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A New Distributed Scheduling Algorithm for Bandwidth Allocation in IEEE 802.16 Mesh Networks

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Abstract

Multi-hop WiMAX networks has the potential of easily providing high-speed wireless broadband access to areas with little or no existing wired infrastructure. IEEE 802.16 incorporates the quality of service (QoS) mechanisms at the Media Access Control (MAC) level, but it doesn't define a specific allocation algorithm. The implementation was left open to the service providers' diligence. Scheduling in WiMAX became one of the most challenging issues, since it was responsible for distributing available resources of the network among all users. Providing QoS in multi-hop WiMAX networks such as WiMAX mesh or mobile multi-hop relay networks is challenging as multiple packets can collide if they are scheduled at the same time. To warranty the QoS requirements, the 802.16 equipment must run some algorithm to allocate slots for connections. We propose an efficient distributed algorithm for packets scheduling in multi-hop WiMAX mobile networks. It is based on the 802.16e parameters, bandwidth request sizes and QoS requirements. The algorithm ensures a dynamic bandwidth allocation for the 802.16 various service classes. Assuming that the packets arrivals follow a Poisson process we build an algorithm witch calculate the number of time slots required for each packet according to its service class and its length.

Keywords: QoS, WiMAX mesh, mobile WiMAX, multi-hop, scheduling algorithm.

1 Introduction

Wireless broadband networks are being increasingly deployed and used in the last mile to extend the Internet connectivity for fixed and/or mobile users on the edge of the wired network [1]. The IEEE 802.16 recommends an air interface for broadband wireless access systems witch support multimedia services [2]. Unlike the traditional wireless ad-hoc networks, in a mesh network, nodes are minimally mobile or fixed and wire-powered; moreover the mesh networks are self configured and emerge as flexible wired infrastructure networks extension. Wireless mesh networks employ multi hop relay which is an optional deployment that may be used to extend

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coverage or performance advantage in an access network [3]. WiMAX is regarded as a disruptive wireless technology and has many potential applications because of his high data rate, large network coverage, strong QoS capabilities and cheap network deployment and maintenance costs [1][2].

In IEEE 802.16 protocol stack, the Medium Access Control layer (MAC) can be configured to work in different modes, Point-to-Multipoint (PMP) or mesh mode (multipoint-to-multipoint). In the PMP mode, the Base Station (BS) is connected to the internet and communicates directly with multiple subscriber stations (SSs) [1]. Whereas, in the multi-hop mesh mode, the communication can be established directly between SSs or via a BS by involving multiple hops using IEEE 802.16j relay, which is developed by IEEE 802.16's Relay Task Group.

The mesh topology which, not only increases the wireless coverage, but also provides a fast deployment, reconfiguration and a lower backhaul deployment cost, can be employed as a high speed wide-area wireless network.

In mobile multi-hop relay network, instead of communicating directly with the BS [4], the SS may communicate with relay station (RS) 802.16j which enable multi-hop communication in mobile WiMAX. A SS without direct links to BS can relay the data to each other through other SSs. The wireless network uses Time Division Multiplexing (TDM) mode between SSs and BS to access to the radio resources. In this mode a radio channel is divided in to physical slots (PSs). The PSs are grouped as a frame, which is divided into two subframes: control subframe and a data subframe. The control subframe consists of Transmission Opportunities (TOs) used to carry signaling messages for scheduling. The data subframe, divided in to 256 mini-slots and it's used to carries the user data.

To provide Quality of Service to applications with real time constraints such as Video (Internet protocol television (IPTV), video on demand (VoD) and audio Voice over IP (VoIP)) streaming the WiMAX considers QoS as one of the most important shutter. The WiMAX define five service classes with different parameters like latency, jitter, minimum and maximum rate. An important aspect of QoS is packets scheduling witch take in account all parameters of the five different flow service classes. As no scheduling mechanism was specified in the WiMAX standard and it was left to the services providers' diligence it is a very active research area. In WiMAX mesh, scheduling is one of the major problems that can seriously impact the system performance [5] [6].

