

Multicast Gain for IPTV Transmission in WiMAX Multi-hop Relay Networks

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Abstract—Due to characteristics such as: **multicast support, wide coverage range, high bandwidth and mobility support, WiMAX could be a leading solution to deliver bandwidth-hungry IPTV services to mobile users. Mobile multi-hop relay (MMR) was proposed as an amendment of the current mobile WiMAX standard to provide relaying capabilities. Relays are deployed as a cost-effective solution to extent coverage area and increase throughput without deploying expensive base stations. In this paper, we introduce multicast gain as a performance criterion, which can be used for computing multicast efficiency. In order to quantify the benefits of multicasting, we analyze multicast transmission for delivery of live TV channels in MMR networks, and determine the gain of access and relay links. The quantification of the efficiency of multicasting can be used by IPTV service providers in resource provisioning, access control or decision support mechanisms in delivery of different TV channels.**

Index Terms—WiMAX; IPTV; multicast gain; relay networks

I. INTRODUCTION

Internet Protocol TV (IPTV) describes a system capable of transmitting, receiving and displaying a video stream representing a TV channel and being encoded as a series of IP packets [1]. IPTV is undoubtedly a killer application and it is one of the fastest growing services in the Internet. This rapid growth is partially due to the advances in media encoding and compression techniques (e.g., H.264/AVC) and partially because of the enormous improvement of networking technologies. To provide ubiquitous delivery, IPTV service providers have to pay special attention to wireless broadband technologies as their access networks.

Worldwide Interoperability for Microwave Access (WiMAX) technology which is based on IEEE 802.16 air-interface standard provides a specific QoS class for bandwidth-hungry and delay-sensitive applications and therefore, it can be a leading solution to deliver IPTV streams to fixed and mobile subscribers [2].

In a WiMAX cell, a number of subscriber stations or mobile stations (SS or MS) are served by a base station (BS), which controls the access to the wireless medium in a centralized manner. Due to the signal attenuation,

subscribers located near the cell edge, can not obtain the required signal-to-noise ratio (SNR) to receive high data rates. As a solution, the service provider can shrink the size of the cell by increasing the number and density of base stations. This requires a large infrastructural cost for wired backhaul for the additional BSs. Using relays is a cost-effective alternative solution. Relays have significantly simpler hardware and software architecture, and hence lower cost. In addition, they operate at lower powers and without connection to any wired backhaul. Inserting relays into the cell can extent coverage area and increase throughput. Such networks are called multi-hop relay networks.

IEEE 802.16 has formed a task group to extend the IEEE 802.16e-2005 standard to include multi-hop communication, and address the problems of relaying. This amendment is called IEEE 802.16j or mobile multi-hop relay (MMR) and is fully compatible with 802.16e mobile and subscriber stations [3]. Relays in MMR are organized in tree structure, rooted at the BS.

For the applications like IPTV and video conferencing which require communication among or to a group of users, multicasting becomes a favorite transmission method. Multicast allows the sender to transmit a message (destined for multiple receivers) only once, instead of sending it to each end-point separately and clogging up the bandwidth with the multiple transmissions of the same data. An interesting feature of WiMAX which makes it quite suitable for IPTV services is support of multicast using Multicast Broadcast Service (MBS) [4]. MBS allows the transmission of commonly demanded data (e.g., a TV channel) to a group of users using shared system resources. To manage overall operations of MBS, an MBS controller (server), is needed in the system. Note that, like a regular IP host, an MBS server which provides IPTV service for subscribers, joins all multicast groups (all TV channels) using Internet Group Management Protocol (IGMP).

Using a multicast session usually outperforms multiple unicast sessions in terms of bandwidth efficiency. However, there are several challenges in multicasting as mentioned in [5] and [6]. Therefore, the efficiency of multicasting must be formally specified to find out whether it is worthwhile to use multicasting or not. For

example, for a rarely watched and unpopular TV channel, multicasting is not reasonable.

In [7], J. Aaltonen et al. evaluated the multicasting gain over unicast in cellular networks, for cells with a specific target call blocking probability. They used Monte-Carlo simulation for multicast sessions and the traditional Engset model for the unicast traffic and modeled a mobile cell as a single transmission link and calculated the number of users that can be served with a given link capacity in unicast and multicast cases. They used the ratio N_{mc}/N_{uc} as multicast gain where N_{mc} and N_{uc} are the number of served clients in multicast and unicast schemes, respectively. A. Phonphoem and L. Suchaisri in [8] used a 2-dimensional Markov model for both unicast and multicast to derive analytical expressions for the steady state behavior of a live streaming media system. They showed that multicast outperforms unicast with lower bandwidth per session and also a lower blocking probability. We introduced multicast gain as the bandwidth saved by means of using multicast instead of multiple unicast in our previous works [5][6]. In [9] we generalized our original measure (which didn't cover wireless links between mobile nodes) for two different link models: fixed data rate links and variable data rate links. The application of the generalized measure in WiMAX-based single hop and multi-hop networks is given in [9] and [10], respectively.

