A Cross-layer QoS Scheme of Non-real-time Service in WiMAX

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Abstract

Worldwide Interoperability for Microwave Access (WiMAX) is one of the next generation broadband wireless access technologies. The WiMAX features longer transmission distance and more accomplished support of Quality of Service (QoS) than other wireless access technologies such as IEEE 802.11. Specifically, QoS has become an important role in the context of a variety of applications which utilize network resources. Radio Resource Management (RRM) always plays important role in providing the QoS guarantees. In WiMAX, Medium Access Control (MAC) protocol defines a wide variety of mechanisms for bandwidth allocation and QoS provision. Although different types of QoS classes have been defined by WiMAX, the scheduling architecture is left to be vendor specific. Numerous QoS schemes in WiMAX have proposed for real-time services, but few novel QoS schemes are designed for non-real-time services due to their lower strict priority. In this paper, we propose a QoS scheme based on Modified Deficit Round Robin (MDRR) of packet scheduling and Call Admission Control (CAC) with the channel condition for non-real-time service. Simulation results illustrate the proposed scheme can increase the throughput and decrease the packet loss rate in non-real-time service significantly.

Keywords: *WiMAX, Quality of Service (QoS), Modified Deficit Round Robin (MDRR), Call Admission Control*

1. Introduction

Broadband Wireless Access (BWA) is designed to provide high speed wireless access to displace the “last mile” in metropolitan area networks. IEEE 802.16 standard [1, 2, 3] ,called WiMAX, is one of the most emerging technologies for BWA to provide various services of the high mobile internet and more cost-effective service and receives wide attention from the industry and researchers. The demands of mobile network are broadening the scope with a strong tendency toward never-ending increasing need for high traffic capacity at all times and mobility in the access links within the wireless links. IEEE 802.16 is proposed to achieve the requirement of wide-area wireless broadband access at low cost recently.

A typical IEEE 802.16 network system consists of one base station (BS) and several subscriber stations (SSs) and is named Wireless MAN (Metropolitan Area Network) or WiMAX. It covers a metropolitan area of several kilometers. One of the important principles of IEEE 802.16 is connection oriented that means an SS must register to the base station before communicating.

Since the increasing popularity of broadband wireless networks, QoS becomes a key issue for the design and deployment. WiMAX specifies mechanisms of QoS like bandwidth requests and the bandwidth allocation. To support QoS, WiMAX uses the concept of service flow. It specifies five different services in MAC layer to meet the QoS requirements of differentiated traffic treatment: Unsolicited Grant Service (UGS), real-time Polling Services (rtPS), non-real-time Polling Service (nrtPS), Best Effort (BE), and Extended real-time Polling Service (ertPS). Even though the standard specifies the principles to satisfy the QoS in MAC layer. The details of the specification are left to vendors to design. In WiMAX network, how to design a scheduling algorithm of QoS is still an open issue and it is important to use radio resources efficiently.

Because the communication between BS and SSs is connection oriented, the SS negotiates the initial QoS requirements with BSs during the registrations and these requirements can be changed later. The QoS requirements of connection may be either grant per-connection (GPC) or grant per-subscriber station (GPSS). In this paper, the GPC is taken into account for discussions. On the downlink (from BS to SS), the transmission is simple and the BS is the only one that transmits data packets during the downlink sub-frame. The data packets from the BS are broadcasted to all SSs and an SS only picks up the packets destined to it. The BS finishes the scheduling for downlink direction and provides the QoS guarantees. Only the downlink transmission will be discussed in this paper, because most of the applications on the Internet are downloading data, especially non-real-time service. Thus, a cross-layer scheduling algorithm based on Round Robin (RR) algorithm has been proposed in this paper.

2. Background

2.1 IEEE 802.16 MAC layer

To satisfy different QoS requirements, WiMAX specifies five types of services as shown in Table 1.

The IEEE 802.16 MAC layer identifies a connection between the base station (BS) and subscriber station (SS) by a unidirectional connection identifier (CID). Each connection is associated with a traffic service, which is characterized by a set of QoS parameters.

A service flow is a MAC transport service that provides unidirectional transport of packets either to uplink and downlink traffic, and is a key concept of the QoS. Each service flow is characterized by a set of QoS parameters such as latency, jitter, and throughput.

1. Unsolicited Grant Service (UGS): BS periodically receives fixed size grants without the need to request them. The mandatory QoS parameters are traffic rate, latency, and jitter.

