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Design of Cross-layer QoS Scheme in WiMAX Networks

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Abstract

The IEEE 802.16 working group developed the WMAN to achieve broadband wireless access (BWA). IEEE 802.16 is a high-speed wireless network technology that can provide multimedia services and quality of service (QoS) support for multi-level service types. The IEEE 802.16 standard provides QoS support for four service types: UGS, rtPS, nrtPS, and BE. In order to achieve end-to-end multimedia services, the 802.16 MAC QoS should be integrated with an IP QoS such as RSVP. In this paper, we propose a cross-layer QoS mechanism that combines both the IP layer and the 802.16 MAC layer to provide cooperative QoS operation. The proposed mechanism attempts to integrate an IP layer with the 802.16 QoS, aggregate L3 flows to the L2 connection, to design mapping rules for RSVP and L2 QoS, and produce an efficient RSVP refresh scheme. Furthermore, our cross-layer scheme can support seamless MH handoff in the IEEE 802.16 domain without additional overhead. A simulation study shows that our mechanism performs well in terms of signal cost, throughput, and packet loss.

Keywords: 802.16 PMP; QoS; Cross-layer; WiMAX; RSVP

1. Introduction

The IEEE 802.16 (802.16-2009 [1]) standard is one of the most popular wireless standards developed recently. Owing to the growing popularity of multimedia applications, a QoS (Quality of Service) concept for the Internet is proposed to enhance the quality of data transmission. Current IP layer QoS protocols feature two protocol types: IntServ and DiffServ. The router will confirm the requested transmission quality of the flow and determine how to serve the flow. In the MAC layer of IEEE 802.16, the base station (BS) and subscriber station (SS) should confirm the request of the L2 connection for transmission quality and determine how to serve it. In the IEEE 802.16 standard, related service types are defined for parts of the QoS, such as connection, *bandwidth request (BW-REQ)* transmission, broadcasting, and *UL_MAP*. However, there are some related mechanisms for QoS that have not been defined thus far, e.g., a detailed algorithm for admission control and bandwidth for connections allocated by the BS. Consequently, after the IEEE 802.16 standard was suggested, it has been the subject of many studies.

For the IP layer and the MAC layer of IEEE 802.16 embedded in the QoS functionality, some researchers proposed a mechanism of QoS cross-layer integration. For example, J. Chen et al. [2][3] proposed a mechanism whereby the IP layer service type corresponds to the MAC layer service type. Later, Y. W. Chen et al., referring to the integration mechanism proposed in [4], proposed another mechanism of

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cross-layer integration. With further performance analysis, some weaknesses were detected in connection management and signal reduction. Furthermore, to support seamless MH micro-mobility in the 802.16 network area, a *bicasting* or *multicasting* system should be adopted. For this reason, we propose a mechanism of QoS cross-layer integration for WiMAX PMP networks.

The rest of the paper is organized as follows. Firstly, a survey of research work on the 802.16 PMP QoS and IP layer QoS are presented in section 2. The proposed Cross-layer QoS Scheme in the IEEE 802.16 PMP network is presented in section 3. Simulation study for performance evaluation and comparison is presented in section 4. Finally, section 5 concludes this paper.

2. Related Works

2.1. IEEE 802.16 QoS

IEEE 802.16 facilitates the development of *broadband wireless access (BWA)* system, and its main purpose is to define an operating system for the PHY and MAC layers. Considering data transmission scheduling in WiMAX network, the article [5] proposed the transmission with Group Key to achieve multicast in 802.16e network. Besides, the research study [6] proposes a scheduling architecture in order to improve the delay and throughput for rtPS flows, which is an extension research work [7]. It implemented a two-layer scheduling structure for bandwidth allocation to support all types of service flows. *Direct Fair Priority Queue (DFPQ)* was used in the first layer to distribute total bandwidth among flow services in different queues (total depending on service class and direction). In the second layer of various scheduling algorithms are used for each class traffic. For rtPS flows the packet with the *EDF* is scheduled first.