In this article, we put more emphasis on the effect of tree structure on multicast gain. We compare the multicast gain for transmitting TV channels in three different trees. Moreover, we investigate the effects of the user distribution and density of users in the different levels of the tree on the obtained gain.

Literature on IEEE 802.16j networks have discussed various issues such as performance evaluation [11][12], multicasting [13][14][15], resource scheduling [16][17] and relay placement [18]. In [14], Güvenc et al. discussed the applicability of MMR networks in emergency situations. They proposed two techniques to improve the reliability of transmitting MBS data over MMR networks in multicast or unicast MBS pre-transmission over relay links. W. H. Kuo and J. F. Lee in [15] addressed the resource allocation problem for multicast recipient maximization, subject to limited resource budget over MMR networks. The authors proved that recipient maximization is an NP-hard problem, and proposed a heuristic solution called dynamic station selection (DSS). To increase the performance of MBS in MMR networks, adaptive modulation and coding is employed in [13] by C. H. Cho et al. They evaluated the performance of their proposed method in transparent relay mode.

C. -Y. Yang et al. in [19] tried to minimize latency of MBS in MMR networks. They proposed the Multi-Rate Selection Algorithm (MRSA) for multicast and broadcast data delivery to determine the Modulation and Coding Scheme (MCS) and transmission scheme.

T. Qiu et al. in [20] studied a large-scale IPTV service provider in the United States, with more than one million subscribers and over 500 different live TV channels. They showed that channel popularity is highly skewed

and can be captured quite well by a Zipf-like distribution, such that, if all channels are sorted in descending order of popularity, the resulting distribution is typically close to Zipf-like.

In this paper we investigate the benefits of multicasting in OFDMA-based multi-hop WiMAX access networks. To the best of our knowledge, this is the first work on quantifying the efficiency of multicasting in such networks.

The remainder of this article is organized as follows. In Section II, required background information regarding IPTV, WiMAX and MMR networks will be introduced. Section III, describes multicasting in MMR networks. In Section IV, we define the problem in a detailed manner and introduce the required notations. The definition of multicast gain for access and relay links and the calculation method of multicast gain for MMR networks, is given in Section V. Section VI, presents some numerical results and case studies of our analysis; and finally we conclude the paper in Section VII.

II. BACKGROUND

In this section some background information about IPTV, WiMAX and relay networks is discussed.

A. Overview of IPTV Systems

IPTV is one of the fastest growing services in the last decade. Commercial deployments of IPTV services by Telcos around the world continue to increase; cf. e.g., [21][22].

In general, IPTV services can be divided into two classes, namely Video on Demand (VoD) for stored contents and Broadband-TV (BTV) for live TV channels. Unlike the native broadcast in traditional TV systems, in IPTV, video streams are distributed using IP unicast and multicast toward subscribers. Typically, unicast is used in the case of video on demand and multicast is employed by BTV service for the delivery of live TV channel streams. Each individual TV channel is mapped into a dynamic multicast stream with a unique multicast address. When a user switches into a specific channel, the Set-Top Box (STB) sends a request to join the corresponding multicast stream using IGMP protocol, and then if successful, the user can receive and start to watch the required content after a short buffering and decoding delay.

Fig. 1 illustrates a typical WiMAX-based IPTV service network architecture. In this paper, our focus is on the WiMAX based multi-hop access networks and therefore it will be introduced in the following subsection in some more detail.

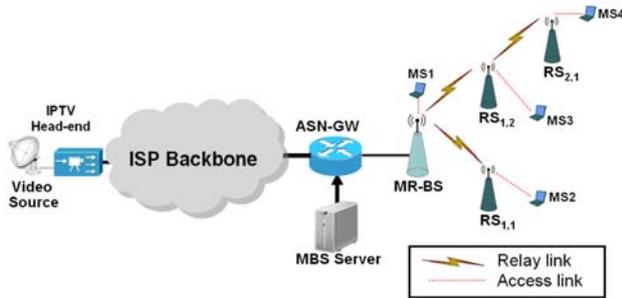


Fig.1 – IPTV system structure

B. Overview of WiMAX

WiMAX is a broadband wireless access technology based on IEEE 802.16 standards which define physical and MAC layers of the air interface.