2. Real-time Polling Service (rtPS): BS provides periodic unicast request opportunities to subscribers; these opportunities ensure delay bound and minimum bandwidth guarantees. The mandatory QoS parameters are maximum traffic rate, minimum traffic rate, and latency.

3. Extended real time Polling Service (ertPS): A grant mechanism similar to the one in UGS connections is used, except that the BS can ensure the ertPS a default bandwidth (corresponding to the maximum sustained traffic rate as for UGS) and dynamically provide additional resources.

4. Non-real-time Polling Service (nrtPS): BS offers periodic unicast request opportunities, but uses more spaced intervals than rtPS, as well as minimum bandwidth guarantees The mandatory QoS parameters are maximum traffic rate, minimum traffic rate and traffic priority.

5. Best Effort (BE): BE service flow shares contention request opportunities with the nrtPS service flow. The mandatory QoS parameters are maximum traffic rate and traffic priority.

Table 1. IEEE 802.16e Service Flow and QoS Parameters

Service flow	Applications	Parameter
UGS	VoIP	Maximum sustained traffic rate Maximum latency Tolerate jitter
ertPS	Voice with activity detection (VoIP)	Minimum reserved traffic rate Maximum sustained traffic rate Maximum latency Tolerate jitter Traffic priority
rtPS	Streaming audio or video	Minimum reserved traffic rate Maximum sustained traffic rate Maximum latency Traffic priority
nrtPS	Data transfer, Web browsing, etc.	Minimum reserved traffic rate Maximum sustained traffic rate Traffic priority
BE	File Transfer Protocol (FTP)	Maximum sustained traffic rate Traffic priority

Among five service flows mentioned above, the UGS is designed to support real-time service flows with fixed-size data packets on a periodic basis, such as T1/E1 and VoIP without silence suppression. The rtPS is designed to support real-time service flows with variable size data packets on a periodic basis, such as moving pictures experts group (MPEG) video. The nrtPS is designed for the delay-tolerant applications that generate variable size data packets and require a minimum data rate, for example, the Hypertext Transfer Protocol (HTTP). The BE is designed for traffic with weak QoS requirements, such as E-mail and File Transfer Protocol. The ertPS is designed to support real-time service flows with variable size data packets on a periodic basis, such as VoIP services with silence suppression.

2.2 RR-based Scheduling

The RR scheduler is a simple and common algorithm which distributes the equal resource without priority. It is simple, starvation-free and easy to implement, but it does not guarantee any QoS requirements. Some enhanced RR-based schedulers are proposed, such as the weighted round-robin (WRR) [4] and the deficit round-robin (DRR) [5].

In WRR, each packet flow or connection has its own packet queue. It is the simplest approximation of Generalized Processor Sharing (GPS). While GPS serves infinitesimal amounts of data from each nonempty queue, WRR serves a number of packets for each nonempty queue. When it applies in WiMAX, each SS is assigned a weight as its priority. The WRR scheduler allocates the bandwidth accounting to the static weight.

DRR, also named the Deficit Weighted Round Robin (DWRR), is a modified weighted round robin scheduling discipline. It can handle packets of variable size without knowing their mean size. A maximum packet size number is subtracted from the packet length, and packets that exceed that number are held back until the next visit of the scheduler. The difference between WRR and DRR is that WRR serves every non-empty queue whereas DRR serves packets at the head of every non-empty queue whose Deficit Counter (DC) is greater than the size of the packet at the Head of the Queue (HoQ).

If the DC is lower, then the queue is skipped (the HoQ packet is not served) and its Credit (Ct) is increased by some given value called Quantum (Q). This increased value is used to calculate the DC in the next round when the scheduler examines this queue for serving its head-of-line packet. If the queue is served, then the Ct is decremented by the size of packet being served.

The major advantage of this method of scheduling is that it does not require the size of the incoming packets on the different links to be known to the scheduler, as opposed to a simpler weighted round robin scheduling. DRR is a modified of WRR discipline, when it applies in WiMAX, DRR scheduler sets a fixed Q and a DC to each flow; it allows provision of different quanta for each SS. A higher Q can be assigned to higher priority SSs.

In [6], WRR is used for rtPS and nrtPS service classes, and RR is used for BE service classe if there is any remaining bandwidth. In [7], WRR scheduler is used as uplink scheduler and DRR scheduler is used as downlink scheduler for performance evaluation of WiMAX.