Mechanisms of QoS support, such as admission control and bandwidth allocation in IEEE 802.16, have been extensively researched. Based on the connection-oriented concept, the admission control system [8]-[10] must be properly designed to decide whether a new request for traffic flow can be granted. The new request is granted only when the bandwidth requirement of the request can be satisfied and the quality of the existing traffic flow is not degraded. In addition, the design of an efficient scheduling mechanism for bandwidth allocation of IEEE 802.16 has been researched and proposed [11][12]. The common objectives of the scheduling scheme are dynamic allocation of time slots according to the service type of the traffic flows and higher network utilization. RSVP support has been proposed for WiMAX and Wi-Fi heterogeneous networks [13][14]. To discuss the deep QoS effects of the IEEE 802.16 network, the 802.16 MAC layer QoS performance results have been presented [15]. In addition, some useful IEEE 802.16 network QoS mechanisms have been described in a survey paper [16].

The IEEE 802.16 standard also defines three functions: establishing connections, delivering BW-REQ, and BS broadcasting UL_MAP for QoS connection setup. These functions are discussed below.

1) Establishing connections:

The data transmission between the SS and the BS is connection oriented. Therefore, it is necessary to build the connection first. The connection is built as follows. The SS will send *DSA-REQ* to the BS asking for a connection. When the BS receives *DSA-REQ*, it will determine the QoS level and check if the available resources can serve the connection using admission control. Later, the BS will reply to the SS of the final result with *DSA-RSP*.

2) Delivering BW-REQ:

After building the connection, the data can be actually delivered actually. If the SS wants to transmit data with this connection in the next time frame, it must send BW-REQ to the BS within the time frame. When the BS receives the message, it will determine how to allocate the required bandwidth to the SS according to the bandwidth request in the message.

3) BS broadcasting UL_MAP:

The BS will broadcast UL_MAP information in the first time frame to each SS. The content of the message describes the allocated number of the slot and the time of allocation for each SS in the time frame. After receiving UL_MAP, the SS will know which period it obtained and when it can upload the data.

By following the three steps described above, the BS can control and manage both the QoS flow among the SSs and the source distribution in 802.16.

2.2. Integrated Scheme of RSVP and 802.16 QoS

In the studies of cross-layer integration of QoS, the proposed IP-layer service type mapping to MAC layer service type in IEEE 802.16 in [2][3][4]. Besides, in IEEE 802.16 PMP network, SS and BS will use DSA-REQ, DSA-RSP to build L2 connection and reserved bandwidth before transmitting data. Such feature is similar to RSVP on the IP layer. Hence, J. Chen, Y.W. Chen et al adopts such point and suggests the message mapping process of RSVP and 802.16.

1) IQC GLOBECOM

J. Chen et al. proposed a mapping mechanism in [2][3] known as *IQC-GLOBECOM*. The overall environmental structure of *IQC-GLOBECOM* is shown in Fig. 1. The concept is as follows. The SS that manages the senders receives relational control messages from RSVP and determines the L2 control message content to be sent to the BS. The detailed steps are described below.

1) To build RSVP for flow_A, PATH is sent to the SS_S via AP_S.

2) When the SS_S receives PATH, it will determine the QoS parameter based on the *traffic specification information (Tspec)* on PATH and send a DSA-REQ message to BS and the SS_R.

3) When the SS_R receives DSA-REQ, it will judge the original *Tspec* content of the flow according to the QoS parameter. Then, the SS_R will add the content into the PATH message and send it back to the MH_R.

4) The MH_R will determine the request of the QoS according to *Tspec* in PATH and write its request into the RESV message. Later, the MH_R will transmit RESV to the SS_R via AP_R, and then the SS_R will extract and map it to DSA-RSP and send DSA-RSP to BS.

5) When the BS receives DSA-RSP, it will determine whether or not to accept the flow for building an RSVP connection via admission control. If it is accepted, BS will transmit the result to the SS_S.

6) After receiving DSA-RSP, the SS_S will transfer it to the RESV message and transmit the RESV message to the MH_S.

Finally, the RSVP connection has been successfully built. The message flowchart is shown in Fig. 2.

However, there is a shortcoming in this mechanism. The definition of “connection” for this mechanism is one flow mapping to one connection. Therefore, if one flow is created or deleted, the connection must also be created or deleted by BS. This signal procedure will burden BS with signal and system resources.

