2010 2nd International Conference on Education Technology and Computer (ICETC)

A Scalable QoS Scheduling Architecture for WiMAX Multi-Hop Relay Networks

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***Abstract*—WiMAX Mobile Multi-hop Relay (MMR) network has been introduced to increase the capacity and extend the coverage area of a single WiMAX Base Station (BS) by the use of a Relay Station (RS). WiMAX provides broadband access for services having different QoS requirements and different traffic priorities. However, it is the responsibility of the medium access control (MAC) layer to schedule the traffic flows and allocate bandwidth such that the QoS requirements of each flow is satisfied. This scenario is even more complex when multi-hop relays were introduced into the network. Nonetheless, the IEEE 802.16j standard does not specify any QoS scheduling architectures. In this paper, we propose a Scalable QoS Scheduling Architecture (SQSA) for IEEE 802.16j networks in order to (1) guarantee QoS demands of different applications, (2) find the appropriate QoS that each flow requests and to ensure this QoS. The SQSA is fully compliant QoS architecture; we present complete description of the SQSA modules and functions.**

Keywords-IEEE 802.16j; multihop relay; scheduling; QoS; bandwidth allocation

I. INTRODUCTION

WiMAX (Worldwide Interoperability for Microwave Access- IEEE 802.16) [1] is a wireless broadband standard that promises high bandwidth solution with long range for Metropolitan Area Networks (MAN). Providing seamless information access via wireless links to end users over a geographically large area is an important goal for wireless communications technology. However, it is challenging to deploy broadband wireless access for sparsely populated rural areas, non line of sight coverage in urban environments, in-building coverage as well as addressing coverage holes where there is limited or no backhaul connectivity due to geographical barriers, greater geographical distance, limited resources and expensive backhaul requirements [33]. Consequently, WiMAX enabled multi-hop relay [2] has been standardized to address the connectivity problems found in single BS based WiMAX configurations.

The relays can be used to increase the capacity of a wireless system and extend the coverage of Multi-hop Relay Base Station (MR-BS) [3]. For the case of centralized scheduling, the MR-BS will manage the RS in such a way that the RS does not need to perform complex scheduling operations. Therefore, the complexity of the RS can be reduced. Furthermore, since RS works as link layer repeater, a wired backhaul is not needed in the relay [33]. To our knowledge, IEEE 802.16j standard does not specify any QoS scheduling architecture or scheduling algorithm for scheduling of the slots to different MSs/SSs or address QoS issues arising from the multi-hop scenario. Thus, there is a lack of a proper QoS scheduling architecture and related QoS algorithms for this standard. In this paper, we propose a Scalable QoS Scheduling Architecture (SQSA) for WiMAX multi-hop relay network. To support tiered QoS for users located at different distances from the MR-BS in terms of the numbers of hops and to optimize network QoS behaviours.

The focus of this paper is on the design of an uplink scheduling QoS architecture for an IEEE 802.16j OFDMA network working in centralized scheduling mode. Centralized scheduling has advantages of collision free scheduling over the link to and from the MR-BS and less complexity where the scheduling is carried out by the MR-BS that determines the bandwidth allocation slots and generate the corresponding MAPs in a scheduling frame consist of multiple time slots for all access and relay links.

The rest of the paper is organized as follows. Section II discusses related work. Section III presents the existing WiMAX QoS architecture. Section IV presents an overview of IEEE 802.16j networks. Section V presents an overview of scheduling and QoS service classes in WiMAX. Section VI presents the SQSA design with description of the SQSA modules and functions. Section VII concludes the paper.

II. RELATED WORK

Some QoS architectures [15], [16], [17], [18] were proposed for IEEE 802.16 network and several scheduling and bandwidth allocation schemes have been proposed and evaluated in the literature for IEEE 802.16 WiMAX PMP network in a single hop scenario. However, none of these schemes were designed for WiMAX multi-hop relay topologies. Some studies were based on legacy algorithms [18], [19], [21], [22], adapted for WiMAX scheduling; others were designed specifically for WiMAX [20], [23], [29]. Other algorithms were proposed centralized as well as distributed scheduling for WiMAX multi-hop networks such as WiMAX mesh [25], [26] and mobile multi-hop relay networks [27], [28], [29]. The proposals can be classified into two categories; single hop algorithms for Orthogonal Frequency Division Multiplexing (OFDM) networks and multi-hop algorithms consist of mesh and mobile multi-hop relay for Orthogonal Frequency Division Multiple Access (OFDMA) networks. Furthermore, scheduling algorithms were needed for both downlink scheduling (traffic flows from the BS to the SS/MS) and uplink scheduling (traffic flows from the MS/SS to the BS). Although there is solid literature on scheduling in single hop networks [18-29] these algorithms cannot be applied directly to the multi-hop relay scenario where the RS has different rates over different sub-channels. Most of the research work on multi-hop networks focused on the downlink scheduling for mesh network whereas scheduling algorithms for multi-hop relay networks remain open research problem, especially with regards to uplink scheduling. Furthermore, IEEE 802.16j standard does not specify an algorithm for scheduling of the slots to different MSs/SSs.