2.3. Call Admission Control

Call admission control (CAC) plays a cardinal role in providing the desired quality of service in networks. CAC is the practice or process of regulating traffic volume in communications, particularly in wireless mobile networks and in Voice over Internet Protocol (VoIP). CAC is an essential component of IP telephony system, especially those involve multiple sites connected through an IP WAN. It can also be used to ensure, or maintain, a certain level of audio quality in communications networks, or a certain level of performance in Internet nodes and servers where traffic flow exists.

Most CAC algorithms work by regulating the total utilized bandwidth, the total number of calls (or connections), or the total number of packets or data bits passing a specific point per unit time. If a defined limit is reached or exceeded, a new call may be prohibited from entering the network until at least one current call terminates.

Many CAC schemes have been proposed but the method of call admission control has not been defined in WiMAX standard and it left to be implemented by venders or providers. The method of Minimum Reserved Traffic Rate (MRTR) is currently most adopted. Due to any services has their own MRTR except BE and to be assumed as rmin(i, j) that represents the MRTR of the jth connection for the ith class of service flow, the CAC can be designed easily and summarized by Eq. 2.1.

$$C_a = C_{total} - \sum_{i=0}^{I} \sum_{j=0}^{J_i - 1} r_{min(i,j)} \qquad (2.1)$$

Where, I stands for the total type of service classes in WiMAX network, and J is the number of connections in I type service class. Ca and Ctotal represent the available capacity of current system and the total capacity of whole system, respectively. Once a new connection intends to add to the system, the newer Ca in Eq. 2.1 will be recalculated and checked if it is greater than 0 or not. It is worth mentioning that BE will always enter the system if BE is not limited by its MRTR and it will cause unsuitable side effect under such a heavy system load.

3. Proposed Scheduling Scheme

3.1 Signal-aware Call Admission Control

In IEEE 802.16 standards, there are three types of control regions may be allocated in one uplink sub-frame: Ranging, Fast-Feedback channel region, and Hybrid Automatic Repeat reQuest (HARQ) Acknowledge (ACK) region. In IEEE 802.16e-2005, 8.4.4.5 Uplink transmission allocations, the maximum number of ranging region allocated in one uplink sub-frame is specified. In IEEE 802.16e-2005, 8.4.5.4.1 UIUC allocation, the maximum number of Fast-Feedback channel region allocated in one uplink sub-frame is specified.

IEEE 802.16e specifies a Fast-Feedback channel region can be assigned in the uplink sub-frame, and it provides several uplink control channels to send messages to rapid exchange cross-layer information [8]. One of those is Channel Quality Information Channel (CQICH), which SSs used to reply the signal strength (such as Signal to Noise Ratio, SNR) of received messages to BS, then BS according to the SNR SSs replied to choose modulation and coding techniques communicating with SSs.

A cross-layer CAC has been proposed in this paper, a general idea of MRTR and SNR of connections is taken as the conditions to decide whether the new connection is established or not. The proposed mechanism is called Signal-Aware Call Admission Control (SACAC) which is based on MRTR principle. There are two conditions,1) the SNR of new connection, SNRi, must be higher than the threshold, SNRtlv2), according to Eq. 2.1, Ca must be greater than 0. The SNRtlv can be set by referring the loading of e network system, if the loading is light, the SNRtlv can be set less, and vice versa.

MRTR has been chosen in the proposed CAC due to the proposed scheduling scheme is designed for non-real-time service (nrtPS), and this traffic service has lower strict priority (priority order: UGS>ertPS>rtPS>nrtPS>BE) in WiMAX QoS specification. Connections with lower SNR easily cause packet loss and need to repeat, it will reduce the system performance and waste radio resources.

3.2 Customized Modified Deficit Round Robin

Modified Deficit Round Robin (MDRR) is based on Deficit Round Robin [10]. In MDRR scheduler, each queue defines two variables: Quantum Value (QV) and DC. QV is the average number of bits that will be served for each round, and DC is initialized to the quantum value and each packet served decreases the DC by a value equal to its length in bytes in each round.

If DC of queue is greater than 0, the packets in this queue will be served and DC will minus the bit length of the sent packet. If DC is zero or negative, this queue is no longer being served. In each new round, DC of non-empty queue will be coupled with QV.