2) DBM AINAW

Y. W. Chen et al. proposed a mapping process in [4] known as *DBM-AINAW*. In the *DBM-AINAW* mechanism, the definition of IP layer connection is modified. The connection is defined in the following way: When there are several L3 flows within the same SS management group, the IP layer QoS service type for every flow is made the same. Then, these flows will be integrated into the same connection. In the structure of *DBM-AINAW*, there are four service types in 802.16 network. Thus, there are four categories of connections that will be created between the SS and the BS in a single direction.

The following paragraphs will discuss the operation of the mechanism. The overall environmental structure is also shown in Fig. 1, and the steps are listed below.

1) When there is a newly created IP layer flow, the MH_S will send PATH to the SS_S. After receiving the PATH message, the SS_S will judge and determine if the mapping connection exists. If it does, the SS_S will send DSC-REQ for this connection to the BS. If it does not, the SS_S will send DSA-REQ to BS adding the new 802.16 connection.

2) If the BS receives DSA-REQ, it will determine whether or not to accept the request according to the admission control policy. If it is accepted, the BS will send DSA-REQ to the SS_R asking it to build downlink connections between BS and the SS_R; in addition, it will send DSA-RSP to the SS_S to notify it of the accepted request. However, if DSC-REQ is received, after it is judged by admission control, the BS will send DSC-RSP to the SS_S then send DSC-REQ to the SS_R asking for the change in bandwidth of the downlink connection between the BS and the SS_R.

3) After the SS_R receives DSA-REQ, it will send DSA-RSP to BS and transform DSA-REQ to PATH. Later, the SS_R will transmit the PATH message to the MH_R. If the SS_R receives DSC-REQ, it will do the same thing: reply, transform, and transmit the PATH message to the MH_R.

4) After receiving PATH, the MH_R will send back RESV to the SS_R. When the SS_R receives RESV, it will check the bandwidth request of the MH_R. If the bandwidth request of the MH_R is smaller than the request of DSC-REQ or DSA-REQ made by the SS_S, the SS_R must transmit DSC-REQ to the BS and ask it to modify the BW-REQ of the downlink connection between the SS_R and BS. At the same time, it will transmit RESV to BS using a *Secondary CID*.

5) After the BS receives RESV, if the SS_R has sent DSC-REQ to the BS and asked it to modify the bandwidth of the connection, the BS must send DSC-REQ to the SS_S asking for the modification of the bandwidth of the uplink connection between the SS_S and BS. At the same time, it will transmit RESV to the SS_S using a *Secondary CID*. When the SS_S receives RESV, it will transmit RESV to the MH_S. The RSVP connection has now been built (see Fig. 3).

3) Problem of IQC and DBM

Having discussed the *IQC-GLOBECOM* and *DBM-AINAW* schemes, some weaknesses are presented.

1) In the proposed scheme of *IQC-GLOBECOM*, the SS that manages the receiver has built a downlink connection with the BS. However, before BS builds the uplink connection to the SS that manages the sender, BS must first perform the admission control mechanism. If it finds that there is not enough bandwidth to build the uplink, the built downlink connection is useless. In addition, the BS must send an extra DSD-REQ to remove the previous connection. This step is also wasteful.

2) In traditional RSVP, because the reserved bandwidth in the router adopts the soft-state method, the reserved bandwidth will be released over a period of time if it is not used. Therefore, using the flow in RSVP, the sender must send a renewal message periodically to confirm the state of the reserved bandwidth. In an IEEE 802.16 PMP network, deleting the reserved sources for the link between the BS and the SS must be accomplished through the DSC-REQ or DSD-REQ control messages. In the *DBM-AINAW* scheme, periodic renewal must still be performed for the SS and the BS. As a result, the signal cost will increase.

Moreover, to achieve seamless MH mobility, better QoS support in the IEEE 802.16 micro-domain must be provided. If the multicasting concept is applied, the MHs can have a smooth roaming environment with lower overhead. For this reason, the method proposed for this integrated cross-layer QoS issue will improve the above-mentioned points through cross-layer QoS signal aggregation intended to enhance the overall performance of the IEEE 802.16 network.

