Control (CAC) algorithm. The CAC algorithm assigns thresholds to each class to avoid starvation of lower priority classes. The scheduling algorithm first grants bandwidth to SSs of the UGS class. The algorithm then allocates bandwidth to SSs of the rtPS class using EDF algorithm and restricting the allocation to the maximum grant size. Finally, the algorithm allocates minimum required bandwidth to SSs of the nrtPS and BE classes, in that order.

2.2. Hybrid algorithms

Wongthavarawat and Ganz [7] propose a hybrid scheduling algorithm that combines EDF, WFQ and FIFO scheduling algorithms. The overall allocation of bandwidth is done in a strict priority manner. EDF scheduling algorithm is used for SSs of the rtPS class, WFQ is used for SSs of the nrtPS class and FIFO for SSs of the BE class. Besides the scheduling algorithm, an admission control procedure and a traffic policing mechanism are also proposed.

Vinay et al. [8] propose a hybrid scheme that uses EDF for SSs of the rtPS class and WFQ for SSs of nrtPS and BE classes. This algorithm differs from [7] in that WFQ is used for SSs of both nrtPS and BE classes and the overall bandwidth is allocated fairly, however, the authors did not describe the mechanism for fair allocations. Settembre et al. [9] propose a hybrid scheduling algorithm that uses WRR and RR algorithms with a strict priority mechanism for overall bandwidth allocation. In the initial stages, bandwidth is allocated on a strict priority basis to SSs of the rtPS and nrtPS classes only. The WRR algorithm is used to allocate bandwidth amongst SSs of rtPS and nrtPS classes until they are satisfied. Any residual bandwidth is distributed between the SSs of the BE class using the RR algorithm.

A vital component of hybrid algorithms is the distribution of bandwidth among the diverse traffic classes. We have selected to evaluate hybrid (EDF + WFQ + FIFO) and hybrid (EDF + WFQ) schemes, which use very different mechanisms of distributing bandwidth among the traffic classes. The hybrid (EDF + WFQ + FIFO) algorithm applies the strict priority mechanism, whereas the hybrid (EDF + WFQ) keeps track of the bandwidth allocated to all the service classes and perform dynamic distribution of bandwidth by providing fair service to all the traffic classes. In our evaluation, we use the Minimum Reserved Traffic Rate (MRTR) of a SS as the core of this fair approach (details were not available in [8]). More specifically, bandwidth is distributed with respect to the relative MRTR of all SSs in a class, i.e. the available bandwidth is multiplied by the ratio of sum of MRTR of SSs in a class to the sum of MRTR of all the SSs in the network.

2.3. Opportunistic algorithms

A Cross-Layer scheduling algorithm is proposed in reference [10] whereby each SS is assigned a priority based on its channel quality and service status. The SS with the highest priority is scheduled for transmission in each frame. The algorithm considers all the required QoS parameters of the scheduling services specified in the IEEE 802.16-2004 standard. Class coefficients are utilized to assign relative priority to the different traffic classes. Rath et al. [11] propose to use an opportunistic extension of the Deficit Round Robin (DRR) algorithm with the purpose of satisfying delay requirements of multi-class traffic in WiMAX. The heart of the algorithm lies in selecting an appropriate polling algorithm. At the beginning of a polling interval, a set of schedulable SSs are selected that constitute a schedulable set. Until the next polling interval, SSs are selected only from the schedulable set.