

# Improving IPTV Forwarding Mechanism in IEEE 802.16j MMR Networks Based on Aggregation

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Mohamed-el-Amine Brahmia, Abdelhafid Abouaissa, and Pascal Lorenz

Internet protocol television (IPTV) service depends on the network quality of service (QoS) and bandwidth of the broadband service provider. IEEE 802.16j mobile multihop relay Worldwide Interoperability for Microwave Access networks have the opportunity to offer high bandwidth capacity by introducing relay stations. However, to actually satisfy QoS requirements for offering IPTV services (HDTV, SDTV, Web TV, and mobile TV) for heterogeneous users' requests, providers must use a video server for each IPTV service type, which increases the network load, especially bandwidth consumption and forwarding time. In this paper, we present a solution for forwarding IPTV video streaming to diverse subscribers via an 802.16j broadband wireless access network. In particular, we propose a new multicast tree construction and aggregation mechanism based on the unique property of prime numbers. Performance evaluation results show that the proposed scheme reduces both bandwidth consumption and forwarding time.

**Keywords:** WiMAX, IEEE 802.16j, MBS, IPTV services, forwarding time, bandwidth consumption, multicast tree, aggregation.

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## I. Introduction

In metropolitan area networks, Worldwide Interoperability for Microwave Access (WiMAX) or IEEE 802.16 [1] is typically considered the most reliable wireless access technology [2]. Because obtaining a high bitrate and reaching a large area in a single base station (BS) are possible using this technology, connecting with end users is cost-effective.

Recently, to overcome such aspects as coverage holes, cell capacity shadows, and non-line-of-sight limitations, the 802.16j extension [3] proposed adding relay stations (RSs). It has been proven that mobile stations (MSs) can reach higher throughput and/or lower energy consumption with the help of RSs [4]. Emerging multihop wireless networks provide a low-cost and flexible infrastructure that could be simultaneously utilized by multiple users for a variety of applications, such as delay-sensitive multimedia transmission. However, this wireless infrastructure is often unreliable and provides dynamically varying resources with only limited quality of service (QoS) support for multimedia applications [5].

WiMAX multihop relay (MR) technology is an appropriate choice to provide broadcast TV services for both fixed and mobile users because it supports QoS-based multicasting functionality [6]. Users will be able to access and consume a rich set of multimedia content over dynamic networks and heterogeneous devices. However, to provide a variety of Internet protocol television (IPTV) services (that is, HDTV, SDTV, Web TV, and mobile TV) for the same video stream content, providers transfer one copy of video content for each IPTV service type. This process results in significant

consumption of network resources in terms of bandwidth and processing time. To address this problem, we propose a solution that aims to achieve better network resource management and to support a variety of IPTV services.

The remainder of this paper is organized as follows. An overview of the proposed solution is described in section II. A survey of related work and the mechanisms used is presented in section III. Section IV provides details about the proposed forwarding mechanism. Section V presents simulations of the proposed scheme and the performance results. Finally, conclusions and future work are discussed in section VI.

## II. Proposed Solution

In this paper, we are interested in IPTV, a system whose use is rising. In the last five years, the number of subscribers has increased significantly owing to new technologies that offer more resources in terms of telecommunication and video coding. This evolution allows for a variety of services (that is, HDTV, SDTV, Web TV, and mobile TV) for the same video stream. Currently, providers are obliged to send each service type separately. This process can increase the network consumption of providers, and multicast tree management thus becomes more complex. This complexity is mainly due to the size of the media access control (MAC) layer forwarding table, which holds the identity of all multicast groups and the identity of the corresponding output interface. However, an RS can forward the received packets to their destinations. The RS must browse all forwarding tables to find all possible output interface identities. This mechanism inevitably influences forwarding packet processing time because browsing more forwarding tables results in a longer processing time.

To address this problem, we propose a new multicast routing protocol in WiMAX MR networks, which allows for a reduction in bandwidth consumption and forwarding time while satisfying customers' requirements.

Our solution has two major steps: multicast tree construction and the aggregation process. The main outline of the proposed mechanism is as follows:

- To decrease bandwidth consumption, we use Scalable Video Coding (SVC) to send only one copy of IPTV video stream, and each intermediate RS has the intelligence to navigate video content to each destination.
- A single video streaming server for all IPTV services is used.
- A prime number for each video service type (HDTV, SDTV, Web TV, and mobile TV) is used by RSs to extract video content and route it toward its destination with the requested quality.
- A new multicast tree construction method uses the full

capability of prime numbers.

- An aggregation process reduces the number of entries in the forwarding table.

This paper is an expansion of our work in [7], which was our basic research to integrate SVC. This work was only concerned with the amount of bandwidth consumed using SVC in multihop networks. In this paper, we also use SVC; however, we change the signaling flow for multicast broadcast service (MBS). We propose using a prime number for each IPTV service. This prime number is used in the aggregation and disaggregation processes, which can optimize the forwarding time and end-to-end delay.