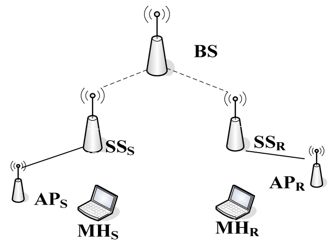

Fig. 1 Cross-layer QoS architecture in WiMAX network

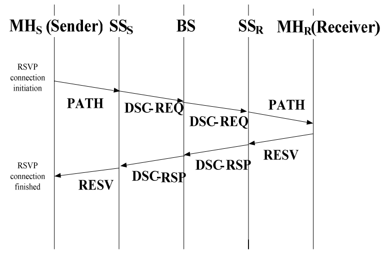

Fig. 2 RSVP connection setup in WiMAX network

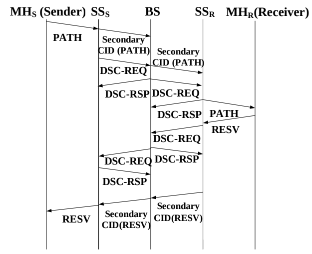

Fig. 3 RSVP connection setup of DBM scheme

3. Cross-Layer QoS Mechanism

3.1. Integrated Scheme of RSVP and 802.16 QoS

We propose a new mechanism of cross-layer QoS and introduce it based on the same topology.

1) The MH_S will send PATH to the SS_S. When the SS_S receives PATH, it will send it to BS using a Secondary CID. The BS will send it to the SS_R in the same way and then to the MH_R. The MH_R will return RESV to the SS_R in the same way.

2) After receiving RESV, the SS_R will determine which L2 connection will be mapped to flow_A. If the connection exists, the SS_R will send DSC-REQ to BS. If the connection does not exist, the SS_R will send DSA-REQ to the BS as a new connection setup procedure.

3) If *BW_remaining* $\geq$ *2*BW_flow_A*, the BS will send DSA-REQ or DSC-REQ to the SS_S based on the reception of DSA-REQ or DSC-REQ. Next, the SS_S will send RESV to the MH_S. If *BW_remaining* < *2*BW_flow_A*, BS will return DSA-RSP to the SS_R to refuse the request of the SS_R. After receiving DSA-RSP, the SS_R will know that the request was refused, and it will send a ResvError message to the MH_R. The connection is now finished (see Fig. 4).

4) If the MH_S receives RESV, it can reply to the SS_S with ResvConf. Then, the SS_S will transform the message to DSC-RSP or DSA-RSP based on the ResvConf QoS information. Finally, the SS_S will send the response to BS. After receiving signal, BS will send ResvConf to the MH_R (see Fig. 5).

3.2. QoS Refreshing State

In traditional RSVP, the reserved bandwidth is made in the direction of the soft state. Consequently, the message will be exchanged and renewed periodically to keep the bandwidth reserved. However, in an IEEE 802.16 PMP network, the reserved bandwidth between the SS and the BS will not be released after a period of time elapses. For this reason, except for the renewal of the internal data of the receiver, the RSVP renewal process of the flow can be adjusted. The renewal process is designed as follows:

1) The MH_S sends PATH to the SS_S.

2) After receiving PATH, the SS_S will check the average rate of flow_A. If the flow rate is increasing or decreasing, the SS_S will send PATH to the BS using a Secondary CID. When the BS receives the CID, it

sends PATH to the SS_R. After the SS_R receives this message, it will send PATH to the MH_R. If there is no change, the renewal message will not be sent every time. The message will be sent by referring to the RSVP timeout. That is, the SS_S sends PATH to the BS using a Secondary CID every few times until the SSS sends PATH to the MHR (see Fig. 6 and Fig. 7).

3) If the MH_R receives PATH, it will send RESV to the SS_R.

4) If the SS_R receives RESV, it will know the bandwidth of the required state of flow_A, and it will process the message according to steps 3–6 in section 3.1 to build the connection.

3.3. Mobility Supporting

The handoff of MHs is discussed in some research studies [17]. However, in the 802.16 network, we focus only on the handoff of MHs with micro-mobility. If we can assume that the MHs are inside one 802.16 network, the same group members are under all SSs. The L3 flow is formed in an IEEE 802.16 network; it makes a connection, and it is assigned a corresponding CID. This is similar to the multicast group transmission—MHs want to access the same data resources and the same server from the next Access Point after handoff. If we ensure that communication exists between the IP Multicast and the CID, the BS only needs to transmit data to all the SSs once using physical broadcasting, as shown in Fig. 8. Therefore, we intend to develop an approach that makes IP Multicast technology circulate smoothly in the Internet and IEEE 802.16 when transmitting data for the micro-mobility of MHs.

