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Performance Evaluation of Multicast Routing Protocol in WiMAX Multi-Hop Relay Environment

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Abstract

Multicast/Broadcast Service (MBS) in WiMAX refers to the ability of the WiMAX network to provide flexible and efficient mechanisms to send common content to multiple users who are sharing radio resources. WiMAX multi-hop relay technology is a key enabler to expand WiMAX infrastructure to eliminate blind spots in coverage and to enhance user throughput with a lower capital expenditure and operational expenditure. To support MBS in a WiMAX multi-hop relay network, one must consider several design issues such as the dynamic relay topology discovery in response to the mobility of the relay station, the dynamic group membership management, the service activation due to join/leave operations of MBS users, the radio resource allocation and the connection management to support these dynamic behaviors. This thesis studies and develops a WiMAX relay architecture, its relay protocol and the optimal multicast algorithms to solve the above issues.

To resolve the above-mentioned issues, we have created a model for our multi-hop WiMAX relay architectures. This model incorporates an inter-layer protocol design that would allow the IP layer to use its IGMP/PIM snooping capability together with WiMAX MAC layer relay protocols. Among the MBS server, the WiMAX BS (Base Station) and the MS (Mobile Station), we adopted existing IETF protocols (including IGMP and PIM) to implement some common multicast procedures at the networks layer in order to provision MBS service. To support dynamic formation of a relay network topology, we have proposed and implemented a BS-oriented source-routing protocol to automatically discover the relay path. Finally, we have implemented our MBS in an OPNET simulator, and verified their operations. We have also evaluated the performance of the video and voice applications in WiMAX relay networks under different network sizes, and discussed their performances. The performance results demonstrate the Point to Multi-Point characteristic of WiMAX.

Acknowledgements

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AP	Access Point	1.1
ARQ	Automatic Repeat request	2.3.2
ASN	Access Service Network	3.3
ASP	Access Service Point	2.1.2
AVC	Advanced Video Coding	2.6
BE	Best Effort	2.3.1
BS	Base Station	1.2
BS-ID	Base Station Identifier	3.2.1
CID	Connection Identifier	2.2.1
CPS	Common Part Sublayer	2.2
CS	Convergence Sublayer	2.2
CSN	Connectivity Service Network	4.2
CTC	Combine Transform Coding	2.6
DL	Downlink	2.2.1
DL-MAP	Downlink Access Definition	3.2.1
DPF	Data Path Function	Appendix A
DR	Designated Router	2.5.1
DSL	Digital Subscriber Line	1.1
ECRTP	Enhanced Compressed Real Time Protocol	2.2.1
FEC	Forward Error Correction	2.6
IETF	Internet Engineering Task Force	1.4
IGMP	Internet Group Management Protocol	1.2
IPv4	Internet Protocol Version 4	2.4
MAC	Medium Access Control	1.1
MAC-SS	MAC Security Sublayer	2.2
MBS	Multicast and Broadcast Service	1.2
MIMO	Multiple Input Multiple Output	6
MR	Multi-Hop Relay	1.2
MS	Mobile Station	1.2
MT-CID	Management Tunnel CID	1.4
M-CID	Multicast CID	1.4
MPDU	MAC Packet Data Unit	4.1
MRIB	Multicast Routing Information Base	2.5.1
NAP	Network access Provider	2.1.2

NRM	Network Reference Model	2.1.2
NSP	Network service Provider	2.1.2
nrtPS	Non-real-time Polling Service	2.2.1
OFDMA	Orthogonal Frequency Division Multiple Access	4.3
PDU	Packet Data Unit	2.1.1
PIM-SM	Protocol Independent Multicast - Sparse Mode	1.2
PMP	Point to Multiple Point	1.4
PPPoE	Point to Point over Ethernet	2.1.1
QoS	Quality of Service	1.1
RIP	Routing Information Protocol	4.3.1.2.1
RNG-REQ	Ranging Request	3.3.1
RNG-RSP	Ranging Response	3.3.1
ROHC	Robust Header Compression	2.1.1
RP	Rendezvous Point	2.5.1
RS	Relay Station	1.2
RTG	Relay Task Group	2.4
RTP	Real Time Protocol	2.6
rtPS	Real-time Polling Service	2.2.1
SDU	Service Data Unit	2.2.1
SFID	Service Flow ID	2.2.1
SLA	Service Level Agreement	2.1.2
SPT	shortest path tree	2.5.1
SS	Subscriber Station	1.2
T-CID	Tunnel CID	3.2.1
TOS	Term of Service	2.2.1
UDP	User Datagram Protocol	4.2
UGS	Unsollicited Grant Service	2.2.1
UL	Uplink	2.2.1
VLAN	Virtual Local Area Networks	2.2.1
VoIP	Voice over IP	1.1
Wi-Fi	Wireless Fidelity, refers to 802.11 standards, including 802.11b, 802.11a, and 802.11g	1.1
WiMAX	Worldwide Interoperability for Microwave Access	1.1

Table of Symbols and Notations

		Section of First Appearance
N	The N-th Hop of WiMAX MR Network	3.2.1
Px	The Path ID X	3.2.1

Chapter 1
Introduction

WiMAX (Worldwide Interoperability for Microwave Access) Forum was formed in June 2001 to promote conformance and interoperability of the IEEE 802.16 standard, officially known as WirelessMAN [WiFo07]. WiMAX is a broadband wireless technology that is largely supported by the computer and the telecom industry, which is cost-effective and standard-based. It is engineered to deliver the latest type of ubiquitous fixed and mobile services such as VoIP, Information Technology and Video at very low cost. WiMAX systems are able to cover a large geographical area, up to 50 km, and to deliver significant bandwidth to end-users up to 72 Mbps theoretically [WiKi07].

1.1 Overview

Mobile WiMAX, a term brought up after 802.16e-2005[IEEE16e], is a broadband wireless solution that enables convergence of mobile and fixed broadband networks through a common wide area broadband radio access technology and flexible network architecture. It offers scalability in both radio access technology and network architecture, thus providing a great deal of flexibility in network deployment options and service offerings. IEEE 802.16's Relay Task Group is developing a draft under the P802.16j PAR, which addresses the "Air Interface for Fixed and Mobile Broadband Wireless Access Systems - Multihop Relay Specification."[IEEE16j]

MBS (Multicast and Broadcast Service) is an optional feature that refers to a network's ability to provide flexible and efficient mechanisms of sending common (the same) information content to multiple users using shared radio resources. The MBS framework may be used to offer real-time streaming applications or non-real time file transfer/download for store and play usage. The type of information transmitted may be any type of data, e.g., text, multimedia, and streaming media. The MBS may deliver content to MBS users groups, based on local policy and subscription.

The key advantages of WiMAX compared with WiFi [WiKi07] is that in Wi-Fi, media access controller uses contention access, i.e., all subscriber stations that wish to pass data through a wireless AP (Access Point) are competing for the AP's attention on a random interrupt basis. This can cause subscriber stations distant from the AP to be repeatedly interrupted by closer stations, thus greatly reducing their throughput. This makes services such as VoIP (Voice over IP) or IPTV, which depend on an essentially constant QoS (Quality of Service), difficult to maintain for more than a few simultaneous users.

In contrast, the IEEE 802.16 MAC uses a scheduling algorithm for which the subscriber station needs to compete only once (for initial entry into the network). After that, it is allocated an access slot by the BS (Base Station). The time slot can expand or contract, but it remains assigned to the SS (Subscriber Station), which means that other subscribers cannot use that time slot. The IEEE802.16 scheduling algorithm is stable under overload and over-subscription (unlike IEEE802.11), and it can also be more bandwidth efficient. The scheduling algorithm allows the BS to control QoS parameters by balancing the time-slot assignments among the application needs of the SSs.

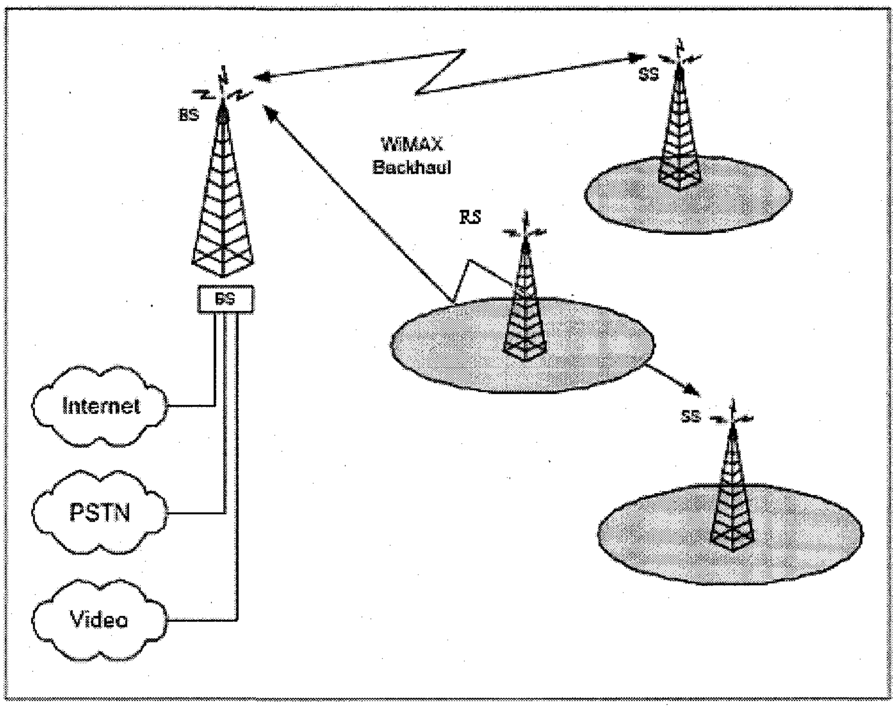


Fig 1.1: WiMAX Usage Scenarios

Fig 1.1 shows the usage scenario that WiMAX will use in the wireless network backhaul environment to replace cable or DSL (Digital Subscriber Line) for data transportation. WiMAX technology can easily deployed with other wired or wireless networks [DoGr06], and is especially practical in the places lacking an infrastructure. The BS can send the traffic to the destinations using one or more RSs (Relay Stations). Due to the special characteristics of the RS protocol stack that will be introduced in Section 2.1.1, it is necessary to find a solution to reduce the operation cost and to increase transmission efficiency of the MBS traffic. Therefore an approach to interpret the relationships between IP layer and MAC layer in order to transfer the traffic efficiently successfully from all IP-core networks. IP-core networks are popular nowadays to the WiMAX networks.

1.2 Motivations

Like the development of other wireless technologies, the WiMAX Forum [WiFo07] and IEEE 802.16 Working Group [IeWg07] have proposed many regulated documents from different perspectives. The WiMAX Forum refers to limit the scope to backhaul network access only, and would not consider an air interface for multi-hop relay (i.e., for the usage scenario where BS is connected to SS without RS.). On the other hand, IEEE 802.16 Relay Task Group is on its way to develop and define the WiMAX MR (Mutli-hop Relay) System Specifications. Unfortunately, there is not much technical detail so far on how multicast traffic in WiMAX multi-hop relay networks is to be supported. We found very few existing research related to IEEE 802.16's MAC schemes such as those documents above. In particular, we are not aware of the inter-layer approach to implement MBS (Multicast and Broadcast Service) in wireless relay topology network. Therefore, we would like to study the multicast service in multi-hop relay environment.

A scheme has been proposed for reliable MAC layer multicast services using CDMA codes [LeCh05]. The congestion and error control is discussed for video multicast [HuHw07]. They are concerned with reducing the error rate of MBS traffic, and there is no discussion of different transmission of MBS traffic with less cost.

1.3 Objectives

We are in general interested in the provision of multicast service for WiMAX networks. Specifically, we want to

1) Propose an efficient algorithm to support the multicast and broadcast service in WiMAX MR (Multi-Hop Relay) Networks

2) Implement a simulator based on the WiMAX multi-hop relay architecture to evaluate the performance of the multicast and broadcast service

3) Verify the feasibility of the WiMAX multi-hop relay architecture and the algorithms via simulation and performance evaluation

1.4 Approaches and Methodologies

To accomplish our objectives, we first propose the relay network architecture based on the current the IEEE802.16e 2005 Standards [IEEE16e] and the contributed documents from the 802.16 Relay Working Group [Hua07a] [IEEE16j]. Of the several design approaches (e.g., using a MAC layer protocol to transmit the multicast and broadcast traffic all along the network), we use an inter-layer design to implement our multicast service process in this architecture because it conforms with the baseline network model proposed by WiMAX Forum. To do so, we consider the collaboration of IP layer multicasting protocols with the special characteristics of relay in the WiMAX's MAC layer. Between the MBS server, the BS and the MS, we adopt the existing IETF protocols of IGMP and PIM to implement the common multicast procedures at the Network Layer that are capable of providing MBS service provisioning and user tracing. 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 an router interface. The detail advantage of the tracking ability will be explained in Section 5.1. In the MAC layer, we implement the procedures for topology discovery, the creation of multicasting tree, and the binding between multicast tunnel connectivity and relay paths. In order to support MBS efficiently, we introduce radio resource utilization for MBS traffic in 802.16j Relay Network and MT-CID (Multicast Tunnel CID). We couple the MT-CID with a multicast relay tree created from IGMP snooping so that the RS would only need transfer to one copy of content (multicast traffic) downstream. Each intermediate RS would have intelligence (associated with multicast relay tree) to navigate the content to each destination.

In order to demonstrate the feasibility of our design, we implement our proposal in an OPNET simulator to evaluate the multicast traffic performance in WiMAX MR Networks. A queuing model of the BS and RS as well as the traffic model are chosen to test the multicast algorithm. Performance could be measured in term of jitter, packet end-to-end delay, throughput, etc. We did not change any source code of WiMAX in the physical layer due to its complexity. We only use the physical layer of WiMAX for the access link.

1.5 Contributions

The contributions of our research work are:

1) A multicast service processing system for MR networks that are proposed on a WiMAX Forum baseline model.
2) An inter-layer design approach (adjacent layer connection to map network layer multicast group membership to MAC layer relay tree) to support MBS in WIMAX MR Networks
3) New protocols and algorithms for relay topology discovery and connection management for MBS
4) An OPNET simulator for MBS over WiMAX relay network
5) Performance evaluation via simulation

1.6 Thesis Organization

The remaining of the thesis is organized as follows: Chapter 2 gives a detailed literature survey of related work. Chapter 3 presents the system model/architecture, terminology, assumptions and new multicast algorithm used throughout this thesis. Chapter 4 provides the related simulation results to verify the algorithms. Chapter 5 gives the simulation results as the multicast traffic performance in WiMAX MR Networks. Chapter 6 lists the limitation and restriction we met when we use OPNET WiMAX Module Version 3. Chapter 7 provides conclusion and suggests some future work.

Chapter 2
Background

Before we design our protocol, we shall provide some common technical information of WiMAX on which our design is based. This consists of the WiMAX MR Network architecture especially the MAC layer. We also describe the routing and management protocol to support the general multicast service. Examples are provided as illustrations.

2.1 WiMAX MR Network Architecture

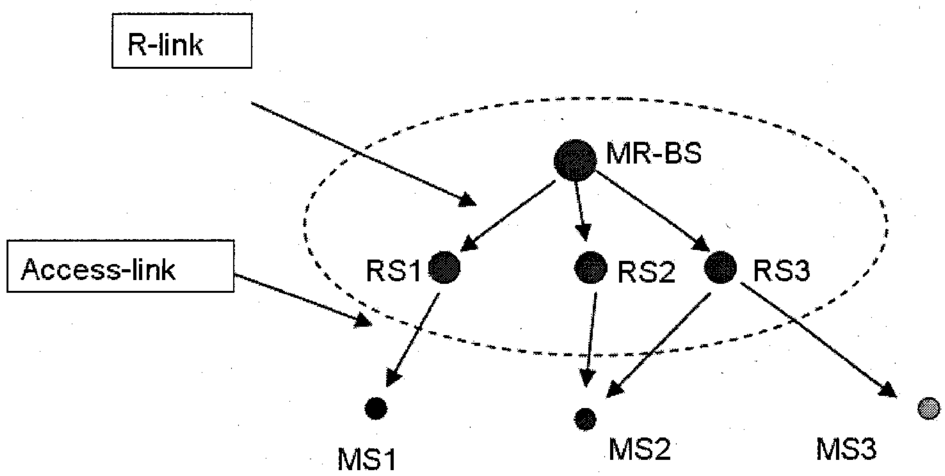


Fig 2.1: MR Network Architecture

Fig 2.1 shows the MR System Architecture proposed by IEEE 802.16 Relay Task Group (RTG), which has introduced the concept of the following components.

- An "RS is a generalized equipment set, dependent of a MR-BS (Multihop Relay Base Station), providing connectivity, management, and control of other RSs or SS. The air interface between an RS and an SS is identical to the air interface between a BS and an SS." Access RS refers to those RSs that connect the MS directly. Intermediate RS refers to those RSs that connect between MR-BS and Access RS.
- An Relay Link is also called R-link, it is the link between the BS/RS and the RS, and Access Link refers to the link between the Access RS and the MS.
- An MR-BS (MR-enabled Base Station) is a generalized equipment set providing connectivity, management, and control of the RS and the MS, which also support the multicast traffic forwarding function.

- A "MS is a user device station in the mobile service intended to be used while in motion or during halts at unspecified points. An MS is always a SS unless specifically except otherwise in the standard."

Note that the current 802.16j MR system only supports tree-topology (i.e., not the mesh) as depicted in Fig 2.1. IEEE 802.16j is backward compatible with 802.16e-2005 (16e) at access link (i.e., no change to MS's WiMAX air interface)

2.1.1 WiMAX MR Protocol Stack

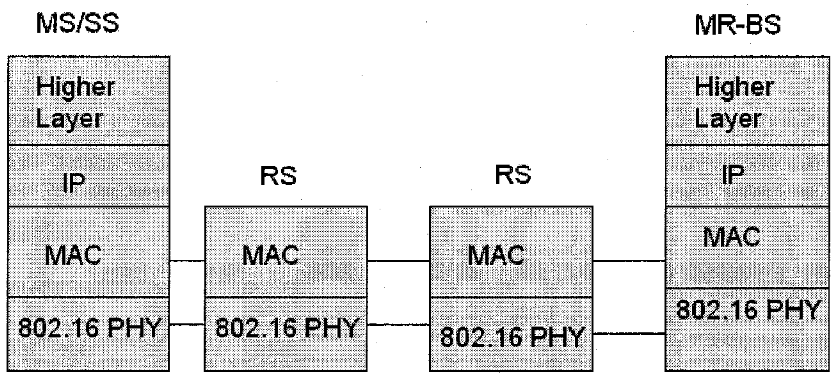


Fig 2.2: The MR Protocol Stack

Fig 2.2 shows the protocol stack adopted by the MR system. During the control and data plane transmission, an RS as a switch with 2 layers: the Physical layer (Layer 1) and the MAC Layer (Layer 2). The information (application, data, etc.,) passed from the higher layer at MR-BS will be encapsulated as MAC PDUs when they are transferred in RSs, and then forwarded upward to the higher layer in the MS/SS.

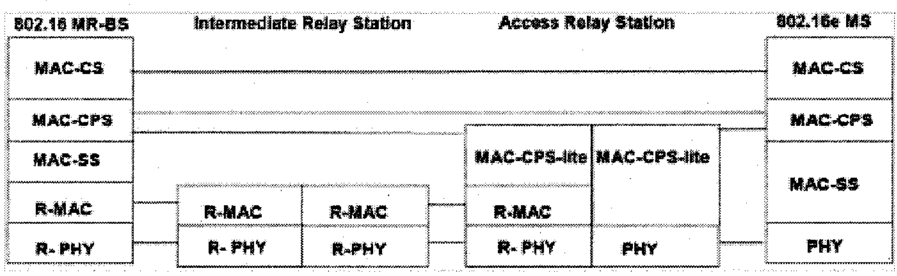


Fig 2.3: An example of the MR data Protocol Stack for a simple RS to perform MS traffic relaying [IEEE16j]

Figure 2.3 shows an example of a protocol stack for MS traffic relaying. An end-to-end

MS connection is established between the MR-BS and the MS to support the privacy management. The R-MAC sub-layer provides efficient MAC PDU relaying/forwarding and control functions. This sublayer is applicable to the links between the MR-BS and Intermediate RSs, and the links between Intermediate RSs and Access RSs. The functions of the few MAC sublayers will be discussed in Section 2.2.

2.1.2 MBS Network Architecture for Single Hop Network

MBS (Multicast and Broadcast Service) is an optional feature to provide flexible and efficient mechanisms of sending common (the same) information content to multiple users using shared radio resources. To facilitate end-to-end interoperability and service environments, the WiMAX forum specified a WiMAX NRM (network reference model), which is a logical representation of the network architecture for a single-hop system [WiFo06].

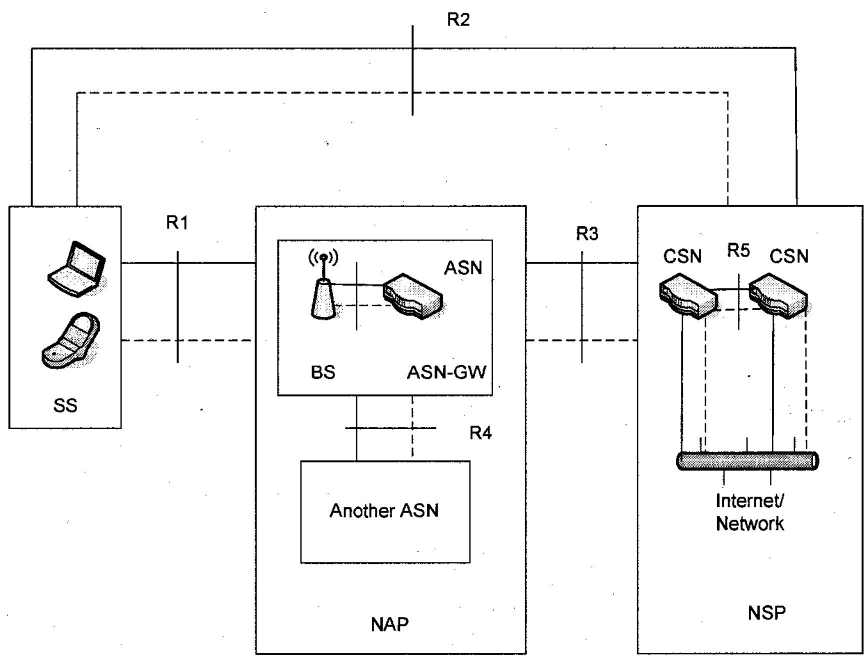


Fig 2.4: WiMAX Network Reference Model (Single-Hop) [WiFo06]

As depicted in Fig. 2.4, an NRM is based on an all-IP core network and a packet-switched air interface. An IP core network is an IP-based network which covers the original core network, the distribution layer and the corresponding service management parts. The network provides such capabilities as end-to-end QoS, service security, reliance, service high performance and service management and optimization. The IP-core also defines reference points for the interconnection of the logical entities. Six key normative reference points, R1 to R6, are shown in Table 2.1 along with their functions. Noted that only the control functions will go through the interfaces.

Table 2.1 Interface Function

Interface Number	Function
R1	IEEE 802.16e specification
R2	MBS Controller discovery Service subscription Authentication, security, etc.
R3	Transmission of MBS datagram Multicast tree topology management Session management MBS Authentication, Charging etc.
R4	User mobility and MBS zone advertisement Authentication, Charging etc.
R5	Roaming support to MBS user
R6	MBS zone management and maintenance MBS data path management Synchronization and transmission of MBS datagram if the MBS data management function locates in the AGW

The IP-core network has the following logical entities:

(1) the NAP (Network Access Provider) which is defined as a business entity that provides radio access infrastructure to one or more Network Service Providers.

(2) the NSP (Network Service Provider) which is defined as a business entity that provides IP connectivity and network services to subscribers compliant with the SLA it establishes with sub-scribers. To provide these services, an NSP establishes contractual agreements with one or more NAPs.

(3) the ASN (Access Service Network) which is defined as a logical boundary that represents an aggregation of nodes in a mobile WiMAX radio access network. Typically, an ASN consists of multiple BS that performs radio-related functions and a gateway node (ASN-GW) that interfaces with a CSN and provides IP connectivity services to the WiMAX MS/SS.

(4) the CSN (Connectivity Service Network) which is defined to be the logical representation of the functions of a NSP, e.g., Connectivity to the Internet, ASPs (Access Service Points), AAA (Authentication, Authorization and Accounting), IP address

management, mobility and roaming between ASNs, policy & QoS management based on a SLA.

(5) the BS (Base Station) which is defined as a generalized equipment sets providing connectivity, management, and control of the SS (Subscriber Station).

(6) the MS/SS (Mobile Station/Subscriber Station) which is defined as the generalized collection of functions to provide connectivity between mobile/subscriber equipment and the BS.