## III. Related Work

IEEE 802.16j defined two different forwarding schemes intended to maximize system efficiency by aggregating traffic where possible: the connection ID (CID)-based scheme and the tunnel-based scheme. This traffic aggregation results in less signaling information being sent and makes it possible to handle groups of flows simultaneously, improving efficiency and simplifying management, respectively. The CID-based scheme does not employ tunnels and supports only the legacy management and transport connections as defined in the 802.16e-2005 standard. Although more complex than the CID-based scheme, the tunnel-based scheme uses tunnels to aggregate traffic, and each tunnel is characterized by a unique CID, two specific endpoints, and QoS requirements. If the MS is served by an RS group, tunnel connections are established between the MR-BS and the superordinate station of the RS group; therefore, the superordinate station is considered the access station for the tunnel connection that is the end of the tunnel in the downlink (DL) and the beginning of the tunnel in the uplink (UL) [3].

In [8], the authors proposed a standard-based, cost-effective solution to support MBS in WiMAX MR networks. They defined a BS-oriented source-routing protocol to automatically discover relay network topology in which the mobile RS forms an ad hoc topology. They used the Internet Group Management Protocol (IGMP) on the BS to automatically track the MBS group membership and service activation. The authors in [8] introduced multicast tunnel CID (MT-CID), which maps the relay paths to form an MBS tree in the 802.16j MAC layer to support MBS. By using the MT-CID approach, an RS acquires the knowledge to navigate the content to each destination. However, the authors in [8] did not specify this knowledge, and they did not take into account the forwarding table size, in which the number of entries of each relay forwarding table was equal to the number of multicast sessions. Browsing the entire forwarding table results in a significant amount of time spent

processing packets, which can affect the QoS for real-time applications.

Several researchers have examined multicast gain for IPTV transmission in WiMAX MR networks. For example, in [9], the authors introduced a performance benchmark, the multicast gain, which compares multicast and unicast efficiency in terms of required slots. Based on this new measure, they analyzed the advantages of multicasting in tree-structured mobile multihop relay (MMR) networks based on IEEE 802.16j and proposed an analytical method to calculate multicast gain in relay and access links. The authors evaluated their formula in a case study for different scenarios and discussed the effects in terms of number of users, link qualities, user density, and user distribution on multicast gain. They obtained desirable results but did not specify the quality of IPTV services and the type of video codec.

The researchers in [10] presented a new invention related to a multicast router of a content distribution system and an associated method adapted to receive from an upper level of a multiplexed network in scalable video compression encoded television channel bitstreams. Their mechanism adapted the television channel bitstreams according to the available bandwidth by using scalable video compression, which means that the output quality of video stream is proportional to the available bandwidth. For example, if we have high available bandwidth, the output video stream will be sent with the best quality. The authors in [10] did not take into account the constraints of QoS required by users. However, in our proposal, we adapt the video stream to users' requests, while reducing the network load.

In [11]-[15], the authors proposed resource allocation mechanisms for IPTV service over IEEE 802.16 WiMAX networks. To address an NP-hard resource allocation problem, the authors combined multicast, SVC, and adaptive modulation of transmissions. The objective was to dynamically adjust the number of each user's layer according to its channel condition, available bandwidth, and scheduling decisions. However, the proposed scheme adapts multicast IPTV service only to users' requests. The goal is to optimize bandwidth consumption and maximize QoS, in terms of forwarding time and video quality.

## IV. Proposed IPTV Forwarding Mechanism

### 1. Scalable Video Coding

As discussed in [16], the SVC extension of the H.264/AVC video codec standard allows for desirable scalability at a bitstream level, although at the cost of an increase in decoder complexity compared to single-layer H.264/AVC. The many

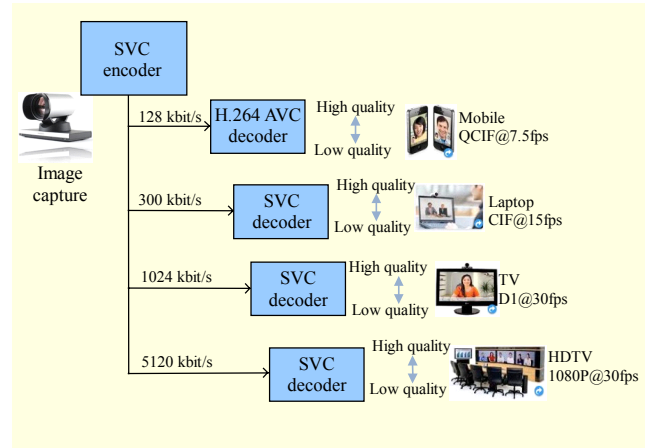


Fig. 1. SVC principle.

functions supported by SVC improve transmission and storage applications.

The video codec standards developed prior to SVC are not capable of providing the coding efficiency and scalability that SVC provides. The implementation of SVC has proven highly beneficial for various video applications (for further details, refer to [16]).

