Performance Evaluation of a WiMAX Multi-Hop Relay System to Support Multicast/Broadcast Service

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Abstract – This paper studies and evaluates a WiMAX relay architecture and its protocols to support multicasting/ broadcasting service and to address several related design issues. Performance of a video application is evaluated in term of different QoS measures. Our results demonstrate that the proposed architecture is feasible for real implementation and in line with the PMP characteristics of WiMAX.

Keywords: Video, Inter-layer, Multicast, Relay.

1. Introduction

WiMAX (Worldwide Interoperability for Microwave Access) is a broadband wireless technology that is largely supported by the computer and the telecom industry. It is aimed to be cost-effective and standard-based. It is engineered to deliver the latest type of ubiquitous fixed and mobile services such as VoIP and video at a low cost. WiMAX systems can cover a distance up to 50 km, and to deliver significant bandwidth to end-users up to 72 Mbps theoretically [1].

WiMAX multi-hop relay technology is a key enabler to expand the WiMAX infrastructure to eliminate blind spots in coverage and to enhance user throughput with a lower capital and operational expenditures. The WiMAX Forum presently limits the scope to backhaul network access only, and would not consider an air interface for multi-hop relay. On the other hand, IEEE 802.16 Relay Task Group is developing and defining the WiMAX MR (Mutli-hop Relay) System Specifications [2].

Multicast/Broadcast Service (MBS) in WiMAX refers to the ability of the WiMAX network to provide flexible and efficient mechanisms by sending common content to multiple users sharing the same radio resources. Current 802.16j solution only defines a unicast tunnel between a BS (Base Station) and a designated access RS (Relay Station). If we use this method to support MBS, multiple unicast tunnels have to be configured for every destination MS (Mobile Station). This degrades the radio resource efficiency, and lengthens the latency for handover procedure. More importantly, MBS service requires that all the subscribers should receive the same data at the same time (Unfortunately, this means an access RS with a shorter path has to delay its transmission). To coordinate the time synchronization over multiple individual unicast tunnels would increase the operation complexity.

Different multicast routing protocols can be used to forward the multicast traffic. The DVMRP (Distance Vector Multicast Routing Protocol) [3] is very limited flexibility, functionality, and scalability. The MOSPF (Multicast extensions to OSPF) [4] is an extension of the popular OSPF (Open Shortest Path First) algorithm used sporadically in some specialized applications. A family of latest protocols called PIM (Protocol Independent Multicast) are not dependent upon any one specific routing protocol. Instead, they will take advantage of existing routing tables to forward multicast data. There are two kinds of PIM: PIM-DM (Dense Mode) [5] and PIM-SM (Sparse Mode) [6]. The most commonly implemented form is the PIM Sparse Mode (PIM-SM).

From the above discussion, one sees that there can be different design issues to support an MBS in a WiMAX multi-hop relay network. These include dynamic relay topology discovery, service activation due to join/leave operations of MBS users, as well as radio resource allocation and connection management to support these dynamic behaviours. Some protocols have been proposed to address some of these issues. There is a scheme for reliable MAC layer multicast services using CDMA codes [7]. The congestion and error control is discussed for video multicast [15]. However, they are all concerned with reducing the error rate of MBS traffic, and there is no discussion of different transmission of MBS traffic. To the best of our knowledge, there is not much public technical detail so far on how multicast traffic in WiMAX multi-hop relay networks is to be supported.

In view of the above, we have developed a unique and interesting architecture for multicast services on WiMAX multi-hop networks. Its relay and multicast algorithms use IGMP (Internet Group Management Protocol) snooping at the Network layer and map the service flows to MT-CID (Multicast Tunnel Connection Identifier). An inter-layer design is adopted for procedures of topology discovery, multicasting tree creation and path binding.

In order to demonstrate the feasibility of our design, we implement our proposal in an OPNET simulator to evaluate the multicast video traffic performance in WiMAX MR Networks. Performance is evaluated in term of jitter, packet end-to-end delay and throughput of the video applications.

2. Network Operation

Figure 1 depicts the multi-hop relay network we would like to study and evaluate. It is evolved from the relay network architecture in the current the IEEE802.16e 2005 Standards [8] and the contributed documents from the 802.16 Relay Working Group [9, 10].