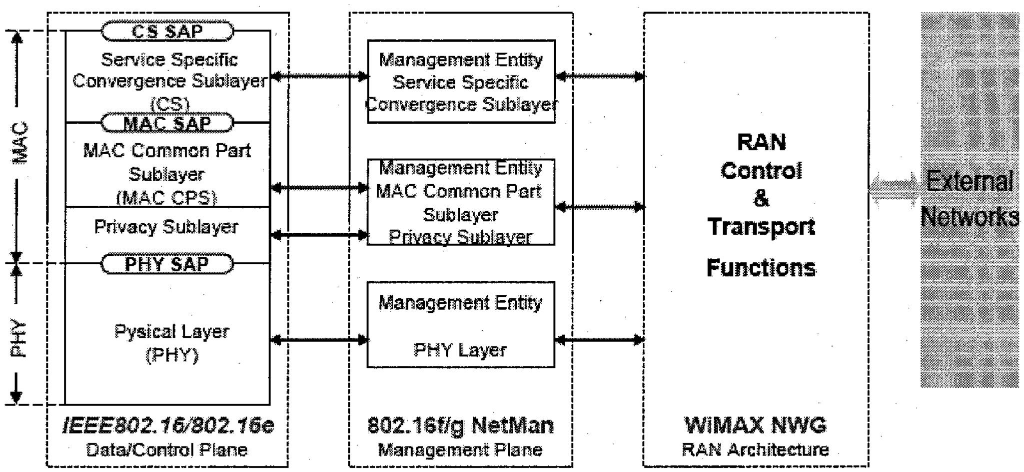


Fig 2.5: MAC Structure of WiMAX [IEEE04]

2.2 WiMAX MAC Feature [IEEE04]

In WiMAX, the MAC layer is divided into three sublayers. As shown in Fig. 2.5, they are: CS (Convergence Sublayer), CPS (Common Part Sublayer), and SS (Security Sublayer) [IEEE04]. The Security sub-layer provides subscribers with privacy across the fixed broadband wireless networks. It does this by encrypting connection between an SS and a BS. The functions of the CS and CPS are discussed in the subsections below. For clarity reasons, most of the acronyms are not expanded. They can be found under the Table of Acronyms in the front portion of the thesis.

2.2.1 CS (Convergence Sublayer)

The CS performs the following functions: (1) accepting higher layer protocol data units (PDUs) from the higher layer (2) performing classification of higher layer PDUs
(3) processing (if required) the higher layer PDUs based on the classification (4) delivering

CS PDUs to the appropriate MAC SAP(service access point) (5) receiving CS PDUs from the peer entity

IEEE 802.16 CS types have been interpreted to apply as follows:

- For Ethernet network services (PPPoE, VLAN, ...)
  - ETH-CS (Ethernet over Convergence Sublayer), VLAN/802.1Q-CS
- For IP network services with intra- and inter-technology optimized handovers and single host support
  - IP*-CS (IP over Convergence Sublayer) (with or without ROHC, ECRTP)
  - IP*oETH-CS (IP over Ethernet over Convergence Sublayer) (with or without /ROHC/ECRTP)
- For IP network services with intra- and inter-technology optimized handovers and full multiple hosts support
  - IP*oETH-CS (with or without /ROHC/ECRTP)

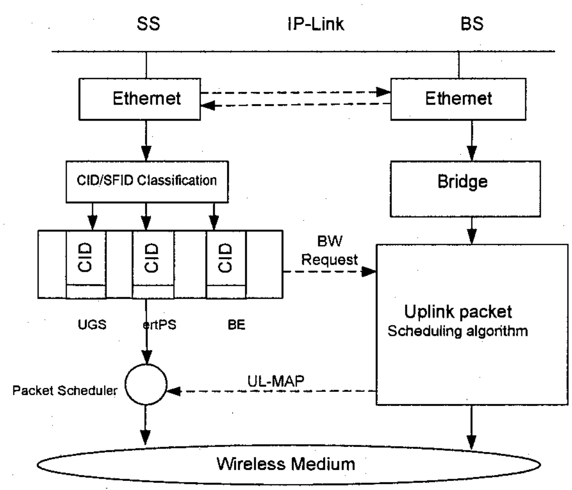


Fig 2.6: IPoETH Link Model (Single-Hop)

Fig 2.6 described the basic link Model for IP*oETH-CS (IP over Ethernet over Convergence Sublayer) in the WiMAX single hop networks. An IP Link is defined as a communication facility or medium over which nodes can communicate at the link layer, i.e. the layer immediately below IP. A well known example is Ethernet. IEEE802.16 provides point-to-point connections between SSs and the BS without enabling any direct SS to SS connectivity. Ethernet is realized on top of IEEE802.16 by implementing by providing the links between the hosts and the bridge on top of the BS [Rieg06]. The 802.16 CS can also be a bridge between other IEEE 802 protocols and WiMAX. It is the component of the MAC layer that is responsible for assigning transmit-direction SDUs (originating from a higher layer application, e.g., an IP stack at the BS or the SS to a specific outbound transport connection.)

The CS maintains an ordered "classifier table". Each entry in the classifier table includes a classifier and a target CID. The classifier, in turn, consists of a conjunction of one or more subclassifiers where each subclassifier specifies a packet field (e.g. the destination MAC address in an Ethernet frame, or the TOS field of an IP datagram contained in an Ethernet frame) together with a particular value or range of values for the field. To perform classification on an outbound SDU, the CS proceeds from the first entry of the classifier table to the last, and evaluates the fields of the SDU for a match with the table entry's classifier. When a match is found, the CS associates the SDU with the target CID (for eventual transmission), and the remainder of the 802.16 MAC and PHY processing can take place. The target CID here is called the "Connection ID" which is a 16-bit value that identifies a transport connection or a UL/DL pair of associated management connections (i.e., belonging to the same SS to equivalent peers in the MAC of the BS and the SS). Each CID is associated with a Service Flow ID. The SFID-CID mapping is a main function of the CS, which defines the QoS class of the service flow associated with the connection.

"Scheduling services represent the data handling mechanisms for data transport on a connection. Each connection is associated with a single data service. Each data service is associated with a set of QoS parameters that quantify aspects of its behavior." [IEEE04] Table 2 provides a brief description of five supported scheduling services (UGS, rtPS, ertPS, nrtPS, and BE) including the mandatory QoS parameter that shall be includes in the service flow definition.

For example, we can see from Table 2 that the UGS (Unsollicited Grant Service) is designed to support real-time data stream consisting of fixed-size data packets issued at periodic intervals. An example is the T1/E1 and Voice over IP without silence suppression. The mandatory QoS service flow parameters for this scheduling service are Maximum sustained Traffic rate, Maximum Latency, Tolerated Jitter, and Request/Transmission Policy.

Table 2.2 Mobile WiMAX Application and Quality of Service [DoGr06]

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

2.2.2 CPS (Common Part Sublayer)

The MAC CPS provides the core MAC functionality of system access, bandwidth allocation, connection establishment, and connection maintenance. These main functions are carried out in both the data and control plane. The control plane is in charge of network entry and initialization, addressing and managing connection, bandwidth allocation, and implementing ARQ operation. The data plane processes data handling mechanism by MAC scheduler.

Management Message Type	Management Message Payload

Fig 2.7: MAC Management message formats

The control plane functions make use of MAC Management message whose format is defined in Fig 2.7, and the MAC Management messages shall be carried in the payload of a MAC PDU. So Management Message is a payload of MAC PDU. All the messages should begin with a Management Message Type which is defined in Table A.1 of Appendix A.

2.3 General Multicast Service Procedures in WiMAX Networks

Reception of an MBS multicast service is enabled by the procedures [Hua07b] illustrated in the Figure 2 below.

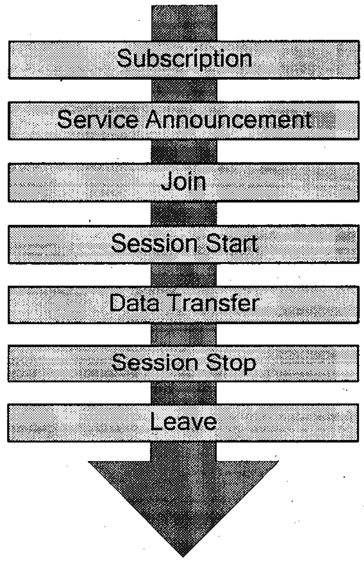


Fig 2.8: Multicast Service Procedures

1) Subscription is the procedure which establishes the relationship between the user and the service provider, thus allowing the user to receive the related MBS multicast service. (e.g., The MS will subscribe the interested program according to the IPTV program list)

2) Service announcement is used to distribute to users information about the MBS service. During the service announcement, MBS service information will be downloaded to MS. MS picked up and saves the favorite MBS information. This information includes MBS traffic description such as movie title, TV channel.

3) Joining is the process by which a subscriber joins a multicast group, i.e. the user indicates to the network that he/she wants to receive Multicast mode data of a specific MBS service. There are two types of join procedure:

   a) MS initiation based on MS's favorite:

   According to its preference, an MS can join the favorite IP multicast group at any time. If the MS wants to join the IP multicast group, it will pick up the IP multicast address from the reserved MBS service information and send an IGMP report to the ASN to notify which MBS group wants to join.

b) Network initiation based on user profiles or operator policy:

Based on the user profiles or the operator policy, a network can also initiate and invite an MS to receive certain MBS traffic. But the final decision of receiving this traffic or not is at the discretion of the MS. If MS wants to join, it should have implemented a related interface to join the corresponding IP multicast group.

(4) Session Start is the point at which the MBS server is ready to send data. Session Start occurs independently of activation of the service by the user. Session Start is the trigger for bearer resource establishment for MBS data transfer.

(5) Data Transfer is the phase when MBS data are transferred to the MSs, which takes two stages to transfer multicast data from MBS contents provider to subscriber users.

a) First stage: multicast traffic is forwarding from MBS server to BS using traditional IP multicast routing protocol such as PIM-SM.

b) Second stage: In single-hop networks, the multicast traffic is forwarding by a predefined MBS service flow. In mutli-hop networks, the process is more complicated since the multicast traffic needs to be sent via RSs. We will discuss Multicast Service in Relay Networks in details at 3.4.

(6) Session Stop is the point at which the MBS server determines that there will be no more data to send for some period of time - this period being long enough to justify removal of bearer resource associated with the session. At a Session Stop, the bearer resources are released.

(7) Leaving is the process by which a subscriber leaves a multicast group, i.e. the user no longer wants to receive Multicast mode data of a specific MBS service.

2.4 IGMP (Internet Group Management Protocol)

The IGMP (Internet Group Management Protocol) is used by IPv4 systems (hosts and routers) to report their IP multicast group memberships to any neighboring multicast routers. IGMP is used by IP hosts to register their dynamic multicast group membership. Multicast routers use IGMP to learn which groups have members on each of their attached physical networks. A multicast router keeps a list of multicast group memberships for each attached network, and a timer for each membership.

Till now, it has been developed to IGMP version 3[CaDe02]. Version 1, specified in [Deer89], was the first widely-deployed version and the first version to become an Internet Standard. Version 2, specified in [Fenn97], added support for "low leave latency", that is, a reduction in the time it takes for a multicast router to learn that there are no longer any members of a particular group present on an attached network. Version 3 adds support for "source filtering", that is, the ability for a system to report interest in receiving packets only from specific source addresses, as required to support Source-Specific Multicast, or from all but specific source addresses, sent to a particular multicast address.

Host can initialize its decision to join or leave a multicast group by sending an unsolicited message to the assigned router. Or the router will send a general query message to the attached hosts every certain period. Upon received the query, the hosts who wish to join the multicast group will send a report to the router.

2.4.1 IGMP Snooping Protocol

The purpose of developing IGMP snooping protocol [ChSo01] is based on the MAC Layer (Layer 2) multicast efficiency. As we know, in traditional Ethernet networks, the switch has no ability to distinguish the broadcast or multicast traffic. It did the same operation for both traffics, which is to forward a copy into each of the network segments or network interfaces. This approach works well for broadcast packets that are intended to be seen or processed by all connected nodes. In the case of multicast packets, however, this approach could lead to less efficient use of network bandwidth, particularly when the packet is intended for only a small number of nodes.

IGMP snooping 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 by mapping full IP group addresses to link layer addresses, furthermore, to port or interface information.

2.5 Multicast Routing Protocol

There are several different multicast routing protocols, and each one has its own unique technological solution. The DVMRP (Distance Vector Multicast Routing Protocol) [WaDe88] is the earliest protocol for multicast routing. It is a distance-vector protocol that provides very limited flexibility, functionality, and scalability. DVMRP has largely been superseded by some of the newer protocols. The next incarnation of multicast routing was an extension of the popular OSPF (extensions to Open Shortest Path First) protocol called MOPSF (Multicast extensions to Open Shortest Path First) [MoYj94]. MOSPF is used sporadically for some specialized applications, but it is not prevalent.

A new breed of multicast routing protocols was developed in the late 1990s. This family of protocols is collectively known as PIM (Protocol Independent Multicast). The name PIM is derived from the fact that these multicast forwarding protocols are not dependent upon any one specific routing protocol. Instead, PIM will take advantage of the existing routing tables, regardless of how they were constructed, in order to forward multicast data. There are two kinds of PIM: PIM-DM (Dense Mode) [AdSi05] and PIM-SM (Sparse Mode) [FeHa04]. The most commonly implemented form of Protocol Independent Multicast is PIM Sparse Mode (PIM-SM) which we will introduce in Section 2.5.1.

2.5.1 Protocol Independent Multicast - Sparse Mode

PIM-SM [FeHa04] is a multicast routing protocol that can use the underlying unicast routing information base or a separate multicast-capable routing information base. It builds unidirectional shared trees rooted at a RP (Rendezvous Point) for every specified multicast group, and optionally creates shortest-path trees per source.

PIM relies on an underlying topology-gathering protocol to populate a routing table with routes. This routing table is called MRIB (Multicast Routing Information Base).The primary role of the MRIB in the PIM protocol is to provide the next hop router along a multicast-capable path to each destination subnet. The MRIB is used to determine the next hop neighbor to which a PIM Join/Prune message is sent. As long as there is a data flow, the MRIB gives reverse-path information according to the Join messages, and indicates the path that a multicast data packet would take from its origin subnet to the router that has the MRIB.

To set up an RP tree, PIM-SM depends on IGMP or MLD to collect the information of the multicast group membership running on that interface. One of the receiver's local routers is elected as the DR (Designated Router) for that subnet. Upon receiving the receiver's expression of interest, the DR sends a PIM Join message towards the RP for that multicast group. By collecting all the join messages, a distribution tree (thus called the RP tree) for certain multicast group can finally be established for the RP. When a multicast traffic flow arrives destined for a multicast group, the sender's designated router forwards them directly to the RP, then the RP sends the traffic out according to the route recorded in the RP tree.

In order to optimize the path to avoid the unnecessary detour, the router on the receiver's LAN, usually DR, can initiate a source specific join towards source. If it succeeds, then when there is data flow next time, the packet will follow the SPT (shortest path tree) instead of the RP tree. Afterwards, the receiver will send a prune message to RP in order to eliminate the path from the RP trees.

2.6 System Example

There are several MBS architectures for the single hop networks based on the baseline model in Fig 2.4 proposed by the WiMAX Forum. Since there is no WiMAX MR Network yet, we will propose one in Section 3.1. Here we shall present one proposed MBS-NRM that can provide more understanding of our design later. Other NRMs can be found in Appendix A

The NRM Proposal (Motorola) in Fig 2.9 is the closest example that can illustrate the general architecture and operation. The multicast traffic is generated at the MBS Content Source. After an MS (subscriber) books the content it is interested in, the MBS flow request is forwarded to the IGMP clients located at the ASN-GW. When the multicast service begins, it first passes through an ordinary multicast capable network to the ASN-GW. Then the MBS controller and the IGMP client will coordinate the resources and send them to the IP networks where the multicast protocols IGMP and PIM-SM are used. The multicast traffic sent by the IP network terminated at the BS. The BS will multicast the traffic according to what is defined in 802.16e [IEEE16e] for single-hop WiMAX networks.

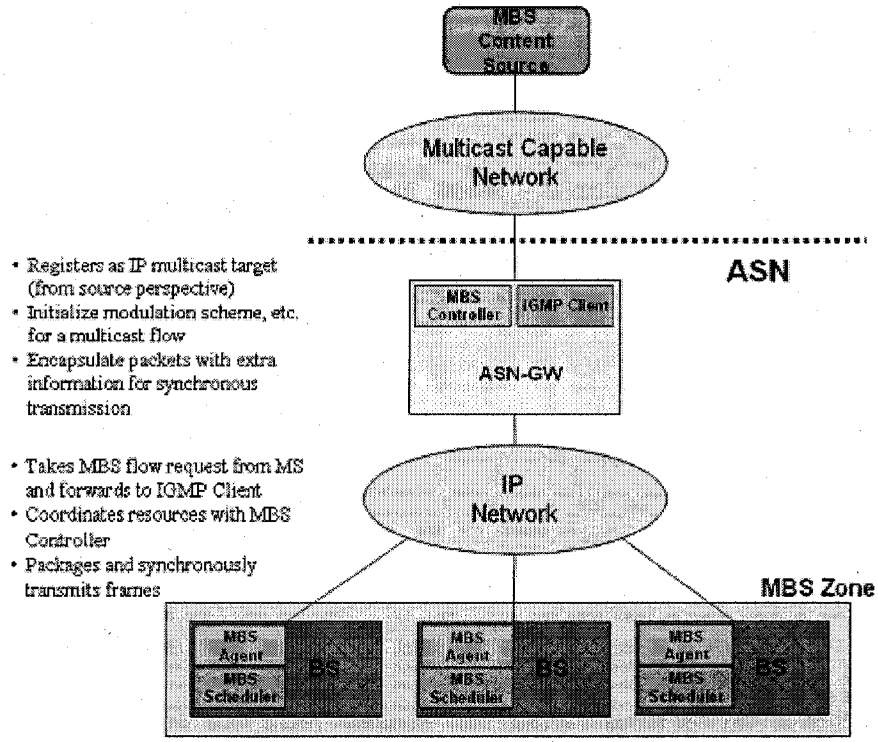


Fig 2.9: NRM Proposal (Motorola)

Fig 2.10 proposed an MBS enhanced model over WiMAX network. "In mobile WiMAX PHY/MAC layers, there are three functional entities to support MBS over WiMAX: The MBS server, the MBS client, and the communication entity between MBS server and the BS."[WaVe07]

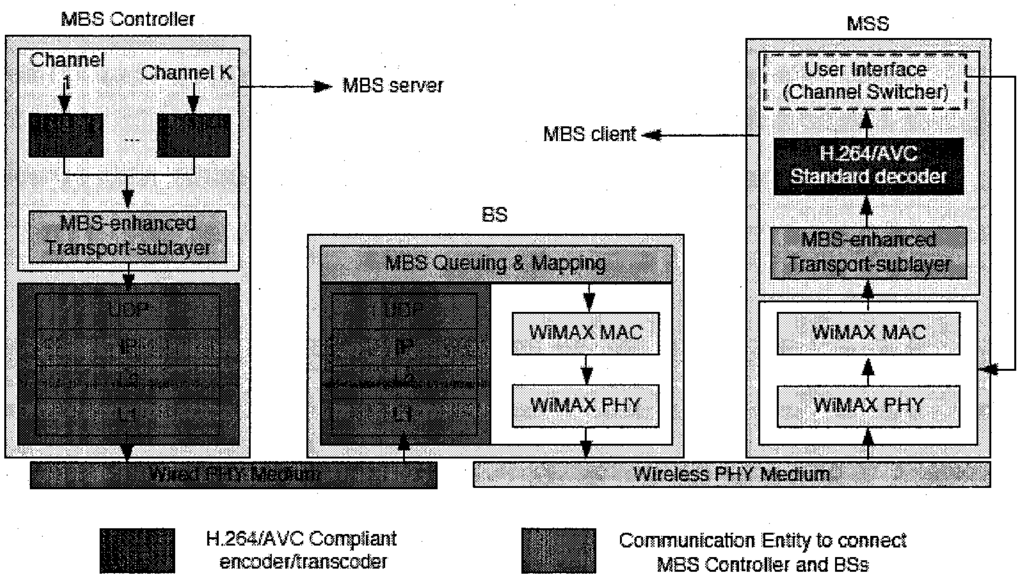


Fig 2.10: MBS enhanced model over WiMAX network

The MBS-enhanced transport-sublayer at the MBS server performs the following functions: (1) Map one video channel to one multicast CID, (2) Shape video traffic according to congestion status, (3) Add encryption, Apply Reed-Solomon (RS) outer FEC coding, (4) Construct MBS MAC PDU fit for transmission over WiMAX PHY/MAC, (5) Choose appropriate inner CTC coding scheme for each MBS MAC PDU, (6) Schedule and multiplex MBS MAC PDUs (from multiple video channels) in burst fashion, (7) Allocate OFDMA data region to each MBS MAC PDU.

The MBS-enhanced transport-sublayer at MBS client side has the following functions: (1) Construct Reed-Solomon block, (2) Correct Reed-Solomon section error, (3) Remove encryption, (4) Construct RTP video packet understood by standard H.264/AVC decoder.

Chapter 3
WiMAX Multicast Operation, Modeling, Definitions and Assumptions

In this Chapter, we shall propose our WiMAX relay network architecture for the multicast simulation, and the network operations to support the designed MBS traffic. We propose the WiMAX relay network architecture we will use in our simulation, and give the assumptions for our network architecture and operation process. We than explain the multicast operations and discuss the inter-layer design of the BS.

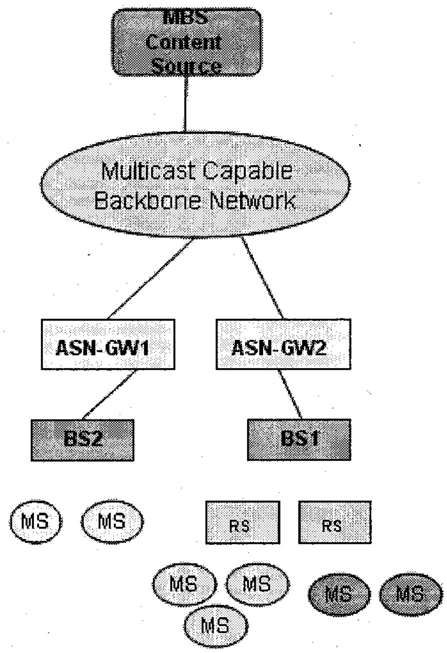


Fig 3.1: WiMAX Relay Network Architecture for Single BS Access

3.1 WiMAX Relay Network Architecture

Figure 3.1 depicts the multi-hop relay network architecture. It is an extension of the single-hop NRM model proposed by Motorola Company (Fig 2.9). The reason why we considered the relay network architecture for the IP traffic to MPDU transfer is to conform to the view of WiMAX Forum [WiFo06]. According to OFDMA [IEEE16j], our Physical Profile uses OFDMA as the protocol chosen for the physical layer here. An air interface refers to a hardware interface consisting of a physical profile with different frequencies. Only those components who have an air interface can transmit their traffic conforming to the specified WiMAX physical profile. Only single BS is considered here because the multi-BS access can always be decomposed as multiple single- BS accesses with coordinate at the ASN-GW, and all single BS-access cells will show the same behavior. In addition to the components already defined in Section 2.1.2, our WiMAX Relay Network Architecture (Fig 3.1) has more components as follows.

1) MBS Content Source: This component provides the content of MBS services, like multimedia flows, data files, etc. The content provider can belong to the NSP or be a third party outside the WiMAX network. The interface between MBS Server and Content Provider is out of scope of this specification.
2) Multicast Capable Backbone Network: This is the backhaul network part which support a IP multicast service, and has the ability to transfer multicast traffic into Access Service Network.
3) RS (Relay Station): An RS has the ability to forward the multicast traffic to the MSs (Mobile Subscribers). It also has the ability to allocate the bandwidth in a distributed manner according to different QoS requirement. The RS is the component with the WiMAX interfaces in order to connect with the BS and the SS.

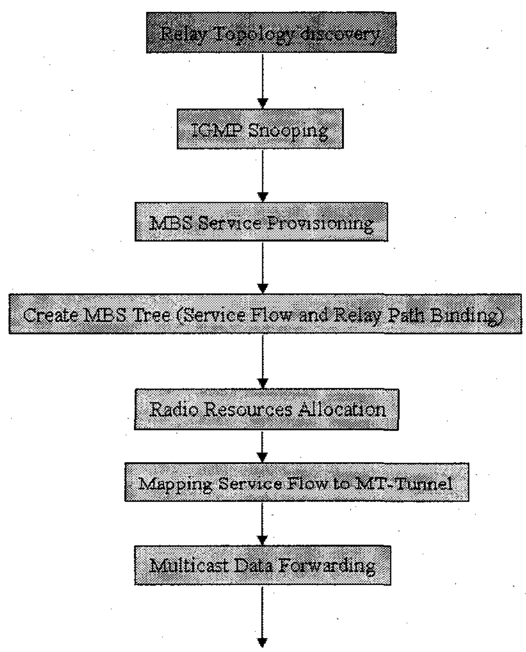


Fig 3.2: MBS Relay Network Overall Operations Flow

Fig 3.2 illustrated the operations flow, which we propose, to support the MBS traffic in WiMAX MR Networks. Fig 3.3 below illustrates the overall multicast network process of each unity.