In our proposed mechanism, we integrate SVC functionalities for all network RSs to extract IPTV video streams to different formats (for example, HDTV, SDTV, Web TV, and mobile TV), as shown in Fig. 1.

### 2. Multicast in WiMAX MR

MR is an optional deployment that could be used to provide additional coverage or a performance advantage in an access network. Traffic and signaling between the MS and MR-BS are relayed by RSs to extend the coverage and performance of the system in areas where RSs are deployed. Each RS is under the supervision of an MR-BS [3]. In a system consisting of more than two hops, traffic and signaling between an access RS and MR-BS may also be relayed through intermediate RSs. The RS may be fixed in location (that is, attached to a building) or, in the case of an access RS, it could be mobile (that is, traveling with a transportation vehicle). The MS may also communicate directly with the MR-BS.

MBS in WiMAX refers to the ability of the WiMAX network to provide flexible and efficient mechanisms to send common content to multiple users sharing the same radio resources [8]. To support multicast in WiMAX MR technology, we propose a solution that is based on SVC and prime numbers. SVC technology allows video conferencing devices to send and receive multilayered video streams composed of a small base layer and optional additional layers that enhance resolution, frame rate, and quality. On the other hand, we

Table 1. IPTV service prime number mapping.

IPTV service	Prime number
High definition (HDTV)	IDtx =3
Standard definition (SDTV)	IDtx =5
Web TV	IDtx =7
Mobile TV	IDtx =11

associate a prime number with each video stream service, as shown in the Table 1. The prime number represents the transmission identity (IDtx) used by the MR-BS and RSs. The IDtx enables the BS and RS to send only one copy of video stream with high quality.

For this context, we propose a new multicast routing strategy that supports heterogeneous users' requests by using SVC and reduce resource consumption through introducing a forwarding table optimization mechanism. This mechanism is based on a multicast tree construction and aggregation technique.

### 3. Multicast Tree Construction

As mentioned in the IEEE 802.16j standard [3], the multicast traffic is transmitted from the MAC layer of the WiMAX relay network. Since the multicast traffic transmitted from the access service network gateway or other multicast-capable network uses the IP network layer, the mapping table must be used to solve the traffic transmission problem. Examples of mapping tables and the details of transmitting the application traffic from the IP network layer to the MAC layer are shown in Table 2.

A mapping table (Table 2) is necessary to map the multicast group IP address with a multicast CID (MCID). A multicast group address is an address for the multicast group in the IP layer. One can give the same multicast IP address to the MSs that receive the same multicast traffic. An MCID is an address in the MAC layer that allocates the same video content to MSs in the same multicast group [8].

To utilize the radio resources for the MR network, a "tunnel" is introduced to reduce MAC overhead and processing in the relay link [4]. There are two modes for tunnel connections. In tunnel burst mode, only stations at the egress of the tunnel read the encapsulated MAC protocol data unit (MPDU), and other stations along the tunnel directly forward the MPDU after decoding the MAP information element with destination T-CID. Alternatively, in tunnel packet mode, every station along the tunnel receives the encapsulated MPDU and reads the relay MAC header to see whether a T-CID is placed or not. If a destination T-CID appears, intermediated stations forward the MPDU without reading the payload and only the station at

Table 2. IP multicast address to multicast CID mapping.

IP multicast address	MCID
224.0.10.1	MCID1
224.0.10.2	MCID2

the egress of the tunnel reads the content of the payload [17].

In WiMAX MR networks, the MR-BS must control and manage several RSs simultaneously. Compared to unicasting identical control messages for every RS, multicasting control messages via the MR-BS for the RSs is more suitable and efficient. In our solution, we suggest performing multicasting along the tunnel in tunnel packet mode by using the MT-CID, which allows for the identification of a single link between two RSs or between one RS and the MR-BS. With this scheme, we can achieve multicasting along tunnel connections using less processing and resources.

Using the topology information obtained from topology discovery mechanisms or the updating process, the MR-BS makes centralized computations for the path between the MR-BS and an access RS for both the UL and DL. The path creation is subject to the constraints of tree topology as well as such constraints as availability of radio resource, radio quality of link, load condition of an RS, and so on. After creating an information path to the destination MS according to the DL MAP, table information that contains mapping between the MCID and the path needs to be updated. A new tunnel (MT-CID) is generated between the MR-BS and an access RS or when a new connection (identified by an individual CID) is established for an RS or MS and the new connection is not put into a tunnel. The MR-BS selects a path to carry the traffic for the new connection and informs all RSs on the path of the binding between the path-ID and supported CIDs by sending a dynamic service addition request (DSA-REQ) message to all RSs on the specified path [4]. Figure 2 shows an example of an MR WiMAX network by introducing an MT-CID.

The MR-BS may initiate a multicast distribution tree for MBS. When an MS wants to initiate an MBS, it sends a DSA-REQ message to the MR-BS to specify that it wants the MBS [17]. The procedures to establish the multicast distribution tree are as follows.