All queues are serviced in a round-robin fashion with the exception of the Priority Queue (PQ). You can define this queue to run in one of two ways: in strict priority or alternate priority mode. In strict priority mode, the PQ is serviced whenever the queue is nonempty. In alternate priority mode, the PQ is serviced alternating between the PQ and the remaining queues. Each queue of MDRR can be specified relative weights (W). When the congestion occurs, the weight assigned to each queue is relative to the available bandwidth.

Due to the average amount of data that was sent for each queue being close to the default, it helps the scheduling to fulfill the fair resource allocated easily. A Customized Modified Deficit Round Robin with SNR (CMDRRs) is proposed in this paper. First, the variables of queues need to be transformed and second, the weight of queue will be assigned. Three parameters, Quantum Value (QV), Deficit Counter (DC), and Weight can be designed and summarized in Equations 2.2, 2.3, and 2.4, respectively.

$$\text{Quantum Value} = BW_i^{alloc} / FPS \tag{2.2}$$

$$\text{Deficit Counter} = \text{Quantum Value} \tag{2.3}$$

$$\text{Weight} = \text{Quartile of } SNR_i \tag{2.4}$$

Where, BW_i^{alloc} means the allocated bandwidth of i_{th} connection, and FPS is the Frames Per Second. QV is the amount of data that can be transmitted for each frame of a connection in nrtPS, and a time frame is assumed to be a round. DC is equal to QV initially, but if there are resources remaining in the system, then DC will be modified by Eq. 2.5.

$$\text{Min}\begin{cases}\text{Deficit Counter}_{\text{initial}} * (1+\frac{1}{\text{weight}}) \\ \text{The Maximum Sustained Traffic Rate of } i_{th} \text{ Connection}\end{cases} \quad (2.5)$$

Eq. 2.5 indicates that the queue of connection with higher SNR can transmit more data in around. For the weight of queue, the quartile was adopted to assign weights for each queue. The proposed scheme will record the SNR of all SS in system and calculate the quartile in BS, and then compares the quartile with the SNR of SS and the Connection ID (CID) to assign the weights:

Step1: If SNR_i is lower than the lower quartile (Q1), then the weight of i_{th} connection is 4.

Step2: If SNR_i is lower than the median (Q2) but higher than Q1, then the weight of i_{th} connection is 3.

Step3: If SNR_i is lower than the upper quartile (Q3) but higher than Q2, then the weight of i_{th} connection is 2.

Step4: If SNR_i is higher than Q3, then the weight of i_{th} connection is 1.

When a new connection adds into the network system, but remaining resources in the system are not enough, then DC will be modified by Eq. 2.6.

$$\text{Max}\begin{cases}\text{Deficit Counter} * \frac{1}{\text{weight}} \\ \text{Minimum Reserved Traffic Rate of } i_{\text{th}} \text{ Connection}\end{cases} \quad (2.6)$$

In MDRR, a queue in a group can be defined as a Priority Queue (PQ). The PQ will always be served in each round and does not consider the order. For example, there are four queues in scheduling, assuming that 0 is the PQ, and the queue area served in the following order: 0, 1, 0, 2, 0, 3. In this paper, the queue with the shortest length is temporarily assigned as the PQ. This means that it will transfer the data in queue completed and release the occupied resources quickly. If there are more than one queues with the shortest length, the queue with the lowest weight will be assigned first. The queue with lower weight means that the connection has better channel condition, and it will not waste the radio resource for the transmission of packets in repeating.

4. Simulation Results and Discussion

In this section, simulations are conducted to evaluate the performance of the CMDRRs QoS scheme by the throughput of non-real-time service (nrtPS) for downlink traffic and Packet Loss Rate (PLR). Discussions of BE service will be ignored, because this traffic service originally doesn't have any QoS guarantees in need. The simulations were implemented in NS-2 with the following parameters for the PHY and MAC layer as shown in Table 2.

Table 2. Simulation Parameters

Parameter	Value
SS distance from BS: SS1 SS distance from BS: SS2 SS distance from BS: SS3 SS distance from BS: SS4 SS distance from BS: SS5	100 m 200 m 400 m 600 m 800 m
Source model Maximum sustained traffic rate Minimum reserved traffic rate	Constant bit rate (CBR) 100 ~ 200 Kbps 50 ~ 100 Kbps
Maximum latency: nrtPS	1 sec (ITU-T Class 4)
Total Bandwidth Log-normal shadowing standard deviation	6 Mbps 9 dB

The architecture of simulation network adopts the operation mode of Point-to-Multi-Point (PMP) and composes of one BS and five SSs based on IEEE 802.16e standard. To simplify the simulation, the SSs only request of nrtPS service. In the scenario 1, SSs request a new connection requirement every 10 seconds. The simulation had lasted for one minute and repeated 10 times to obtain average value. In the simulation, the MRTR CAC and RR scheduler with the SACAC and CMDRRs scheduler are compared.