A research work has been presented by Roy in [30] for IEEE 802.11e WLAN. The author proposed QoS capable Station (QSTA) uplink scheduler which schedules the packets based on the packet transmission weight (PTW). The estimation of the PTW is based on the application QoS parameters and the system parameters.

III. EXISTING QOS ARCHITECTURE OF WIMAX

An existing QoS architecture of WiMAX is illustrated in Fig. 1. [31], [18]. Since the MAC protocol of WiMAX is connection oriented, the applications in the SSs first set up the connection via the signalling mechanism (connection request, connection response) with the BS and the associated service flow (UGS, rtPS, nrtPS and BE). BS will assign the connection with a unique connection ID (CID). The connection may represent one application or a group of applications (all belong to one SS) sending data with the same CID [18].

Connection classifier in the SS receives the packets from the application layer as input, classify the packets based on CID and forward them to the appropriate queue. At the SS, the scheduler responsibility is to retrieve the packets from the queues and transmit them to the network in appropriate time slots as defined in the UL-MAP sent by the BS. The UL-MAP is determined by the UL bandwidth allocation scheduling module located at the BS based on the BW-Request message from the SS which report the current queue size of each connection in the SS. The UL-MAP contains the number of time slots in which the SS can transmit during the UL subframe [18], [31], [32].

The IEEE 802.16 standard [1] defines (a) the signalling mechanisms between SS and BS, for example, connection request connection response, bandwidth request and UL-MAP (b) as well as the uplink scheduling for UGS service flow. However, the standard does not define the admission control, traffic shaper and policing, as well as uplink scheduling for rtPS, nrtPS and BE service flows were left undefined.

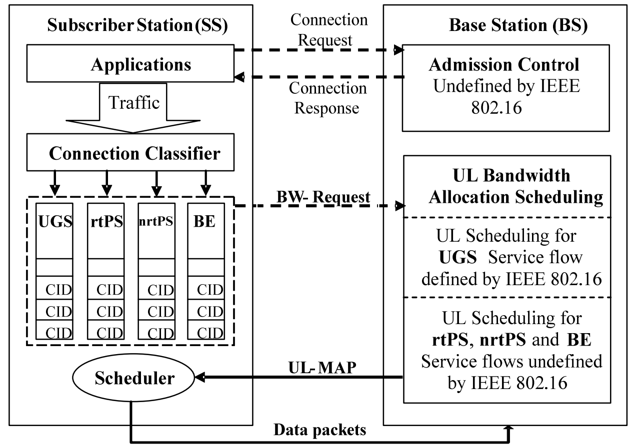

Figure 1. IEEE 802.16 QoS architercure

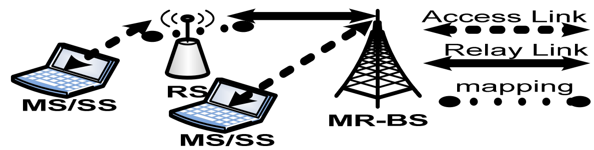

Figure 2. Example of a simple IEEE 802.16j network topology

IV. OVERVIEW OF WIMAX MMR NETWORK

Mobile multi-hop relay (MMR), also known as IEEE 802.16j [2], was introduced by the IEEE 802.16 Relay Task Group [4] to enhance coverage, user throughput and system capacity of WiMAX networks. This standard is compatible with the previous IEEE Standard 802.16-2004 and IEEE Standard 802.16e-2005 [5]. Therefore, traditional WiMAX clients will work normally in a MMR enhanced infrastructure. In the following section, some key features of WiMAX multi-hop relay are presented.