Mobile WiMAX utilizes the Orthogonal Frequency Division Multiple Access (OFDMA) where the spectrum is divided into many subcarriers and different users can be served simultaneously by allocating different subsets of subcarriers. In addition, in wireless environments, fluctuations in channel conditions prevent the continuous use of a high bandwidth-efficient modulation. Therefore, based on subscriber’s received SNR, Adaptive Modulation and Coding (AMC) is used to provide a tradeoff between throughput and robustness. Inside the BS coverage area, each MS can use the most suitable modulation and coding scheme (MCS) irrespective of the others.

MAC layer in WiMAX is divided into three distinct sublayers: convergence sublayer, common part sublayer and security sublayer. In WiMAX, MAC layer is connection oriented and each connection is identified by a unique 16-bit connection identifier (CID). WiMAX MAC layer supports five QoS service types namely, UGS, rtPS, nrtPS and BE. The real-time Polling Service (rtPS) which is designed to support real-time service flows that generate variable size data packets on a periodic basis (e.g., MPEG video), is ideal for IPTV applications.

A great advantage of WiMAX is to support multicasting using MBS. Taking advantage of MBS, in downstream connections multicast CIDs (MCID) can be used to transmit the same content to a group of subscribers. Multicast CIDs are in the range 0XFEA0 to 0XFEEF and suited for IP multicast data transmission [2].

Bandwidth allocation in WiMAX frames consists of OFDMA symbols in one dimension and frequency subchannels in the other dimension. The smallest logical unit for bandwidth allocation is called a *slot*. The definition of a slot depends on the type of subcarrier permutation and varies for uplink and downlink. For downlink Partial Usage of SubChannels (PUSC), a data slot is composed of one subchannel (24 data subcarriers + 4 pilot subcarriers) and two OFDMA symbols [23]. For example, the data region depicted in Fig. 2, occupies five slots. The number of bits inside a slot (slot capacity) is variable and depends on the modulation and coding schemes used. For instance, the capacity of one 64-QAM 3/4 slot, is three times as the capacity of one QPSK 3/4 slot (See Table I). In this work, we use the term slot as

the basic allocation unit to compare multicast and multiple unicast bandwidth requirements.

In Time Division Duplex (TDD) mode the frame structure is divided into DL and UL sub-frames separated by transition gaps to prevent DL and UL transmission collisions. Typical frame duration is 5ms. In Fig. 2, a combination of multicast and unicast in the downlink subframe is shown.

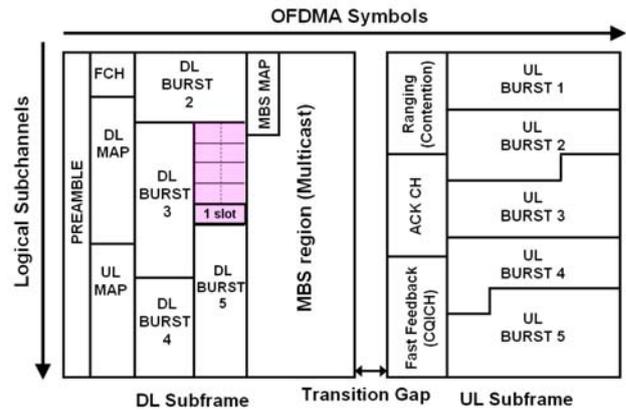


Fig.2 – WiMAX TDD frame structure

C. IEEE 802.16j (MMR)

The IEEE 802.16j mobile multi-hop relay (MMR) standard is proposed to provide a suitable solution for both throughput enhancement and coverage extension of IEEE 802.16e networks, as illustrated in Fig 3. The BS needs to be modified to support relay operations and it is called multi-hop relay BS (MR-BS) to reflect this capability.

The subscribers which are near enough to MR-BS can communicate with it directly. Using relay stations (RS), MSs in the border of the coverage cell, can receive the signal with higher data rate. For example, MS1 and MS2 in Fig. 3(a), both have the same distance from the MR-BS. But, MS1 receives the data which is relayed by RS, with higher rate than MS2 which receives data directly from BS. Thanks to relay stations, the MSs outside the coverage area, can also receive the signal. (See Fig. 3(b))