4. Experiments

4.1. Simulation Environment and Results

We adopt the integrated RSVP and 802.16 network environment as shown in Fig. 9. BS is the IEEE 802.16 PMP network manager. Simulation parameters are listed in Table I.

In Fig. 10, we compared the quantities of the L3 signals among the above-mentioned three methods. The proposed scheme has lower signals than the other two because there is only one signal that can be used to create and finish the connection. After completing the connection, most of the L3 signals will be renewed by RSVP. The number of L3 signals used by the proposed method is the smallest; naturally, the total number of L3 signals is also the smallest. For a load of 0.1 to 0.5, the connection is stable because each flow can create an RSVP connection at one time under light load circumstances. When the load is above 0.6, the performance of the proposed scheme will be similar to that of the methods used in *IQC-GLOBECOM* and *DBM-AINAW*. The reason for this is that the connection is being deleted owing to setup failure increases that occur after reaching a load of 0.6. Thus, periodic renewal will be accomplished with less flow. When the load reaches 0.6, the proposed scheme will be finished. When the load is heavy, an increasing number of flows cannot be created within one connection, and re-establishing the connection becomes necessary. If the connection is re-established and the system still fails, the L3 signal will be larger han the created signal owing to successful connection and RSVP renewal. Hence, the number of signals will increase according to the load. The proposed scheme also has the lowest L3 signals, as shown in Fig. 11. As a result of the increasing load and the number of flows, the signal will also increase linearly.

Fig. 12 provides information on the L2 signal. Our method again exhibits the best performance. In the *IQC-GLOBECOM* method, the curve increases gradually when the load is smaller than 0.6 because, with a light load, the SS will have more chances to send BW-REQ. However, with a heavy load (more than 0.6), part of the connection cannot be created, and BW-REQ cannot be sent out. Thus, the L2 signal will decrease. In *DBM-AINAW*, the integration of the connection is the same as in the proposed scheme. Even though there are many flows in the SS, only one BW-REQ will be sent out. Therefore, the amount will be smaller. Following the increasing load, the L2 signal will grow linearly. However, when the load is more than 0.6, part of the connection might not be created, and there will be fewer chances for sending BW-REQ. In Fig. 13, the curve linearly increases as a result of the criterion of the number of flows.

Because the L3 control message is transmitted through the data subframe in the 802.16 network, the quantity of the L3 signal will influence the size of data throughput. In Fig. 14, the throughput indicated is that related to transmitting data packets. It will increase according to the increase in the load. However, when the load becomes greater than 0.6, the L3 control message that occupies the data subframe is affected. Therefore, the throughput for the *IQC-GLOBECOM* and *DBM-AINAW* methods under heavy loading will be lower than that of the proposed scheme. This is why the L3 signal occupies part of the data subframe. The same result is found in Fig. 15. In Fig. 16, the throughput is that related to sending L3 signals and data. When the load is below 0.6, there are more L3 signals in the data subframe with the *IQC-GLOBECOM* and *DBM-AINAW* methods. Thus, the total throughput will be greater. Under heavy loading, the space for the data subframe has almost been used up. Hence, the three lines will overlap. The same reason applies to Fig. 17.

Considering the mobility of the MHs, the proposed scheme can deliver the same traffic to each SS when the MHs are roaming in an IEEE 802.16 PMP network. In Fig. 18 (mobility rate=0.5), the number of SSs will have an obvious effect on SS collection; however, in the traditional approach, the same multicast member sends a control signal to the BS through the SS. Thus, we understand that, in the traditional approach, the number of L2 handoff signals depends on the number of MH handoffs. If we integrate a flow into an SS and the BS, the number of control signals clearly decreases. As a result of the multicasting transmission scheme, each SS can transfer and buffer the data traffic for the MH, so the MH only loses a few packets after the handoff procedure. However, the handoff latency of the traditional multiple unicast scheme (without multicasting transmission) might become longer as a result of MH registration and transmission path rebuilding. In Fig. 19, the proposed scheme can reduce the high packet loss rate.