When an MR-BS initiates an MBS or receives an MBS request from an MS, it checks whether the requested MBS has been created. If not, the MR-BS creates a multicast distribution tree for this MBS and allocates an MCID to it. The MR-BS also determines the path(s) to carry this multicast service flow and assigns a prime number (IDtx) to each MS video stream request. For example, as shown in Fig. 2, after creating paths



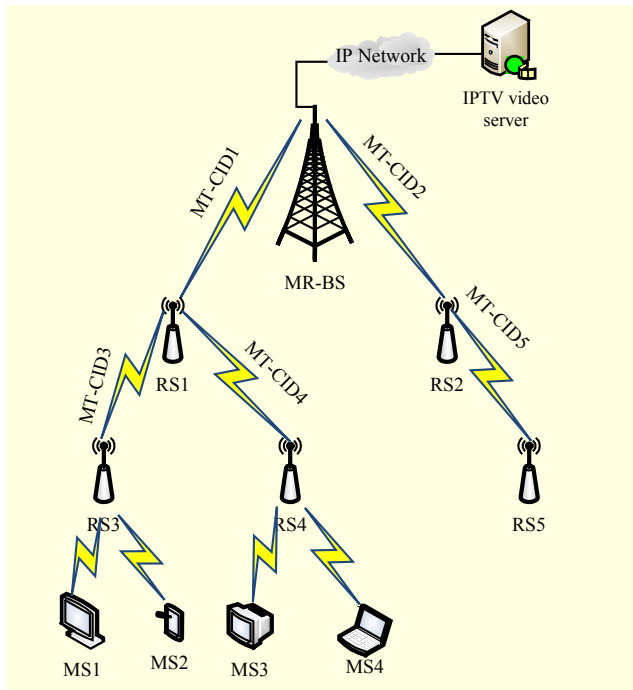


Fig. 2. MR WiMAX network example.

(illustrated in Table 3), the MR-BS creates mapping between the determined path and the MT-CID, as shown in Table 4.

The MR-BS stores all information in its diffusion table to indicate to the RSs with which quality (IDtx) they must send the video stream for each MCID. However, the MR-BS informs all RSs on the path of the binding between the path-ID, MCID, and IDtx by sending a DSA-REQ. Each RS along the path stores the path-ID, MCID, and IDtx binding information for forwarding multicast data with the appropriate quality (IDtx). The MR-BS adds this path to the multicast distribution tree and records the number and identification information of the MSs using the path for multicast communications. A multicast distribution tree may consist of multiple paths.

If the multicast distribution tree has been created and an MCID has been allocated to this MBS, the MR-BS determines the path to carry this multicast service flow. If the path is already in the multicast distribution tree (due to the prior establishment of the MR-BS or the request of another MS using the same path), the MR-BS simply updates the number and identification information of MSs using the path for the MBS in the multicast tree. The MR-BS also updates its diffusion table and informs all RSs about this change.

A path may be removed from a multicast distribution tree by the MR-BS. When an MS needs to leave the multicast service, the MS sends a dynamic service deletion request (DSD-REQ) message to the MR-BS to request removing it from the multicast service flow. First, the MR-BS will update the number and identification information of the MSs that are

Table 3. Relays belonging to path.

Path-ID	Relay
Path-ID1	RS1, RS3
Path-ID2	RS1, RS4
Path-ID3	RS2, RS5

Table 4. MT-CID with path-ID mapping.

MT-CID	Path-ID
MT-CID1	Path-ID1, Path-ID2
MT-CID2	Path-ID3
MT-CID3	Path-ID1
MT-CID4	Path-ID2
MT-CID5	Path-ID3

receiving the MBS along the path to this requesting MS. The MR-BS determines whether the path can be removed from the tree-MCID. If no more MSs use this path for the MBS, the path may be removed from the multicast distribution tree. Otherwise, the path shall not be removed from the multicast distribution tree. If the path is removed from the tree-MCID, then the MR-BS removes the binding between the path and the MCID by sending a DSD-REQ, and the MR-BS updates its diffusion table and informs all RSs in the corresponding path.

When the parameters for a multicast service flow change, an MR-BS or MS may also send a dynamic service change request (DSC-REQ) message to update these changes. All RSs in the multicast distribution tree of the MBS are informed of these changes. This is achieved by the MR-BS sending a DSC-REQ message to all of the RSs along all of the paths in the multicast distribution tree.