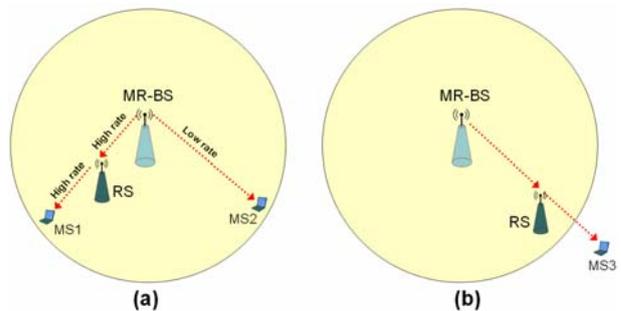


Fig. 3 - Relaying for (a) Throughput enhancement, and (b) Coverage extension

The topology of an MMR network is a tree with the MR-BS as the root of the tree. The first-hop station that MS communicates with is called *access station* for that MS and may be the MR-BS or an RS. The station that a

relay transmits to in the uplink is its *superordinate* station; a relay station that another relay or MR-BS transmits to in the downlink is its *subordinate* relay. For example, in Fig. 1, $RS_{1,2}$ is superordinate of $RS_{2,1}$ and it is subordinate of MR-BS. In addition, access station for MS2 is $RS_{1,1}$ and access station for MS3 is $RS_{1,2}$. MS1 is directly served by the MR-BS.

An MMR network includes two types of radio links: relay links and access links (see also Fig. 1). The links between two relay stations or between a relay and MR-BS are called relay links. The access link is the radio communication between an MS and its access station (MR-BS or RS).

The frame structure which was discussed earlier is designed for single-hop wireless networks. To accommodate the relaying capability, downlink and uplink subframe are divided into an *access zone* and a *relay zone*. In both DL and UL subframes, access zone is dedicated for communication with directly served MSs. More specifically, in access zone, the MS transmits/receives in the uplink/downlink direction. The relay zone consists of communication between RSs or between MR-BS and its subordinate relays. MR-BS and relays can use advanced antenna techniques (e.g., directional antenna, sectorized antenna, beam-forming) to reduce interference and achieve more spatial reuse. To have a clear view of access and relay links, see Fig. 4.

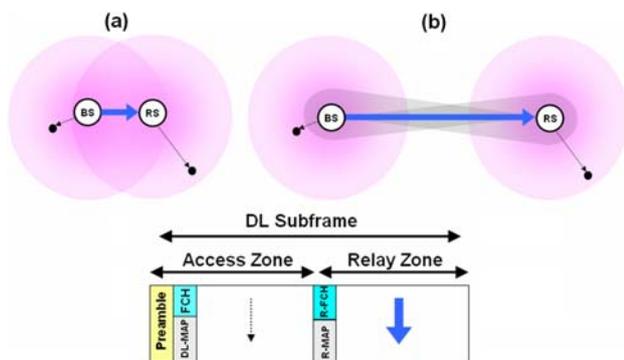


Fig. 4 – Downlink access and relay links

In the Figure 4(a), access link and relay link are created by omni-directional antennas. In Fig. 4 (b), directional antennas are used for relay links and omni-directional antennas for access links. In both cases, data transmission in access and relay links are separated in time domain using access zone and relay zone in DL-subframe.

Two types of relay operation modes are included in the IEEE 802.16j standard, *transparent* mode and *non-transparent* mode.

A relay in transparent mode, does not broadcast control signaling (i.e., Preamble, FCH, DL-MAP and UL-MAP). In this mode, an MS associated to an RS is located within the coverage of the MR-BS; but it can achieve higher throughput by using two hops instead of direct communication with MR-BS. The control signaling from the BS is always transmitted with the most robust

modulation scheme and can directly reach the MSs. The data traffic is relayed via a relay station. Transparent relay only supports centralized scheduling. MR-BS coordinates and allocates the radio resources to MSs and RSs within the cell by distributing control information and arbitrating access requests. In addition to throughput enhancement, transparent relays can solve the problem of coverage holes [24].

Conversely in non-transparent relay mode, all data and control signaling transmissions between MR-BS and MS are relayed and therefore, a non-transparent relay can increase coverage area. The non-transparent RS can operate in both centralized and distributed scheduling. Non-transparent relays can assist the MR-BS for MS management, including network entry, resource allocation, authorization, and data transmission. In distributed scheduling mode, some functionality like resource scheduling or security control can be given to relays. Relays in non-transparent mode can be as complex as a BS. Therefore, the cost of non-transparent relays is much higher than for transparent ones.

III. MULTICASTING IN IEEE 802.16J NETWORKS

There exist several challenges in transmitting multicast data over multi-hop relay networks. In the following we will briefly explain some of the problems and the proposed solutions by 802.16j task group.

A. MBS Connection Management and Distribution Tree Creation

Similar to unicast services in IEEE 802.16, the MBS service flows are managed through a DSx (Dynamic Service Addition/Deletion/Change) messaging procedure used to create, change, and delete a service flow for each MS. Some important service flow information such as QoS, service flow identifier (SFID), and multicast connection identifier (MCID) are exchanged between MS and BS via the DSx handshaking procedure.