5. Conclusion

In this paper, a cross-layer integrated IP QoS mechanism has been proposed for WiMAX networks. The overall concept is to integrate RSVP in an IP layer into an IEEE 802.16 PMP network. The operation of our mechanism can be divided into four parts:

First, we redefine the L2 connection state. That is, if many flows are within the same SS and the service types for these flows are the same, the flows will map into the same L2 connection. Thus, in an IEEE 802.16 PMP network, the total number of L2 connections will decrease. Second, considering the insufficient remaining resources, the RSVP connection is designed to prevent waste of the resources of the downlink connection created by the BS. Third, the reserved bandwidth between BS and the SS in IEEE 802.16 will not be released automatically as time goes by. Each time the RSVP is periodically renewed, the SS will exchange the renewal signal with BS when the internal data of the receiver is renewed. Thus, the signal cost can be greatly reduced. Fourth, the proposed scheme with multicasting transmission can effectively reduce packet loss and signal cost when the MHs are roaming in an IEEE 802.16 PMP network.

The results of our simulation prove that the signal cost of our method is lower than contrast methods. The proposed scheme redesigns the periodic renew signal rule; the internal state will be renewed only if the SS needs to exchange control messages. Thus, our scheme can reduce the signal cost whenever the periodic renewal is made. In addition, in our method, the L3 control message, which occupies the data subframe, does not present such a serious problem. The throughput performance of data transmission under heavy loading is also better in our method.

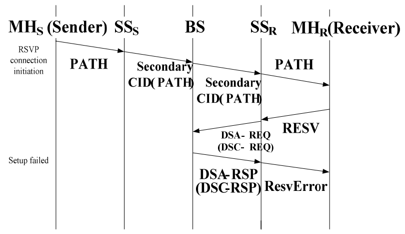

Fig. 4 RSVP Connection Setup Failed

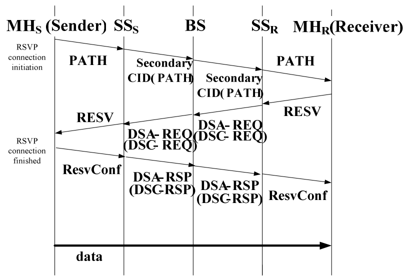

Fig. 5 RSVP Connection Setup Successfully

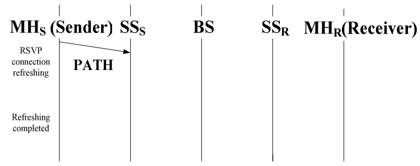

Fig. 6 RSVP locally Refresh

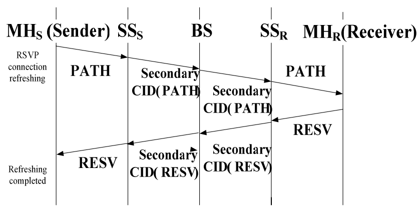

Fig. 7 RSVP overall refresh

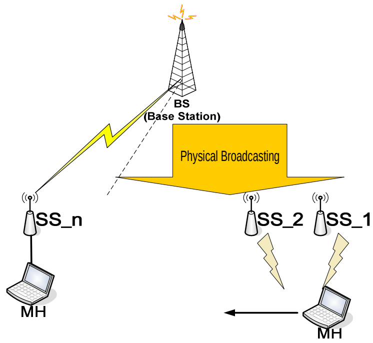

Fig. 8 Multicasting Transmission for MH Handoff

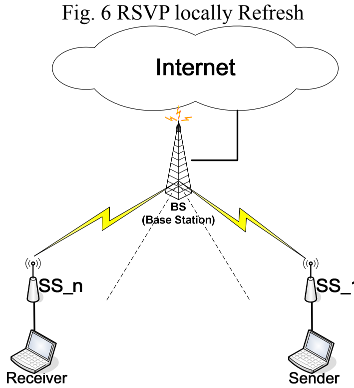

Fig. 9 Simulation Structure

Table 1 Simulation Parameters

Parameter	*Value*
Link capacity (bps)	UL: 20M DL: 20M
MAC Frame size	10 ms
Simulation time	10 sec
Flow service type	rtPS
# of flow	100
Control/Data subframe	8:17
RSVP refresh interval	120 ms
# of re-established	3
# of SS	8
Move probability	0.1~0.9