The signaling flow for an MS's joining or leaving an IPTV program in a WiMAX TV system is shown in Fig. 3. When an MS selects a TV program, in addition to sending an IGMP join message, it must establish a multicast connection with a CID via a three-way DSA procedure at the MAC layer. At the same time, it can know the various parameters of the requested TV flow to associate the prime number adequate to this flow, which will be used during the forwarding process. When IP packets of the TV program are routed to the BS, they are delivered for all RSs over relay links before being sent to the MS on the established multicast connection over access links. When an RS sends packets of one TV stream via the same MT-CID, it is based on the assigned IDtx. In this case, the stream has the highest quality of the video stream requested by neighbors' RSs. We apply the same procedure to all RSs and all

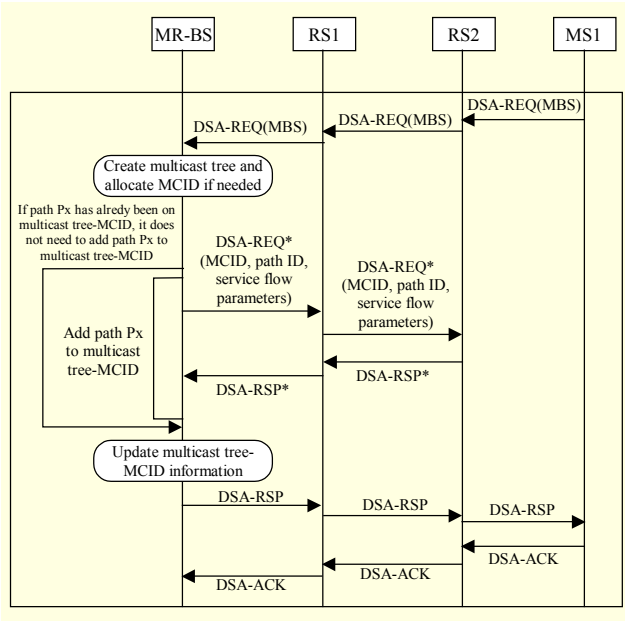


Fig. 3. Illustration of multicast connection management procedures [18].

video streams, so as to support the user's heterogeneity and for better resource management. If we have several RSs that require the same video stream content with different qualities, the parent RS ensures the extraction of the flow toward all required qualities by using SVC.

For a better understanding of our proposed solution, we use the topology shown in Fig. 2 as an example for application. If we assume that, initially, the MR-BS diffusion table is empty and user MS1 requests the MCID1 video stream flow with HD quality ( $ID_{tx}=3$ ), then the BS will create a first line (Step1), as seen in Table 5.

The number in parentheses after each item in the list in the fourth column, "MR-BS & relays," reflects the quality of the video stream to be transmitted to the next node in the list (or broadcast to terminals, that is, "access relay" in the case of the last element of the list).

Later, if user MS2 requests the MCID2 video stream flow with mobile TV quality ( $ID_{tx}=11$ ), the MR-BS will add a second line (Step 2) to the diffusion table (Table 5).

Then, if user MS3 requests the MCID1 video stream flow with SD quality ( $ID_{tx}=5$ ), the MR-BS will note from the first line of the diffusion table that flow MCID1 has already been transmitted in HD quality from the MR-BS to RS1 through the MT-CID1 tunnel. However, the path to user MS4 also uses the MT-CID1 tunnel, as shown in Table 4. Thus, it is not necessary to additionally transmit the MCID1 video stream flow with SD quality in the MT-CID1 tunnel. The MR-BS adds a third line (Step 3) to the diffusion table (Table 5) that indicates the highest quality of the MCID1 flow between the MR-BS and

Table 5. Diffusion table (Steps 1-3).

Line	Path-ID	MCID	MR-BS & relays
1st	Path-ID1	MCID1	MR-BS(3), RS1(3), RS3(3)
2nd	Path-ID1	MCID2	MR-BS(11), RS1(11), RS3(11)
3rd	Path-ID2	MCID1	MR-BS(3), RS1(5), RS4(5)

Table 6. Diffusion table (Step 4).

Line	Path-ID	MCID	MR-BS & relays
1st	Path-ID1	MCID1	MR-BS(3), RS1(3), RS3(3)
2nd	Path-ID1	MCID2	MR-BS(7), RS1(11), RS3(11)
3rd	Path-ID2	MCID1	MR-BS(3), RS1(5), RS4(5)
4th	Path-ID2	MCID2	MR-BS(7), RS1(7), RS4(7)

RS1, for which the prime number  $ID_{tx} = 3$ .

The prime number  $ID_{tx}$  that indicates the transmission quality of the MCID1 stream to the MS4 user by the MT-CID1 tunnel is listed in bold to highlight it. If user MS4 requests the MCID2 video stream flow with Web TV quality ( $ID_{tx}=7$ ), the MR-BS will find that the MCID2 flow has already transmitted the mobile TV quality flow from the MR-BS to RS1. Thus, the MR-BS updates the diffusion table by adding a new line to the requested flow and changing the second line (Step 4) to indicate the highest quality (see Table 6).

Finally, after each diffusion table update, the MR-BS sends a message to each RS to adapt its respective transition table and forwarding table. In the example above, the RS1 relay creates its transition table, and each line indicates a multicast flow identifier MCID, a prime number  $ID_{tx}$  that represents video transmission quality, and a tunnel MT-CID to which the identified flow must be sent.

#### 4. Aggregation Process

In general, the number of entries in the forwarding table of an RS participating in a multicast communication increases exponentially as the number of existing multicast sessions increases [19]. To address this problem, we use prime numbers associated with various IPTV video stream services for aggregation identity. The aim is to aggregate all multicast sessions that use the same MT-CID. An RS's identity aggregation is updated by the join/leave packets that the RS receives from MSs desiring to either join or leave multicast groups.