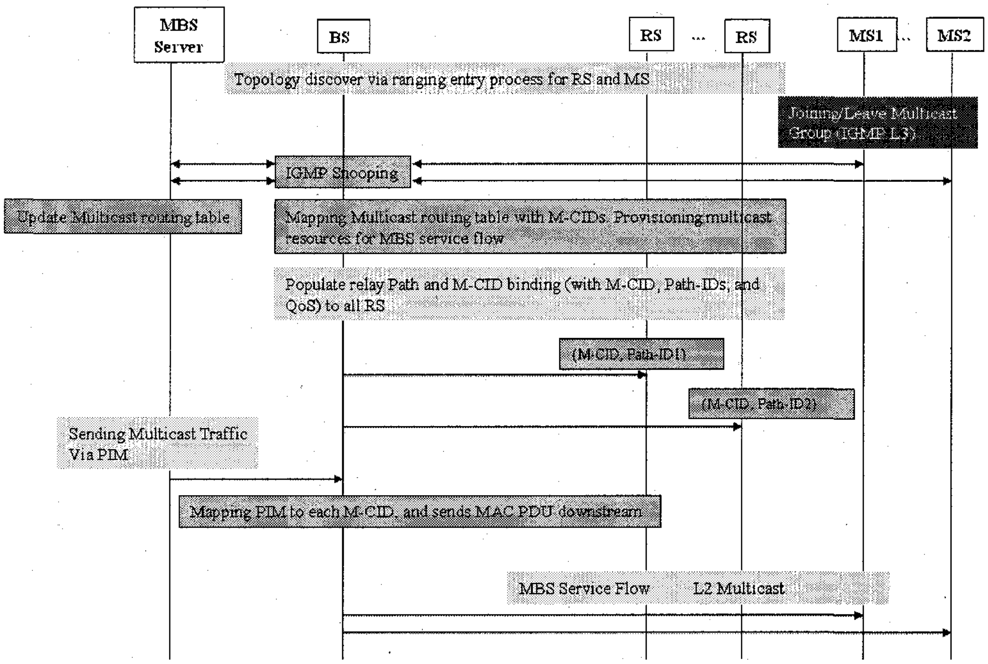


Fig 3.3: MBS Relay Network Overall Operation Procedures

3.2 MBS- enabled Relay System Operations Flow

From this section, we are going to explain each step of the MBS relay network operations in detail.

3.2.1 Topology Discovery

Topology Discovery via network entry process, also called Ranging process, is the first step for both unicast and multicast traffic. It is used for MR-BS and RS to detect the topology in order to build the DL-MAP. In the single hop system, the MS directly attaches to the BS, therefore the BS knows the MS is just one hop away. But in the MR system, there could be one or more RSs between an MR-BS and an MS. Of the two options (the per-tunnel-based option, the other one is per-flow-based) in 802.16j [IEEE16j] for topology discovery, we adopt the per-tunnel-based option.

We propose a BS-oriented source-routing protocol called "Tunnel Topology protocol". Tunnel CID is a group of relay CID, and it is used in MAC header or DL-MAP to navigate the relay of data bursts from the BS to each MS. A tunnel connection is a unidirectional connection between the MR-BS and an RS (in either direction) that is used to carry MPDUs from a set of service flows assigned to traverse the tunnel. We did not consider the power negotiation function in our proposal because it is out of scope of our topology discovery algorithm, and the decision is made by different vendors.

The Tunnel Ranging protocol is used to build relay tree topology layer-by-layer, and it is executed recursively as following description. The stopping criterion depends on the certain time period set up for the periodical topology discovery.

Tunnel Topology Discovery Protocol Procedure:

1) Initiate a relay tree to contain only one BS. This is N = 1 Layer
2) Assume the N-th layer has been built up (N>=1), which consists of the BS as the root and the RS at each layer to form the tree branches. This partial tree information is stored in the BS and all RS.
3) The BS periodically broadcasts a DL-MAP including BS-ID. Every RS receives the DL-MAP and replaces the superordinate's ID by its own ID. Meanwhile the RSs continue to broadcast DL-MAP downstream.
4) When a new node receives the DL-MAP, it should conduct the network entry process by sending a RNG-REQ to the selected RS.
5) The RS then put its ID in RNG-REQ and forwards it upstream to the BS. Based on the pre-established topology, the BS will create a new (N+1)-th layer path for the attached new node and populate the new path to all the RS along the new branch. BS then sends RNG-RSP to the new node to finish the entry process
6) An MR system repeats step (2) ~ (5) for further topology discovery.

Example:

According to the diagram of Fig 3.4, the BS scans the radio signals (e.g., DL-MAP) from all adjacent RSs. After initial CDMA ranging, the new node issues RNG-REQ to the selected access RS. RNG-REQ is forwarded to the BS. So at first the DL-MAP saved at the BS only has a memory of the BS itself, i.e., P0 = {BS}. After one time scanning, the BS has the knowledge of RS1.Then the BS assigns the Basic CID for the new discovered RS and updates its DL-MAP to P1 = {BS, RS1}

After the RS1 finishes its entry process, the BS will assign a T-CID (Tunnel ID) for the path from the BS to the RS1. So Path 1 becomes P1 = {P0, RS1}, T-CID1. The RS2 and the MS follows the similar procedure according to the algorithm proposed in 3.2.1. The BS will have the DL – MAP with every detected node. In summary, the DL-MAP is generated as

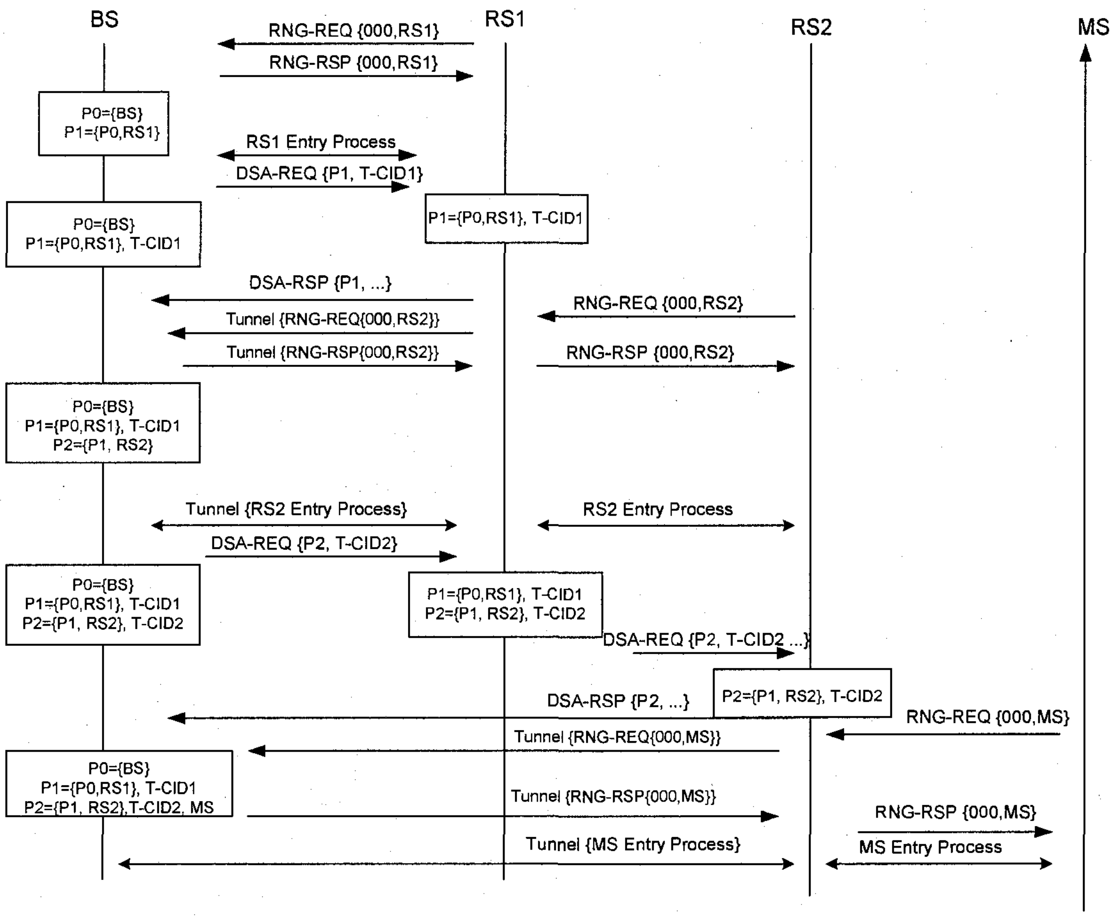


Fig 3.4: Discovery and Path Management Procedure under Tunnel Mode

P0 = {BS}

P1 = {P0, RS1} T-CID1

P2 = {P1, RS2} T-CID2, MS

The topology discovery procedure for more nodes is the same as what we illustrated. The ranging process stops after the regulated time period.

After the topology discovery, Tunnel CID binding will be triggered by the BS during tunnel provisioning. Note that binding is defined as the mapping between the path and its stations alongside. So P0 is mapping with BS. P1 is mapping with all the stations include in P0, and RS1. Legacy (802.16e-2005) CID binding is triggered by the BS or the MS during service flow provisioning depending on whether it is tunnel based connection or flow based connection.

3.2.2 Bandwidth Allocation Mechanism in Multi-Hop Relay Networks

Similar to the bandwidth allocation in signal-hop networks discussed in section 2.2, the bandwidth in the relay networks also needs to be allocated in advance at the MR-BS and the RS. There are two kinds of bandwidth allocations in multi-hop relay system: distributed bandwidth allocation and centralized bandwidth allocation.

a) Distributed Scheduling: In the multi-hop relay system with distributed scheduling, each MR-BS and RS individually determines the bandwidth allocations on the links it controls (i.e. downlinks to or uplinks from its immediate downstream stations) and creates its own MAPs reflecting these decisions. The MR-BS may send RS scheduling information (RS-SCH management message) in advance to its subordinate RS to indicate when and how much bandwidth it will schedule for the service in the future.

b) Centralized Scheduling: In systems with centralized bandwidth allocation, the MR-BS shall determine the bandwidth allocations for all links (access and relay) in its MR-cell. Thus, before a station can transmit a packet to the MR-BS, that station's bandwidth request must first reach the MR-BS, which then creates bandwidth allocations on the links along the path from the station to the MR-BS.

Some globally defined service flows may carry broadcast or multicast information that should be delivered to a plurality of SS or MS. Since a multicast or broadcast transport connection is associated with a service flow, it is associated with the QoS and traffic parameters for that service flow. Each group of multicast traffic is assigned to a Multicast CID (M-CID). The function of M-CID is similar to the multicast group address in IP layer. For the downlink multicast service, the same value is assigned to all MSs on the same channel that participate in this connection. It is assigned at MAC layer because the traffic needs to be transmitted via RS in MR Networks, and RS only has the function of PHY layer and MAC layer. According to the demands for different multicast traffic, MR-BS and RS along the path will provision certain bandwidth for later multicast traffic.

3.2.3 Multicast Tunnel CID Approach for MBS in Multi-hop Relay Network

Current 802.16j solution only defines unicast tunnel between a BS and a designated access RS. If we use that method to support MBS, multiple unicast tunnels have to be configured for every destination MSs. During the data forwarding, the BS has to make multiple copies for each destination due to the use of unicast tunnel. This degrades the radio resource efficiency, and causes the latency for handover procedure. More importantly, MBS service requires that all the subscribers should receive the same channel at the same time (i.e., the access RS with the shorter paths have to delay the transmission). To coordinate the time synchronization over multiple individual unicast tunnels would increase much complexity for operation.

We propose a solution called Multicast Tunnel CID (MT-CID) in order to better support MBS. During the multicast traffic transmission, there are always two actions: Predestination and Data Forwarding Reaction. Predestination means the assignment of the paths before the multicast traffic arrives. It is a control action for allocating the paths for the data forwarding action later.

1) Predestination: The Control Plane is used to predestinate all the resources and path.
2) Data Forwarding Reaction: We use the Data Plane to react and deal with the data forwarding when data traffic comes according to the predestinate information assigned by control plane.

The different functions are explained in term of these two planes in the following subsections.

3.2.3.1 Control Plane

Different subscribers will send message to the MBS server to subscribe the traffic according to the content (channel) they chose. Internet Group Management Protocol (IGMP) is used to manage membership of different multicast receivers.

The joining message is sent by MS/SS towards MBS server directly. After certain period, MBS server will collect all the joining information and generate the multicast groups table. The multicast group table reserves all the information to identify the MS/SS belongs to certain multicast group. PIM is implemented over MBS server and ASN-GW to create Layer 3 multicasting tree for multicasting routing in the access network. We install IGMP snooper on every BSs to snooping IGMP configuration information. The usage of IGMP snooper is to create Layer 2 multicasting tree for multicasting routing within BS relay cell. BS will use IGMP snooper to intercept application layer group configuration information (e.g., MS IGMP joint/leave). From IGMP messages, the BS automatically learns the MS and which multicast group it belongs to, and the BS determines the access RS the MS currently is attached to. Then the BS checked the existing allocated MT-CID and the learnt group. If it does not exist before, the BS will map IGMP group into MT-CID and associated MBS tree. This procedure can be triggered dynamically or manually. MT-CID is bundled with multiple relay paths. This binding forms an MBS tree in the BS routing data base. BS then signals all the intermediate RSs to populate the MBS tree information. The signaling message will use Multicast Management CID as the MAC header to indicate that it is a broadcasting message for signaling usage, and the body of the message will include MT-CID and the path IDs associated with the designated RSs. The MT-CID/Path binding relationship is populated to all the intermediate RSs via signaling message dynamically. After receiving the signaling message, the intermediate RSs will store this binding Info in their forwarding tables (if they are along the given path).

3.2.3.2 Data Plane

When the BS receives the MBS traffic (e.g., routed by PIM protocol), the BS will map the SDU into 802.16 MAC PDU by using MT-CID, then creates a tunnel MAC PDU by wrapping MT-CID and encapsulates multiple 802.16 MAC PDU up into the tunnel (if they are in the same MBS group), and then sends MPDU downstream.

After receiving the MAC PDU, each intermediate RS will check MT-CID against the forwarding table. If the RS find a match, it will forward the MAC PDU to the next hop. Otherwise, the RS simply drops the MAC PDU. This process will be repeated until the

MPDU reaches the access RS. The access RS will decapsulate the MAC PDU, and sends the inner MAC PDU to the attached MSs.

3.3 Internal Functions and Entities Design of a Base Station

Fig 3.5 shows the internal functions and entities of the BS to illustrate the interlayer design of a BS. The BS has several special entities in order to support MBS and relay networks: MBS agent, IGMP snooper, Inter-Layer Controller, MBS Radio Resource Scheduler, Relay Routing Information Base and Mobility Enabler. Besides, the BS also has the knowledge of its attached RSs and the MSs according to the DL-MAP which it has. The inter-layer controller has the following functions:

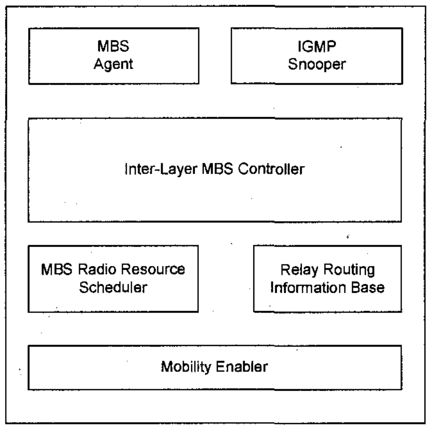


Fig 3.5: Interlayer Design of Internal Function in a Base Station

1. User Management: The user management part of BS has the information of all termination points.
2. Path Finding: According to the topology discovered by the ranging process and the multicast group information inspected by IGMP snooper, the interlayer controller will find the suitable path for the multicast traffic.
3. QoS Binding: According to the different QoS requirement for different channels, the interlayer controller is in charge of binding the related QoS demand to the related channels.
4. Synchronize: Entity taking care of packaging of frames and frame synchronization of transmission time scheduling
5. Channel Scheduler: According to the number size belongs to different relay station, the

interlayer controller will allocate the channel resources intelligently.

3.3.1 Mapping Tables

The Inter-Layer MBS controller generates and maintains the mapping tables which are used to support the multicast service in MR networks

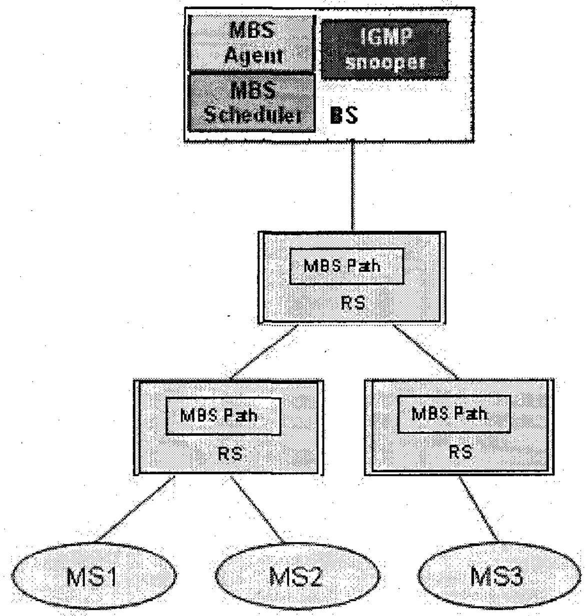


Fig 3.6: Example Topology for Mapping Table Explanation

Fig 3.6 is an example which we will use to illustrate the relationship between the mapping elements. As previously shown, the multicast traffic will be transmitted at MAC layer for the WiMAX relay network. However, the multicast traffic transmitted from the ASN-GW or other multicast capable network is using IP network layer. The following are the same mapping tables in order to transmit the application traffic from IP network layer to MAC layer.

Table 3.1 IP Multicast Address to Multicast CID Mapping

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

1. IP Layer (Layer 3) Multicast IP address to Mac Layer (Layer 2) Multicast CID Mapping

A mapping table (Table 3.1) is necessary to map the multicast group IP address with M-CID (multicast CID). A Multicast Group Address is an address for the multicast group in the IP layer. Instead of listing each station's IP address, one can give the same multicast IP address for the SSs which are receiving the same multicast traffic. M-CID is the address in the MAC layer, which allocates the SSs in the same group to subscribe the same content instead of giving the MAC address of each SS.

Table 3.2 Multicast CID to Group Member Basic CID Mapping

M-CID	Member Basic CID
Group A	MS1 MS3
Group B	MS1 MS2

2. Multicast CID to Group Member Basic CID Mapping

   Similar to the multicast management in IP network layer, we also need to know the SSs in each multicast groups in the WiMAX MAC layer. M-CID has the information of each basic connection identifier (SS and its access RS) that needs to forward the multicast traffic. Because of this, a mapping table (Table 3.2) is created in order to map the Multicast CID with the SS Basic CID.

Table 3.3 Path CID with Basic CID Mapping Table

Path CID	Basic CID
Path CID1	RS1 RS2
Path CID2	RS1 RS3

3. Path CID with Basic CID Mapping

   Besides knowing the M-CID information and its related member basic CID, the ASN also lacks the information from the BS to the access RS if there are more than one RS in the tree connected with the BS. So we need to find the multicast path in order to forward the multicast traffic to the destination RSs. Path CID with Basic CID of RS Mapping Table (Table 3.3) is generated in order to find the corresponding Path and merge them into a Path-ID in order to save the overhead.

Table 3.4 Multicast Tunnel CID with Path-ID Mapping

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

4. Multicast Tunnel CID with Path-ID Mapping

After we build up the path information along to the destination SS according to DL-Map and Relay Routing Information Base, the next thing we need to consider is to map the Multicast CID with the path ID it need to forward the multicast traffic. (Table 3.4)

Table 3.5 Multicast CID with Service Flow and Qos Mapping Table

M-CID	SFID QoS
Group A	SFID1,QoS1
Group B	SFID2,QoS2

5. Multicast CID with Service Flow and QoS Mapping

After we binded the Path-ID with the M-CID to make sure the multicast traffic can be forwarded to the correct route, we also need to concern ourselves with the classification of the traffic characteristic and to provision the SFID (service flow) according to its QoS requirement into different Multicast CID (different Multicast Group). Table 3.5 clearly shows this mapping relationship.

3.3.2 Multicast MAC PDU

There are two types of multicast PDU used in the multicast service. One multicast PDU is used at the control plane which is a signaling massage. The other is used at the data plane which is a data packet.

a) Multicast MAC PDU Format (Control Plane)

During the first step (Control Plane), the BS sends the signaling message with Multicast Management CID indicated. Multicast management CID is used to signal the establishment of MT-CID and MBS tree. It's a broadcasting message for signaling usage, and the body includes MT-CID and the path IDs associated with designated RS. Table 3.6 shows the multicast MAC PDU format for the signaling massage.

Table 3.6 Multicast MAC PDU Format (Control Plane)

Multicast Management CID	
MT-CID1	Path-ID1
	Path-ID2
MT-CID2	Path-ID3
	Path-ID4

b) Multicast MAC PDU Format (Data Plane)

When the BS receives the MBS traffic (e.g., routed by PIM protocol), the BS would map the SDU into 802.16 MAC PDU by using MT-CID, then it creates a tunnel MAC PDU by using MT-CID and encapsulates multiple 802.16 MAC PDUs into the tunnel (if they are in the same MBS group), and then sends it downstream. Table 3.7 shows the multicast MAC PDU format when the BS transmits the real multicast traffic.

Table 3.7 Multicast MAC PDU Format (Data Plane)

Multicast Tunnel CID		
M-CID1	M-CID2	M-CID3
Channel1	Channel2	Channel3
CRC (optional)		

Multicast CIDs (each represents one service flow, saying one TV channel or more) can encapsulates multiple multicast traffic to the designated MS for the subscripted TV channels

3.3.3 Other Considerations

As we mentioned in Section 3.2, the operation process we proposed in Section 3.3 is not only limited to a static network, it can also support the mobility of WiMAX Networks. When an MS travels from the serving BS to the target BS, if the correspondent MT-CID is already established for the new access RS, the MS just simply share the same MT-CID in the new tree. Otherwise, a new MT-CID is created for the MS under the new tree. This greatly reduces the latency of handover and keeps the session MBS continuity. It also effectively utilizes the nature of multi-tier PMP topology of 802.16j relay network, and associate M-TID with RF boundaries such as sectors, virtual clusters, cells and paging groups. All the nodes in MBS tree will share the RF resources.

3.4 Concluding Remark

We have proposed a standard-based, cost-effective solution to support MBS services in WiMAX multi-hop relay network. The importance lies in:

1. Our solution defines a BS-oriented source-routing protocol to automatically discover relay network topology where the mobile relay station forms an ad hoc topology (e.g., when relay station is installed over moving vehicles)
2. Our solution utilizes IGMP snooping protocol on the BS to automatically track the MBS group membership and service activation. The inter-layer controller collaborates IGMP/PIM grouping with the MAC layer functions of relay topology and radio resource allocation. The inter-layer controller also maps L3 multicasting tree to the L2 multicasting tree seamlessly.
3. Our solution introduces Multicast Tunnel CID (MT-CID) which maps the relay paths to form a MBS tree in 802.16j MAC layer to support MBS services. In this MBS tree, BS is the root and all the access RSs within a given group are leaves. The MCBCS tree topology is preconfigured at all the intermediate RS to navigate the traffic forwarding
4. By using MT-CID approach, RS would only need transfer one copy of content downstream and each intermediate RS would have the intelligence to navigate the content to each destination. By using the PMP mode of a relay tree, there is no need to make multiple copies to every destination.
5. QoS sub-header and Frame Synch sub-header (defined in P802.16j/D1) can be used to support end-to-end frame QoS and timing synchronization in relay network.

Chapter 4
Protocol Verification

In this chapter, we shall implement our proposal in an OPNET simulator based on the MBS operation procedures we described in Fig 3.4. We also will describe the new provision scheme, which we will use for another scenario in our simulation to better allocate the radio resource for different QoS requirement of different multicast groups. All these will help to demonstrate the feasibility of our proposal.

4.1 Topology Discovery using with Tunnel Connection Method

We already discussed the topology discovery correlating with Tunnel Connection Method in Section 3.3.1. Tunnel based option has many advantages, such as saving the overhead in MS handover cases, capability in collective time synchronization and more efficient QoS transmission. We shall use source routing on the BS to verify the feasiblility of tunnel connection. As a preparation stage for data transmission, our method here can be used for unicast operation in addition to the multicast operation.