A. *IEEE802.16j Architecture and Terminology*

MMR network consists of three elements: A base station that is capable of supporting multi-hop relay, called MR-BS, multiple Relay Stations (RSs) and Mobile Stations (MSs)/Subscriber Stations (SSs). The standard does not limit the number of hops between MR-BS and MS/SS; meanwhile the path between the MR-BS and MS/SS must contain only RSs [6]. Based on [7], [8], [9], the maximum number of hops recommended for a MMR network is not more than three hops, to guarantee sufficient capacity for local clients to access the network.

An example of IEEE 802.16j network topology is shown in Fig. 2. A radio link between a MR-BS or RS and a MS or between an MR-BS or RS and a subordinate RS during network entry is called an **access link**. The access link can be either an uplink or a downlink. While a radio link between a MR-BS and a RS or between a pair of RSs is called a **relay link**. This can be either a relay uplink or downlink. A station that provides a point of access into the network for an MS or RS is an **access station**. An access station can be a MR-BS or a RS. The station that an RS transmits to in the uplink is its **super-ordinate station**; a relay station that an RS or MR-

BS transmits to in the downlink is its **subordinate RS** [2], [6], [33].

B. RS Types and Deployment Scenarios

RS can be defined as Fixed RS (F-RS), Nomadic RS (N-RS) or Mobile RS (M-RS) to suit different deployment scenarios or usage models. These RSs can be used for the system performance enhancement by allowing coverage extension and increasing the throughput. In certain scenario, the ISP may choose different types of RS to be deployed according to the topology, traffic and mobility within the surrounding area of each RS location. Hence, in such MMR network each usage scenario might include multiple RS types and multiple usage models [10], [11]. The most important RS types and usage scenarios are shown in Fig. 3. Listed below are the possible reasons that ISP might deploy RSs:

1) Enhanced Data Rate Coverage: This can be achieved by providing higher uniform Signal to Interference and Noise Ratio (SINR) to the users within the MMR cell coverage. In other words, this can also be done by providing higher throughput to individual MS within the MMR cell coverage.

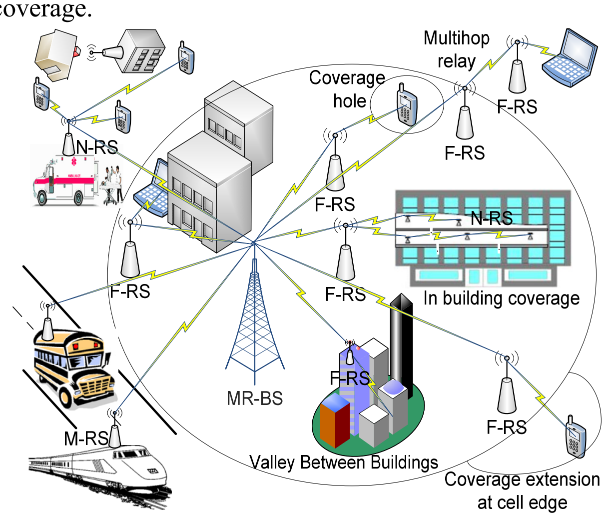

Figure 3. Examples of relay station types and their usage scenarios [33]

2) Range Extension: In order to provide coverage to group of users located outside of the BS coverage where the SINR is low and limited for instance, rural area or outskirts area, RSs are deployed to extend the coverage area beyond the perimeter of the BS coverage.

3) Capacity Enhancement: System capacity can be achieved by allowing aggressive frequency reuse within the BS cell and by enhancing the SINR where the SINR is limited. Thus RSs are deployed to increase the system capacity to high load regions within the BS cell. Where RS might be deployed individually or in clusters around the perimeter of the BS cell according to the needed capacity.

V. SCHEDULING AND QOS SERVICE CLASSES IN WIMAX

WiMAX has the ability to provide different QoS constraints. The MAC layer provides QoS differentiation for different types of applications through five scheduling services: Unsolicited Grant Service (UGS), Real-time Polling Service (rtPS), Extended Real-time Polling Service (ertPS), Non-real time Polling Service (nrtPS) and Best Effort service (BE) defined by the MAC scheduler for uplink flows.

(1) UGS class, designed to support real time service flows, such as VoIP application without silence suppression. (2) rtPS class, designed to support real time service flows that generate variable size data packets in which delay is an important QoS requirement, such as Moving Picture Experts Group (MPEG) Video application. (3) ertPS class, builds on the efficiency of both UGS and rtPS, designed to support variable data rate real-time applications which have data rate and delay requirements, such as VoIP applications with silence suppression. (4) nrtPS class, designed to support non-real time delay-tolerant service flows that require variable size data grant burst on a regular basis for which a minimum data rate is required such as FTP. (5) BE class, designed to support data streams that don't have strict QoS requirements, such as Data transfer, web surfing and Email. Each connection in the uplink direction is mapped to one of these services [2], [12], [13], [14], [33]. In particular the five scheduling services support in WiMAX has different QoS requirement and different characteristics summarized in Table I.