In this figure, MS (Mobile Station) is a station in

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motion but halting at unspecified points. An MS is always a SS (Subscriber Station) with mobile service unless otherwise stated in the standard. An RS (Relay Station) has a WiMAX interface for connection to the BSs (Base Stations) and MSs. It also has the ability to allocate the bandwidth in a distributed manner according to different QoS (Quality of Service) requirements of the service flows. An MR-BS (Multi-hop Relay Base Station) is a generalized equipment set providing connectivity, management, and control of the MSs. The R-link is the Relay Link between MR-BS and RS, and an Access Link is the link that allows an MS to access an RS directly.

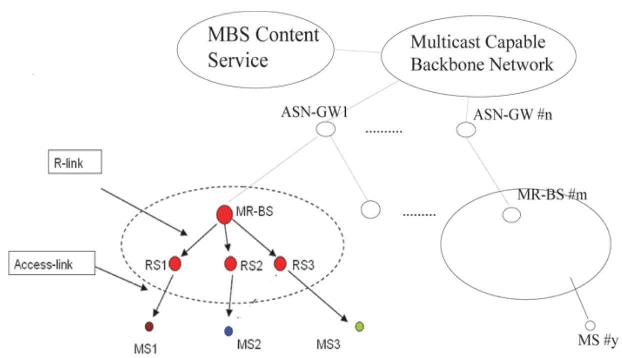

Fig.1: The WiMAX Relay Network Architecture

The Multicast Capable Backbone Network is the backhaul network capable of supporting an IP multicast service, and transferring multicast traffic into the ASN (Access Service Network) via gateways called ASN-GW. The ASN is defined as a logical boundary that represents an aggregation of nodes in a mobile WiMAX radio access network. Our Multicast/Broadcast Service (MBS) is an extension of the single-hop NRM (Network Reference Model) proposed by the WiMAX Forum [1]. Of the several design approaches (e.g., using a MAC layer protocol to transmit the multicast and broadcast traffic), we have adopted an inter-layer design to implement our multicast service process because it conforms to the baseline network model proposed by the WiMAX Forum. In fact, we are not aware of any inter-layer approach to implement MBS in wireless relay topology network. Fig. 2 depicts the operation flow in our design to support MBS traffic in WiMAX MR Networks. Each component/step is described in the following:

1) Relay Topology Discovery:
Although it is easy to detect the topology of a single hop system (because the BS knows the MS is just one hop away), the task of MR is more difficult because there could be more than one RS between an MR-BS and an MS. Therefore, one needs a BS-oriented routing protocol to automatically discover the relay path in order to support the dynamic formation of a relay network topology. The choice of routing protocol has been made easy by the PIM-SM [6] because this multicast forwarding protocol is not dependent upon any specific routing protocol. Instead, PIM will take advantage of the existing routing tables to forward multicast data, regardless of how they were constructed.

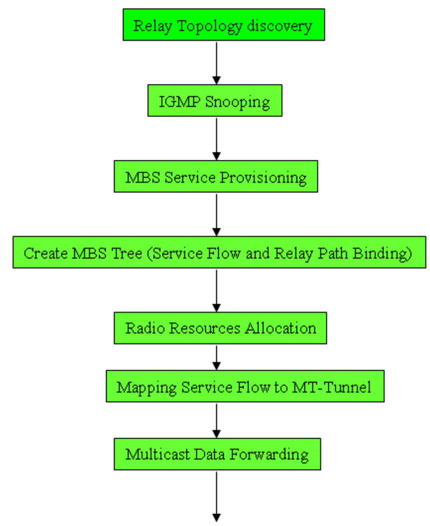

Fig 2: MBS Relay Network Overall Operations Flow

To improve the MBS, we had also invented the MT-CID (Multicast Connection IDentifier) method to reduce the number of multiple copies to forward and to allocate bandwidth dynamically. Each MT-CID represents one service flow (say one TV channel). Some more details will be discussed in other sections below especially in Section 2.1.

2) IGMP Snooping:
To utilize the network bandwidth efficiently in multicasting, we make use of IGMP (Internet Group Management Protocol) snooping [11] to solve this problem by giving the switch the ability to listen for (and in some cases intercept) IGMP messages. The switch can maintain a forwarding table where full IP group addresses are mapped to link layer addresses, and furthermore, to ports or interfaces. We adopt IGMP Version 3 in our MBS MR network operation because IGMP v3 has the ability to track the status of per-host membership on a router interface. At the MAC layer, IGMP Snooping facilitates the creation of a multicast relay tree in (4). At the Network layer, it can support the MBS service provisioning in (3) and user tracing as in (5).