The WiMAX MAC protocol defines bandwidth requests mechanisms and specifies when and how a WiMAX device (BS or SS) may initiate transmission on the channel without detailing any scheduling algorithm.

In this paper we focus on the packets scheduling in the WiMAX mesh networks. We use an algorithm for resources allocation proposed by Shih in [7], which give a simple method for finding solution of special classes of resources allocation, to build an efficient distributed algorithm for packets scheduling in multi-hop WiMAX mobile networks which ensures a dynamic bandwidth allocation for the 802.16 various service classes.

2 Related Works

The WiMAX standard defines five service classes with different parameter requirement. The existing wire line and wireless schedulers do not adapts nor perform very well with the recently defined quality of service classes. So it has become necessary to build and design other appropriate scheduling. Many scheduling algorithms have been proposed which can adapt to the recently adopted QoS classes.

In Lin and Sirisena [8] presents a modified Weighted Round Robin (MWRR) algorithm which satisfies throughput and delay requirements of the multi class traffic in WiMAX. The model, called Multi-class Uplink Fair Scheduling Structure (MUFSS) is based on Grant per Subscriber Station grant bandwidth. The authors use a modified Weighted fair queuing for Unsolicited Grant Service (UGS) services and Real-Time Polling Service (rtPS), a modified Weighted Round Robin for nrtPS connections and FIFO is for BE connections. Any details of the modifications to the Weighted Round Robin discipline are provided by the authors.

In Wongthavarawat and Ganz [9] propose a hybrid scheduling algorithm which allocates bandwidth in a strict priority manner. The algorithm combines three different data packets scheduler such as Weighted Fair Queuing (WFQ), Earliest Deadline First (EDF) and First in First out (FIFO). Each data packets scheduler is assigned for a type traffic flow: the EDF is for the reel time poling service (rtPS) flows, the WFQ for the non reel time poling service (nrtPS) flows and FIFO for the best effort (BE) flows traffic. The strict priority manner may starve the packets flows with low priority.

In Vinay et al. [10] give a hybrid algorithm which combine earliest dead line first (EDF) and weighted fair queuing (WFQ) to allocate bandwidth respectively for rtPS services flows and nrtPS and BE service classes. The bandwidth allocation is not done in a strict priority manner, but in a fair manner. Since there is no QoS requirements for the best effort service flows, using such a complex algorithm as WFQ is not needed.

In Shetiya and Sharma [11] presents the routing and centralized scheduling based on the traffic models such as constant bit rate (CBR) and variable bit rate (VBR) traffic.

In Settembre et al. [12] uses Round Robin (RR) and Weighted Round Robin (WRR) to build a hybrid algorithm with strict priority mechanism. For rtPS and nrtPS service classes the WRR is used with strict priority manner to allocate bandwidth until they are satisfied. For BE service classes, the RR algorithm is used to distribute the remained bandwidth. This algorithm may starve lower priority service classes.

In Sun et al. [13] proposes a method that guarantees the minimum bandwidth for each service flow and ensures fairness and QoS in distributing excess bandwidth among all connections. At the same time, the scheduler in SS can provide differentiated and flexible QoS support for all of the four scheduling service types. The main idea of the proposed method is the up-to-date information, the scheduler inside the BS may outdate information about the current state of each link due to the large Round Trip Delay and an additional scheduler in each SS is needed to reassign the received transmission opportunities among different connection. Since the traffic is generated at SS, the distributed scheduler is able to arrange the transmission based on and then provide QoS guarantee for its connections. But the proposed algorithm is suffered by starvation of lower priority service classes.

In Ozel et al. [14] examine a buffer partitioning method for unbalanced load according to the arrival and service statistics. There work shows the separability of the optimal buffer partitioning and user scheduling. The result encourages further study of optimal scheduling and buffer management in more realistic system models.

In Alexander Sayenko et al. [15] proposes a scheduling solution for the 802.16 base station in PMP mode. The solution based on round robin scheduling simplifies the translation of the QoS requirements in to a number of slots in the frame. The solution take into account connection parameters but the slots assignation is static.

