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A Survey of Scheduling Algorithms for QoS Class Differentiation in WiMAX Networks

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Abstract: In the last few years, demand for high-speed wireless broadband network access and multimedia applications has increased rapidly. Existing wireless Technologies that can satisfy the requirements of heterogeneous traffic are very expensive to deploy in rural and "last mile" access. Recently, IEEE 802.16, known as Worldwide Interoperability for Microwave Access (WiMAX) has received much attention due to its capability to support multiple types of applications with diverse QoS requirements. Beyond what the standard has defined, radio resource management (RRM) still remains an open issue. Existing RRM techniques have limitations in service differentiation between real time (RT) and non-real time (NRT) classes of traffic. This paper presents a survey of some of the existing scheduling algorithms for WiMAX. These algorithms are limited in terms of inter-class scheduling. PDD model is a solution to the problem. "HPD" is one of the scheduling mechanisms with the best features that can implement the PDD model. However, manual selection of the HPD-parameter "g" is a major challenge. An optimization scheme should be used for selection of the parameter.

Keywords: QoS, WiMAX, Scheduling, Class Differentiation and HPD

1. Introduction

Traditionally, wireless networking and communication systems depend on high capacity and long-range coverage it can provide to end users. However, new technologies such as Worldwide Interoperability for Microwave Access (WiMAX) and Third-Generation Partnership Project (3GPP) Long-Term Evolution (LTE) rely very much on the quality of service (QoS) it can provide and satisfy to end users in terms of applications and service demands. WiMAX is based on wireless metropolitan area networking (WMAN) standards developed by the IEEE 802.16 group. WiMAX network utilizes a shared medium to provide efficient transmission services. This medium is shared in either point-to-multipoint (PMP) or mesh topology wireless networks. The IEEE 802.16 standard specifies the Physical and Medium Access Control (MAC) layers for a Broadband Wireless Access (BWA) communication protocol (Daniele, Romano, & Marco, 2006). Its characteristics provide performance similar to WiFi with data rate (near 100 Mbps) and average coverage area of 50Km range. Thus making IEEE 802.16 the best way to carry BWA connections in remote areas, where the wired links would be too expensive. WiMAX has several advantages: faster deployment, high scalability, low maintenance, less cost as well as modular investments for upgrades (Amir & Nidal, 2011). The standard defines a connection-oriented MAC protocol with a mechanism for QoS support. However, scheduling algorithms for Uplink (UL) and Downlink (DL) bandwidth allocation are left open for development by the vendors/operators. Existing scheduling schemes are limited in traffic separation between the RT and (NRT) applications. The motivation for this approach is to have an in-depth analysis of the QoS differentiation between the real time and non-real time applications, and to establish parameters to quantify the differentiation based on Fairness and Utilization measurements. Further motivation is to develop a packet scheduling scheme with the ability to distinguish the Inter-Class versus Intra-Class QoS requests, and to deliver QoS support at both levels. In IEEE 802.16 network (Dusit & Ekram, June 2006), the physical layer of the IEEE 802.16 air interface operates at either the 10–66 GHz (i.e., IEEE 802.16) or 2–11 GHz. (IEEE Standard for Local and Metropolitan Area Networks, 2004), IEEE 802.16 standard defines four types of service flow

- Unsolicited Grant Service (UGS). The UGS is designed to support real-time service flows that generate fixed size data packets on a periodic basis, such as TI, El and Voice over IP without silence suppression. The service offers fixed size grants on a real-time periodic basis.
- Real Time Polling Service (rtPS). The rtPS is designed to support real-time service flows that generate variable size data packets on a periodic basis, such as MPEG video.
- Non-Real Time Polling Service (nrtPS). This service is for non-real-time flows which require better than best effort service, e.g. bandwidth intensive file transfer like FTP applications.
- Best Effort Service (BE). This service is for best effort traffic such as HTTP. There is no QoS guarantee.

The rest of the paper is organized as follows: section 2 gives a review of the existing scheduling technique as applied to IEEE 802.16/WiMAX networks. Section 3 presents detail review of the PDD-based schedulers and shows feasibility of using these schedulers for WiMAX. Section 4 concludes the survey paper and suggests new solutions to the problem identified.