4.2 Verification Scenarios of Topology Discovery

Fig 4.1 is our simulation scenario to verify the correctness of the tunnel connection method for the topology discovery. We set up the simulation topology with two braches. Each branch has one relay station and one mobile station. The network is a two-hop WiMAX relay networks. We will use this topology in the scenarios later on. As a preparation stage for data transmission, our method can be used for unicast operation in addition to the multicast operation.

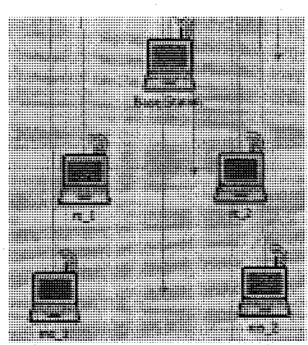


Fig 4.1: OPNET Tunnel Establishment Scenario

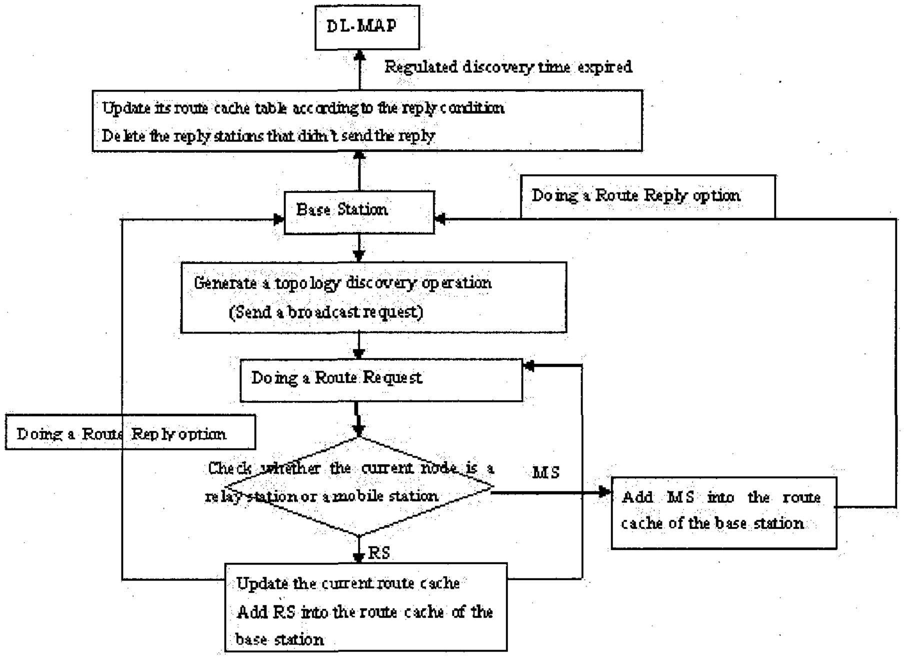


Fig 4.2: Simulation Design Flow Chart

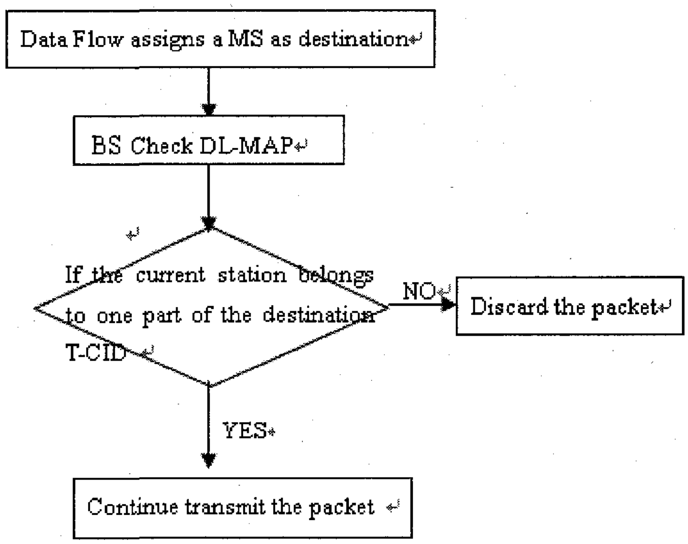


Fig 4.3: Data Flow Process

We have implemented the test scenarios under OPNET 11.5 [OpMo06]. Fig 4.2 is the simulation design flow chart to show how to establish a tunnel connection in OPNET according to Section 3.3.1. The BS can establish the DL-MAP based on the reply information it obtains from the broadcast request. If the station that receives the broadcast route request, it sends the route reply message back to the BS to help the BS build up the DL-MAP. Fig 4.3

shows how the traffic can be forwarded from a BS to the destination MS. When BS want to transmit a data flow, it will check the DL-MAP first to see if the data flow is pre-assigned to the destination MS. The data flow will be transmitted to the destination MS-CID contained in the T-CID. On the RS side, when a RS receives a data flow, it will first check if itself belongs to the T-CID binding with the data flow. If it does, the RS will forward the packet. Otherwise, the RS simply discards the packet. After several hops, the data flow will arrive at the destination MS finally.

All the parameter values we use in our simulation/demonstration are the default values used in DSR protocol [JoMa04]. The traffic we use is a broadcasting message designed for ranging request. The simulation time is 600 seconds which is long enough to see how the tunnel connection proceeds for the topology Discovery.

We are going to verify the tunnel topology discovery algorithm through the following scenarios. The purpose of Scenario 1 is to detect the basic topology discovery ability for the BS using its radio components, so we did not put the RS in Scenario 1. From Scenario 2, we added the RS between the BS and the SS in order to verify the BS source routing algorithm we proposed for tunnel connection in MR network. In order to test the robust of the algorithm, we planned two sub-scenarios: the RS is working normally during the topology discovery process and the RS fails during the process.

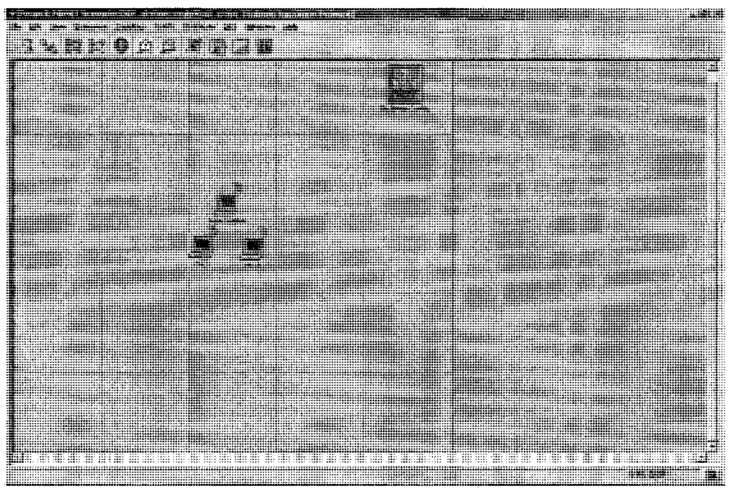


Fig 4.4: OPNET Scenario1

4.2.1 Scenario 1: Base Station detects Mobile Station without Relay Station

The purpose of Scenario 1 is to test the ability of a BS to detect a MS without any RS if the MS is within the transmission range of the BS. As shown in the topology of Fig 4.4, there is one BS on the top, and two MSs are randomly scattered in the bottom part, which are within the transmission range of the BS. The icon on the top right corner is the utility node (also called Dynamic Receiver Group Configuration Node) used to compute the set of possible receivers that a node can communicate with. It is computed based on the three criteria: 1) Channel Match 2) Distance Threshold 3) Pathloss Threshold. This utility node can greatly speed up a simulation by eliminating receivers that do not match. The speed enhancement depends on the following factors: 1) Number of possible neighbors each node has with respect to the total number of receivers. 2) Number of refreshes during the simulation (refresh interval). Instead of investigating the effect of these factors, we used the default threshold in our simulation according to OPNET [OpNe07]. The value is binding with the path loss mode, which can not be obtained separately.

	Time	Source Node Name	Destination Node Name	Hop Count	Routing Path
1	100.004242	192.0.0.1 (Office Network.Base Station)	192.0.0.2 (Office Network.ms_1)	1	192.0.0.1 (Office Network.Base Station)
2					192.0.0.2 (Office Network.ms_1)
3					
4					
5	100.008303	192.0.0.1 (Office Network.Base Station)	192.0.0.3 (Office Network.ms_2)	1	192.0.0.1 (Office Network.Base Station)
6					192.0.0.3 (Office Network.ms_2)
7					

Done Local intranet

Fig 4.5: DL-MAP Report of Scenario 1

Fig 4.5 shows the DL–MAP Report of Scenario 1 generated after the ranging request. The BS has detected two MSs which are directly connected to it (Line 2 and Line 6) and the hop count is 1.

4.2.2 Scenario 2: Base Station detects Mobile Station through Relay Station

The purpose of Scenario 2 is to test the ability of a BS to detect a MS in a WiMAX MR network when the MS is set beyond the transmission range of the BS. The following are different circumstances we should verify.

4.2.2.1 Normal Operation

Normal operation prevails when no nodes fail in the WiMAX network

<u>Scenario 2A: Base Station detects topology via the Relay Stations</u>

The purpose of scenario 2A is to test the ability of a BS to detect the MS via the RS if the MS is beyond the transmission range of the BS.

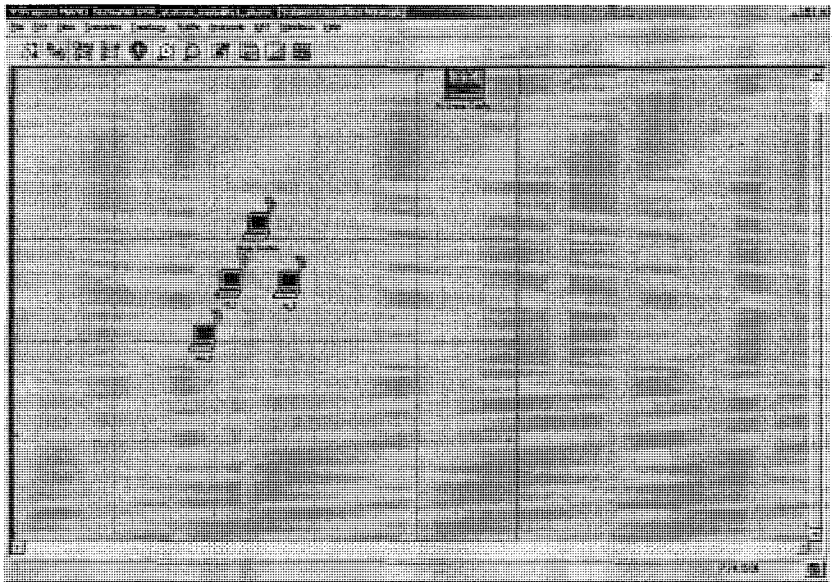


Fig 4.6: OPNET Scenario 2A

As shown in Fig. 4.6, the BS is located on the top, and two RSs (rs_1 and rs_2) are randomly scattered in the lower part which are within the transmission range of the BS. We put the MS below one RS so that it is within the transmission range of the RSs while beyond the transmission range of the BS.

	Time	Source Node Name	Destination Node Name	Hop Count	Routing Path
1	100.004242	192.0.0.1 (Office Network.Base Station)	192.0.0.2 (Office Network.rs_1)	1	192.0.0.1 (Office Network.Base Station)
2					192.0.0.2 (Office Network.rs_1)
3					
4					
5	100.008303	192.0.0.1 (Office Network.Base Station)	192.0.0.3 (Office Network.rs_2)	1	192.0.0.1 (Office Network.Base Station)
6					192.0.0.3 (Office Network.rs_2)
7					
8					
9	100.009887	192.0.0.1 (Office Network.Base Station)	192.0.0.4 (Office Network.ms_3)	2	192.0.0.1 (Office Network.Base Station)
10					192.0.0.2 (Office Network.rs_1)
11					192.0.0.4 (Office Network.ms_3)
12					
13					
14	100.013406	192.0.0.1 (Office Network.Base Station)	192.0.0.4 (Office Network.ms_3)	2	192.0.0.1 (Office Network.Base Station)
15					192.0.0.3 (Office Network.rs_2)
16					192.0.0.4 (Office Network.ms_3)
17					

Done Local intranet

Fig 4.7: DL–MAP Report of Scenario 2A

Fig 4.7 shows the DL–MAP Report of Scenario 2A is generated after the ranging request process. The BS can detect there are two RSs directly connected to it (see rs_1 in Line 2 and rs_2 in Line 6). The hop count is 1 between the BS and rs_1 and rs_2. The MS connected to the BS via the RS (Line 9 to 11) and (Line 14 to 16). There are two connection options for the MS, it can either connect to the BS via rs_1 (Line 9 to 11) or rs_2 (Line 14 to 16).

4.2.2.2 Failure Operation

Failure means the station does not have the normal function for transmitting, receiving, and relaying any traffic. There are two scenarios that we should consider here for the failure operation.

Scenario 2B: Base Station detects topology when One Relay Station failed

The purpose of interest for scenario 2B is to test the changeable ability of the BS whether it can detect the node failure of the RS, thus choose the robust path in order to find the MS.

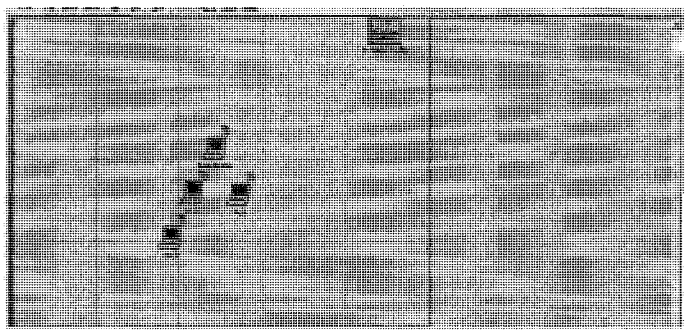


Fig 4.8: OPNET Scenario 2B

As shown in Fig. 4.8, the BS is located on the top, and two RSs (rs_1 and rs_2) are randomly scattered in the lower part which are within the transmission range of the BS. We put the MS below one RS so that it is within the transmission range of the RSs while beyond the transmission range of the BS. We assume the RS (rs_1) can't work properly in this scenario.

	Time	Source Node Name	Destination Node Name	Hop Count	Routing Path
1	100.005897	192.0.0.1 (Office Network.Base Station)	192.0.0.3 (Office Network.rs_2)	1	192.0.0.1 (Office Network.Base Station)
2					192.0.0.3 (Office Network.rs_2)
3					
4					
5	100.012582	192.0.0.1 (Office Network.Base Station)	192.0.0.2 (Office Network.ms_3)	2	192.0.0.1 (Office Network.Base Station)
6					192.0.0.3 (Office Network.rs_2)
7					192.0.0.2 (Office Network.ms_3)

Done Local intranet

Fig 4.9: DL-MAP Report for Scenario 2B

Fig 4.9 shows the DL–MAP Report of Scenario 2A is generated after the ranging request process. The BS can detect the existence of an RS (rs_2) which is directly connected to it (Line 1 to 2). The hop count is 1 between the BS and rs_2. The MS connected to the BS via the RS (rs_2) (Line 5 to 7). We can not detect the other RS (rs_1) because it has already been disabled, nor can we detect another route for the MS to connect to the BS via the RS (rs_1).

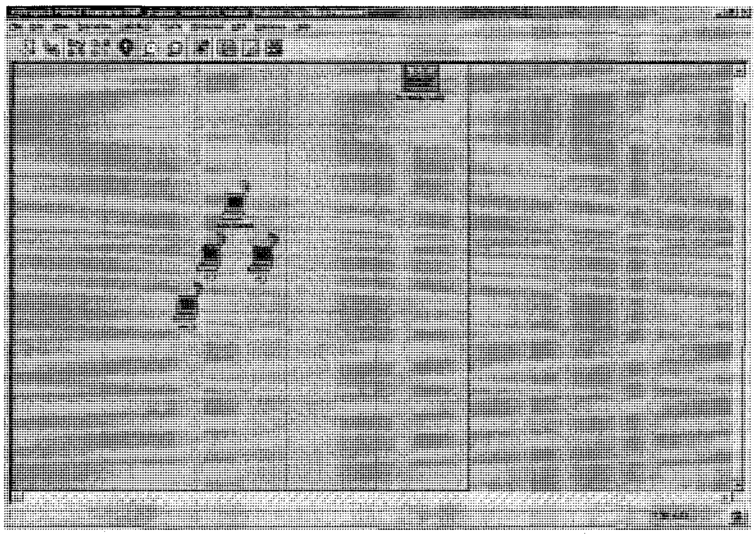


Fig 4.10: OPNET Scenario 2C

<u>Scenario 2C Base Station detects topology when two Relay Stations failed</u>

The purpose of scenario 2C is to test the changeable ability of base station that can detect the node failure of the RSs. As shown in Fig. 4.10, the BS is located on the top, and two RSs (rs_1 and rs_2) are randomly scattered in the lower part which are within the transmission range of the BS. We put the MS below one RS so that it is within the transmission range of the RSs while beyond the transmission range of the BS. We assume both RSs (rs_1 and rs_2) can not work properly in this scenario.

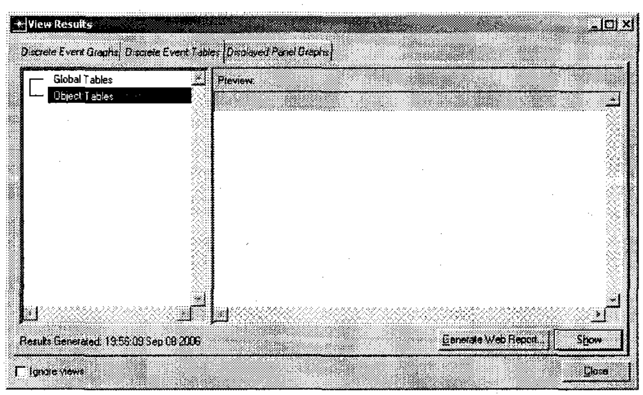


Fig 4.11: DL – MAP Report for Scenario 2C

Fig 4.11 shows the DL–MAP Report of Scenario 2A is generated after the ranging request process. No RS or MS was detected in this scenario. The reason is that both RSs are out of work in the scenario, and the BS can not detect the MS directly because the MS is beyond the transmission range of the BS.

4.3 OPNET Simulation of MBS in MR networks

The above scenarios in topology discovery show the correctness of the tunnel connection algorithm for topology discovery in WiMAX MR Networks. Topology Discovery is the first and necessary operation in multicast relay networks as we mentioned in Section 3.3. We now verify the remaining operations to accomplish a multicast traffic forwarding process.

Unlike OPNET 11.5 used in the verification of Topology Discovery, we use OPNET 12.0 instead because this version provides a module called the WiMAX Module PL3 to provide WiMAX features and operations. For the verification of Topology Discovery simulation, OPNET 11.5, and OPNET 12.0 have the same module and build in process. So we did not verify the whole process again in OPNET 12.0. However, the mobility and relay functions in OPNET 12.0 are not yet supported in the Physical Layer and MAC Layer. Therefore, we all forced to use Ethernet line in the OPNET simulator as an expedient to emulate the functions of the WiMAX relay between the BS and the RSs.

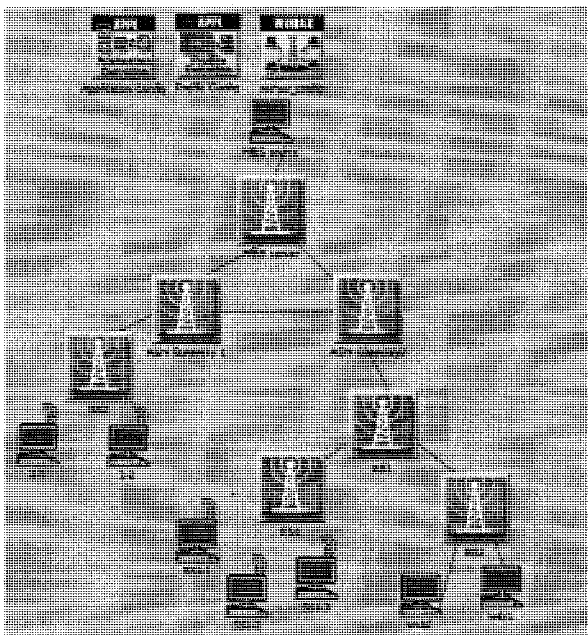


Fig 4.12: OPNET MBS Simulation Topology

Fig. 4.12 shows the MBS simulation topology set strictly according to the WiMAX relay network architecture proposed in Section 3.1. The MBS source on the top is the multicast content sender in our simulation. The MBS server is regarded as a simple multicast capable backbone networks. The ASN-GW and the BS together regard as the ASN here. The BS, the RSs and the MSs compose of the WiMAX MR network as shown. The three icons on the top from left to right is Application Definition node, Profile Definition node, WiMax Configuration node, which are used in OPNET simulation. Application Definition node is used to specify the applications using available application types. You can specify a name and the corresponding description in the process of creating new applications. The Profile Definition node can be used to create user profiles. These user profiles can then be specified on different nodes in the network to generate application layer traffic. WiMax Configuration node is used to configure parameters such as service classes and PHY profiles especially for WiMAX. Physical Profile here means the protocol chosen for the physical layer.

In the simulation, we use different applications to generate multicast streams to test the performance of multicast performance in WiMAX relay networks. All the application uses UDP (User Datagram Protocol) because it is the only suitable transfer protocol for multicast traffic available from OPNET [OpMo07].

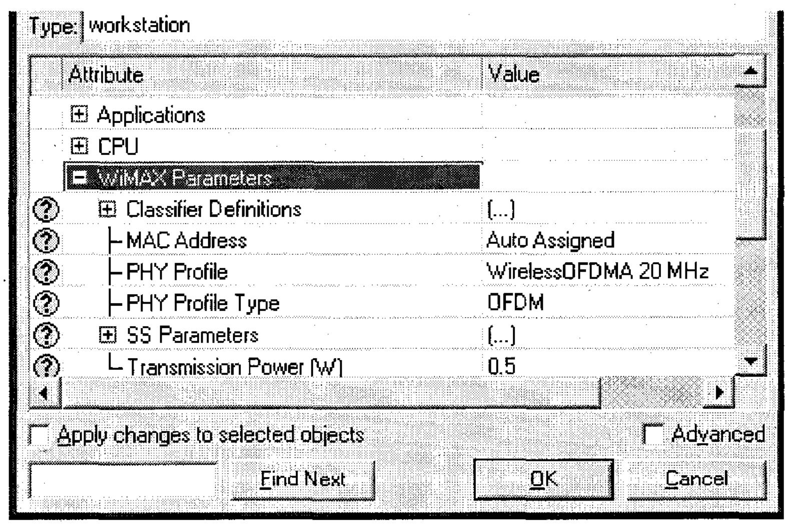


Fig 4.13: OPNET WiMAX Parameter Setting

Fig. 4.13 shows the parameters and their values in our WiMax OPNET simulation. We use the Wireless OFDMA 20 MHZ because 802.16j PAR has specififed enhancements to the

OFDMA Physical layer to enable the operation of relay stations. As seen, the transmission power is set at the default value of 0.5W in the OPNET WiMAX module.

From Section 3.3.2, we know that a BS will provision the resources for a MBS service flow after the BS has the knowledge of the Join message, the MBS flow QoS or other requirements. In Scenario 3, we provide enough resources for transporting multicast traffic in the BS.

4.3.1 Scenario 3

Fig 4.12 depicts the MR network we use in this scenario. We use the video application as a real time stream for the multicast traffic. The video application stream uses Best Effect (BE) QoS level with a frame inter-arrival time of 0.1 sec.

4.3.1.1 Verification of the Control Plane Functions

The control plane is a very important part in the whole MBS operation process, successful transmission of the multicast traffic depends on the pre-assigned MBS path that the control plane built before. The function of the control plane can be summarized as:

(1) announce different subscribers, who send the join message (2) install IGMP snooper on every BS (3) map IGMP group into MT-CID and associated MBS tree (4) MBS Provision(5) Relay Path and M-CID binding (6) signal all the intermediate RSs to populate MBS tree information The detailed description of the control plane can be found in Section 3.3.3.1.

4.3.1.1.1 Join Procedure

After Topology Discovery, we want to verify the correctness of an MS joining a multicast group of their choice. In our Scenario 3, we would like to set SS1-1, SS1-2, SS1-3, wsk1, and wsk2 to join the video conferencing multicast group while the two mobile stations "SS2-1" and "SS2-2 unsubscribe any multicast group. The reason why we left SS2-1 and SS2-2 idle is because OPNET WiMAX PL3 did not support the scenario where more than one BS coexisted, it would cause the WiMAX air interface to compete between different BSs and lead to random, unstable measurements.