The main idea of this aggregation is based on prime numbers, which are characterized by the uniqueness of the factorization of prime factors, which ensures the aggregation and

Table 7. RS1 transition table.

MCID	IDtx	MT-CID
MCID1	3	MT-CID3
MCID1	5	MT-CID4
MCID2	11	MT-CID3
MCID2	7	MT-CID4

Table 8. RS1 forwarding table (aggregation process).

MT-CID	IDag
MT-CID3	3*11
MT-CID4	5*7

disaggregation operations and that the multicast packets are only forwarded toward the concerned nodes. In the next paragraph, we present a mathematical reminder of prime numbers and consequences constituting our aggregation approach.

**Gauss theorem:** Consider that  $x$ ,  $y$ , and  $z$  are integers. Suppose that the product of  $y*z$  is divided by  $x$ . If  $x$  is relatively prime with  $y$ , then  $x$  divides  $z$  [20]. If  $yz|x$  and if the greatest common divider is  $(x,y)=1$ , then  $x|z$ .

**Consequence:** If a prime number  $p$  divides the product of  $y * z$ , then  $p$  divides  $y$  or  $z$ .

To apply the aggregation process and to optimize the entries of the forwarding table, we use RS transition table information that contains the following: the MCID (to indicate the requested video stream), the MT-CID (to indicate the tunnel to be crossed), and the corresponding IDtx (to indicate video stream quality). In addition, the forwarding table contains the MT-CID and the corresponding aggregation identity "IDag," which is the product of prime numbers IDtx indicated in the transition table in correspondence with the identified tunnel. This product composes aggregation identity toward the next neighbors. Thus, the forwarding table contains only  $p$  entries, where  $p$  is the number of immediate RS neighbors, which simplifies forwarding table optimization.

If we apply the aggregation process to our example, the RS1 relay updates its forwarding table by aggregation of its transition table. Specifically, RS1 operates IDtx prime numbers corresponding to different transmission qualities to determine aggregation identity IDag. Thus, in the example of the RS1 transition table (Table 7), the corresponding forwarding table is as follows (Table 8).

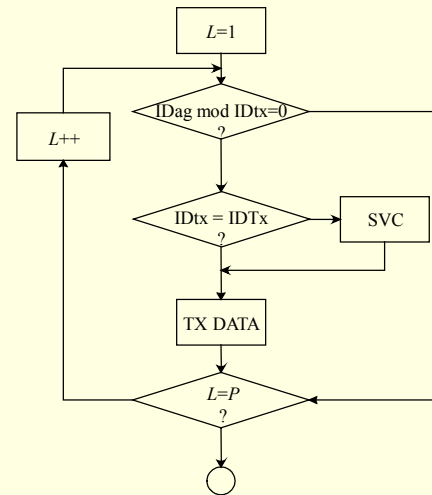
When an intermediate RS receives a multicast packet, it will first extract a group's address (MCID) and then the corresponding IDtx from its transition table. Second, for each

```

Begin
for (i=1; i< p; i++);
if (IDag < IDtx) then
if ((IDag mod IDtx) = 0) then
if (RS transition table IDtx = Packet header IDtx) then
Transmission packets;
else
SVC extraction;
Transmission packets;
end
end
end
end
end
end
end
end

```

(a) Pseudocode



(b) Flow chart

Fig. 4. (a) Pseudocode and (b) flow chart of proposed FA.

entry in the forwarding table, the proposed forwarding mechanism algorithm (FA) is executed to decide toward which tunnel the packets will be replicated and with which video quality stream they will be transmitted. Figure 4 shows the pseudocode and the flow chart of the FA.

In our example, we assume that RS1 receives the MCID1 video stream sent by the MR-BS on the HDTV service. To apply the FA, RS1 traces its forwarding table starting with the tunnel MT-CID3 (see Table 8). Then, RS1 knows that the value of IDtx is 3 (HD) and it computes  $(3*11 \text{ mod } 3 = 0)$ . Next, RS1 sends the video data packets through the tunnel MT-CID3 without changing the quality of the video stream, because it has been receiving in HDTV format. Otherwise, for the tunnel MT-CID4, RS1 calculates  $(5*7 \text{ mod } 5 = 0)$  to verify that the tunnel supports this type of flow, and it notes that the MAC header IDtx is different than the transition table IDtx  $(5 < 3)$ . This means that RS1 must transmit the video stream through tunnel MT-CID4 with a lower video quality (SDTV service).

## V. Simulation Performance Evaluation

In this section, using Matlab, we compare the performance of the proposed IPTV forwarding scheme with the performance of the traditional scheme, which requires transmitting one copy of each video stream service by using four IPTV video servers. Contrary to this approach, in the proposed solution, we assume that there is a single IPTV streaming video server source transmitting multicast packets to the MR-BS. The number of subscribers and IPTV channel requests are assigned randomly. The simple scenario consists of one MR-BS and multiple RSs are considered, and we suppose that multihop WiMAX network capacity is greater than 512 Mbps. Table 9 summarizes the parameters used in the simulation.