In an MMR network, in order to distribute multicast traffic, a *multicast distribution tree* for each MBS service must be established. In this way, the multicast data is transmitted only to the RSs associated with the MSs that have requested the MBS. Multicast data is transmitted only once along the path toward those access stations of the MSs which receive the MBS. Thus, the bandwidth utilization for multicast is improved.

In order to explain the establishment and maintaining of a multicast distribution tree, the concept of *path* must be introduced. The set of relays between a specific relay station and MR-BS is called a path. In an MMR network, the number of paths is equal to the number of relay stations. Fig. 5, depicts four paths in the tree as follows:

$P1 = \{MR-BS, RS1\}$, $P2 = \{MR-BS, RS1, RS2\}$, $P3 = \{MR-BS, RS1, RS3\}$, $P4 = \{MR-BS, RS1, RS3, RS4\}$.

Each multicast distribution tree consists of some paths and is defined as follows:

Distribution tree = {MCID, Number of paths, set of ordered pairs (P_i, N_i) },

where, P_i is the path identifier in the tree and N_i represents the number of MSs that receive the specific MBS flow through path P_i .

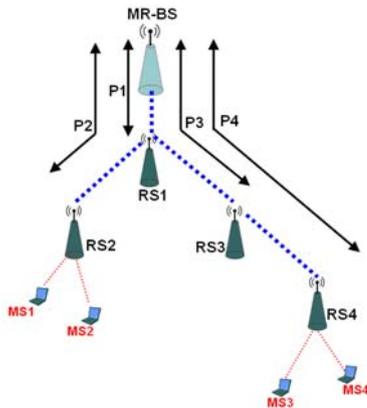


Fig. 5 – Paths and multicast distribution tree

For example, if MS1, MS2 and MS3 belong to a multicast group and receive a common multicast flow (e.g., with MCID 0XFEB3), the multicast distribution tree for this multicast group would be:

Distribution_tree = {0XFEB3, 2, (P2,2), (P4,1)}.

The procedure for establishing a multicast distribution tree is as follows [3]:

When the MR-BS receives an MBS request from an MS, it first checks whether the requested MBS has been created previously or not. If it is the first request, the MR-BS creates a multicast distribution tree for the requested MBS and allocates a multicast CID (MCID) to it. The MR-BS also determines the path to carry this multicast service flow and creates the mapping between the determined path and the MCID. Then, all the RSs along the path will be informed about the binding between the path ID and MCID. The RSs on the path store the path ID and MCID binding information for forwarding multicast data with the MCID. They use this information to build-up their forwarding tables. 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.

If the multicast distribution tree has been previously created and an MCID has been allocated to the requested MBS, but the path is not in the multicast distribution tree, the MR-BS adds this path to the tree and binds it to MCID and informs all the RSs along the path. If the path is already in the multicast distribution tree, the MR-BS simply updates the number and identification information of the MSs using the path.

The process of removing a path from a multicast distribution tree is done in a similar manner. If the last MS from a specific access station leaves the multicast service, the path must be removed from the multicast distribution tree. In this case, all the RSs on the path are informed about the path deletion.

B. MBS Synchronization

In order to achieve higher data rates using macro-diversity and seamless handover, the transmission of MBS data must be synchronized. In an MMR network,

the relay's hop count from the MR-BS or their processing delay may be different. Each RS calculates its downlink processing delay (DR) in unit of a frame, and reports it to the MR-BS as a capability parameter in the SBC-REQ message [25]. The MR-BS determines the maximum cumulative delay, DM, of all RSs based on their positions in the tree and their individual processing delays. Then, the MR-BS calculates the required waiting time, for each RS based on the value of DM and each RS's cumulative delay and notifies each RS of its waiting time via an SBC-RSP message. If relays are heterogeneous and have the same capabilities, their processing delay is equal and the delay of each relay depends on the depth (hop count) of the relay.

When an MBS transmission is necessary, the MR-BS forwards the MBS data over the relay downlink as a pre-transmission, and this happens DM frame durations before transmitting this MBS data over the access link. Each RS in the MBS zone must forward the MBS data it receives over the relay downlink. Finally, once the MR-BS has waited DM frame durations and each RS has waited its specified waiting time, the MR-BS and RSs synchronously transmit the MBS data over the access link. For example, as shown in Fig. 6, it is assumed having two relays RS1 and RS2 with the delays of one frame and two frames, respectively. Therefore, after pre-transmission, the MR-BS must wait two frame durations (DM=2), while RS1 waits one frame after the processing delay and RS2 can transmit the MBS data after its downlink processing delay immediately. The final result is synchronous transmission of the MBS data burst.