Figure 1 illustrates that the throughput of the proposed scheme is higher than the MRTR CAC and RR scheduler, and the effect will more be significant for connections case. Because the RR scheduler does not reallocate the resources assigned of each connection after the MRTR CAC admitted the connection into the system, even if there are available resources not to be assigned in the system. It causes that the utilization of resource and the throughput in whole network system will be decreased. The decrease becomes more apparent in the more connections situation.

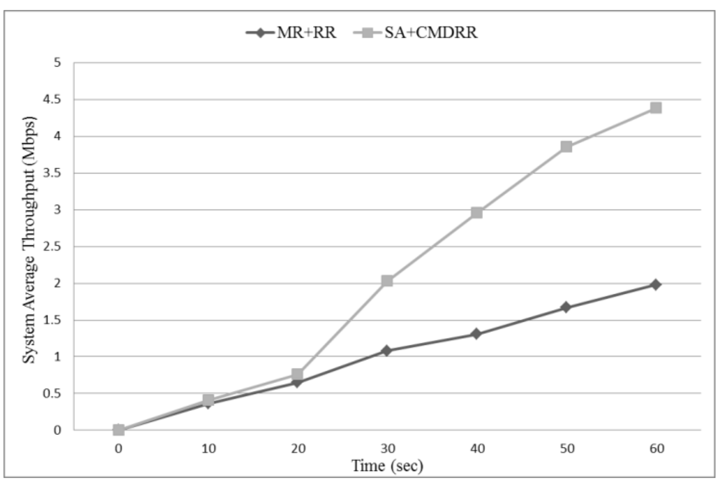

Figure 1. System Average Throughput

In Figure 2, the result proves that the CMDRRs scheduler meets the original intent of our design: The connection with higher SNR can transmit more data. According to the propagation loss of wireless communication, the distance between BS and SSs is an important factor to affect the radio wave transmission. In other words, the distance will affect the signal strength received by SSs and it cannot be resisted. In the simulation, SSs have different distance between BS and the SNR strength of SSs in order is: SS1 > SS2 > SS3 > SS4 > SS5. As shown in Figure 2, SS1 with the highest SNR has the utmost throughput, other SSs have different throughput corresponded to their own SNR strength in order.

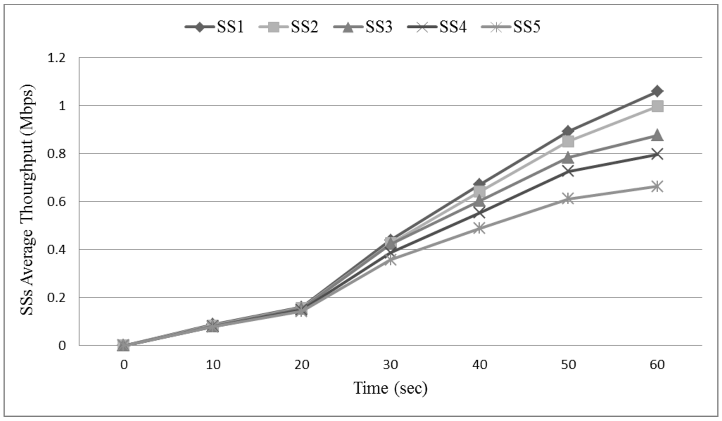

Figure 2. SSs Average Throughput

Although the QoS of nrtPS traffic is guaranteed, the packet loss ratio is not important in particularly. However, it has great significance for overall system in the utilization of resource. If the packet loss ratio is high, it means that the allocated bandwidth has not been effectively used in transmission. Since the lost packets need to be re-transmission again and part of the bandwidth will be occupied by the re-transmission. This will result in reducing the efficiency of system resources, and the throughput will be affected.

In Figure 3, due to it is simpler only nrtPS service in the simulation, the packet loss ratio is few lower than normal reality. The result proves that the average packet loss ratio of the proposed scheme is lower than MRTR CAC with RR scheduler, and it means that the SACAC with CMDRRs have better efficiency of RRM than the MRTR with RR.