3) MBS Service Provisioning
A multicast or broadcast transport connection is associated with a service flow specified by its QoS and traffic parameters. Each group of multicast traffic flows (usually with same QoS requirements) is assigned to an MT-CID so that an MBS tree can be built later. A BS can then provision the resources after it has learned the QoS requirements of all flows.

To allocate bandwidth for all traffic flows in the multi-hop relay system, we adopted the "bandwidth with distributed scheduling" allocation scheme. In this scheme, the MR-BS and RS can individually determine the bandwidth allocations on both the up- and down-links from its immediate downstream stations, and store the decision in a "MAP" database The MR-BS may send RS scheduling information in advance to its subordinate RS to indicate when and how much bandwidth it will schedule for the service in the future.

4) Create an MBS Tree

We want to create a tree for the service flow and for relay path binding later. The MT-CID method allows us to form an MBS tree in the 802.16j MAC layer. In an MBS tree, a BS is the root, and all access RSs within a given group are leaves. Pre-configuring trees at all the intermediate RS would greatly facilitate traffic forwarding.

After obtaining its MBS tree, a BS binds the paths in the tree by signalling all intermediate RSs in order to populate the MBS tree information. The signalling message uses the multicast management CID in the header, and its body contains the MT-CID and the path IDs associated with the designated RS. The intermediate RS completes the binding by storing this binding information in their forwarding table (if they are along the given path) which will be used in (7). The tree information can be used in different scenarios such as determining if two MSs requiring MBS services are associated with the same path.

5) Radio Resource Allocation

This is one feature of the inter-layer design. To increase the efficiency of utilizing radio resource, we provision the BS with the capability to dynamically allocate downlink bandwidth to different groups at the MAC layer. The inter-layer controller uses IGMP/PIM to collaborate with the MAC layer functions and to achieve radio resource allocation. This is made possible by the IGMP snooping procedure from which a BS has acquired the knowledge on the subscriber number of each multicast group. We can now regulate the bandwidth of different multicast groups at different time periods as the MSs move around to attach to different Access RSs and to subscribe to different multicast traffic contents.

6) Mapping Service Flows to MT-Tunnels:

This is essentially the mapping of the IP Layer multicasting tree to the MAC Layer multicasting tree seamlessly. We use the Inter-Layer MBS controller to generate and maintain the mapping tables for the support of multicast service in MR networks.

7) Multicast Data Forwarding:

This is the data transfer phase when MBS data are transferred to the MSs. By looking up the binding information stored in the forwarding table, an RS only needs to transfer one copy of content (multicast traffic) downstream and each intermediate RS would have the intelligence to navigate the content to each destination. So there is no need to make multiple copies to every destination.

2.1 Multicast Tunnelling

MT (Multicast Tunneling) has a few advantages. By using the PMP (Point to Multiple Point) mode of the relay tree, there is no need to make multiple copies to every destination. Furthermore, the QoS sub-header and Frame Synch sub-header (defined in P802.16j/D1) can be used to support end-to-end frame QoS. Different mapping tables can be formulated for the procedural steps above. Below are two examples of mapping tables.

Table 1: IP Multicast Address to Multicast CID Mapping

IP Multicast Address	M-CID
224.0.6.1	Group A
224.0.6.2	Group B

Table 1 shows an example of a mapping in Step-6 where the Multicast Group Address in the IP layer is mapped to the M-CID (Multicast CID) in the MAC layer in order to allow the application traffic from IP network layer to be transmitted to the MAC layer. Instead of listing each station's IP address, one can give the same multicast IP address for all MSs which are receiving the same multicast traffic. Likewise, instead of giving the MAC address of each MS, the M-CID allocates the same content to all MSs in the same group.

Table 2: Multicast Tunnel CID with Path-ID Mapping

Multicast CID	Path ID
MT-CID1	Path-ID1 Path-ID2
MT-CID2	Path-ID1

After building up the path information to the destination MS, Table 2 shows an example of mapping the Multicast Tunnel CID with the path ID for the BS to forward the multicast traffic. The mapping table is used in the MBS Tree Creation step. Depending on the MBS tree created, two different MT-CID (representing different service flows grouping) can share the same path.

Multicast tunnelling can also facilitate the synchronization of frame transmission time in the relay network. If there is MBS zone exists, the MBS synchronization function in the BS along with the MT-CID will synchronize the MBS across muli-BS.

In summary, one sees that "Tunneling" here does not take on the normal meaning where data packets have a first set of headers encapsulated in a second set of headers. Due to the multi-tier point-to-multipoint radio broadcast mechanism, and with the help of MT-CID, intermediate relay stations need not find out the details of the "tunneled" packets. Much overhead and processing of the packets can be saved, and the radio resource allocation can be optimized to relay packets to the targeted receiver only.