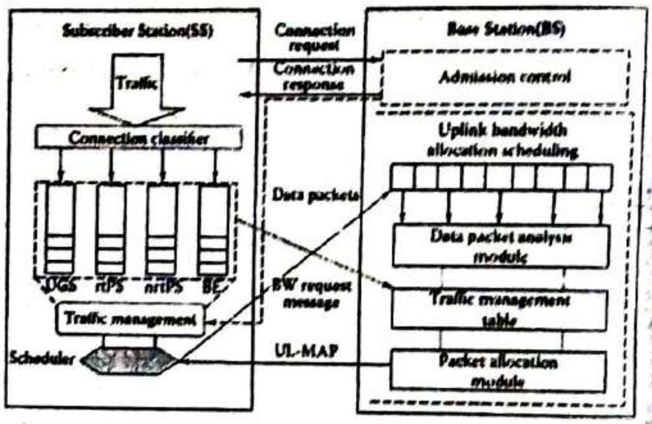

Fig 1: Structure of the QoS Framework (Yan & Hsiao-Hwa, 2007)

2 Review of PS schemes for WiMAX

Many researchers have studied packet scheduling (PS) schemes for WiMAX and are categorized as uplink/downlink, centralized/decentralized, RT/NRT, homogeneous/hierarchical or intra-class/inter-class.

2.1 Homogeneous scheduling algorithms.

These are legacy scheduling algorithms originally proposed for wired networks. They address issues such as providing QoS, flow isolation and fairness. Some of the existing homogeneous algorithms in Wimax are Weighted Round Robin (WRR), Deficit Round Robin (DRR), Modified deficit Round

Robin (MDRR), weighted fair queuing (WFQ) and earliest deadline first (EDF) algorithm. (Najah, Prank, & Hossam, 2009). In (Cicconetti, Erta, Lenzini, & Mingozzi, January 2007), WRR is evaluated for the uplink traffic while DRR is evaluated for the downlink traffic.

(Ruangchaijatupon, Wang, & Ji, October 2006), also evaluate the performance of the Earliest Deadline First (EDF) algorithm. Their result shows that EDF is more suitable for SSs belonging to the UGS and rtPS scheduling services. The authors also evaluated weighted Fair Queuing (WFQ) for the uplink traffic in WiMAX.

2.1.1 Earliest Deadline First (EDF)

EDF algorithm is mostly used for real-time applications because it selects SSs based on their delay requirements. The algorithm assigns deadline to arriving packets of a SS.

2.1.2 Weighted Round Robin (WRR)

The WRR scheduling algorithm is a variant of the round robin (RR) scheduler, originally proposed for ATM traffic in (Katevenis, Sidiropolous, & Courcoubetis, October, 1991). WRR has been implemented in (Cicconetti, Erta, Lenzini, & Mingozzi, January 2007) to evaluate the IEEE 802.16 MAC layer on how it supports QoS requirements of the heterogeneous traffic. The WRR algorithm determines the allocation of bandwidth among the SSs based on their weights. The assigned weights reflect the relative priority and QoS requirements of the SSs. Other variants of RR are deficit round robin (DRR) and Modified DRR (MDRR).

2.1.3 Weighted Fair Queuing (WFQ)

WFQ also assigns weights to each SS. When allocating bandwidth to the SSs, unlike the WRR algorithm, the WFQ also considers the packet size and the channel capacity. An arriving packet is tagged with finish time calculated based on the weigth of the SS, the packet size and the uplink channel capacity. However, homogenous algorithm is not a good choice for inter-class scheduling, only suitable for applications with the same QoS. Hierarchical scheduling algorithm was proposed in (Kitti & Aura, 2003) as a solution to the drawback.

2.2 Hierarchical Scheduling Algorithms

Packet Scheduling and Bandwidth Allocation in hierarchical schemes are designed in multiple levels. In most cases, the traffic from different service classes is separated in the first level, and then scheduled within each class in the second level as shown in figure 2.

(Kitti & Aura, 2003), Proposed an uplink hierarchical scheduling algorithms for bandwidth allocation for IEEE 802.16 systems. The proposed implementation of Uplink Packet Scheduling (UPS) is shown in figure 2. The entire bandwidth is distributed in a strict priority manner at the first level. UGS has the highest priority, followed by rtPS, then nrtPS and BE. An uplink packet scheduling with call admission control mechanism using the token bucket is proposed in (Tsu-Chieh, Chi-Hong, & Chuang-Yin, 2006). Their algorithm adopts Earliest Deadline First (EDF) mechanism proposed in (Kitti & Aura, 2003). In (Yanlei & Shinduang, 2005), the authors propose a hierarchical packet scheduling model for WiMAX uplink. Their model is able to distribute bandwidth between BE and other classes of traffic efficiently and guarantees fairness service classes.