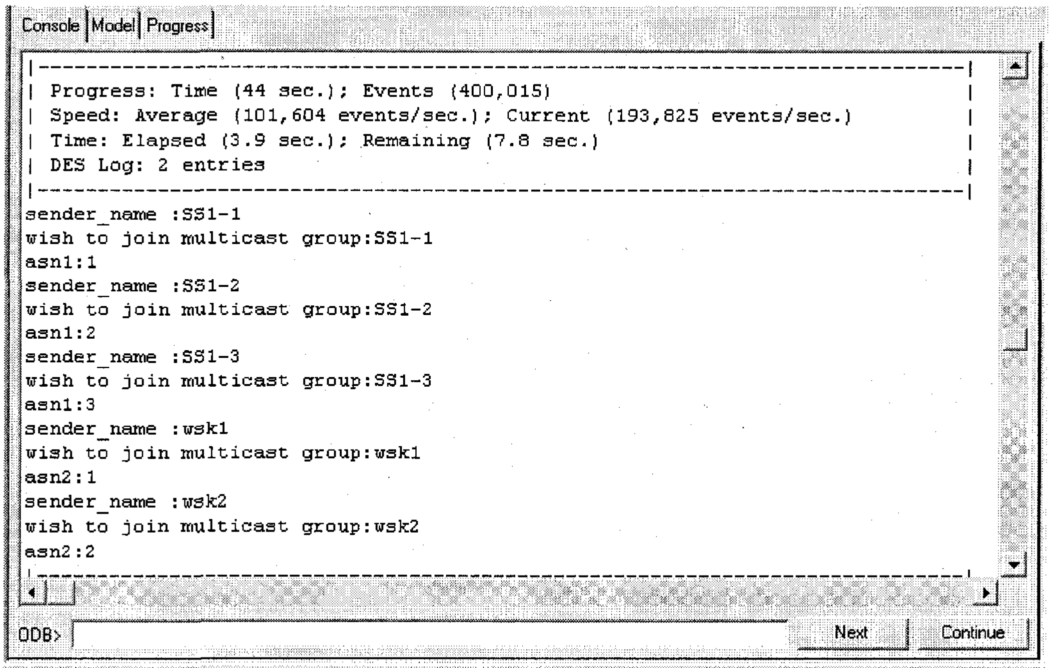


Fig 4.14: OPNET Console Windows showing multicast group membership

Fig. 4.14 is the OPNET Console Windows showing multicast membership. We can see how an SS joins an attached RS. As seen from the first lines below the dotted box, SS-1 announces it wish to join the multicast group by sending a Join message to the attached Relay Stations. The Join message is forwarded (not shown) finally to the ASN. The other lines show similar actions taken by SS1-2.

We can see the MBS server will collect all the joining information as to which multicast group an MS/SS wishes to join.

4.3.1.1.2 IGMP Snooping

Fig. 4.15 is the OPNET Console Windows showing receiving Join Notification from Subscribers. We can see how the BS snooping occurs when it is intercepted with the join information sent by the SSs. As seen from the first lines, BS1 detected wsk1 joined the multicast group by snooping a Join message sent to the ASN. The BS also learns which access RS the MS currently attached to. For example, wsk1 attached to RS2. The other lines show similar snooping results as wsk2 joined the multicast group and it attached to RS2, SS1-1, SS1-2 joined the multicast group and they attached to RS1.

```
joined DR Name :RS2
Receive Join notification from Subscriber: wks_name :wsk1

                        (ODB 12.0.A: Event)

joined DR Name :RS2
Receive Join notification from Subscriber: wks_name :wsk2

                        (ODB 12.0.A: Event)

joined DR Name :RS1
Receive Join notification from Subscriber: wks_name :SS1-1

                        (ODB 12.0.A: Event)

joined DR Name :RS1
Receive Join notification from Subscriber: wks_name :SS1-2

                        (ODB 12.0.A: Event)

joined DR Name :RS1
Receive Join notification from Subscriber: wks_name :SS1-3

                        (ODB 12.0.A: Event)
```

Fig 4.15: OPNET Console showing receiving Join Notification from Subscribers

4.3.1.1.3 Multicast routing table mapping with M-CID

For the first time when BS checked the new multicast group information, BS allocates Multicast CID and creates MBS tree for the learnt group (if it does not exist before).

```
|--------------------------------------------------------------------------
| Progress: Time (55 sec.); Events (500,017)
| Speed: Average (105,288 events/sec.); Current (160,003 events/sec.)
| Time: Elapsed (4.7 sec.); Remaining (8.1 sec.)
| DES Log: 5 entries
|--------------------------------------------------------------------------
Sending Signal message
Sending Signal message
Multicast IP Address:224.0.6.1------Related Mapping MT-CID:1

                        (ODB 12.0.A: Event)
```

Fig 4.16: OPNET Console showing Multicast IP Address Mapping with MT-CID

Fig 4.16 is the OPNET Console window showing the mapping from the Multicast IP address, in the IP network layer to the MT-CID in the MAC layer. According to the message below the dotted line box, we can see that the BS sends a signaling message with an important content. As shown in the bottom line, the Multicast Group IP address (224.0.6.1) is mapped with the MT- CID (ID: 1).

4.3.1.1.4 MBS service Provisioning

Of the two kinds of bandwidth allocations for the multi-hop relay system we introduced in Section 3.3.2, we have simulated the "bandwidth with distributed scheduling" allocation scheme. In this scheme, the MR-BS may send scheduling information to the RS in advance to indicate when and how much bandwidth it will allocate and schedule for the service in the future.

WiMAX.BS Admission Control Statistics for...

File Edit View Help

	Statistic	Value
1	Total Capacity (Msps)	12.211200
2	-> Uplink Capacity (Msps)	5.299200
3	-> Downlink Capacity (Msps)	6.912000
4	Admitted Capacity (Msps)	7.626600
5	Number of Admitted Connections	21
6	Number of Rejected Connections	1

Fig 4.17: RS1 Admission Control

Fig 4.17 shows an example of the results for the RS1 admission control which gives us an overview of the capacity usage and admission control. In this provision bandwidth allocation (bandwidth with distributed scheduling), we can see (Line 6) the RS has rejected one connection.

	Service Subscriber	Direction	Class	Scheduling Type	Requested BW (bps)	Polling Overhead (bps)	Rejected BW (sps)	Modulation
1	SS1-3	Uplink	Gold	UGS	5,000,000	N/A	1,673,400	16-QAM
2								
3	Total				5,000,000	0	1,673,400	

Fig 4.18: RS1 Rejected Connections

Fig. 4.18 above shows (Line 1) that UGS is the highest class (Gold class) in the QoS level. It is rejected because the requested bandwidth it requires is too much for the RS to accommodate along with others.

Fig 4.19 shows detail admission control results of RS1 in Fig 4.17. The admission control depends on the QoS category of the service flows, the direction of the service flows and the modulation of the SS. According to the QoS class we predefined in the WiMAX

Line #	Service Subscriber	Direction	Class	Scheduling Type	Request BW(bps)	Polling Overhead	Admitted BW(bps)	Modulation	Coding Rate
0	SS1-1	Uplink	System Default	BE	0	N/A	N/A	QPSK	1/2
1	SS1-1	Uplink	Broadcast	BE	0	N/A	N/A	QPSK	1/2
2	SS1-1	Uplink	Gold	UGS	5,000,000	N/A	1,673,400	16-QAM	3/4
3	SS1-1	Uplink	Silver	rtPS	500,000	32,000	199,400	16-QAM	3/4
4	SS1-1	Downlink	System Default	BE	0	N/A	N/A	QPSK	1/2
5	All	Downlink	Broadcast	BE	0	N/A	N/A	QPSK	1/2
6	SS1-1	Downlink	Gold	UGS	5,000,000	N/A	1,115,600	64-QAM	3/4
7	SS1-1	Downlink	Silver	rtPS	500,000	N/A	111,600	64-QAM	3/4
8	SS1-2	Uplink	System Default	BE	0	N/A	N/A	QPSK	1/2
9	SS1-2	Uplink	Broadcast	BE	0	N/A	N/A	QPSK	1/2
10	SS1-2	Uplink	Gold	UGS	5,000,000	N/A	1,673,400	16-QAM	3/4
11	SS1-2	Uplink	Silver	rtPS	500,000	32,000	199,400	16-QAM	3/4
12	SS1-2	Downlink	System Default	BE	0	N/A	N/A	QPSK	1/2
13	SS1-2	Downlink	Gold	UGS	5,000,000	N/A	1,115,600	64-QAM	3/4
14	SS1-2	Downlink	Silver	rtPS	500,000	N/A	111,600	64-QAM	3/4
15	SS1-3	Uplink	System Default	BE	0	N/A	N/A	QPSK	1/2
16	SS1-3	Uplink	Broadcast	BE	0	N/A	N/A	QPSK	1/2
17	SS1-3	Uplink	Silver	rtPS	500,000	32,000	199,400	16-QAM	3/4
18	SS1-3	Downlink	System Default	BE	0	N/A	N/A	QPSK	1/2
19	SS1-3	Downlink	Gold	UGS	5,000,000	N/A	1,115,600	64-QAM	3/4
20	SS1-3	Downlink	Silver	rtPS	500,000	N/A	111,600	64-QAM	3/4
21									
22	Total				28,000,000	96,000	7,626,600		

Fig 4.19: RS1 Admission Control

attribute simulation node, each SS will ask for the certain radio resources. For example, we assigned the Gold class to a QoS category UGS which has a predefined requiring 5,000,000 bps bandwidth per service flow. SS1-1 has the connections of one Gold, and one Sliver for uplink transmission and one Gold one Silver for the downlink transmission. The BS will decide whether to admit or reject the connection according to its own resources.

In our simulation, we simulated the bandwidth with distributed scheduling, which is 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. Fig 4.19 also shows the total admitted bandwidth is 7,626,600 bps as reported in Fig 4.17 (Line 4).

4.3.1.1.5 Populate Relay Path and M- CID Binding

After the MBS provision operation, the BS then signals all the intermediate RSs to populate the MBS tree information. The signaling message uses the multicast management CID in the header, and its body includes the MT-CID and the path IDs associated with the designated RS. The intermediate RS would store this binding information in their forwarding table (if they are along the given path).

There are several binding or also can be called mapping in our approach. Fig 4.20 and Fig 4.21 show how the binding works. The example of how the binding works can refer to Fig 3.4. In Fig 3.4, P1 stands for the Path ID, and Path ID has the information of its along stations after sending DSA-REQ, DSA-RSP back and forth for several times. As seen in Fig. 4.20, when the RS received the broadcasting signaling message sent by the BS, the RS1 (2) will first check if itself is along the path. If it is, the RS1 (2) would store the Path ID in its forwarding table. In Fig 4.20, RS1 received the signal message (Line 1), decapsulated the MAC PDU and found itself in Path ID 1(Line2), so RS1 stored Path ID 1 in its forwarding table (Line3). Fig 4.21 shows the similar actions as we described in Fig 4.20, which is RS2 received the signal message (Line 1).

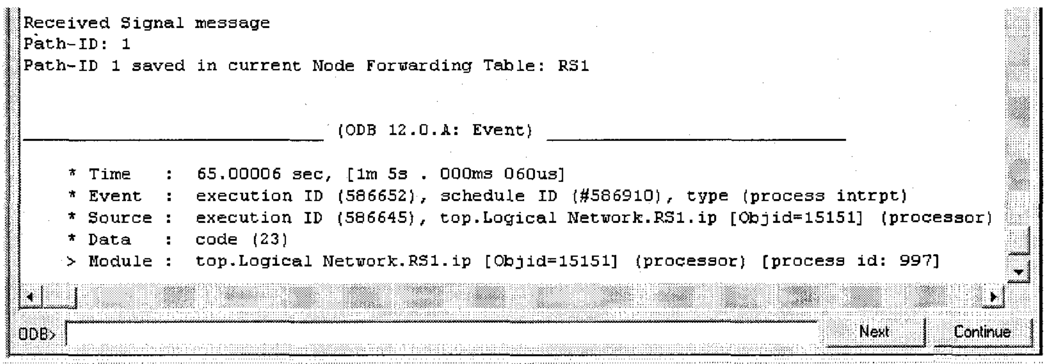


Fig 4.20: OPNET Console Window showing when RS1 received Signal Message

4.3.1.2 Verification of the Data Plane Functions

Section 4.3.1.1 concludes the functions of the control plane. We now verify the functions associated with the multicast traffic forwarding action in the Data Plane.

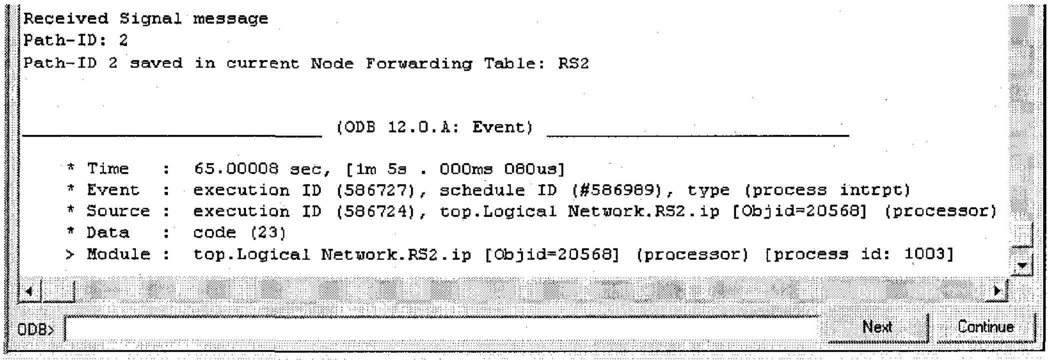


Fig 4.21: OPNET Console Window showing when RS2 received Signal Message

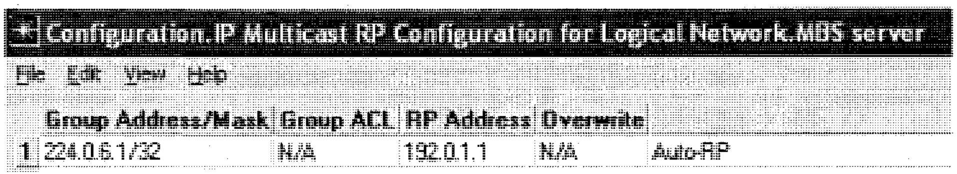


Fig 4.22: OPNET PIM-SM RP Configuration

4.3.1.2.1 Sending Multicast Traffic Via PIM

Fig 4.22 shows the OPNET PIM-SM RP Configuration we set in our simulation. As we mentioned in Section 2.5.1, the router in a PIM-SM protocol has to be assigned as a specific RP for certain multicast group. So the multicast traffic of certain group comes, the access router will unicast the traffic to the RP, and let the RP to transmit the traffic according to an RPT or SPT. We can see certain multicast group address for the RP is 224.0.6.1 (Line 1 Column 1). The IP address we manually assigned to the RP is 192.0.1.1(Line 1 Column 3).The configuration method is Auto-RP (Line1 Column 5).

Fig 4.23 shows how the multicast traffic is forwarded in a CSN (a traditional backhaul network). As introduced in Section 2.5.1, a PIM-SM protocol relies on an underlying topology-gathering protocol to populate a routing table with routes. Here in Column 2 (Source Protocol), one can see the protocol used is RIP (Routing Information Protocol). Take the first line as an example. Because it is the routing table for the MBS server, therefore if the next hop node is the MBS server, it means there is no need to forward traffic. We know this because the source and the destination are the same according to the name showed in the

Next Hop Node column[1]. So in Line 1 of Column 4, we can see the hop count (metric) is 0. The closet path for the MBS server to transmit the traffic to ASN-Gateway 1 can be found in Line 8. In Line 8, we knew the next hop IP address (Column 5) with the matched name in Column 6 IP router1 (ASN-Gateway1). The MBS in this case can directly transmit the traffic to the ASN-Gateway1 because the hop count (metric) is 1 in Column4.

Performance.IP Forwarding Table at End of Simulation for Logical Network.MBS server

File Edit View Help

	Destination	Source Protocol	Route Preference	Metric	Next Hop Address	Next Hop Node	Outgoing Interface	Outgoing LSP	Insertion Time (sec
1	192.0.0.0/24	Direct	0	0	192.0.0.1	Logical Network.MBS server	IF32	N/A	0.000
2	192.0.1.0/24	Direct	0	0	192.0.1.1	Logical Network.MBS server	IF10	N/A	0.000
3	192.0.2.0/24	RIP	120	2	192.0.1.2	Logical Network.IP Router2	IF10	N/A	9.238
4	192.0.3.0/24	RIP	120	3	192.0.1.2	Logical Network.IP Router2	IF10	N/A	15.824
5	192.0.4.0/24	RIP	120	3	192.0.1.2	Logical Network.IP Router2	IF10	N/A	9.238
6	192.0.5.0/24	RIP	120	2	192.0.8.2	Logical Network.IP Router1	IF11	N/A	7.661
7	192.0.6.0/24	RIP	120	1	192.0.1.2	Logical Network.IP Router2	IF10	N/A	9.238
8	192.0.7.0/24	RIP	120	1	192.0.8.2	Logical Network.IP Router1	IF11	N/A	7.661
9	192.0.8.0/24	Direct	0	0	192.0.8.1	Logical Network.MBS server	IF11	N/A	0.000
10	192.0.9.0/24	Direct	0	0	192.0.9.1	Logical Network.MBS server	IF12	N/A	0.000
11	192.0.10.0/24	RIP	120	1	192.0.1.2	Logical Network.IP Router2	IF10	N/A	9.238
12	192.0.11.0/24	RIP	120	2	192.0.1.2	Logical Network.IP Router2	IF10	N/A	9.238
13	192.0.12.0/24	RIP	120	2	192.0.1.2	Logical Network.IP Router2	IF10	N/A	9.238
14	192.0.13.0/24	RIP	120	3	192.0.1.2	Logical Network.IP Router2	IF10	N/A	9.238
15	192.0.14.0/24	RIP	120	3	192.0.1.2	Logical Network.IP Router2	IF10	N/A	9.238
16	192.0.15.0/24	RIP	120	1	192.0.8.2	Logical Network.IP Router1	IF11	N/A	7.661
17	192.0.16.0/24	RIP	120	1	192.0.8.2	Logical Network.IP Router1	IF11	N/A	7.661
18									

Fig 4.23: IP Forwarding Table at CSN Network Session

After we applied PIM-SM multicast routing protocol, we can see from Fig 4.24 which interface (Line 1-2, Column6) should be forwarded the multicast traffic.

Performance.PIM-SM Routing Table at 180 seconds for...

File Edit View Help

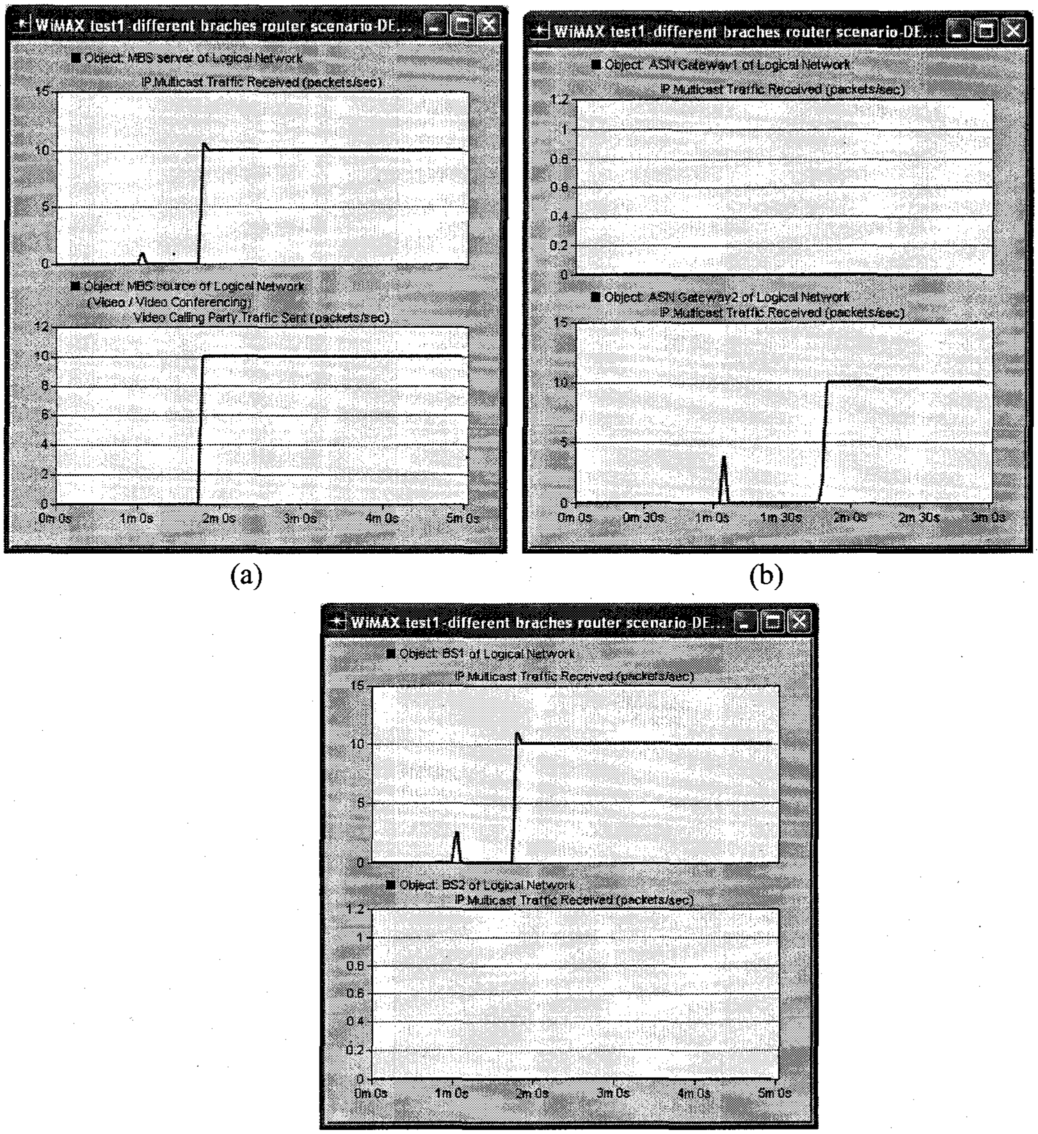
	Group Address	RP Address	Source Address	Type	Incoming Interface	Outgoing Interfaces
1	224.0.6.1	192.0.1.1	192.0.9.2	Shortest Path	IF12	Local Group, IF10
2	224.0.6.1	192.0.1.1	192.0.1.1	Shared Tree	None - RP Node	Local Group, IF10

Fig 4.24: PIM-SM Routing Table for MBS Server

Fig. 4.25 provides the traces at the locations of MBS, ASN1 and BS1. The vertical axis is throughput (packets/sec). From Trace (a), we can see that the MBS source (bottom figure) starts sending the video conferencing stream at 10 packets/sec at time =1m 42s. The MBS serve (top figure), which is attached to the MBS source, immediately transfers the traffic

[1] When we open the IP attribute of each node (not shown here), we can see the assigned IP address, and know the matching relationship between the node name and node IP address.

according to the PIM-SM RP Tree. Because there is no multicast receivers belonging to BS2, so the MBS server automatically prune the tree and prevent the multicast traffic from sending



(a) (b)

(c)

Fig 4.25: MBS Traffic Trace of Difference Locations

(a) Received by MBS server (top); sent at MBS source (bottom)
(b) Received by ASN1 (top); received by ASN2 (bottom)
(c) Received by BS1 (top); received by BS2(bottom)

to BS2 at ASN Gateway2. This can be seen from Fig 4.25 (b) BS 2 received 0 packets/sec multicast traffic from the MBS server (top figure). Fig 4.25 (c) shows the received packet at the location of BS1 and BS2. Because the multicast traffic was already pruned at ASN Gateway2, so as the down link of the ASN Gateway 2, BS2 did not receive any multicast packet sent from ASN Gateway2. The spike in the diagram is the PIM-SM control packet ahead of the real multicast traffic.

4.3.1.2.2 Mapping PIM to each M-CID and send MAC PDU downstream

When a BS receives multicast traffic from an ASN Gateway, it will map the SDU into 802.16 MAC PDU by using the Multicast-CID. Then it creates a tunnel MAC PDU by using the MT-CID and encapsulates multiple 802.16 MAC PDUs into the tunnel (if they are in the same MBS group). Finally, the tunnel MAC PDU is sent downstream.