3 Packets Scheduling In IEEE 802.16 Mesh Networks

3.1 Frame Structure

The WiMAX standard has defined an optional frame structure for mesh mode. In this mode there is no clearly separate down and up link subframes. To facilitate the bandwidth partitioning, each frame is modeled as a stream of multiple and equal duration minislots. The unit of bandwidth allocation is the minislot which consists of a certain number of physical slots. The data rate provided by a minislot depends on the coding and modulation schemes used at transmission time. The minislots are allocated through control messages exchange. The frame is divided in to two parties called data and control subframes [2].

Two types of control subframes are defined to serve different basic functions: The Network Control subframe, which is dedicated for creation and maintenance of cohesion between the different systems, and the Schedule Control subframe, which is used to coordinate the data transfers between systems. Frames with a network control subframe occur periodically while the all other frames have a schedule control subframe.

In the control subframe, the first seven symbols are allocated for network entry, followed by sets of seven symbols for network configuration with mesh network configuration MSH-NCFG messages [2].

MSH-NCFG messages provide a basic level of communication between nodes in different nearby networks. In the Mesh network, all nodes (BS and SS) will transmit MSH-NCFG to report the number of its neighbors [2].

The number of neighbors reported on may be a fraction of the whole set of neighbors known to this SS. A node will also report the Mesh BSs that its neighbors report and report the distances in hops to the BSs.

During the Schedule Control Subframe, the first symbols are allocated to transmission bursts containing Mesh centralized scheduling message (MSH-CSCH) and Mesh centralized configuration message (MSH-CSCF), and the remainder of the Schedule Control subframe is allocated to transmission bursts containing Mesh distributed scheduling messages (MSH-DSCH) [2].

The Fig. 1 shows the mesh frame structure with the two sub frames.