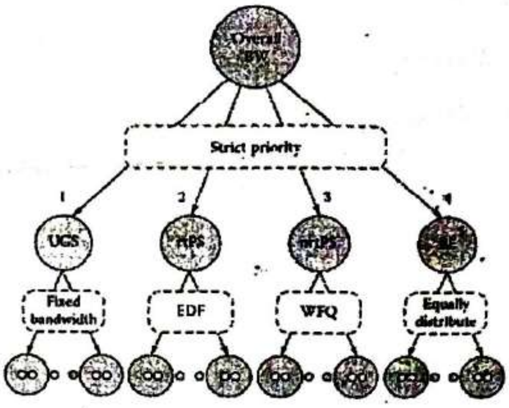

Fig 2, Hierarchical scheduling structure (Yan & Hsiao-Hwa, 2007)

The strict priority bandwidth allocation used for the inter class scheduling in the hierarchical structure causes starvation of lower priority classes in the presence of large number of users in the higher priority classes. Due to this drawback, (Amir & Nidal, 2011) proposed a dynamic QoS-based bandwidth allocation (DQBA). DQBA dynamically changes the bandwidth allocation (BA) for ongoing and new arrival connections based on traffic characteristics and service demand. However, this approach is not predictable as service loads vary. Hence, proportional delay differentiation (PDD) will be a solution to the drawback, if feasible to obtain.

3 PDD-Based Schedulers for IEEE 802.16

Proportional Delay Differentiation (PDD) is a model use to provide service differentiation between real time (RT) and non-real time (NRT) classes of traffic (Constantinos, Dimitrios, & Parameswaran, 1999). PDD model controls the ratios of the average queuing delays between classes i and j, based on specified Delay Differentiation Parameters (DDPs) δ_i CITATION Placeholder3 \t \l 1033 (Constantinos, Di Parameswaran, february 2002). Let $\bar{d}_i$ and average delay of class i and j respectively and δ_j be their corresponding DDPs. Th model requires that:

$$\frac{\bar{d}_i}{\delta_i} = \frac{\bar{d}_j}{\delta_j} \quad i \leq 1, j \leq N \qquad (1)$$

Most of the existing algorithms propo WiMAX are limited in service differe between the RT and NRT applications. inter-class scheduling has been a major c from the literature. However, any schedule on the PDD model would be capable of pr fair inter-class scheduling.

Supposing a scheduler satisfies the PDD m (1). Let $\bar{q}_{ag}$ be the average aggregate back be the class loads and $\bar{L}_n$ be the packet size average delay in class i is

$$\bar{d}_i = \frac{\delta_i \bar{q}_{ag}}{\sum_{n=1}^{N} \delta_n \lambda_n \bar{L}_n} \qquad i = 1, \ldots. N \qquad (2$$

Assuming the N classes have the same packe distribution. Then, $\bar{L}_n = \bar{L} = 1$. Therefore becomes

$$\bar{d}_i = \frac{\delta_i \bar{q}_{ag}}{\sum_{n=1}^{N} \delta_n \lambda_n} \qquad (3)$$

Based on (3), the following properties called dynamics in the PDD model are obtained:

Property 1: increasing the input rate of a increases (in wide sense) the average delay o classes. i.e, when the delay of a class increases, to additional load in that class, the delays of classes will also increase.

Property 2: increasing the rate of a higher cl causes a larger increase in the average delays t increasing the rate of lower class.

Property 3: decreasing the delay differentiation parameter of a class increases (in the wide sense) the average delay of all other classes, and decreasing (in the wide sense) the average delay of that class. This property implies that, if the delay of a class is reduced by lowering its DDPs, then the delay of all other classes will increase. Based on the above assumptions, it is interesting to note that the PDD model is feasible and applicable to class differentiation in WiMAX systems.

The work by (Constantinos, Dimitrios, & Parameswaran) proposed to achieve PDD through the use of packet schedulers. They addressed three schedulers and their performance was compared. The schedulers are the proportional average delay scheduler (PAD), the waiting time priority scheduler (WTP), and the hybrid proportional delay scheduler (HPD).

The **PAD** scheduler aims to equalize the normalized average delay among all classes.