Table 3: Mobile WiMAX Application and Quality of Service [12]

QoS Category	Applications	QoS Specifications
UGS Unsolicited Grant Service	VoIP	• Maximum Sustained Rate • Maximum Latency Tolerance • Jitter Tolerance
rtPS Real-Time Polling Service	Streaming Audio or Video	• Minimum Reserved Rate • Maximum Sustained Rate • Maximum Latency Tolerance • Traffic Priority
ErtPS Extended Real-Time Polling Service	Voice with Activity Detection (VoIP)	• Minimum Reserved Rate • Maximum Sustained Rate • Maximum Latency Tolerance • Jitter Tolerance • Traffic Priority
nrtPS Non-Real-Time Polling Service	File Transfer Protocol (FTP)	• Minimum Reserved Rate • Maximum Sustained Rate • Traffic Priority
BE Best-Effort Service	Data Transfer, Web Browsing, etc.	• Maximum Sustained Rate • Traffic Priority

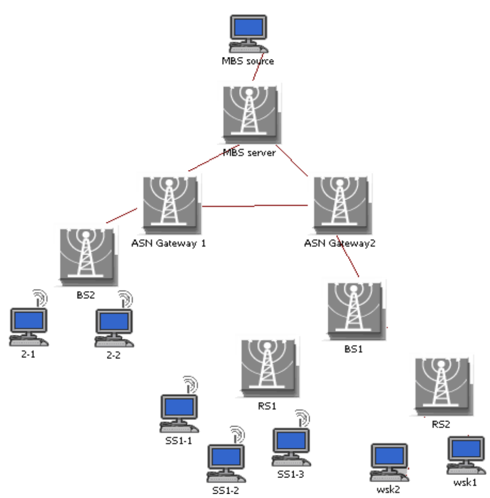

Fig 3: OPNET MBS Simulation Topology

3. Performance Evaluation

WiMax is expected to have five types of scheduling services as shown in Table 3: UGS, rtPS, ertPS, nrtPS, and BE, each of which has its own QoS specification. For example, rtPS is designed to support real-time streaming audio and video, and its mandatory QoS parameters are Minimum Reserved Rate, Maximum sustained rate, Maximum Latency and Traffic Priority. These parameters should be included in the service flow definition discussed above.

In order to test the capability of our architecture and its protocols, we have experimented with video applications and evaluated their performance in our proposed WiMAX multi-hop relay networks. Video applications are considered because they require relatively higher demand of QoS during the transmission. A small network (3 nodes) and a bigger network (30 nodes) are evaluated under different traffic scenarios. We use OPNET 12.0 [13] as the simulation tool because this version provides a module called the WiMAX Module PL3 to provide the basic WiMAX features and operations. Unfortunately, the mobility and relay functions in OPNET 12.0 are not yet supported in the Physical Layer and MAC Layer. Therefore, we have only emulated the WiMAX relay function between the BS and the RSs, and evaluated a static topology instead.

The BS has a total capacity of 12.0 Mbps to be shared up to 120 connections. We also follow the default parameter values used in the OPNET design documentation of WiMax Module. For examples, we use the Wireless OFDMA 20 MHZ because 802.16j PAR has specified enhancements to the OFDMA Physical layer to enable the operation of relay stations. The transmission power is set at 0.5 Watts which is the default value in OPNET WiMAX module.

Fig. 3 shows the simulated topology. Only a single BS is considered here because the multi-BS access can always be decomposed into multiple single-BS accesses to be coordinated at the ASN-GW, and all single BS-access cells will show the same behavior anyway. The whole network is treated as an end to end system which includes all the necessary components from the traffic source node to the end receiver node. For simple simulation, we only built one layer RS in the network model, i.e., the BS transmit traffic to its MS via one RS.

We consider a video conferencing scenario. The priority used is BE (Best Effort). Frame size is kept at 100 bytes. Five frames rates from 10, 12, 15, 23 to 30 frames/sec are used to test to what extent the QoS requirements can be met by the video multicast in the WiMAX MR environment. The following performance measures are used to gauge the QoS requirements:

1. Packet End to End delay (sec) is the duration from the time instant the first bit is sent out until the time instant the last bit is received at the destination.
2. Packet Delay variation is the delay variation incurred by a video application packet while going from a calling party to called party and vice-versa.
3. Throughput (packet/sec) is defined to be the average number of packets per second forwards to the application in this node. Unless explicitly specified, the figure includes loss.
4. Packet Loss Rate is the ratio of discarded packets w.r.t. the total generated in a network, when a device (switch, router, etc.) is overloaded and cannot accept any incoming data at a given moment.