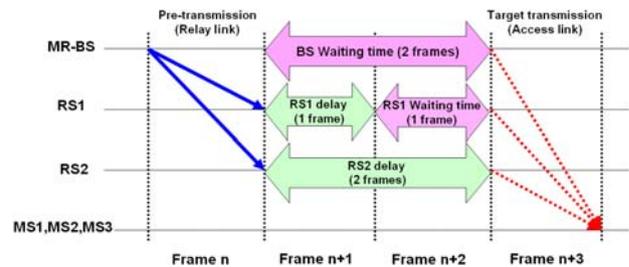


Fig. 6 – Synchronized MBS transmission

IV. REFINED DEFINITION OF THE PROBLEM AND BASIC ASSUMPTIONS

In wireless networks, bandwidth represents one of the most important resources and therefore must be used efficiently. Thus, in this paper, we let our measure of multicast gain focus on the bandwidth requirement for multicast versus unicast transmissions. In particular, we define multicast gain as *amount of saved bandwidth (in terms of OFDMA slots) by using multicast instead of multiple unicast*.

Although benefit and efficiency of multicasting has been extensively studied in the literature, not much effort has been spent to quantitatively compare the performance of multicast and unicast transmission schemes. Gain measurement is conducted in order to find out whether it is worthwhile to use multicasting or not. In the cases

where no significant gain is obtained, there is no need for multicast.

The authors in [6] proposed a measure for the efficiency of multicasting in tree structured distribution networks. In this article we now generalize the measure to wireless links and apply it in WiMAX MMR access networks.

Let us now introduce the scenario and basic assumptions for which we are evaluating the benefits and the gain of multicasting. Assume that N users exist, each of which watches TV (i.e., accesses a given channel C) with probability p . Furthermore, assume each user behaves independently and watching behavior of one user does not affect other users. A user may be either active (watching TV), or inactive. These users can access the TV service via their access stations (i.e., MR-BS or RS) and send their request for the channel. Users may be fixed (using set-top boxes and TV sets) or mobile (using PDAs or mobile phones).

An RS operates in decode-and-forward manner and therefore, may use different MCSs for reception and forwarding of data. This means that each hop has potentially different rates (different link qualities of relay links).

Recall from Section I, the MBS server joins the multicast group of all TV channels and can handle the requests of subscribers and provide TV programs to them on behalf of the IPTV head-end. We assume that the MBS server can be accessed by MR-BS (via ASN-GW) without bandwidth or latency constraints (Fig. 7).

Note that, although in general there exist a lot of different TV channels in the server, analysis is the same for all channels, because they are only different in their watching probability. So, without loss of generality, we restrict ourselves to a single (arbitrary) channel C with access probability p in the rest of the paper. Furthermore, since we are modeling the network at an arbitrarily chosen (but then fixed) instant of time, we don't have to care about arrival and departure rates of clients.

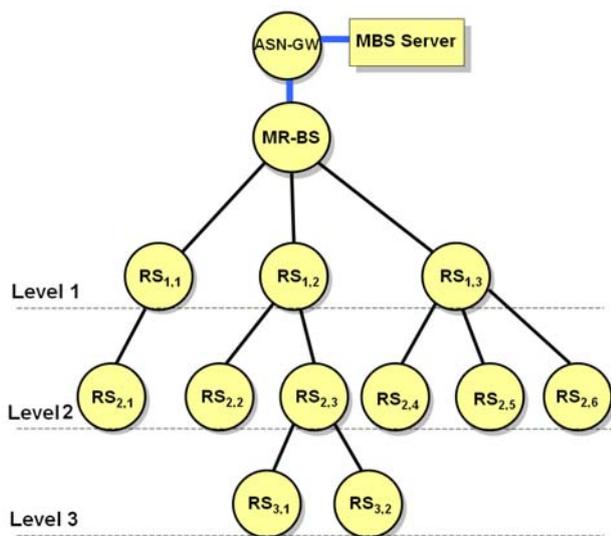


Fig. 7- Tree-structured MMR network to deliver TV programs

We also make the following further assumptions:

- Each channel is considered to be a stream with constant bit rate.
- Access probability of TV channels is defined by their popularity (which could, e.g., have a Zipf-like distribution [26]).
- Streams are unidirectional and are transmitted from the server to the TV clients, so that, only the downlink traffic is considered (downlink subframe).
- Since we are investigating multi-hop relay scenarios (two or more hops), we assume that relays are non-transparent and are able to extend the coverage area of the network.
- Relays are single radio and therefore operate in half-duplex mode.