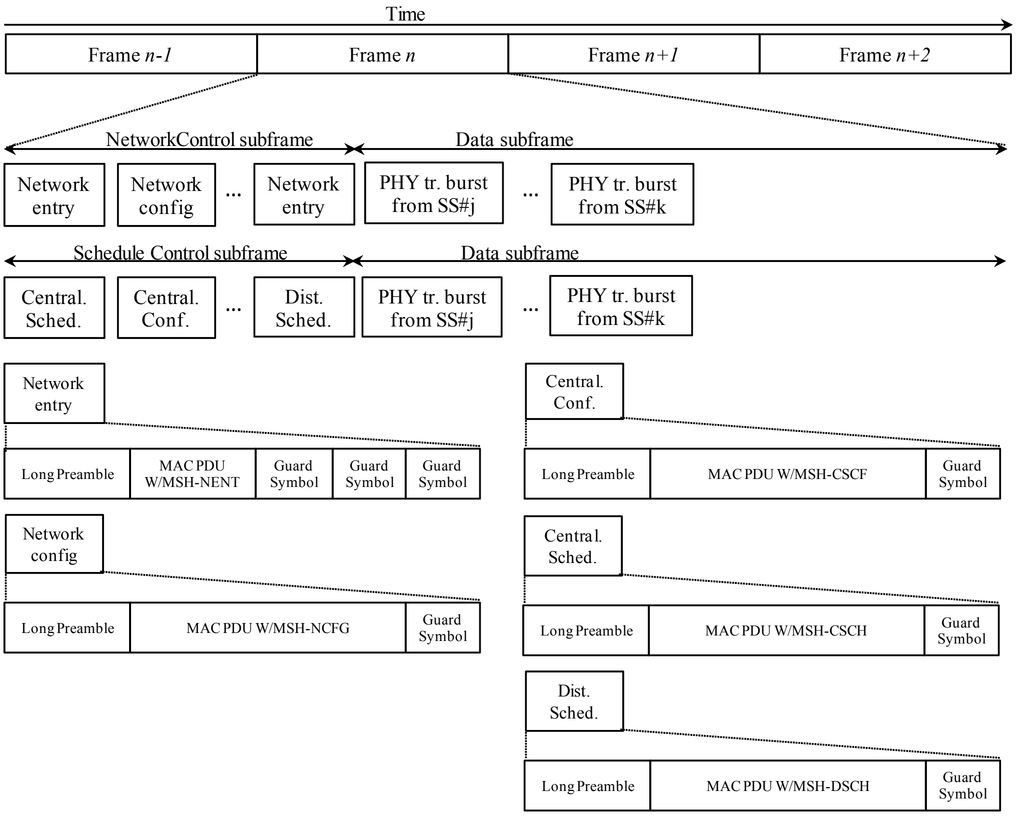

Fig. 1. Mesh frame structure [2]

- MSH-CSCH message: A MSH-CSCH message is created by a Mesh BS for the purpose of centralized scheduling, including collecting bandwidth request from the SSs and delivering the transmission schedule to the SSs. To deliver a transmission schedule to the SSs, a MSH-CSCH message is generated and broadcast by the BS to all its neighbors. Then all the nodes with hop count lower than a threshold, which is configured by the BS, will forward the MSH-CSCH message to their neighbors that have a higher hop count.

- MSH-CSCF message: A MSH-CSCF message is also used in Mesh mode for the purpose of centralized scheduling, and specifically for configuration. The Mesh BS generates and broadcasts the MSH-CSCF message to all its neighbors, and all nodes forward (rebroadcast) the message according to its index number specified in the message. With each new configuration message, the number of Configuration sequence number in the message is incremented by 1. The parameter "NumberOfChannels" in the message indicates the number of channels available for centralized scheduling.

- MSH-DSCH message: During a Schedule Control subframe, MSH-DSCH-NUM Distributed Scheduling messages will occur. The number MSH-DSCH-NUM is indicated in the Network Descriptor included in a MSH-NCFG message. Distributed Scheduling messages may also occur in the data subframe if not in conflict with the scheduling dictated in the control subframe. In the MSH-DSCH message, the parameter "CoordinationFlag" indicates the type of the distributed scheduling, being 0 for Coordinated and 1 for Uncoordinated. A number of Request IEs, Availability IEs, and Grant IEs can be included in the message.

3.2 Scheduling Schemes in WiMAX

To manage the allocation minislots in data subframe in mesh mode, the WiMAX standard has defined three different scheduling schemes [16].

- Centralized scheduling: in this mode the data subframe scheduling, resource allocation, and grant for other nodes is coordinated by the BS. Each SS estimates, itself and its children traffic demands, and then, sends the request message "MSH-CSCH" to its parent which summarizes the total resources requirement "itself and its children requirement" and sends the request message to its own parent and so on until the MSH-CSCH reaches the mesh BS.

  In response, the mesh BS determines the amount of granted resources for each link and broadcasts the message MSH-CSCH: Grant to all its neighbors. All the intermediate nodes forward the MSH-CSCH: Grant message to their own neighbors.

  Intermediate nodes are responsible for forwarding bandwidth requests for nodes listed in the routing tree that are further from the BS [16].

  In centralized scheduling transmissions are coordinated to warranty collision-free scheduling over the links in the routing tree from and to the BS.

- Uncoordinated Distributed Scheduling: in this mode the most important message in the scheduling is mesh distributed schedule "MSH-DSCH" with its four fields:

  - Availabilities information elements "IE": indicates, the starting frame number, the starting minislot within the frame and the number of available minislots for the granter to assign;
  - Scheduling IE: shows the next MSH-DSCH transmission time (Next transmit time "NextXmtTime"), and Hold off exponent "XmtHoldoffExponent" of the node as well as of its neighbor nodes.
  - Request the information element (IE): indicates the resource demand of the node.
  - Grants IE: indicates the granted starting frame number, the granted starting minislot within the frame, and the granted minislots range.

  Every node sends its available channel resource table to neighbor nodes using MSH-DSCH messages. Hence, each node has the knowledge of idle slots throughout its extended neighborhood.

The requester randomly selects an idle slot during data subframe, and sends out the MSH-DSCH: Request message to acquire resource.