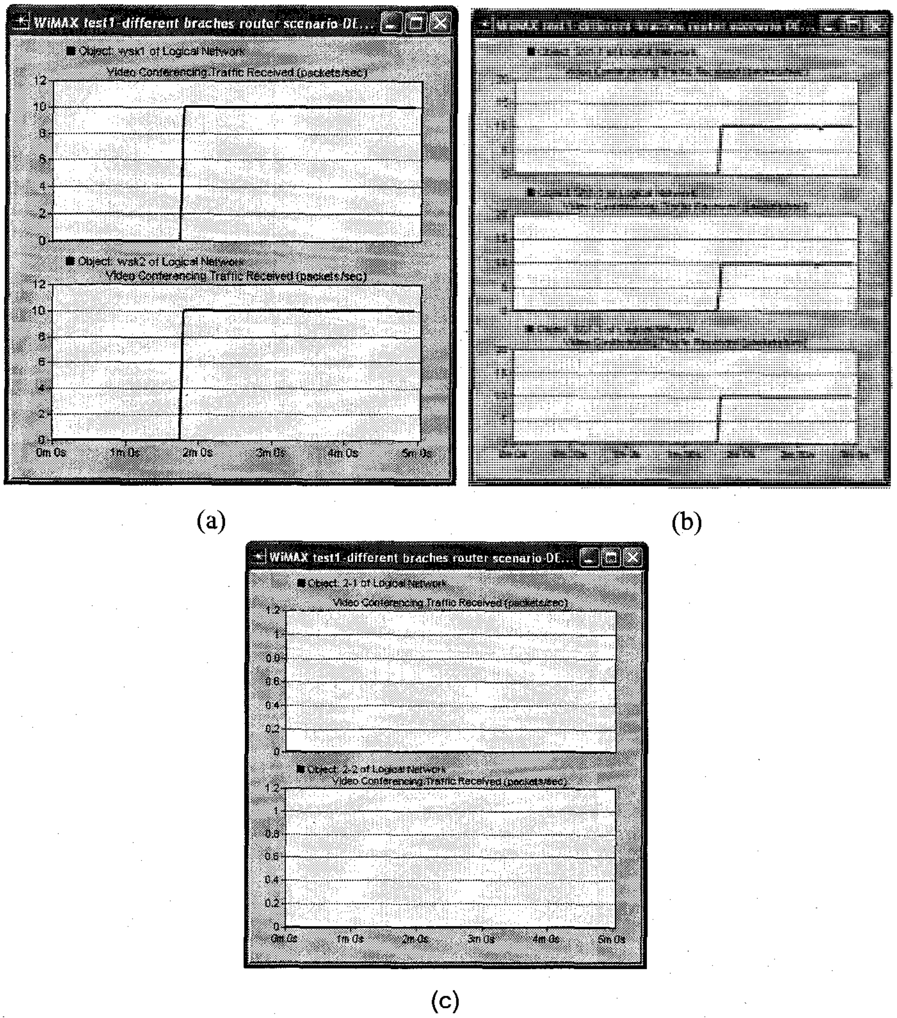


Fig 4.26: Multicast Traffic received at end stations for Scenario 1

By using the Multicast Tunnel CID approach, we can see that in Fig 4.26, only the SSs who subscribe the multicast traffic received the video conferencing traffic eventually. The traffic curve of the received station is almost the same as the source traffic, except in couple times, there is a slight packet drop due to either the instability of the video conferencing transmission.

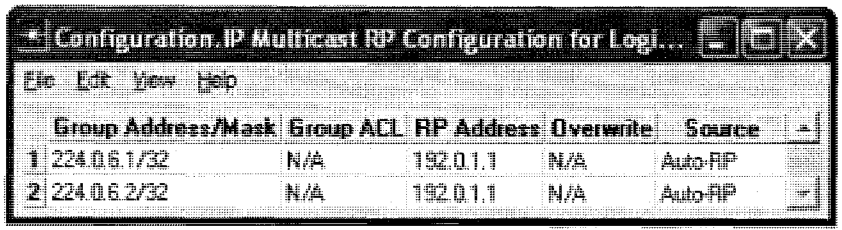
4.3.2 Scenario 4

We want to verify a new provision criterion for the BS resource allocation which is different from Scenario 3. To do this, we allow the BS to have the capability to dynamically allocate downlink bandwidth to different groups at MAC layer. Through an inter-layer design, we can provision the MAC Layer with the MBS knowledge (IP Layer). For example, it will know the number of the subscribers of each multicast group via the IGMP snooping procedure we demonstrated in Section 4.3.1.1.2.

We also want to increase the efficiency of utilizing radio resource through this provision scheme. Here, a BS gives most (2/3) of the bandwidth to those who have more subscribers to assure their multicast traffic demands while those with less subscribers would have a reduced bandwidth. Take IPTV as a real example, different multicast groups would include different numbers of TV channels. In order to satisfy the demand of the audience, we allocate enough bandwidth to a group with large number of TV channels, and set pre-regulated bandwidth in some regulated period for those groups with small number of TV channels.

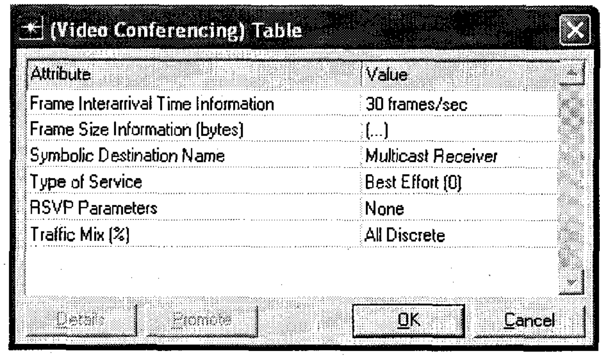
In Scenario 4, we set two multicast groups which have different traffic intensities, and each RS is attached to a different number of the subscriber SSs. On the RS1 side, there are three SSs joined in the multicast traffic group while on the RS2 side, we let wsk1 and wsk2 join another multicast group. We considered regulating the certain bandwidth for different multicast groups at certain time periods (e.g, we set 180 seconds in our simulation) based on the assumption that the SSs belong to different Access RSs and subscribe different multicast traffic contents. The number of subscribers attached to different relay braches is different. In the simulation, we are going to provide enough bandwidth for Multicast Group1 which is on the RS1 side in order to guarantee the multicast traffic of Group 1 to reach the subscribers while restricting the bandwidth for the RS2 side. In our simulation, we use time allocation to represent the bandwidth allocation (i.e., we set 50 seconds to Group1 for traffic transmission and only allow the multicast traffic of Group 2 to forward downlink for 20 seconds (during 130 seconds to 150 seconds).

According to the requirement of Scenario 4, we need to set the multicast group addresses for two different multicast groups and assign the RP for the two multicast groups. According to the requirement of Scenario 4, we need to define an application to Group 1 and Group 2. Fig. 4.27 shows the details of Application 1 which has a Multicast Group address of 224.0.6.1. For these two multicast groups which has group address 224.0.6.1 and 224.0.6.2, We set both multicast groups' RP at MBS server which again is the nearest node to the MBS source, and assign the RP's IP address to be 192.0.1.1.(Line 1-2, Column 3).



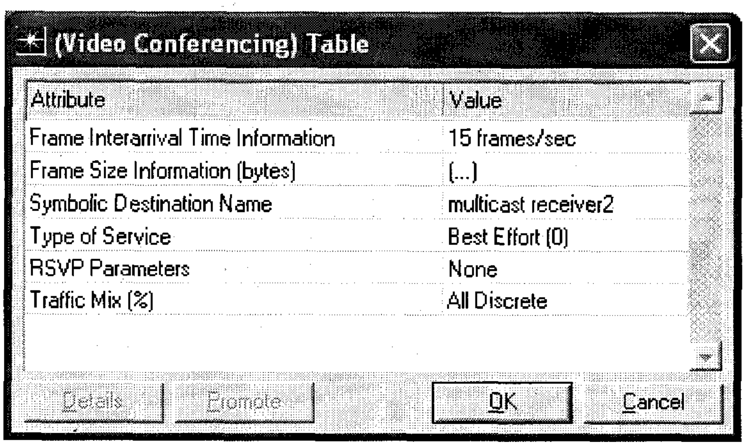
	Group Address/Mask	Group ACL	RP Address	Overwrite	Source
1	224.0.6.1/32	N/A	192.0.1.1	N/A	Auto-RP
2	224.0.6.2/32	N/A	192.0.1.1	N/A	Auto-RP

Fig 4.27: Auto-RP Configuration on MBS Server



Attribute	Value
Frame Interarrival Time Information	30 frames/sec
Frame Size Information (bytes)	(...)
Symbolic Destination Name	Multicast Receiver
Type of Service	Best Effort (0)
RSVP Parameters	None
Traffic Mix (%)	All Discrete

Fig 4.28: Application Definition for Multicast group 1



Attribute	Value
Frame Interarrival Time Information	15 frames/sec
Frame Size Information (bytes)	(...)
Symbolic Destination Name	multicast receiver2
Type of Service	Best Effort (0)
RSVP Parameters	None
Traffic Mix (%)	All Discrete

Fig 4.29: Application Definition for Multicast group 2

Fig 4.28 shows the definition for Application 1: data rate is set at 30 Frames/sec, the frame size is 100 bytes constantly, the type of service is BE. Fig. 4.29 shows the definition for

Application 2 which is very similar to Application 1 except the data rate is set at 15 Frames/sec and its multicast group address is 224.0.6.2.

We skipped the same procedure which we already showed in Scenario 3. The difference is discussed in Scenario 4.

```
Multicast IP Address:224.0.6.1------Related Mapping MT-CID:1

_____________________________ (ODB 12.0.A: Event) _____________________________

   * Time    :  65.0 sec, [1m 5s]
   * Event   :  execution ID (586007), schedule ID (#3306), type (self intrpt)
   * Source  :  execution ID (2794), top.Logical Network.BS1.ip [Objid=6261] (pro
   * Data    :  code (0)
   > Module  :  top.Logical Network.BS1.ip [Objid=6261] (processor) [process id:

Multicast IP Address:224.0.6.2------Related Mapping MT-CID:2

_____________________________ (ODB 12.0.A: Event) _____________________________

   * Time    :  65.518177935915 sec, [1m 5s . 518ms 177us 935ns 915ps]
   * Event   :  execution ID (591568), schedule ID (#591839), type (process intrp
   * Source  :  execution ID (591567), top.Logical Network.RS2.ip [Objid=20682] (
   * Data    :  code (23)
   > Module  :  top.Logical Network.RS2.ip [Objid=20682] (processor) [process id:
```

Fig 4.30: MT-CID and IP Multicast Group Address Mapping

Fig 4.30 is the OPNET console showing the multicast group addresses mapping to different M – CIDs. In Line 1, Multicast Group Address 224.0.6.1 is mapped to M- CID 1. In Line 8, Multicast Group Address 224.0.6.2 is mapped to M- CID 2.

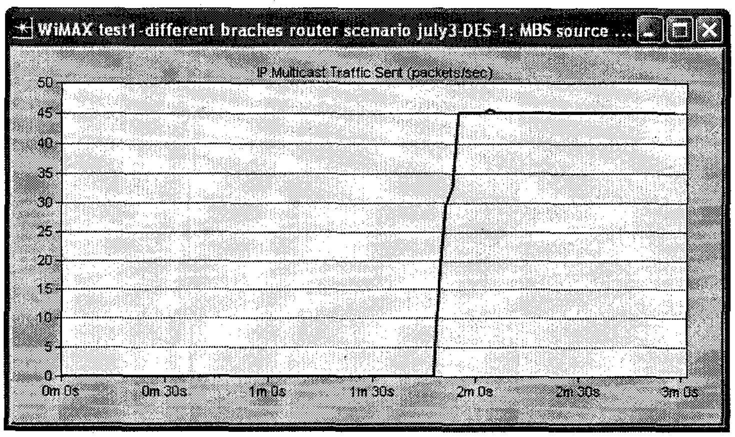


Fig 4.31: Multicast Traffic sent by the MBS Source

Fig 4.31 shows the multicast traffic sent by the MBS source. As we defined in Scenario 4, there are two multicast traffic groups with different data rate (30 Frames/sec, 15 Frames/sec). So the total multicast stream's sending rate is 45 Frames/sec from the MBS source.

According to a different number of subscribers belonging to RS1 and RS2, we know that (the number of subscriber MSs attached to the RS1 = 3) > (the number of subscriber MSs attached to the RS2 = 2). From the application perspective, we can see that the traffic intensity we defined in the multicast group1 is heavier that that of multicast group 2 (see Fig 4.28, Fig 4.29).

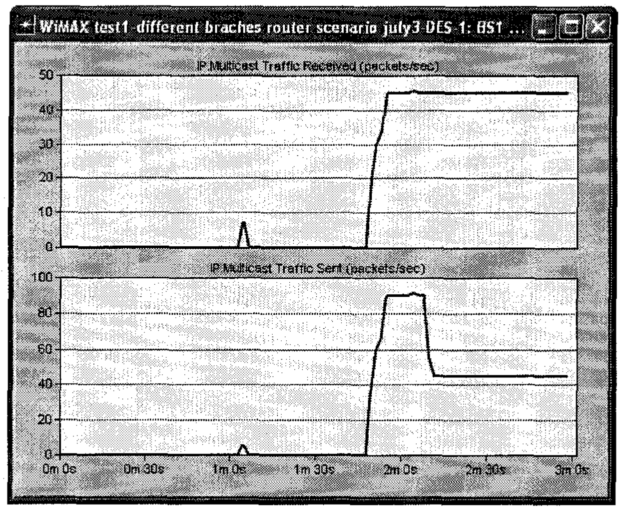


Fig 4.32: BS1 Bandwidth provision according to MBS Info in Scenario 4

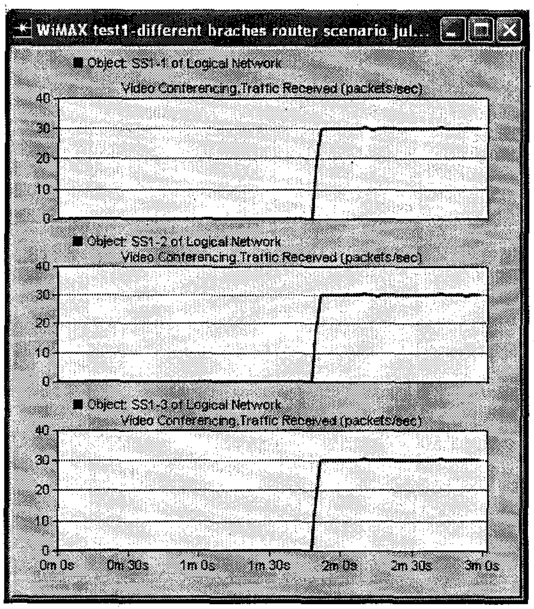


Fig 4.33: Multicast Traffic received at end stations for Multicast Group 1

Fig. 4.32 and Fig 4.33, Fig 4.44(below) provide the received multicast traffic at the location of the BS1, SS 1-1, SS1-2, SS1-3, and wsk1, wsk2 after applying the new provision scheme.

The vertical axis is throughput (packets/sec). Fig 4.33 shows that the throughput of SS1-1, SS1-2, and SS1-3 is stable at 30 Frames/sec without packet drop during the transmission. Fig 4.34 shows that the wsk1 and the wsk2 only received the multicast traffic from 130 seconds to 150 seconds, which is a pre-assigned time period limited by the BS according to the provision scheme. So we can conclude that the provision scheme we proposed can directly affect the throughput quality of the multicast traffic received by the subscribers.

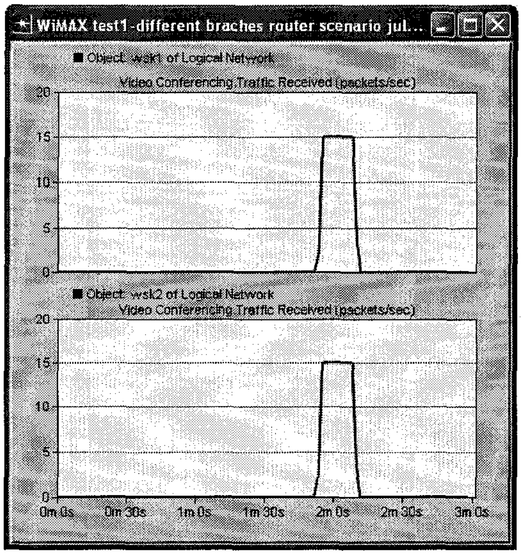


Fig 4.34: Multicast Traffic received at end stations for Multicast Group 2

4.4 Concluding Remark

In this chapter, we have simulated the multicast procedure according to what we proposed in Chapter 3. We started from networking ranging, dynamic topology discovery to discover the current RSs and the MS/SSs. Those MS/SSs who wish to join the multicast groups send the join information to the MBS server. We have installed IGMP snooper in every BS so that the BS can have the same knowledge as the MBS server. Relying on this knowledge, BS can pre-allocate proper bandwidth for each multicast group according the size of the multicast traffic, the number of the subscriber and other QoS parameters. We define an inter layer multicast process, which maps IP Layer (L3) IP multicast IP address to the MAC Layer (L2) M – CID (Multicast CID). We have verified the multicast traffic process for WiMAX relay networks by simulating all the steps. From the result, we can see that the final throughput is almost the same as what is sent by the multicast source. So this algorithm is quite feasible to implement in reality.

In the next chapter, we will use video conferencing and voice stream to evaluate the performance of the multicast traffic in WiMAX MR Networks.

Chapter 5
Modeling of Performance Evaluation of Video and Voice Applications

In this chapter, we shall evaluate the performance of video and voice applications in our proposed WiMAX multi-hop relay networks. We are going to discuss the modeling of the proposed network architecture, and the assumptions which we assumed and applied into our proposed approach and the simulation. The two applications (Video and Voice) are considered because they require relatively higher demand of QoS during the transmission. A small and a big network size are used under different traffic intensities scenarios.

5.1 Modeling and Assumptions

Due to the request to go through BS for data and control operation, our network can be regarded as a tree topology network that has a hierarchical architecture with BS at the top of the hierarchy and the SS in the bottom layer. 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 node receiver. To simplify the simulation, we only built one layer RS in the network model, that is the BS transmit the traffic to its SS via one RS. Further details can be found in Section 3.1 on network modeling. The following are the assumptions we take in modeling our MBS:

1. Only single-BS will be considered: This is because the multi-BS access (i.e., MBS zone case) can always be decomposed as multiple single-BS accesses with the coordination at the ASN-GW, and all single-BS access cells will show the same behavior.
2. The WiMAX multi-hop relay network is static even though our "MT– CID Approach" can support mobility management: This is because the WiMAX module we obtained from OPNET can only support static operation.
3. An Ethernet model [OpNe06] is used for the BS and access RS (R-link) because there is no OPNET module to support WiMAX Relay Architecture.
4. The buffer size of a backhaul station is infinite: This is because we do not want to have queuing delay in a backhaul network to complex the end to end design due to the different buffer size capacity of different vendors. Likewise, we do the same for the MBS server

and ASN in the IP core network.

5. The buffer size of the BS and RS use the default values from OPNET. This is because these buffers are integrated in the WiMAX node by OPNET and we are unable to obtain these values so far. FIFO queuing discipline is used for the scheduling grant buffer of BS and RS according to the OPNET design documentation of WiMAX module [OpNe05].
6. The arrival traffic has a uniform distribution for the inter-arrival time and a fixed frame size.
7. IGMP version 3 is used. This is because we want to take advantage of the suppression of host membership reports which has been removed in IGMPv3.

For readers' information on Assumption 7, note that there is a suppression system for the host report in IGMP version 1, 2. If the host overhears other hosts sending the same multicast group join report, it will cancel sending a pending membership reports. In IETF IGMP v3 draft, the author listed 4 reasons to explain why they remove this suppression system from the standards. The most important factor to us is that routers may want to track per-host membership status on an interface. This tracking ability allows routers to implement fast leave from the subscriber group (e.g., for layered multicast congestion control schemes) as well as to track membership status for possible accounting purposes. The function of track membership is exactly what we want to use in our operation process because of the criteria of the new provision scheme we will mention in Section 4.3.2

5.2 Performance Evaluation

We use different performance measures to evaluate the capability of the multicast networks.

1. Packet End to End delay (sec) is defined to be 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. Jitter (sec) for voice application is defined to be the variation in delay during the traffic transmission period when measured with respect to the source.
3. Packet Delay variation is the delay variation incurred by voice application packet while going from a calling party to called party and vice-versa.
4. 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.

5. Packet Loss (packet/sec) is defined to the discarding of data packets in a network when a device (switch, router, etc.) is overloaded and cannot accept any incoming data at a given moment.

Note that Jitter is an unwanted variation of one or more signal characteristics in electronics and telecommunications. It also has various differences in our OPNET simulation. If two consecutive packets leave the source node with time stamps t1 & t2 and are played back at the destination node at time t3 & t4, then: jitter = | (t4 - t3) - (t2 - t1)|. Supposedly, it is one measuring method of delay variation in (3). However, OPNET has used these two measures separately and we could not obtain the mathematical definition of (3). So we present both measures in the following sections.

Because there is no packet loss metrics in application level for us to measure in OPNET, we only capture the Packet Drop performance in WiMAX level. All measurements are the average of 3 simulation runs (with different seeds of 94737, 87259, and 63856 for the simulation). 95% confidence intervals are also obtained. In general, the confidence intervals are quite small (e.g. (2.77E-03, 2.84E-03) for the Jitter of SS1-1 at 8kbps point in Fig 5.9. Therefore they are not repeated for every figure 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.

The network size is determined by the number of the SSs which are using WiMAX air interface to receive the multicast traffic. In our simulation, we evaluated the performance based on two different network sizes, a small network of 3 nodes, and a big network of 30 nodes.

5.3 Video Applications

In order to obtain an idea of how different sending rate of video applications (measured in bps) will influence the video multicast performance in the WiMAX MR Environment, we use different frames rates (while fixing the frame size to100 bytes) in a video conferencing attribute. The QoS level chosen for the video application is BE (Best Effort). The following are 5 different scenarios we investigated for each video application:

1) A low intensity (10 frames/sec) with a frame size of 100 bytes

2) A medium-low intensity (12 frames/sec) with a frame size of 100 bytes

3) A medium intensity (15 frames/sec) with a frame size of 100 bytes

4) A medium-high intensity (23 frames/sec) with a frame size of 100 bytes

5) A high intensity (30 frames/sec) with a frame size of 100 bytes.

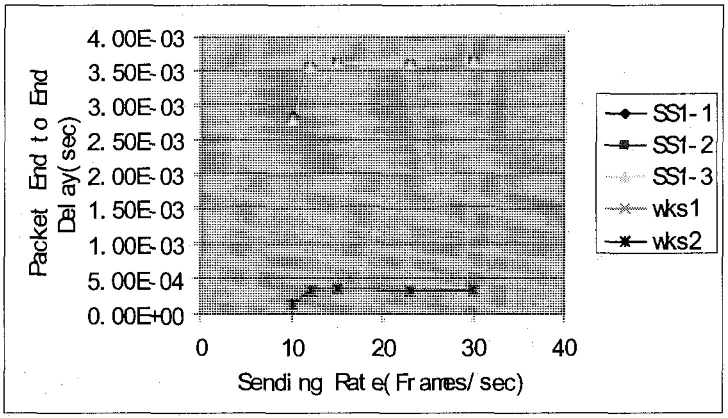


Fig 5.1: End to End Packet Delay vs Sending Rate

5.3.1 Small Networks

We use a network of 3 nodes according to Fig 4.12. In Fig 5.1(above), we can see the packet delay in video applications is very small. The packet end to end 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 rises from a sending rate 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, 1-2, 1-3. This is probably due to the Ethernet line we use to emulate the access link between relay station 2 and wsk1, wsk2. The performance of wired transmission should be better than that of wireless transmission.

In Fig 5.2, we can see the packet delay variation is very slight. 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 it is falling 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. This is probably due to the Ethernet line we use to emulate the access link between relay station 2 and wsk1, wsk2. The performance of wired transmission should be better than that of wireless transmission.