### 1. Bandwidth Consumption

To evaluate and compare the performances of our proposed forwarding scheme performance and the traditional scheme, we develop several scenarios based on bandwidth metrics.

Figure 5 shows the bandwidth consumption of the proposed scheme and that of the traditional scheme. We assume that subscribers request IPTV services until the maximum allowable bandwidth is reached for the IPTV services. We also assume that the maximum number of IPTV channels is 50. Figure 5 shows that the proposed scheme can reduce bandwidth consumption by sending only one copy of video stream. Hence, our solution can provide the same services, but it requires less bandwidth and only a single video server. Our

Table 9. Simulation parameters.

Parameter	value	
Number of subscribers who requested IPTV services	Random	
Maximum number of IPTV channels	50	
Channel requests	Random	
Maximum allowable bandwidth for the IPTV services (Mbps)	512	
IPTV services	Random (1-4)	1 (HDTV)
		2 (SDTV)
		3 (Web TV)
		4 (Mobile TV)
Requested bandwidth by a IPTV service (Mbps)	HDTV	6
	SDTV	2.5
	Web TV	0.650
	Mobile TV	0.350

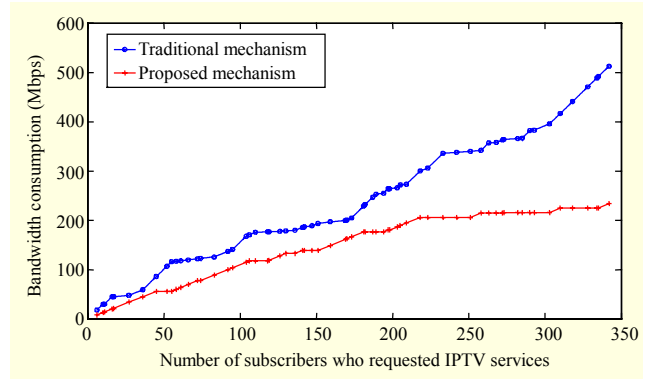


Fig. 5. Average bandwidth consumption in 802.16j zone when maximum number of IPTV channels = 50.

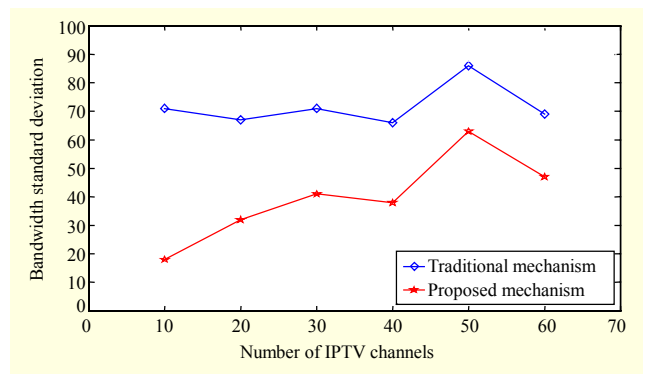


Fig. 6. Bandwidth standard deviation vs. maximum number of IPTV channels.

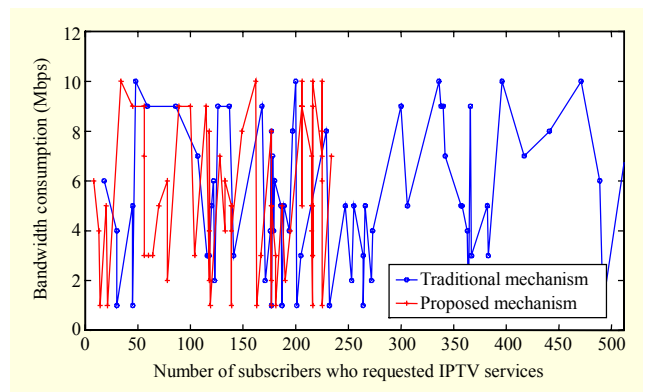


Fig. 7. Average subscriber bandwidth consumption.

proposed mechanism gives the best performance when the number of subscribers or the number of IPTV channels increases.

As shown in Fig. 6, we change the maximum number of IPTV channels to compare the bandwidth consumption standard deviation of the proposed mechanism with that of the traditional mechanism. Figure 6 shows that our solution decreases the average bandwidth consumption for all



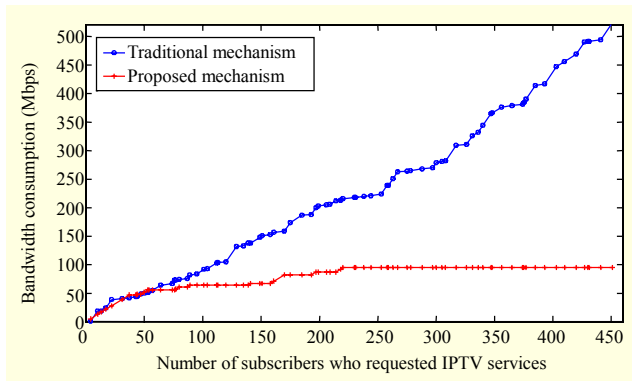


Fig. 8. Average bandwidth consumption in 802.16j zone when maximum number of IPTV channels = 20.