In case of collision in the random-access, the node performs the random back-off algorithm and then sends out the MSH-DSCH: Request again.

On receiving the MSH-DSCH: Request message, the granter evaluates the request through a slot allocation algorithm. If the algorithm returns successfully, the granter replies with the bandwidth grant message MSH-DSCH: Grant to the requester carrying the updated Grants IE.

All neighbor nodes of the granter are able to hear the broadcasted MSH-DSCH: Grant and are aware of the reserved minislots. In confirmation, the requester copies the grant information and acknowledges the resource grant by sending back the MSH-DSCH: Grant Confirmation message to the granter. Then, all neighbor nodes of the requester are able to hear the broadcasted MSH-DSCH: Grant Confirmation and are aware of the reserved minislots. Following this, all neighbor nodes of the requester and the granter are informed about the transmission between the two nodes. Even the latest version, IEEE 802.16e, has not defined a specific slot allocation algorithm. This provides implementation flexibility with respect to diverse requirements under different scenarios. However, the algorithm's absence also gives rise to significant research challenge to accommodate diverse traffic demands and to achieve QoS.

- Coordinated Distributed Scheduling: The main idea of the coordinated distributed scheduling is to coordinate the transmission of MSH-DSCH messages over transmission opportunities in a collision-free manner.

  Through the exchanges of collision-free MSH-DSCH over control subframes, collision-free data slot reservations in the data subframes can be achieved. To achieve the goal of collision-free MSH-DSCH transmission, nodes will exchange 2-hop or 3-hop neighborhood scheduling information with each other. Since nodes shall run the scheduling algorithm independently, a common algorithm has been specified in the standard for each node in the neighborhood to calculate the same schedule. The algorithm is random and predictable by dynamically constructing the seeds of a random number generator for each node according to a common rule. In particular, the seed for a given node is constructed based on its unique node ID and the index of the candidate transmission opportunity. The most important parameters that have significant impacts on the performance of coordinated distributed scheduling are "XmtHoldofExponent" and the eligibility interval "NextXmtmx". They can be used to control the contention on the transmission opportunities and improve bandwidth utilization.

3.3 QoS Parameters in WiMAX Networks

QoS measures the capacity of a network to provide improved service to selected network traffic over various underlying technologies [6]. There are four main parameters that are keys to the performance of the network such as throughput, latency, packets loss and jitter. The IEEE 802.16 standard defines five service classes with different QoS parameters, such as:

- Unsolicited Grant Service (UGS): intended for Constant-Bit-Rate (CBR) services such as VoIP, which means that achieving low latency and low jitter is very important. At the same time, low percentage of packet drops is possible. UGS flows are configured to send fixed size packets at recurring intervals with as possible as little latency and jitter.

  The UGS service has the following set of features:

  - ✓ UGS service flows are buffered separately from each other and from flows in service classes such as nrtPS and BE.
  - ✓ UGS service flows are given strictly higher priority versus all the other services flows such as ertPS, rtPS, nrtPS and BE service flows, which implies that the system serves other services flow packets after it has finished transmitting all outstanding UGS packets.

In the upstream, the system uses UGS to bypass the normal request-grant mechanism for upstream traffic by allowing the BS to give automatic grants to a UGS flow. Also, over-the-air latency in a WiMAX network is small (5-40 ms) relative to the latency on an IP backbone (100ms), which inherently ensures minimal latency.

- Extended Real-Time Polling Service (ertPS): was added by the 802.16e amendment. The standard [2] indicates that ertPS is a scheduling mechanism that builds on the efficiency of both UGS and rtPS. The BS provides unicast grants in an unsolicited manner like in UGS, thus saving the latency of a bandwidth request. However, whereas UGS allocations are fixed in size, ertPS allocations are dynamic. The ertPS is suitable for variable rate real-time applications that have data rate and delay requirements such as voice over IP (VoIP) without silence suppression. The ertPS packets are scheduled in the second priority.