TABLE I. SERVICE CLASSES QOS REQUIREMENTS AND CHARACTERISTICS

QoS Characteristics	UGS	rtPS	ertPS	nrtPS	BE
Max BW	√	√	√	√	√
Min BW		√	√	√	
Max latency	√	√	√		
Tolerated jitter	√		√		
Grant interval	Fixed size periodically		Dynamic size		
Polling interval		Periodic		Regular	
Traffic priority		√	√	√	√
BW request		√	√	√	√
Contention based polling	Not allowed	Not allowed	Allowed	Allowed	Allowed

VI. SCALABLE QOS SCHEDULING ARCHITECTURE (SQSA) DESIGN

A. Network Topology

A proposed network topology is shown in Fig. 4 consisting of one MR-BS, three F-RS and MSs/SSs. These MSs/SSs may connect directly to the MR-BS if it is in the coverage area of the BS otherwise, it will be connected to the network and get the services through the F-RS which is installed as fixed relay stations in order to enhance the coverage and capacity of the MR-BS.

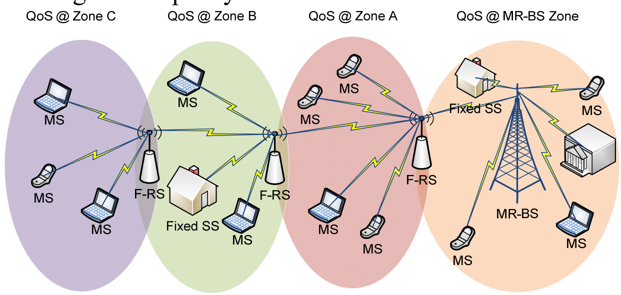

Figure 4. Network topology

In Fig. 4 multi-hop communications between users and MR-BS occurs when the clients are out of the MR-BS range and coverage but in the range of a RS, to connect the users to the network via RSs.

B. SQSA Design: Modules and Functions

Based on the proposed network topology (Fig. 4), since the QoS demands of different traffic flows from multiple wireless zones vary and the system capacity is limited, it is responsibility of the MAC layer to schedule the traffic flows and allocate bandwidth such that the QoS requirements of each flow is satisfied. The IEEE 802.16j standard does not define any bandwidth allocations criteria, QoS architecture or scheduling mechanisms. Therefore, the proposed architecture (Fig. 5) is designed to accommodate all types of service flows with their specific QoS requirements. We focus on centralized uplink scheduling, hence the MR-BS uplink scheduler will schedule and allocate the suitable amount of bandwidth when a bandwidth request was received from the MS/SS. Fig. 5 presents the main functions and modules of the proposed Scalable QoS Scheduling Architecture (SQSA).

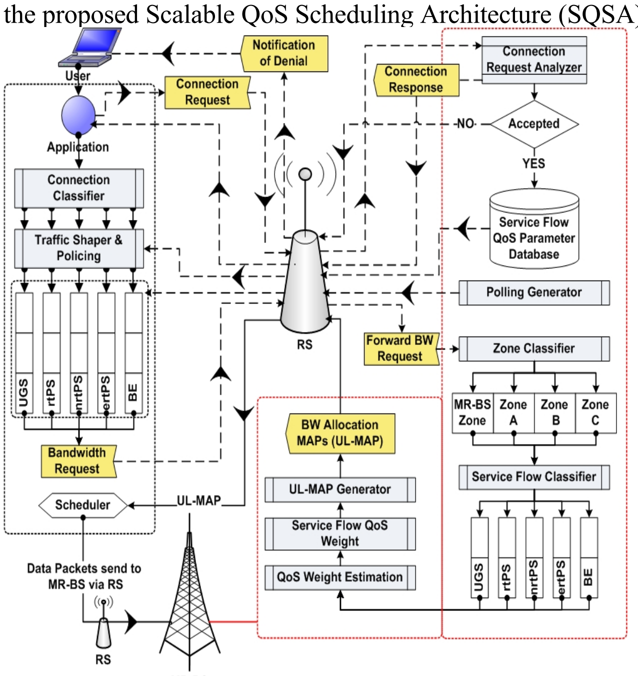

Figure 5. SQSA architecture design diagram.