All measurements are the average of 3 simulation runs; 95% confidence intervals are also obtained. In general, the confidence intervals are quite small and are not shown for clarity reason. The simulation time we set in our simulation is 180 sec. A general simulation run (on a Pentium IV processor (1.86GHZ) computer with 512 MB memory) takes about 22 seconds.

In the performance evaluation diagrams below, "ss" and "wks" represent two different groups of MSs.

3.1 Small Networks

Fig 4 shows that packet delay in video applications is very small. The end to end packet delay of SS1-1 is an increasing function of the sending rate, and it levels off beyond 15 frames. The other curves follow the same trend. That is, the delay increases from a sending rate of 10 frames/sec to 15 frames/sec, and then stays horizontal from 15 frames/sec to 30 frames/sec. The video application delay of wsk1 and wsk2 (bottom two curves) is relatively small compared with that of SS1-1, SS1-2 and SS1-3.

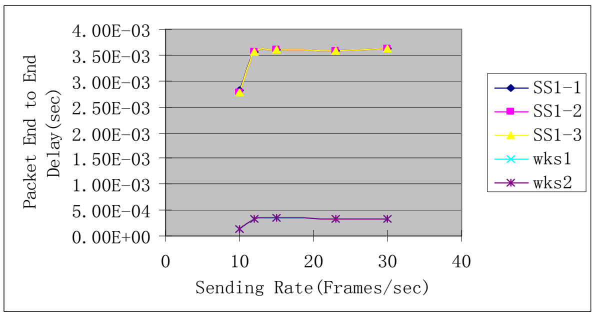

Fig 4: End to End Packet Delay vs Sending Rate

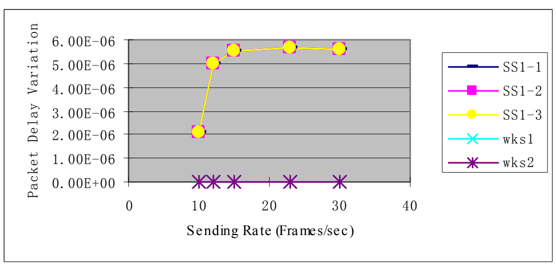

Fig 5: Packet Delay Variation vs Sending Rate

In Fig 5, we can see the packet delay variation is very small. The packet delay variation curve of SS1-1 is an increasing function of the sending rate. It rises very quickly from 10 frames/sec to 15 frames/sec, and then falls a little bit beyond 15 frames/sec. The curve of SS1-3 and SS1-2 are overlapping with that of SS1-1.The packet delay variation of wsk1 and wsk2 is almost 0 from 10 frames/sec to 30 frames/sec.

Fig. 6 shows that throughput of SS1 under the traffic intensity of 10 frames/sec is steady at 10 frames/sec. The small variation spike before the real traffic is the control frame for channel synchronization, power adjustment, etc.

There is no packet loss/drop measured and therefore the performance figure is omitted.

3.2 Large Networks

We can see from Fig. 7 that the packet delay in a video application of the large network size is also very small. The end to end packet delay of SS1-1 is a decreasing function of the sending rate, and it levels off beyond 12 frames/sec. The curve of SS1-3 and SS1-2 are overlapping with that of SS1-1. They follow the same trend, that is, the delay reduces from a sending rate of 10 frames/sec to 12 frames/sec, and then stays horizontal from 12 frames/sec to 30 frames/sec.

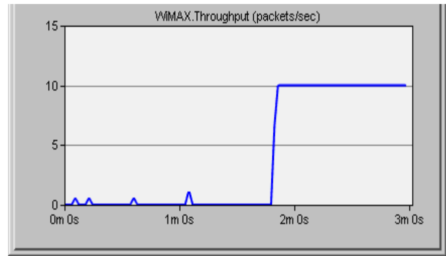

Fig 6: WiMAX Throughput of SS1-1;