- Real-Time Polling Service (rtPS): is designed to support real-time service flow which generates variable size data packets, such as MPEG video. In this service, the BS provides periodic unicast (uplink) request opportunities, which meet the flow's real-time needs and allow the SS to specify the size of the desired grant. This service requires more request overheads than UGS. The polling overhead exists even when the flows are idle, and for as long as they are active. But supports variable grant sizes for optimum real-time data transport efficiency. A major drawback to using this QoS approach is the impact on the overall sector throughput. The packets of this service flows are scheduled in the third priority.

- Non-Real-Time Polling Service (nrtPS): is designed to support delay-tolerant data streams consisting of variable-size data packets for which a minimum data rate is required. The standard considers that this would be the case, for example, for an FTP transmission. In the nrtPS scheduling service, the BS provides unicast uplink request polls on a ‘regular’ basis, which guarantees that the service flow receives request opportunities even during network congestion. The standard states that the BS typically polls nrtPS CIDs on an interval on the order of one second or less. In addition, the SS is allowed to use contention request opportunities, i.e. the SS may use contention request opportunities as well as unicast request opportunities. This service is scheduled in the forth priority.

- Best Effort (BE): is designed to support data streams for which no minimum service guarantees are required and therefore may be handled on a best available basis. The SS may use contention request opportunities as well as unicast request opportunities when the BS sends any. The BS does not have any unicast uplink request polling obligation for BE SSs. Therefore, a long period can run without transmitting any BE packets, typically when the network is in the congestion state. The BE packets are scheduled at the last priority.

4 Packets Scheduling Algorithm

In this section we describe our packets scheduling algorithm. In WiMAX the resources are allocated in the form of data bursts where each burst constitutes an integer number of slots.

All slots are the same duration which is governed by the underlying PHY parameters.

In order to guarantee the QoS to different classes of service, priority-based schemes can be used in a WiMAX scheduler [17]. We assume that each service is assigned with a priority order, from highest to lowest, as follow: (1) for UGS, (2) for ertPS, (3) for rtPS, (4) for nrtPS and (5) for BE.

- Since the service flows packets are not the same size we define five different buffers with different sizes. The size of each buffer depends on the size of the service flows packets. We chose buffers with different sizes, in order to avoid the rapid saturation of the buffers and subsequently the packets loss or the untimely serving of the service flows with low priority. It is most suitable to serve the service flows with low priority once the oldest packet in the buffer has reached the latency threshold that serving them once the threshold buffer occupancy has reached. Each packet is transferred, classified and stored in the adequate buffer with its service flow identification (SFID), packet size and arrival time according to its priority (i.e. service types) with the help of the convergence sublayer Service Flow ID connection ID (SFID-CID) mapping mechanism as shown in Fig. 2.

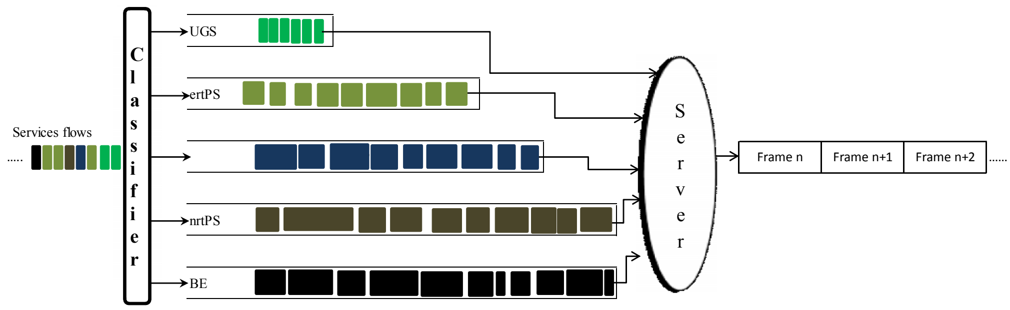

Fig. 2. Classifier mechanisms

The Weighted Round Robin (WRR) discipline is used to serve the next priority when all packets with the highest priority are served and so on.

- For UGS and ertPS the scheduler calculate the number of time slots needed to satisfy the UGS traffic according to the modulation and coding scheme “MCS”.