The following is description of the Architecture modules and functions:

1) Connection Request Analyzer: Analyzed the connection request sent by the MS/SS. The request includes the application QoS parameter set such as requested BW, max sustained traffic rate, min reserved traffic rate, max latency, tolerated jitter and traffic priority. The connection is accepted if the required QoS can be satisfied without affecting the QoS of existing connections.

2) Service Flow QoS Parameters Database: If the request accepted by the admission control module, the QoS attributes and CID of this connection are registered in service flow QoS parameter database

3) SS/MS Connection Classifier: Receives the packets from the application layer as input, classify the packets based on CID and forward them to the appropriate queue.

4) Traffic Shaper and Policing: Reside in the SS, if the admission control at the BS accept new connection request it will notify the traffic shaper and policing module at the SS.

5) Polling Generator: The MR-BS is responsible to poll SS/RS [2]. Each RS along the path is polled sequentially via an RS-SCH management message from the MR-BS and RS poll each SS in its zone. Consequently, each connection provided an opportunity to send their bandwidth request to the RS and the RS forward this request to the MR-BS.

6) Bandwidth Request: Message sent by the MS/SS, it reports the current queue size of each connection at the MS/SS that need to be allocated by the MR-BS

7) Forward BW-Request: In systems with RSs working in centralized scheduling mode, it is the MR-BS responsibility to determine the bandwidth allocations (UL-MAPs) for all the links. Therefore, the RSs will forward all bandwidth request headers and bandwidth request Code Division Multiple Access (CDMA) ranging code information they receive from subordinate stations to the MR-BS [2].

8) Zone Classifier: In centralized scheduling mode, the MR-BS is responsible for determining the uplink bandwidth allocation (UL-MAPs) for all the links [2]. Therefore, since we have different tiers of QoS for different wireless zones and the MR-BS knows the details of each bandwidth request, the zone classifier module at the MR-BS uses the bandwidth requests from the RSs/SS as input, to classify and forward them to the appropriate zone queue.

9) Connection Classifier: In the MR-BS scheduler, classify the request based on the connection request type and forward them to the appropriate queue.

10) QoS Weight Estimation (QWE): Dynamic estimation of QoS weight for Individual QoS parameter belong to the service flow every specific period of time, calculated as the ratio between the achieved QoS and negotiated/target QoS. The dynamic estimation of the QoS Weight results in QoS realization for all active service flows in the various wirelss zones while ensuring fairness among them.

11) Service Flow QoS Weight (SFQW): Is the summation of the QoS weights of the various QoS parameters belong to the service flow.

12) UL-MAP Generator: Determines the number of bandwidth allocation time slots that each MS/SS will be allowed to transmit in an uplink subframe. These time slots will be included in the UL-MAP message and send to the MS/SS scheduler.

13) UL-MAP Message: Contains Information Element (IE) that includes the number of time slots in which the MS/SS can transmit during the UL subframe in order to control all the uplink packet transmissions.

14) MS/SS scheduler: Is Responsible to retrieve the packets from the queues and transmit them to the network in appropriate time slots as defined in the UL-MAP sent by the MR-BS.

The description of modules number 8, 9, 10, 11 and 12 adapted from [33].

VII. Conclusions

The paper deals with the problem of Quality of Service in WiMAX multi-hop networks focusing on the uplink scheduling with centralized scheduling. We have proposed a Scalable QoS Scheduling Architecture (SQSA) in order to find the appropriate QoS that each flow requests and to ensure this QoS. The SQSA is fully compliant QoS architecture that supports all types of service with different service level requirements. The development of SQSA is expected to satisfy the QoS demand of each type of traffic flow, support tiers of QoS for various user application according to their distance from WiMAX BS, achieve high utilization of bandwidth allocation, maintain fairness's between different user's applications, provide bandwidth guarantees and high priority for real-time application and maintain the QoS for the lower tier users. Simulation studies will be conducted to prove that the SQSA will achieve the desired objective.

Acknowledgment

The authors would like to acknowledge Universiti Sains Malaysia (USM) and Institute of Postgraduate Studies (IPS) for funding of USM Fellowship Scheme 2009/2010, Postgraduate Research Grant Scheme (USM-RU-PRGS) for the project entitled "QoS Optimization and Bandwidth Utilization in WiMAX Multi-hop Relay Network" and USM Short-term Grant Scheme for the project entitled "QoS Provisioning and Bandwidth Allocation in WiMAX Mesh Multi-hop Relay Networks".

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