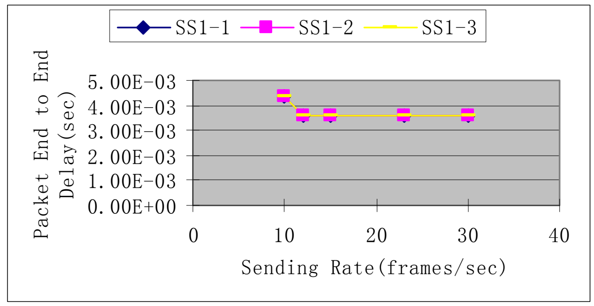

Fig 7: End to End Packet Delay vs Sending Rate

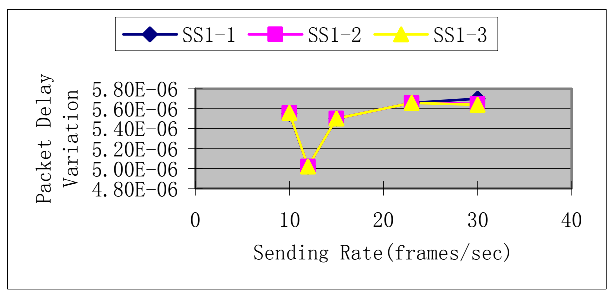

Fig 8: Packet Delay Variation vs Sending Rate

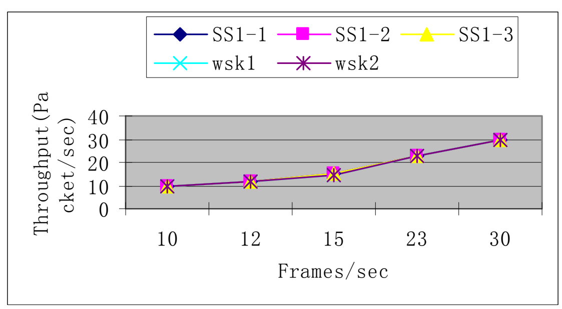

Fig 9: Throughput vs Sending Rate

Fig. 8 shows that the packet delay variation is very small. The packet delay variation curve of SS1-1 is falling down from 10 frames/sec to 12 frames/sec, and then it is increasing slowly from 15 frames/sec to 30 frames/sec. The curves of SS1-3 and SS1-2 follow the same trend as SS1-1. Note that there is a dip from 10 frames/sec to 12 frames/sec, the actual difference is actually quite small (order of 10E-7). The reason may be due to the difference packet delay variation of different station where different streams of packets arrive at the dynamic queues of the router buffer according to RFC3393 [14]. Compared with the packet delay variation in the small network size, there is a slight difference from the results in the large network size, though they are in the same magnitude. This is because when the traffic is transmitted through the WiMAX air interface, networks of different size vary their power and capacity arrangement differently.

We can see from Fig. 9 that the time average throughput is increasing linearly according to what we set for different sending rate (frames per second). Again, there is no packet loss in various scenarios we measure.

From the above performance evaluation, we can see that the multicast traffic can transmit well in WiMAX multi-hop relay networks according to the process and algorithm we proposed. Apart from the increasing complexity, a bigger network has little effect on the multicast performance of video applications. e.g., the delay performances do not change a lot except at a low frame rate.

4. Conclusion

We have implemented via Opnet Simulation a new standard-based solution to support MBS services in WiMAX multi-hop relay network. We do this by adopting the existing IETF protocols (including the IGMP among the MBS server, the WiMAX BS and the MS), and we use PIM to implement common multicast procedures at the networks layer. Our solution consists of two major components: 1) Topology Discovery by both the MR-BS and RS to detect the topology, and *2*) Multicast Tunnel CID mapping to allow the assignment of paths before the multicast traffic arrives, and the provision of bandwidth based on the current radio resources before data are forwarded based on the assigned information. All these are integrated through an inter-layer design which is different from the traditional approach.

Our approach is cost effective because RS would only need to transfer one copy of content downstream and each intermediate RS would have the intelligence to navigate the content to each destination. There is no need to make multiple copies to every destination. This in turn would improve the radio resource efficiency, and reduces the latency for handover procedure, and more importantly, reduces the synchronization time (i.e., the access RS with a shorter path need not to wait a long time).

Our performance evaluation has demonstrated the feasibility and efficiency to complete a multicast service. We have also determined that different network sizes will not have a big effect on its multicast traffic performance as expected according to the PMP MAC layer characteristics of WiMAX. It is in line with our design. where a big network size will not cause extra overhead with respect to separate SS.

As soon as new Opnet simulation features are available for mobile scenario, we would like to test out the mobility feature of our proposal. We expect multicast tunnelling will greatly reduce the latency of handover and keeps the session MBS continuity. The tradeoffs between broadcast and multicast can also be evaluated in terms of power level.

Acknowledgement

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