Let the average delay of class i be $\bar{d}_i$ and the DDPs of class i be δ_i. Then the normalized average delay is given by

$$\tilde{d}_i = \frac{\bar{d}_i}{\delta_i} \quad (4)$$

The PAD scheduler selects the queue with the maximum normalized average delay from a set of backlogged classes. Let $B(t)$ be the set of backlogged classes at time t, $D_i(t)$ be the set of sequence of class i packets that departed before time t (in order of their departure), and d_i^m be the delay of the $m'th$ packets in $D_i(t)$. The normalized average delay of class i at time t is

$$\tilde{d}_i(t) = \frac{1}{\delta_i}\frac{\sum_{m=1}^{|D_i(t)|} d_i^m}{|D_i(t)|} = \frac{1}{\delta_i}\frac{S_i}{P_i} \quad (5)$$

Where S_i is the sum of queuing delays of all packets in $D_i(t)$, and P_i is the number of packets in $D_i(t)$. Supposing a packet will be selected for transmission at time t, PAD chooses the backlogged class j with the maximum normalized average delay as:

$$j = arg \max_{i \in B(t)} \tilde{d}_i(t) \quad (6)$$

The **WTP** scheduling algorithm was first studied by (Kleinrock, 1976), under the name *Time dependent Priorities*, works to minimize the normalized head waiting times of different classes. Each packet is assigned a priority, which increase proportionally to the packet's waiting time. Suppose that class i is backlogged at time t, and that $w_i(t)$ is the head waiting time of class i at t. The normalized head waiting time is given as:

$$\tilde{w}_i(t) = \frac{w_i(t)}{\delta_i} \quad (7)$$

Where $w_i(t)$ is the waiting time of the head packet of a class or queue. The waiting time is measured as the difference between current system time and the time when a particular packet entered the queue.

Every time a packet is to be transmitted, the WTP scheduler selects the backlogged class j with the maximum normalized head waiting time as

$$j = arg \max_{i \in B(t)} \tilde{w}_i(t) \quad (7)$$

The **HPD** scheduler was designed as a packet scheduler that combines the operations of both PAD and WTP. The corresponding normalized average delay for HPD is given as:

$$\tilde{h}_i(t) = g\tilde{d}_i(t) + (1-g)\tilde{w}_i(t) \quad (8)$$

Where g is the HPD parameter. HPD chooses the backlogged class j with the maximum normalized hybrid delay as

$$j = arg \max_{i \in B(t)} \bar{h}_i(t) \qquad (9)$$

The PAD scheduler appears to always meet the PDD model, when it is feasible to do so, PAD, however, exhibits unpredictable behaviors in short time scales. The WTP approximates the PDD model closely even in short time scales, but only in heavy load conditions. The HPD approximates the PDD model closely, independent of class load distribution and also provides predictable delay differentiation even in short time scales. The authors in (Constantinos, Dimitrios, & Parameswaran, february 2002) stated that an optimal selection of g would attempt to maximize a given performance metric that evaluates HPD's ability to approximate the PDD model, and at the same to provide predictable delay differentiation in short time scales.

(Yan & Hsiao-Hwa, 2007) Proposed a hierarchical scheduling algorithm based on PAD to provide differentiated service for rtPS and nrtPS together under a unique polling service framework in WiMAX networks. The work of the authors paved way for the feasibility of using HBD scheduler for class differentiation in WiMAX. However, HBD-parameter was manually selected in (Constantinos, Dimitrios, & Parameswaran, february 2002). An optimization scheme is required for selection of the parameter. This will be our major contribution before applying it to WiMAX systems.

4 Conclusions and recommendations

This paper presents a review of number of scheduling algorithms for WiMAX networks. Existing proposals have been classi[fied] into uplink/downlink, centralized/decentraliz[ed] RT/NRT, homogeneous/hierarchical or int[ra-] class/inter-class. Our study can be used to choo[se] an efficient scheduler for WiMAX networks th[at] address some of the issues observed in the existin[g] schemes. For instance, inter-class scheduling ha[s] been a major challenge in a situation where there is a large number of users requesting for applications from higher priority classes. This causes starvation of lower priority classes. A new scheduler based on the PDD model called the HPD, is recommended. This scheduler is independent of variation in loads and it is also predictable even in short time scales. However, for large observations, an optimization technique is required for selection of the HPD-parameter.

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