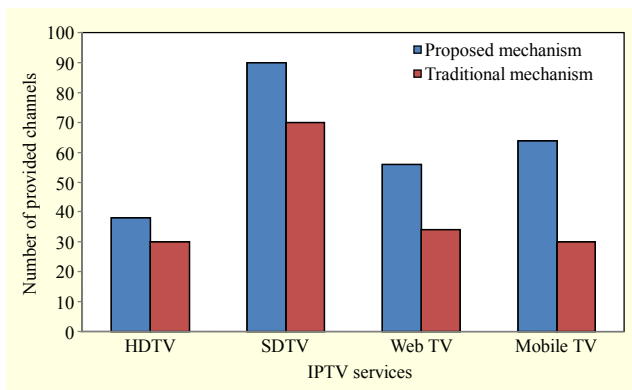


Fig. 9. Average number of provided IPTV channels.

subscribers, regardless of the maximum number of IPTV channels.

Figure 7 depicts the effect of IPTV channel requests, that is, the number of subscribers that request an IPTV channel, on bandwidth consumption. Figure 7 shows that with our proposed mechanism, bandwidth consumption ceases when all IPTV channels are provided (50, in our case). This means that when subscribers request all IPTV channels, there is no need for additional bandwidth, that is, bandwidth consumption is constant. However, with the standard mechanism, the bandwidth consumption continues increasing to provide all IPTV services (that is, HDTV, SDTV, Web TV, and mobile TV).

As shown in Fig. 8, we change the maximum number of IPTV channels to 20 to show that the bandwidth consumption of our proposed mechanism rapidly becomes constant because all IPTV channels have been requested before. On the other hand, the bandwidth consumption of the standard mechanism continues to increase. Figure 8 shows that when the number of the maximum IPTV channels allowed decreases, the number of subscribers can increase by using the proposed mechanism because the network has more available bandwidth, allowing users to request additional service.

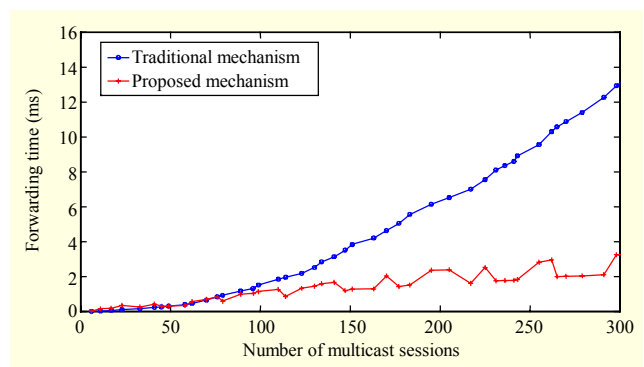


Fig. 10. Average forwarding time.

As shown in Fig. 9, we compare the number of IPTV channels that a provider could offer with the same allowable bandwidth for the IPTV services (in this simulation, 512 Mbps). Simulation results show that the number of channels provided by the proposed scheme is greater than the number provided by the traditional scheme for each IPTV service. This means that the efficiency of our solution is better in terms of bandwidth consumption.

## 2. Forwarding Time

To study the impact of the proposed mechanism in terms of forwarding time, we calculate the RS forwarding time using the aggregation process and compare it to that of the traditional mechanism. As Fig. 10 reflects, the simulation results show that without the aggregation process, when the number of multicast sessions increases, the forwarding time increases linearly. On the other hand, the forwarding time is less with the aggregation process. The forwarding time differentiation between the proposed mechanism and the traditional mechanism is important because the size of the forwarding table becomes great when the number of multicast sessions increases.

## VI. Conclusion

In this paper, a new forwarding mechanism to support all IPTV services in WiMAX MR networks was proposed. Results show that with the proposed mechanism, significant gains can be made to enhance the multicast data routing and IPTV applications in particular. For tree construction, to support IPTV services, we introduced MT-CID, which maps the relay paths to form an MBS tree in the 802.16j MAC layer. By using the MT-CID approach and SVC, RSs only need to transfer one copy of video stream content through each tunnel, which reduces the network load. However, the proposed mechanism supports heterogeneous devices (various IPTV

video stream services) and reduces bandwidth consumption. Furthermore, the proposed approach allows providers to offer more IPTV channels than can be offered by a single video server. The aggregation process reduces the number of entries at the forwarding table level and optimizes computing time to route data.

In a future work, we will focus on adapting the process of resource allocation and admission control to our solution. We will also propose a new path selection method for IEEE 802.16j MMR networks that minimizes latency and maximizes network throughput.

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