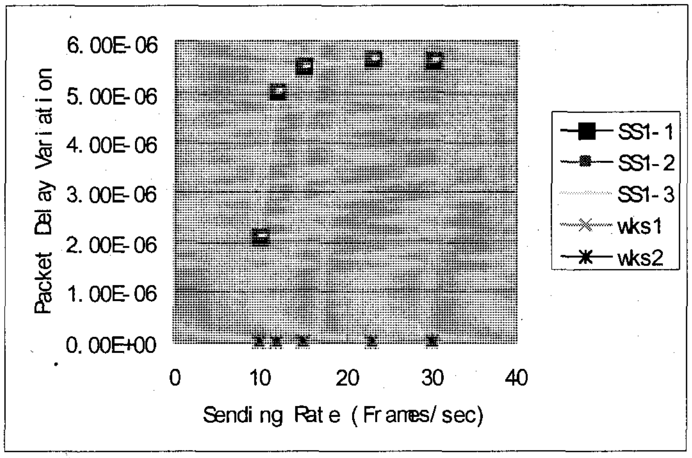


Fig 5.2: Packet Delay Variation vs Sending Rate

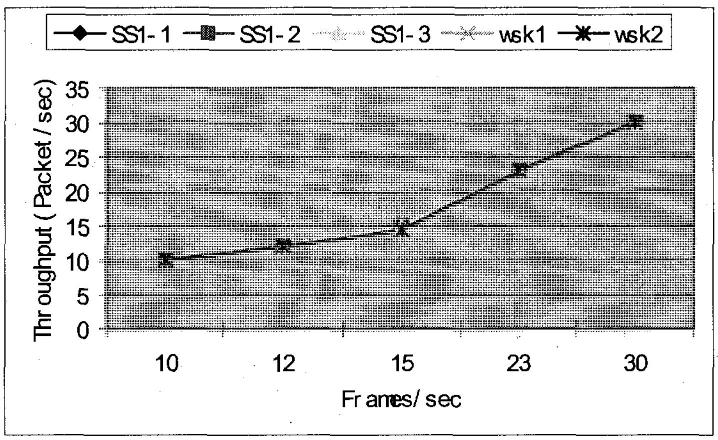


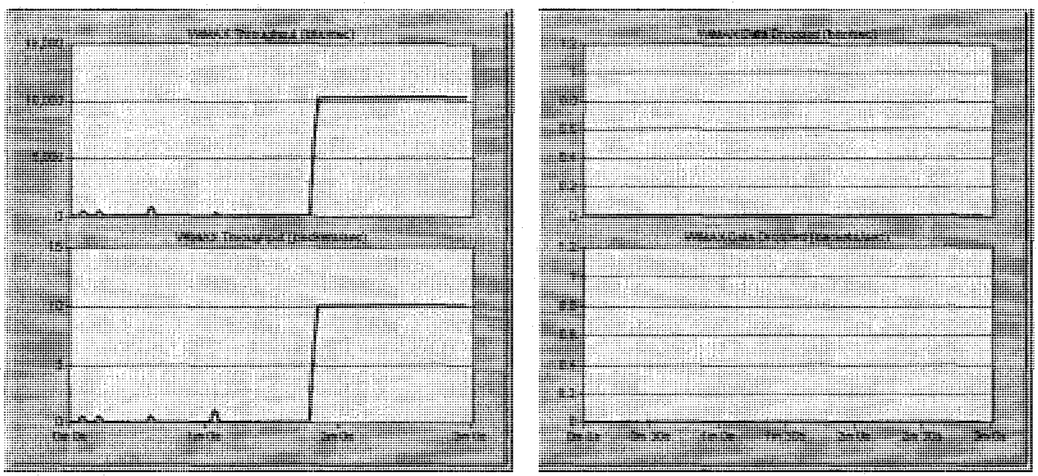
Fig 5.3: Throughput vs Sending Rate

In Fig 5.3, we can see the time average throughput is increasing linear according to what we set for different sending rate (frames per second). There is no packet loss in the three scenarios we measured for the WiMAX (RS to MS) air interface as shown in Fig 5.4 below.

From Fig 5.4, we can see the throughput of SS1 under the traffic intensity of 10 frames/sec is steady at 10 frames/sec (Fig 5.4a) without any packet drop (Fig 5.4b). The small variation spike before the real traffic is the control frame for channel synchronization, power adjustment, etc.

5.3.2 Large Networks

We now increase the network size (the number of SSs using a WiMAX air interface) from 3 to 30 in order to evaluate how the network size will influence the video application performance in WiMAX Multi-Hop Relay Networks. We will not measure the performance of wsk1 and wsk2 in the large network scenario because we use Ethernet line for the wsk1 and the wsk2 to emulate the relay interface. Since we already measure the performance of the wsk1 and wsk2 in the small network size scenario, there is no need to measure the subscriber stations with wired link again for the large network scenario.



(a) (b)

Fig 5.4: WiMAX Throughput and Data Drop

(a) WiMAX Throughput of SS1-1 (b) WiMAX Data Drop of SS1-1

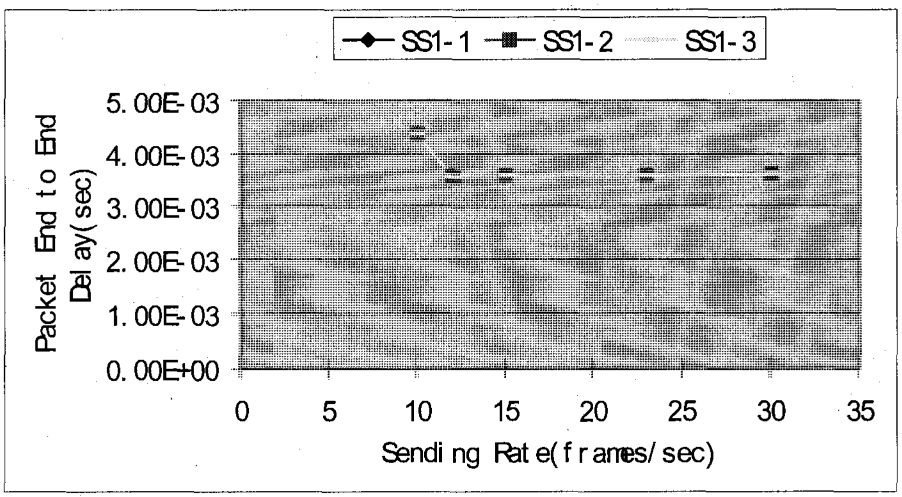


Fig 5.5: Packet End to End Delay vs Sending Rate

In Fig 5.5, we can see the packet delay in video application of the large network size is also very small. The packet end to end delay of SS1-1 is a decreasing function of the sending rate, and it levels off beyond 12 frames. 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 sending rate 10 frames/sec to 12 frames/sec, and then stays horizontal from 12 frames/sec to 30 frames/sec.

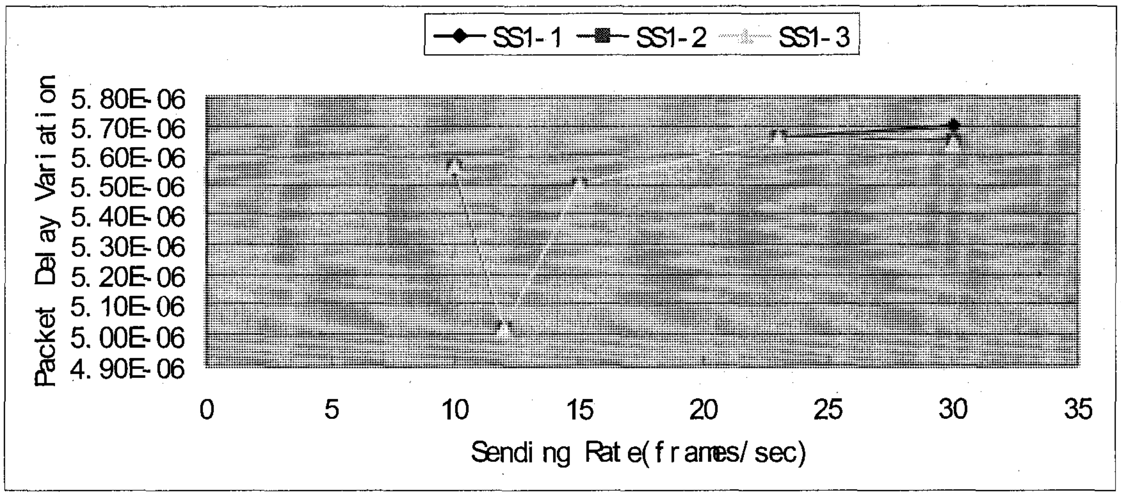


Fig 5.6: Packet Delay Variation vs Sending Rate

In Fig 5.6, we can see 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 curve of SS1-3 and SS1-2 follow the same trend as SS1-1. Though the curve shows a dramatic dip from 10 frames/sec to 12 frames/sec, but if look closely, and found they are all in the same magnitude. The actual difference is small enough to 10E-7. The factor that may cause the difference packet delay variation of different station may be due to different stream of packets coming to the dynamic queues of the router buffer according to RFC3393 [DeCh02]. 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 can be explained because the traffic is transmitted through the WiMAX air interface, different network size will vary the power and capacity arrangement. So size 3 and size 30 will affect the delay in certain level.

Again, for the video application multicasting, there is no packet loss in various scenarios we measure in WiMAX air interface (the RS to the MS) air interface throughput. The time average throughput is increasing linear according to what we set for different sending rate. So we did not put the similar throughput diagram here.

5.3.3 Comparison

We already compared the different parameters in different network sizes in the above section for video applications. In order to show the difference and effect caused by the large network size, we listed the different simulation results under the same circumstances as the following illustrations.

Table 5.1 10 frames/sec Comparison Table (Network Size)

Video 10 frames	Packet Delay Variation	Packet End to End Delay
Size = 3	2.10E-06	2.79E-03
Size = 30	5.56E-06	4.38E-03

Table 5.2 15 frames/sec Comparison Table (Network Size)

Video 15 frames	Packet Delay Variation	Packet End to End Delay
Size = 3	5.52E-06	3.60E-03
Size = 30	5.50E-06	3.59E-03

Table 5.3 30 frames/sec Comparison Table (Network Size)

Video 30 frames	Packet Delay Variation	Packet End to End Delay
Size = 3	5.61E-06	3.63E-03
Size = 30	5.66E-06	3.62E-03

Tables 5.1 to 5.3 are the averages of simulation results obtained from different seeds in one set of the simulation. The tables show that the results did not change as exponential increasing or decreasing, different parameters changed vary according to the simulation results.

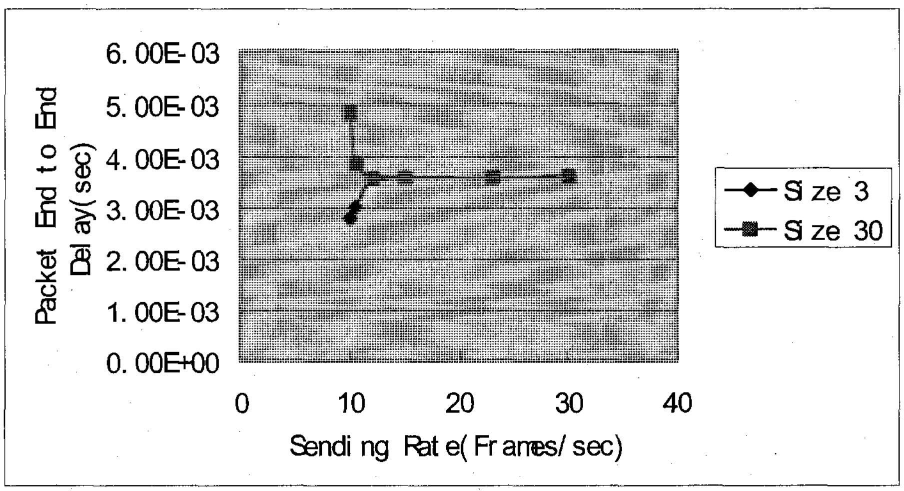


Fig 5.7: Packet End to End Delay vs Sending Rate

Fig 5.7 shows the packet end to end delay situation in different network sizes. The curve for size 3 is falling down from 10 frames/sec to 12 frames/sec, then stay horizontal from 12 frames/sec to 30 frames/sec. However, the behaviour of the network of 3 nodes is the opposite in rising initially. These results are partially affected by the delay components of each link due to the different network size, because of their variety in the power and capacity arrangement. So size 3 and size 30 will affect the delay in certain level.

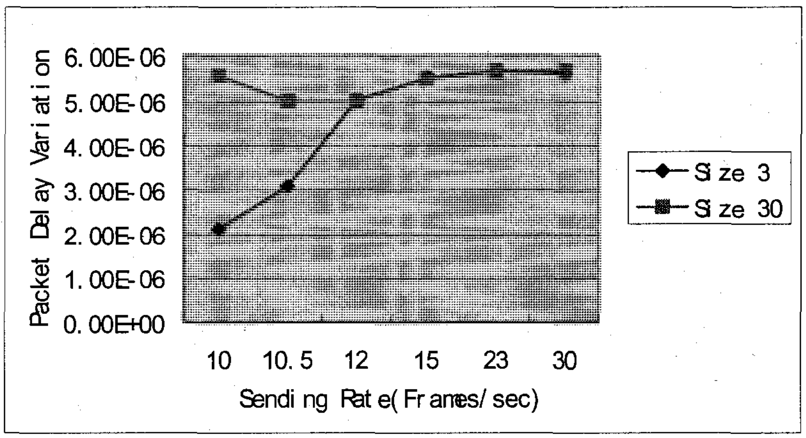


Fig 5.8: Packet Delay Variation vs Sending Rate

Fig 5.8 shows the same situation as we explained for the comparison tables. The curve for network size 3 is almost straight and the variation did not changed with the increasing of the sending rate. The curve of network size 30 rises rapidly from 10 frames/sec to 15 frames/sec, and then stays horizontal from 15 frames/sec to 30 frames/sec. Again, these results are partially affected by the delay components of each link due to the different network size.

The value of the packet end to end delay in the large network is different from what we already got in the small network, though they are in the same magnitude. This can be explained because the traffic is transmitted through the WiMAX air interface, there will be some difference for the power and capacity arrangement between size 3 and size 30. These factors will affect the delay in certain level.

5.3.4 Delay Estimation

The above results are just showing partly of the influence of the increasing of the network size. Each link (or hop) delay consists of four components, processing delay, queuing delay, transmission delay and propagation delay. In order to estimate the total delay, we also need to measure the processing delay, propagation delay and queuing delay in the process of the transmission. In summary, we have Total Delay = processing delay + queuing delay + transmission delay + propagation delay.

Table 5.4 Delay Estimation of Video Application for Network Size 30

	Processing Delay(Sec)	Transmission Delay (Sec)	Queuing Delay (Sec)
MBS Server	6.91E-06	3.75E-07	
ASN Gateway	6.89E-06	3.75E-07	
BS	6.89E-06	3.75E-07	1.99E-03
RS	5.39E-05	6.40E-04	1.99E-03
SS		6.40E-04	
Total Delay(Sec)			5.34E-03

The propagation delay for the Ethernet Line is set to be minimum and assumed be zero in our estimation. The transmission delay can be obtained from the transmission speed, which is set at 30 frames/sec. The processing delay and queuing delay are measured from the OPNET.

So the total estimation delay is 0.00435 sec in our simulation when we are using video application with the sending rate of 30 frames/sec and fixing the frame size as 100 bytes in large network which network size is 30.

5.4 Voice Applications

We use different voice applications to test how the bit rate of the codec will influence the voice multicast performance in the WiMAX MR environment, we use 5 different rates according to the 3 codec schemes (that can be used for different applications): 1) 13 kbps for GSM FR (Full rate) 2) 12.2kbps for GSM EFR (Enhanced full rate) 3) 8 kbps for G.729A, and 4) 6kbps for G723.1 5) 5.3 kbps for G.723.1. We also use an on-off model [WaWi98] for the voice process. We use an exponential distribution for the silence durations $\alpha = 0.65$ for both incoming and outing length. We also use an exponential distribution for the talk spurts with $\alpha = 0.352$ for both incoming and outing length.

5.4.1 Small Networks

In Fig 5.9 Packet End to End Delay vs Codec Rate in Voice Applications, we can see the packet delay in voice applications is also very small. The packet delay of SS1-1 is a decreasing function of the codec rate, and it levels off beyond 8Kbps. The performance of other curves is very close. The curves decrease slowly from G.723.1 to G 729A, then levels off from G729A to GSM FR. This is because of the increasing of the voice processing ability per second.

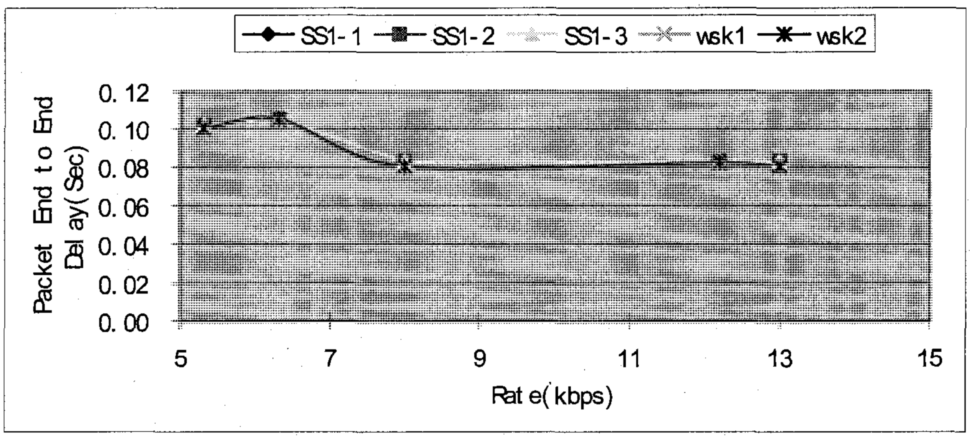


Fig 5.9: Packet End to End Delay vs Codec Rate in Voice Applications

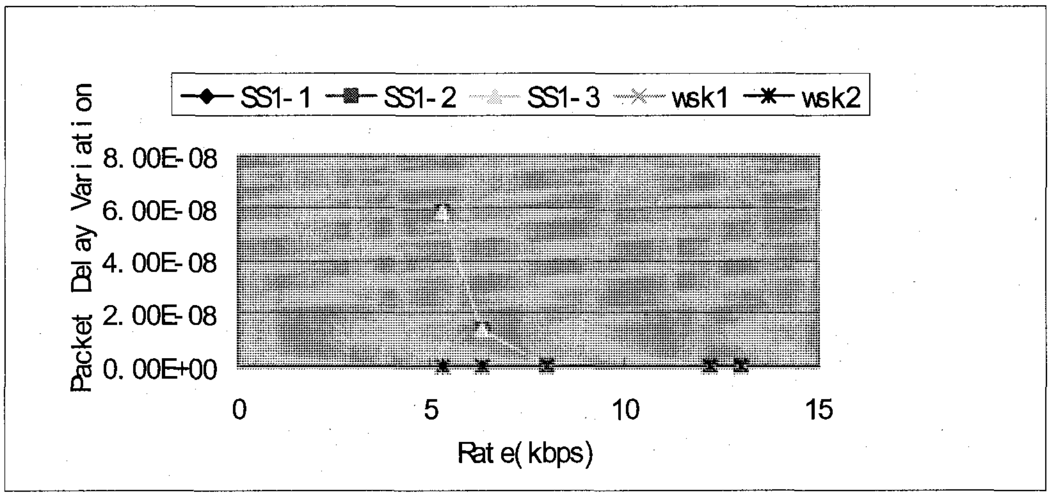


Fig 5.10: Packet Delay variation vs Codec Rate in Voice Applications

In Fig5.10, we can see the packet delay variation in voice application is very small. The packet delay of SS1-1 is a decreasing function of codec rate from 5.3Kbps to 8Kbps, and it levels off beyond 8Kbps. The trend of the packet delay variation of other stations using WiMAX air interface is similar to SS1-1. The curve of wsk1 and wsk2 is linearly parallel to the horizontal axis during the increasing of the codec rate. The difference between the packet delay variation of these stations is because the fact that we currently use Ethernet line to emulate the access link between relay station 2 and wsk1, wsk2. The performance of wired transmission should be better than that of wireless transmission.

In Fig 5.11, we can see the jitter vs codec rate has the similar trend as the packet delay variation on Fig 5.10. The jitter of SS1-1 is a decreasing function of codec rate from 5.3Kbps to 8Kbps, and it levels off beyond 8Kbps. At 8Kbps point, we also plotted the confidence interval as we mentioned in Section 5.2.

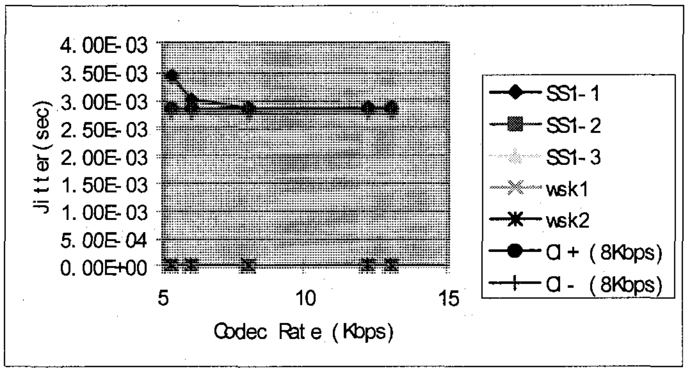


Fig 5.11: Jitter VS Codec Rate in Voice Applications

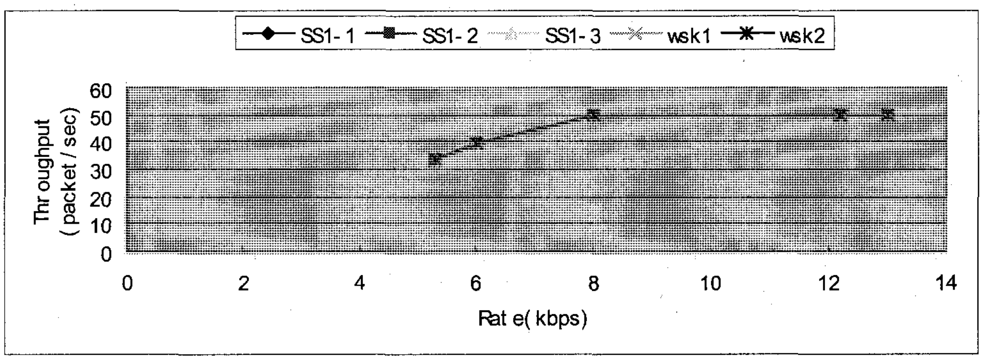


Fig 5.12: Throughput vs Codec Rate

In Fig 5.12, we can see the throughput of different voice applications is different. It's because there is certain capacity for different schemes to transmit per second. According to the simulation results we get, there is almost no packet loss in GSM FR, less loss in G729A. This is because each scheme has different codec rate. The voice processing ability per second is increasing, so it causes less packet delay.

5.4.2 Voice Application for Large Networks

We now increase the network size (the number of SSs using a WiMAX air interface) from 3 to 30 in order to evaluate how the network size will influence the voice application performance in WiMAX Multi-Hop Relay Networks. We will not measure the performance of wsk1 and wsk2 in the large network scenario of voice application as the same reason we explained in Section 5.2.2.

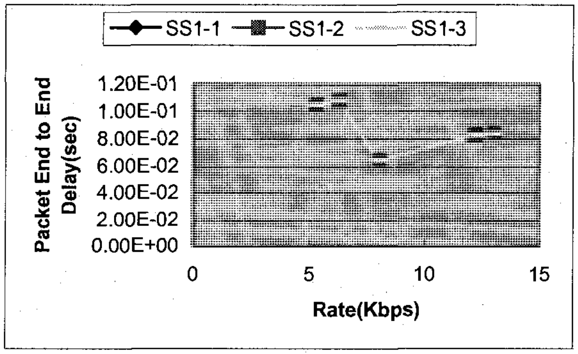


Fig 5.13: Packet End to End Delay vs Codec Rate

In Fig 5.13, we can see the packet end to end delay of SS1-1 is a decreasing function of the codec rate from 5.3Kbps to 8Kbps, and it rises slowly between 8Kbps to 13Kbps. The variable delay for different codec rate may be due to their different compression delay and the WiMAX wireless transmission for the voice traffic. The curves of SS1-2, SS1-3 are overlapping with that of SS1-1, which also follow the same trend.

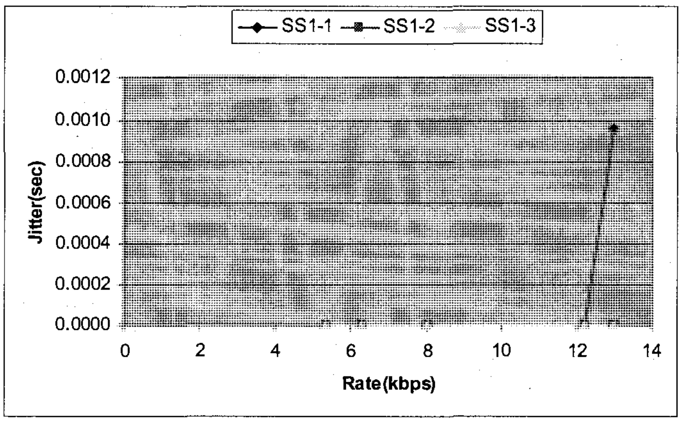


Fig 5.14: Jitter vs Codec Rate

In Fig 5.14, we can see the jitter in voice application is very small. The packet end to end delay of SS1-1 stay constant from 5.3Kbps to 12.2Kbps, then it is increasing from 12.2Kbps to 13Kbps. The jitter curves of SS1-2, SS1-3 stay horizontal from 5.3 Kbps to 13 Kbps. The variation between these three curves is because the results are partially affected by the delay components of each link due to the different network size effect to the power and capacity arrangement with the size 3 and size 30.