V. MULTICAST GAIN IN IEEE 802.16J NETWORKS

In this section, we want to formalize our method of calculating multicast gain in access and relay links. In order to do our analysis, we need some notations as introduced in the following:

RS_{ij} : j -th relay station in level i (i hops away from MR-BS)

p : Probability for the TV channel C to be actually watched by one of its potential users (channel popularity); p is the same for all users

ST_{ij} : Subtree below relay RS_{ij}

$U(ST_{ij})$: Number of users in subtree ST_{ij}

$Ud(RS_{ij})$: Number of users that use RS_{ij} as their access station

$LG(RS_{ij}, RS_{i,k})$: Gain of link between RS_{ij} and $RS_{i,k}$ (or: link RS_{ij} - $RS_{i,k}$ for short)

$P_n(C)$: Probability that at a given instant of time, n clients are watching TV channel C

M : Number of possible modulation and coding schemes (MCS)

MCS_i : i -th modulation and coding scheme

S_u : Average number of slots required for multiple unicasting TV channel C

S_m : Average number of slots required for multicasting TV channel C

S_{AZ} : Number of slots in access zone

S_{RZ} : Number of slots in relay zone

b_c : Bandwidth requirement for transmitting the video stream representing channel C

Note that, the calculation of multicast gain and decision support mechanisms regarding multicasting or unicasting a specific TV channel is up to the service provider and can be done in a static or dynamic (during network operation) manner. In addition, popularity of different TV channels can be easily calculated by monitoring the requests of the subscribers and/or dwell time on each channel during a specific time interval and therefore, the service provider has this information in advance.

Table I.
PARAMETERS FOR DIFFERENT MCSs

MCS	Received SNR (dB)	Bits per Subcarrier	Theoretical DL Throughput(Mbps)	Slot size (bits)	Area fraction	No. of required slots per frame
MCS ₁ : QPSK 1/2	5	1	6.34	48	A ₁ : 0.166352	14
MCS ₂ : QPSK 3/4	8	1.5	9.51	72	A ₂ : 0.287335	9
MCS ₃ : 16-QAM1/2	10.5	2	12.68	96	A ₃ : 0.120983	7
MCS ₄ : 16-QAM3/4	14	3	19	144	A ₄ : 0.10586	5
MCS ₅ : 64-QAM1/2	16	3	19	144	A ₅ : 0.130435	5
MCS ₆ : 64-QAM2/3	18	4	25.36	192	A ₆ : 0.068053	4
MCS ₇ : 64-QAM3/4	20	4.5	28.51	216	A ₇ : 0.120983	3

A. Multicast Gain on Access Links

Access stations use broadcasting to serve their clients and active clients contend for the shared bandwidth. A user with a good channel can receive data at a higher modulation (and thus, higher rate) compared to a user with a poor channel. Meanwhile, sending data at a higher modulation consumes less resources (slots). If we assume that the decreasing of the SNR is only due to the path loss, MCS can be determined by the distance between subscriber and its access station.

Assume d_k is the maximum distance that signals can be received using MCS_k and having N active clients inside the coverage area of a given access station. If i clients want to watch TV channel C simultaneously, in unicast mode (Fig. 8 (a)), i different streams of this channel (with different rates) must be transmitted. In multicast mode, the access station needs to choose an MCS that has lower SNR requirement (and thus lower slot capacity) to fulfill the requirements of all clients. In this mode only one MBS stream but with the lowest rate (most robust MCS) is transmitted as shown in Fig. 8 (b). Note that, if the lowest rate MCS is not chosen, each user arrival and departure may change the MCS of the multicast group and involves signaling overhead and significantly more complexity.

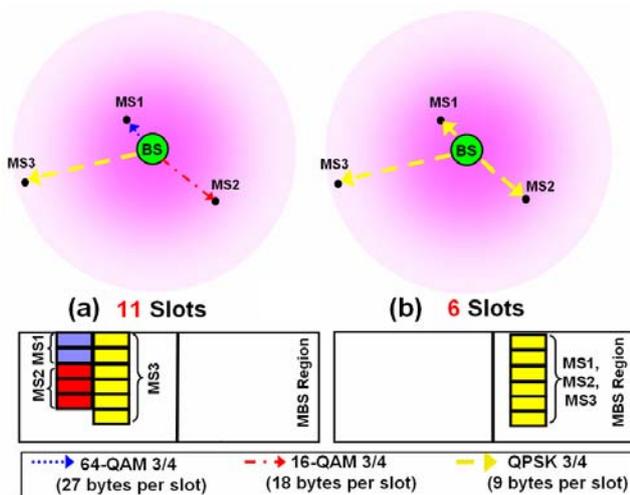


Fig.8 – Multiple unicast, cf. (a), and multicasting, cf. (b), in an access link (transmission in access zone)

With the assumption that decreasing in the signal strength is only due to the free space path loss, d_k can be calculated from the following formula:

$$d_k = \frac{\lambda \cdot 10^{\frac{P_t [dBm] + 10 \log(G_t) + 10 \log(G_r) - SNR_k [dB] - TN [dBm / Hz]}{20}}}{4\pi} \tag{1}$$

where, P_t (43 dBm) is the transmission power, TN (-174 dBm/Hz) is the thermal noise and G_t (16 dBi) and G_r (0 dBi) are transmitter and receiver antenna gain, respectively [23].