Knowing that the UGS packets have a fixed size the number of time slots needed is given by the following formula:

$$N_{UGS} = \left[\frac{B_{UGS}}{K\psi} \right] + 1$$

Where: [X] is the integer part of X,
B_{UGS} is the UGS bandwidth request,
K is the timeslot size which depends on MCS,
Ψ is the number of frames sends by the WiMAX component in one second.

- For rtPS service flows, the packets size is variable. We assume that the packets arrival/served follows a Poisson distribution with parameters respectively λ and μ. Such system model can be assimilated at an M/M/1/L Markov model, where L is the rtPS buffer size. The objective is to maximize the system throughput for this service without exceeding the rtPS delay. To do so the rtPS buffer must be visited by the scheduler at the latest once the rtPS delay is reached. The number of time slots to assigned is calculated as follow:

Let ρ bet the system service rate; $\rho = \frac{\lambda}{\mu}$

Let $T_{\lambda,\mu}$ be the system throughput; $T_{\lambda,\mu}\left(m_i\right) = \lambda\left(1 - \frac{(1-\rho)\rho^{m_i}}{1-\rho^{m_i+1}}\right)$; m_i is the number of time slots assigned to the ith packet.

We have: $\Delta T_{\lambda,\mu}(m_i) = T_{\lambda,\mu}\left(m_i+1\right) - T_{\lambda,\mu}\left(m_i\right) > 0$ (increasing the buffer space increases the throughput) and $\Delta T_{\lambda,\mu}(m_i) > \Delta T_{\lambda,\mu}(m_i+1)$ (due to the function concavity).
The maximal throughput is solution of the following optimization problem [14]:

$$\max_{m_i} \sum_{i=1}^{N} T_{\lambda,\mu}\left(m_i\right), i = 1, 2, ..., N$$ where N is the packets number.

Under constraint $\sum_{i=1}^{N} m_i \le L$

The solution of the problem was given in [7], which is the same of the following algorithm:

Initialize allocation, m_i=1 $\forall i$

For i=1 to N compute $\Delta T_{\lambda,\mu}(m_i)$

WHILE $\sum_{i=1}^{N} m_i \leq L$

For $j = \arg\max_i \Delta T_{\lambda,\mu}(m_i), m_j := m_j + k_{\max}$ where

$$k_{\max} = \max\left\{ k = 1,2,3,.....,L - \sum_{i=1}^{N} m_i \mid \Delta T_{\lambda,\mu}(m_j + k - 1) \geq \Delta T_{\lambda,\mu}(m_i) \forall i \neq j \right\}$$

The allover rtPS timeslots number that the scheduler will assigned is given by the following formula:

$$N_{rtPS} = \sum_{j=1}^{N} m_j$$

To not starves the services flows with lowest priority we define two pointers which measures respectively the occupancy rate of the BE buffer and the latency of the first arrived packet in the BE and nrtPS buffers. We also define a threshold for the occupancy rate of BE buffer "BE_{th}" and another for the latency in the nrtPS buffer "$nrtPS_{th}$". The scheduler works as follow:

- The nrtPS service flow packets are served once the oldest packet in the buffer has reached the nrtPS threshold latency.

- The BE service flow packets are served once the buffer size capacity has reached the BE threshold capacity or the first packet arrival has reached the BE threshold's latency.

5 Conclusions

In this paper we propose an efficient distributed algorithm for packets scheduling in multi-hop WiMAX mobile networks which is based on the 802.16e parameters, bandwidth request sizes and QoS requirements. The scheduling assigned the number of timeslots needed by each service flow according to its QoS parameters. Packets service is scheduled according to service priority. We define two thresholds respectively for nrtPS and BE service to serve packets with lowest priority once the thresholds are reached. Also, in this study, we use an algorithm for resources allocation proposed and proofed by Shih in 1977 to maximize the rtPS throughput, assuming that the packets arrival/served follow an M/M/1/L Markov model.

Competing Interests

Authors have declared that no competing interests exist.

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