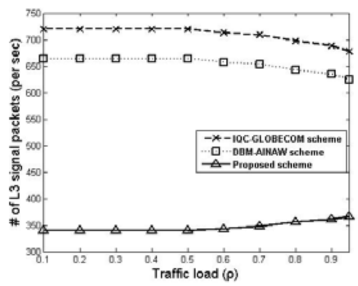

Fig. 10 L3 Signal Cost (Flow avg. Bit-rate)

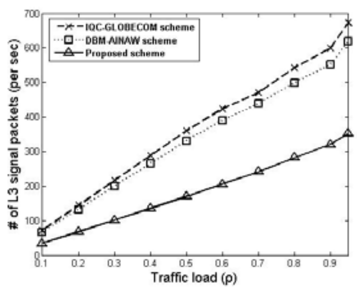

Fig. 11 L3 Signal Cost (# of flow)

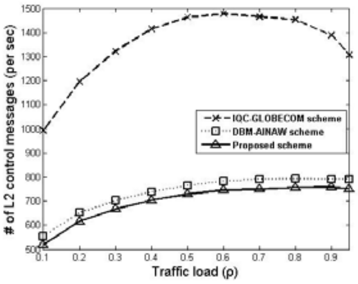

Fig. 12 L2 Signal Cost (Flow avg. Bit-rate)

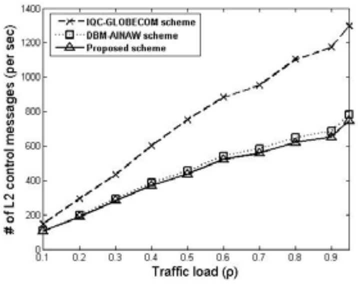

Fig. 13 L2 Signal Cost (# of Flow)

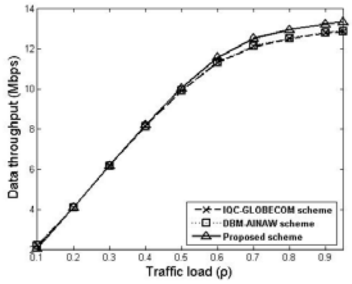

Fig. 14 Data Throughput (Flow avg. Bit-rate)

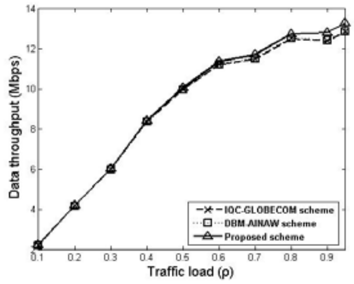

Fig. 15 Data Throughput (# of Flow)

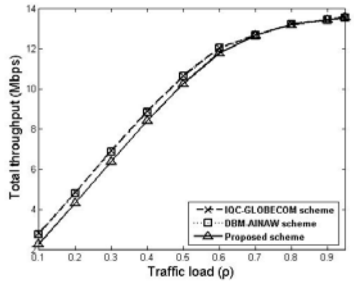

Fig. 16 Total Throughput (Flow avg. Bit-rate)

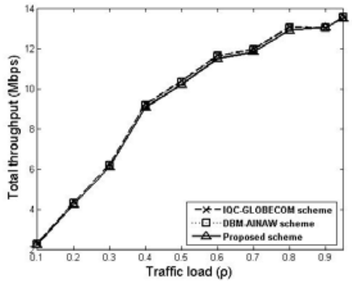

Fig. 17 Total Throughput (# of Flow)

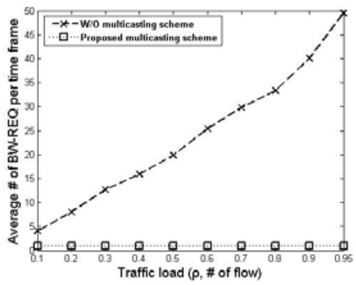

Fig. 18 L2 Handoff Signal Cost (Rate=0.5)

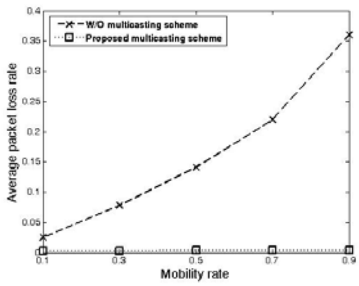

Fig. 19 Packet Loss Rate

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