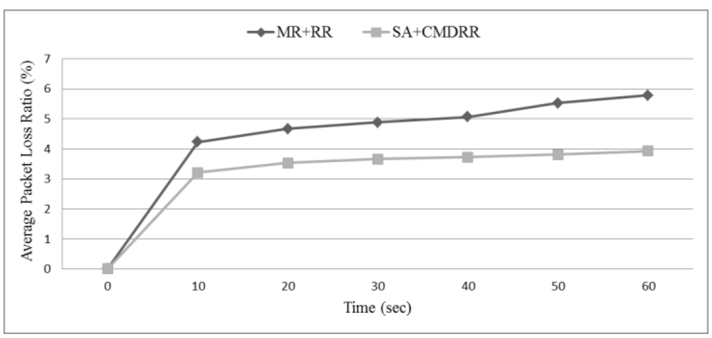

Figure 3. Average Packet Loss Ratio

In the scenario 2, SSs request 50 connections from 0 to 30 seconds. The maximum sustained traffic rate of each connection is 100k bps, and the minimum reserved traffic rate of each connection is 50k bps. After 30 seconds, SSs request more 50 connections continued to the end. The simulation had lasted for one minute and repeated 10 times to obtain average value. In the simulation, the different values of weight are compared.

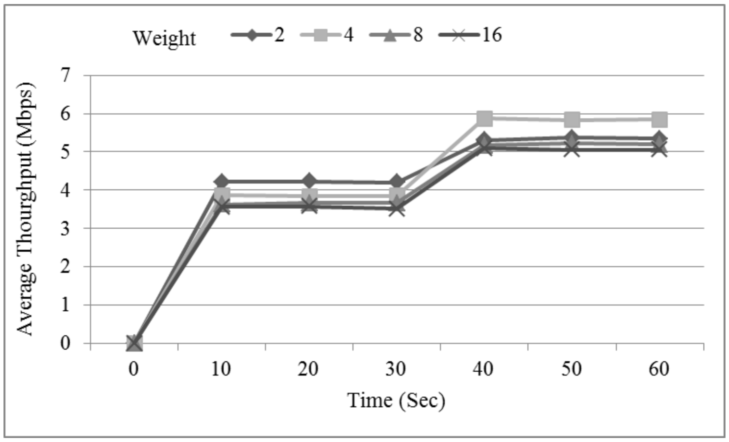

Figure 4. Average Throughput with Different Weight

In Figure 4, from the results, it is not difficult to find that the system throughput is higher when the value of weight is 4 in large number of connections, and this is why we chose 4 as default value of weight. Other values of weight increase the throughput lightly as the system is short of resources to meet QoS requirements of all connections. The value of weight is 2, the allocated resources of each connection is similar before adjusting and after. And the value of weight is 8 or 16, the effect after reallocating resources is still not significantly as 4 when the number of connections is more.

5. Conclusion and Future Work

From the results of the simulation, it is easy to find that the RMM is very important in wireless networks, especially in an efficient scheduler which is one of the most important features in PMP WiMAX architectures. In addition, CAC also plays a basilica role in managing the entry of connections.

A technique for channel condition coupled with a RR based scheduling algorithm is proposed in this paper to preserve QoS and fairness in downlink traffic delivery of non-real-time service, even if the system is in the situation of large number of connections. In this paper, a signal-aware CAC with a RR based scheduling algorithm is proposed for nrtPS of downlink connections in WiMAX. The proposed scheme provides efficient assignation for the BS by dynamically adjusting the allocated resource to SSs according to their own SNR. Owing to the lower priority and less QoS requirements, the throughput is more important than other QoS parameters for nrtPS. On the other hand, it is easy to find that the proposed CAC and scheduling algorithm has a better RRM efficiency by the comparison of packet loss ratio. Based on such a scheme, the fairness of resource utilization can be guaranteed for SSs for long term because of the characteristics of the MDRR.

Moreover, the evaluated scenarios in this paper cover only a very small part of all possible situations, though they take into account more traffic variations than other publications. In the future, the proposed CAC can cooperate with other scheduling algorithm to serve real-time traffic service, like UGS, ertPS and rtPS and take the idea of proposed scheme to design novel schedulers about other traffic services in WiMAX. Further investigate the performance of various parts of the scheme using QoS support, and perform a comparative analysis with other proposed solutions will be made in the future.

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