5.4.3 Comparison

Table 5.5 GSM FR Comparison Table (Network Size)

Voice (GSMFR)	Jitter	Packet Delay Variation	Packet End to End Delay	WiMAX Delay
Size 3	1.10E-07	5.30E-11	8.27E-02	2.69E-03
Size 30	3.20E-04	3.70E-06	8.39E-02	2.90E-03

Table 5.6 G729.1 Comparison Table (Network Size)

Voice (G729.1)	Jitter	Packet Delay Variation	Packet End to End Delay	WiMAX Delay
Size 3	9.51E-04	1.99E-10	6.44E-02	4.07E-03
Size 30	8.10E-07	5.55E-05	8.30E-02	4.19E-03

Table 5.7 G723 Comparison Table (Network Size)

Voice (G723)	Jitter	Packet Delay Variation	Packet End to End Delay	WiMAX Delay
Size 3	1.14E-04	5.89E-08	1.02E-01	4.53E-03
Size 30	0	1.39E-04	1.05E-01	4.96E-03

Table 5.5, 5.6, 5.7 recorded the average simulation results after we tried different seeds in one set of the simulation. From the tables, we can see the results did not change as seriously as exponential increasing or decreasing, different parameters changed vary according to the simulation result.

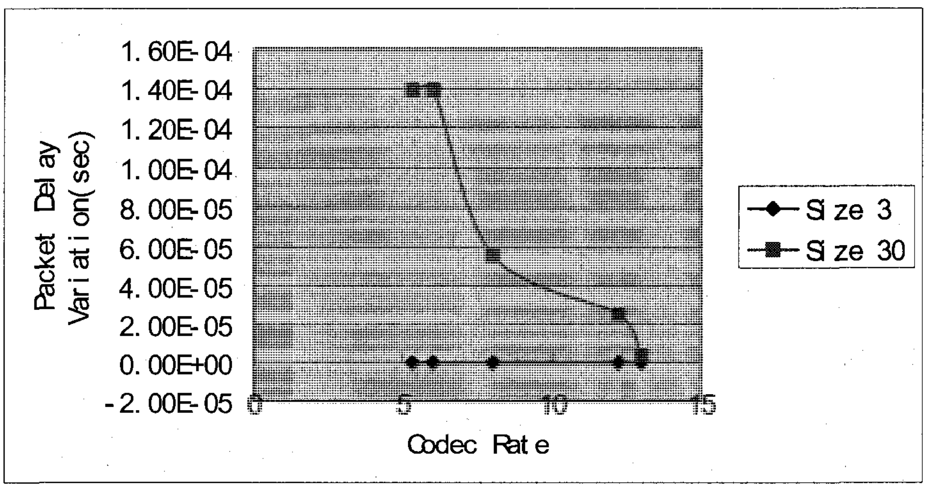


Fig 5.15: Packet Delay Variation vs Codec Rate

Fig 5.15 shows the same situation as we described in the comparison tables. The curve of size 3 is straight and constant at 0. The curve of the size 30 is a decreasing function of the codec rate from 5.3Kbps to 13Kbps. The decrease may be due to the lower codec rate that requires more processing power than the higher codec rate. The dynamic allocation at buffer for the small network size may not have big influence regarding the enough resources. But for large network, the fairly buffer allocation becomes more different with the change of the codec rate, so the higher the codec rate, the more relief it helps to the packet buffer allocation.

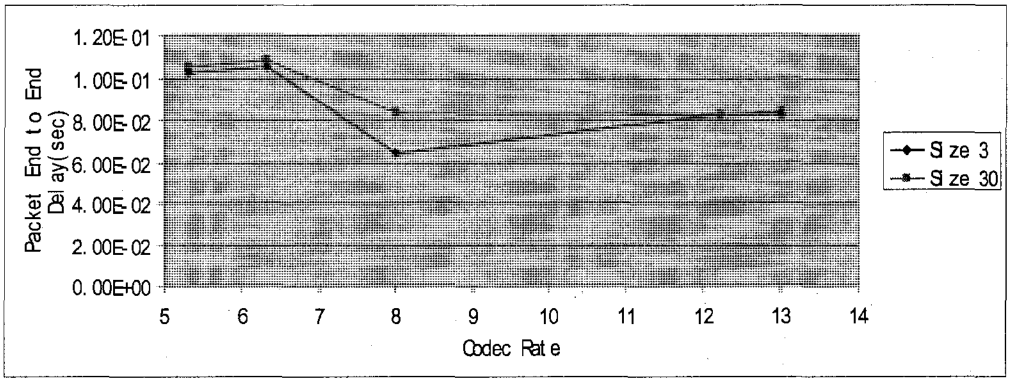


Fig 5.16: Packet End to End Delay vs Codec Rate

Fig 5.16 shows the Packet End to End Delay situation in different network size. Two curves look like the hyperbola shape and they follow the same trend, that is falling down from G723 (5.3Kbps) to G 729 (8Kbps), then rises to the half of its highest value from G729 (8Kbps) to GSM FR (13Kbps). This can be explained because the traffic is transmitted through the WiMAX air interface, the various in the power and capacity arrangement with the size 3 and size 30 will affect the delay in certain level.

We did not provide the throughput for the different network size here again because the large network size has the similar packet loss rate as the small network size. The WiMAX throughput for the large network size has no packet loss.

The above comparison results are just showing partly of the influence of the increasing of the network size. Each link (or hop) delay consists of four components, processing delay, queuing delay, transmission delay and propagation delay. In order to estimate the total delay, we also need to evaluate the processing delay, propagation delay and queuing delay in the process of the transmission.

5.4.4 Delay Estimation

We did not plan to do the similar delay estimation for voice application here because the estimation procedure is similar to what we did in video application in Section 5.3.4. On the other hand, the background processing time of voice application and other time estimations are hard to decide according to different equipment's capacity, and the environment from various standards. So we will not give the estimated results of voice application here.

5.5 Concluding Remark

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. The simulation results of the small size network and the large network follow the rules that we predicted in advance according to WiMAX PMP MAC Layer Design, thus big network size won't cause extra overhead regarding to every separate SS. Besides the increasing complexity due to the network size, the increasing of network size has little effect on the multicast performance of both video and voice applications.

Chapter 6
Design Guideline

Having provided a complete solution for the multicast traffic in the WiMAX MR networks, we should now investigate some limitations of our network model design and OPNET simulation.

6.1 Network Model Design

Normally there is a maximum limit on the numbers of SS a BS can support. This number depends on the capacity of the vendor equipment and the ratio of active SS to sleep-mode SS where an active SS means the SS is currently served by the BS, and has a connection established. "The sleep mode is a state in which an MS conducts pre-negotiated periods of absence from the Serving BS air interface." [IEEE16e]. Here "serving" means those SSs which already negotiate the channel information, the modulation scheme, the synchronization, and are ready to receive the traffic without further steps. The present vendor equipment has a capacity of 37.5 Mbps. The ratio is about 1:3.

As a general rule, the number of SS a BS can supported is 40 (either serving or active) SSs per sector. It means the BS can support 120 active SSs. Therefore, the number of the SS supported by the BS, both active SS and sleep SS is 360. The theoretical throughput can be obtained by using the equation (Data rate = number of uncoded bits per OFDM system / OFDM symbol duration). Taking 16QAM with coding rate =3/4, guard time = 1/16 as an example, the data rate = 192×4× (3/4) / {[256/ (7MHz×8/7)] (1+1/16)}=16.94Mb/s. For the BS design of three sectors, the total throughput for MIMO mode will be 16.94×3 = 50.82 Mb/s. For the downlink traffic supported by the BS, on-site measurement shows that each sector of the BS can support 37.5Mbps using MIMO antenna. The difference between the theoretical result and testing result can be attributed to overheads such as preambles and signaling message present in every frame that are not accounted for in the theoretical value. Due to the capability the Ethernet link used in our simulation, the design limit for the operation connecting rate between the Backhaul Network and the BS is 1Gps.

We did not find any limit on the duration in the simulation model because OPNET allows the users to assign the line capacity and transmission rate. So during the simulation, we use the transmission rate as suggested by the Nortel Standard.

6.2 OPNET Simulation Test

We have found that in the latest version of OPNET, many parameters of supporting SS are optional in the attribute. We are particularly interested in the maximum network size our MBS can support. Therefore, we have tested network size up to 100 SS, when we noticed that the operation system crashed. We also tested the maximum data rate that can be supported. We found that when Frame Interval = 0.0001 sec (that is 10,000 frames/sec) while keeping the frames size constant at 1000 bytes/frame, the OPNET simulation also crashed We hope the above exercise provides some thought in the design of a WiMAX Mutli-hop network.

Chapter 7
Conclusion

We have designed algorithms to support the MBS (Multicast and Broadcast Service) in WiMAX multi-hop relay networks based on the IEEE802.16 standard. The idea of applying traffic engineering (allocate the radio resources efficiently based on the users' need) into our networks and control of WiMAX MR networks. We realized it by enabling each relay station with the intelligence to forward MBS data in 802.16j relay system that allows more radio efficiency.

We used the inter-layer MBS controller to connect a MBS subscriber to a relay topology. We did that by sharing the radio resource scheduling with other subscribers based on the IGMP snooper we inserted at the MR-BS. Based on the IGMP information, the ASN-GW can dynamically build the MAC layer muticasting tree for MBS transmission. The inter-layer design approach also maps the IP Layer multicasting group membership to the WiMax MAC layer mulicasting tree. In order to dynamically discover the relay topology, we have developed a BS-oriented tunnel ranging protocol to automatically discover the relay network topology and to correlate multicast tunnel connections together with relay paths. By using the multicasting tunnel CID to encapsulate multiple MBS service flows, our interlayer approach can handle QoS provisioning, time synchronization and mobility collectively.

We have implemented the above in an OPNET simulator in order to verify their operations, and to evaluate the MBS performance systematically. Our performance results have demonstrated the feasibility and efficiency to complete a multicast service. It also demonstrated the new provision scheme is capable of optimizing the radio resource and control. 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 characteristics of WiMAX

There are some major difficulties encountered. One difficulty is the lack of information for the interlayer design of the MBS controller because an RS only has the functions of a MAC layer and a Physical interface but the application traffic usually needs to be processed from IP layer. Another difficulty comes from OPNET which can not support WiMAX Relay Network yet. So we have to use Ethernet line in the R-link stage to emulate the WiMAX behavior.

7.1 Future work

The nodes in our present simulations are static because OPNET WiMAX module PL3 did not support the mobility function yet. As soon as new OPNET software is obtained we need to investigate in detail the more realistic scenario in which MS/SS, RS and MS can move. Mobility is already included in our design, and together with the idea of virtual RS groups [Nortel07], we will do further investigate on how the speed enhanced utility node can enhance the network performance and on the optimization of the operation process.

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Appendix A: MBS Architecture and MAC Message

In this Appendix, we first listed the Management Message Type which is used in the MAC Management messages as we mentioned in Section 2.2.2. According to Fig 2.7, these messages shall contain a Management Message Type and the management message payload. Table A.1 gives the abbreviation and description of these types. Then we introduced more MBS NRM proposed by different companies in order to supplement Section 2.6. In accordance with the diagrams, we also introduced the components which are used in these NRMs.

Table A.1 MAC Management message

Type	Message Name	Message Description	Connection
0	UCD	Uplink Channel Descriptor	Broadcast
1	DCD	Downlink Channel Descriptor	Broadcast
2	DL-MAP	Downlink Access Definition	Broadcast
3	UL-MAP	Uplink Access Definition	Broadcast
4	RNG-REQ	Ranging Request	Initial Ranging or Basic
5	RNG-RSP	Ranging Response	Initial Ranging or Basic
6	REG-REQ	Registration Request	Primary Management
7	REG-RSP	Registration Response	Primary Management
8		reserved	
9	PKM-REQ	Privacy Key Management Request	Primary Management
10	PKM-RSP	Privacy Key Management Response	Primary Management
11	DSA-REQ	Dynamic Service Addition Request	Primary Management
12	DSA-RSP	Dynamic Service Addition Response	Primary Management
13	DSA-ACK	Dynamic Service Addition Response Acknowledge	Primary Management
14	DSC-REQ	Dynamic Service Change Request	Primary Management
15	DSC-RSP	Dynamic Service Change Response	Primary Management
16	DSC-ACK	Dynamic Service Change Acknowledge	Primary Management
17	DSD-REQ	Dynamic Service Deletion Request	Primary Management
18	DSD-RSP	Dynamic Service Deletion Response	Primary Management
19		reserved	
20		reserved	
21	MCA-REQ	Multicast Assignment Request	Primary Management
22	MCA-RSP	Multicast Assignment Response	Primary Management
23	DBPC-REQ	Downlink Burst Profile Change Request	Basic
24	DBPC-RSP	Downlink Burst Profile Change Response	Basic
25	RES-CMD	Reset Command	Basic

The following diagrams are the extra MBS NRMs proposed by different companies as the supplement Section 2.6. We are going to introduce some components which will be used in the following diagrams first:

1) "MBS Content Provider: MBS content provider provides media flows (audio, video etc.) to MBS Server. It belongs to the NSP or ASP which is a third party outside the WiMAX network.
2) MBS Server-C-Plane: MBS Controller Function maintains the MBS service information, decide and control MBS service session start and stop, etc.
3) MBS Server-U-Plane: MBS Content Server Function is able to store and forward the contents from content provider and or merge one or more media flows from MBS content provider(s). It can encrypt the contents if the higher layer encryption is needed.
4) MBS Proxy: MBS Proxy is C-Plane entity in MBS Zone and responsible for managing MBS Zone's resource. It's unique in one MBS Zone
   - Controlling the MS joining and leaving procedure in ASN for MBS services.
   - Allocating resources related to MBS service: MCID, Logical CID
   - Maintain the ASN-GW list belongs to the MBS Zone.
   - Schedule radio resource for MBS service if macro diversity is supported
5) MBS DPF: MBS DPF is U-Plane entity in MBS Zone and responsible for data plane bear management and MBS data distribution.
   - Support MBS bearer establishment and release
   - Support MBS data transmission and classification
   - Support MBS PHY PDU synchronization mechanism if macro diversity is supported.
6) ASN GW: Access Service Network Gateway should be enhanced to support MBS services. Its functions are to support
   - MBS bearer establishment and release.
   - User joining and leaving MBS service.
   - MBS service data transmission and classification.
   - MBS charging.
   - User counting in order to dynamical bear establishment and release.
   - MS movement management for R6 and R3 interface (See Table 3) when MS has

joined in MBS service.

- Support MBS Key distribution to BSs and Maintenance the information of MBS services that MS has joined the ASN, which acts as MS's Anchor PC when MS goes into IDLE mode.

7) AAA: AAA is maintaining the subscription information about MBS service of MS, which supports identity authentication and service authentication/authorization when MS requesting for MBS service by interacting with MBS Server. And MBS Server controls MS subscribes/registers MBS services according the user profile maintained by AAA.

8) MR: The Multicast Route is working following the IETF protocol RFC 3376 IGMPV3. It distributes the MBS service data as requested when IP multicast is employed. It can be collocated with MBS Content Server.

- MBS Subscriber Profile Manager and Subscriber Profile Database

- They maintain the profile of MS and its MBS subscription information. Subscriber Profile Database is usually collocated with AAA, while MBS Subscriber Profile Manager can be placed into MBS Server, or still be located in the AAA. And their protocols are out of scope of this document."

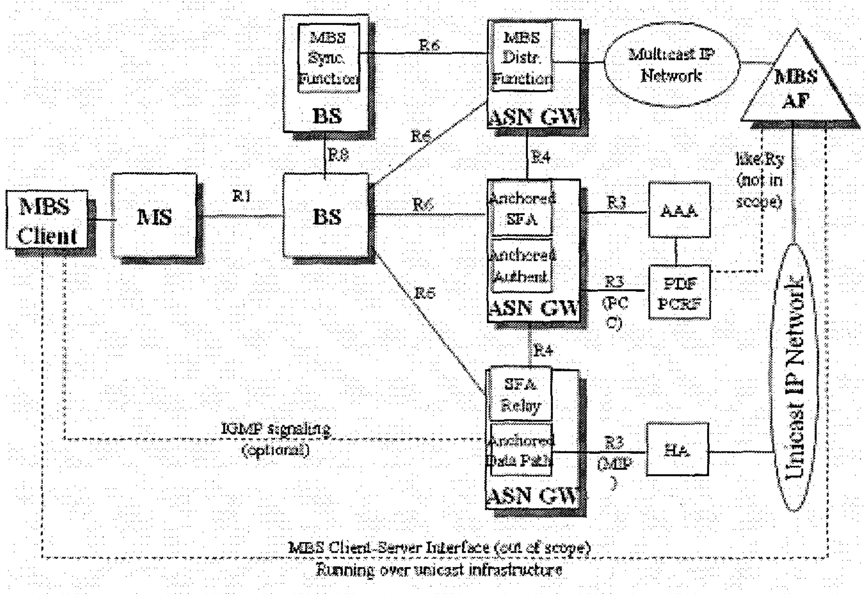

Fig A.1: NRM Proposal (Alvarion) [WiFo06]

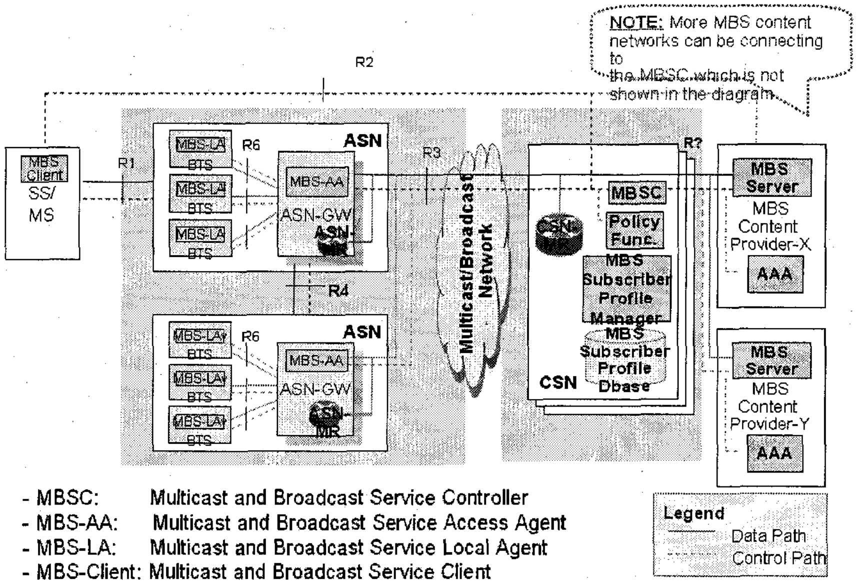

Fig A.2: NRM Proposal (ZTE) [WiFo06]

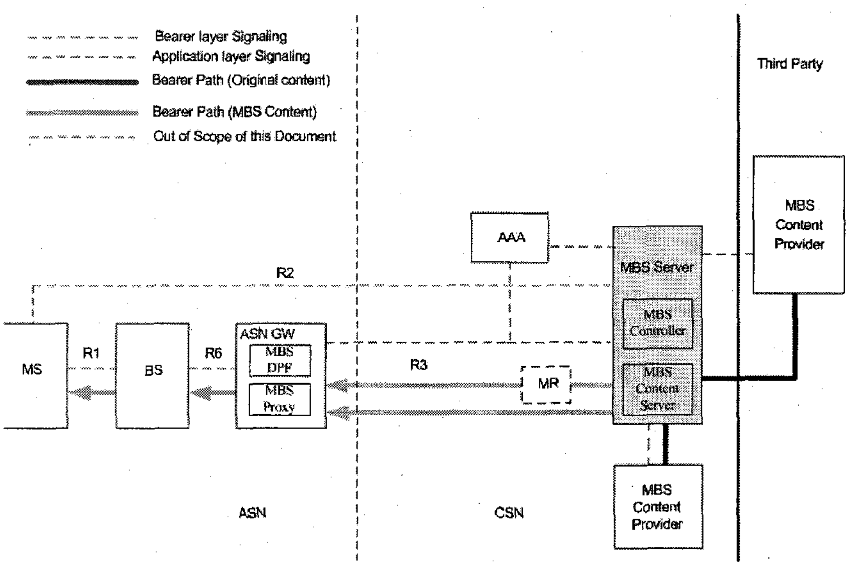

Fig A.3: NRM Proposal (Huawei) [WiFo06]

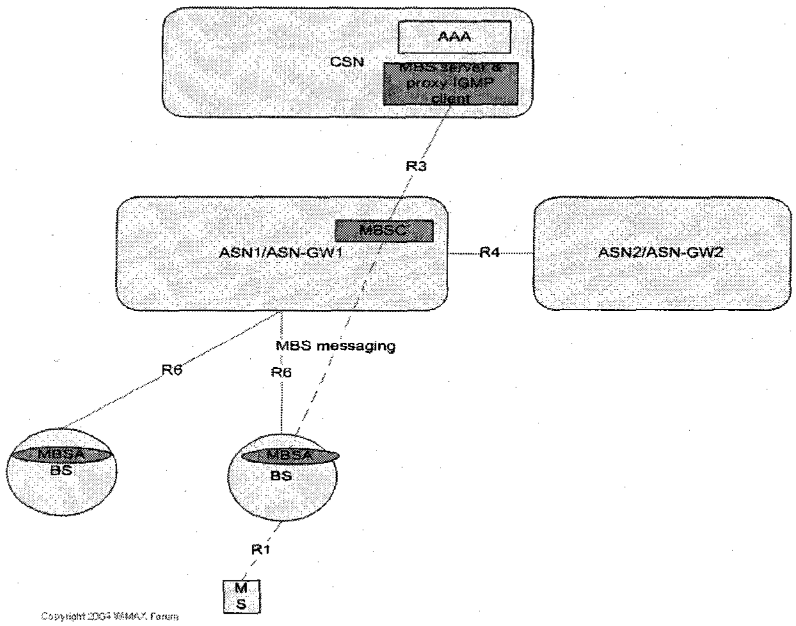

Fig A.4: NRM Proposal (Intel) [WiFo06]

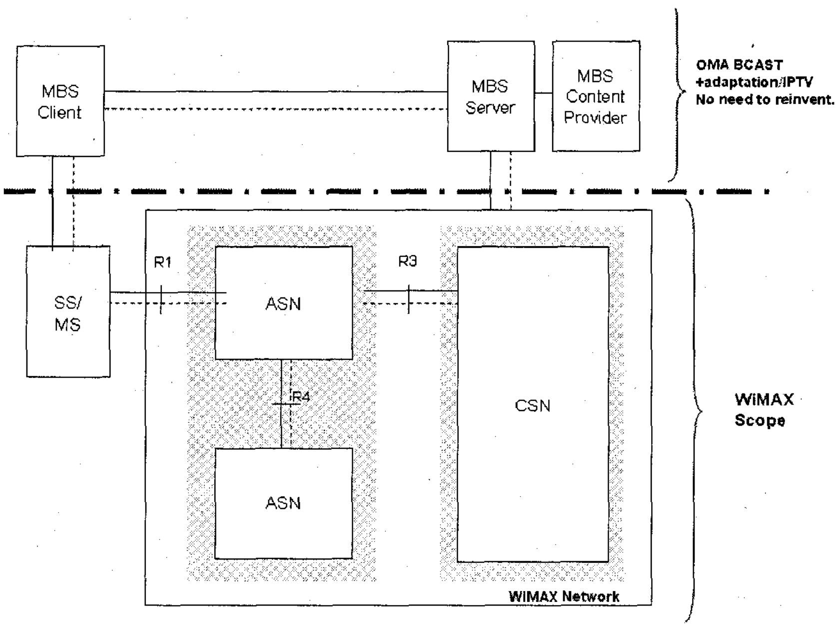

Fig A.5: NRM Proposal (Nokia) [WiFo06]

The NRMs illustrated from Fig A.1 to Fig A.5 are developed based on the baseline NRM proposed by the WiMAX Forum, so the basic entity and function division is similar from one to the others. The MBS traffic is offered by MBS Content Provider, then the multicast traffic pass through Multicast IP Network (or can be called “Connectivity Service Network”) or Unicast IP network into different ASN Gateways. AAA block is used when MS requesting for MBS service by interacting with MBS Server to identity authentication and service authentication/authorization. If there is MBS zone exists, the function entity in the BS called MBS synchronization Function will synchronize the MBS across muli-BS. Synchronization means that the same multicast traffic is transmitted in the same frame and in the same OFDMA data.

MBS Proxy in Fig A.3 is the Control Plane entity in the MBS Zone, which is responsible for managing MBS Zone’s resource. The MBS Proxy is unique in one MBS Zone. MBS DPF is the Data Plane entity in MBS Zone and responsible for data plane bear management and MBS data distribution. Finally, the multicast traffic is transmitted to the end station (MS/SS) by the WiMAX air interface between the BS and the SS.