Therefore, we can divide each cell into M concentric circles (with radius d_k) which represent M different regions in which users can receive signals modulated using different MCSs as shown in Fig. 9.

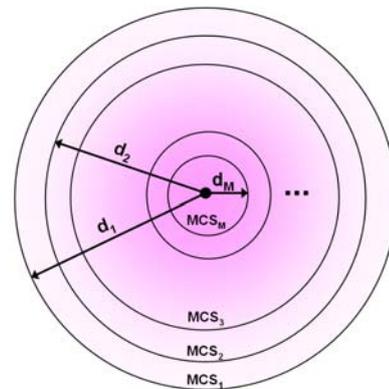


Fig. 9 – The relationship between distance and MCS

As depicted in Fig. 8, the number of required slots is different for multicast and multiple unicast cases. If we assume that clients are uniformly distributed in the area, then the probability that a client is located in a specific region is related to the area fraction of that region. Let A_k be the area fraction of region MCS_k which is bounded by two concentric circles with radii d_k and d_{k+1} , respectively. Then, A_k can be calculated as follows:

$$A_k = \frac{\pi d_k^2 - \pi d_{k+1}^2}{\pi d_1^2} = \frac{d_k^2 - d_{k+1}^2}{d_1^2}, \quad d_{M+1} = 0; \tag{2}$$

Since we assumed that each client behaves independently of the others, and watching behavior of a client does not affect other clients, the probability of having i clients (out of N) watching TV channel C (with watching probability p for each user), can be calculated using a binomial random variable. Therefore:

$$P_i(C) = \binom{N}{i} p^i (1-p)^{N-i}. \quad (3)$$

Similarly, the probability that j users of the above i users are located in MCS_k region is equal to:

$$\binom{i}{j} A_k^j (1-A_k)^{i-j}. \quad (4)$$

For various MCSs, using the slot capacities indicated in Table I, the number of required slots for unicasting and multicasting can be calculated. Therefore, the average number of required slots in unicast mode is equal to:

$$S_u = \sum_{k=1}^M \sum_{j=1}^N \sum_{i=j}^N \left[\binom{N}{i} p^i (1-p)^{N-i} \right] \binom{i}{j} A_k^j (1-A_k)^{i-j} \cdot Slots(MCS_k) \cdot j \quad (5)$$

where, $Slots(MCS_k)$ denotes the required number of slots in a frame to transmit TV channel C using MCS_k .

$$Slots(MCS_k) = \left\lceil \frac{b_c}{SlotSize(MCS_k)} \cdot FrameDuration \right\rceil \quad (6)$$

b_c is the constant bandwidth requirement for transmitting the video stream representing channel C and depends on the format of TV programs and frame rate; $\lceil x \rceil$ denotes the ‘ceiling function’ of x .

For multicast mode, the average number of slots can be calculated according to the following formula:

$$S_m = \sum_{i=1}^N \binom{N}{i} p^i (1-p)^{N-i} \cdot Slots(WorstCondition) = [1 - (1-p)^N] \cdot Slots(WorstCondition). \quad (7)$$

The overheads for control parts (Preamble, FCH, DL-MAP and UL-MAP and MBS overhead) are encoded with MCS_1 (QPSK 1/2) with 4 repetitions so that all the mobile stations can decode them correctly. Therefore, they have a significant impact on overall capacity of the frame.

Each DL-MAP and UL-MAP is composed of a fixed and a variable part. The fixed part includes 104 and 64 bits for DL-MAP and UL-MAP, respectively. In both DL-MAP and UL-MAP, variable parts consist of one entry (MAP-IE) per user burst. Therefore, the size of the MAP messages depends on the number of users. For MBS transmission, the overhead includes MBS-MAP-IE, MBS-MAP and MBS-DATA-IE [4].

Other than the preamble, the rest of the control parts are transmitted in units of slots. The size of the abovementioned fields are as follows:

- FCH : 4 slots ;
- Fixed part of DL-MAP : 104 bits ;
- Fixed part of UL-MAP : 64 bits ;
- DL-MAP-IE : 60 bits for each entry ;
- UL-MAP-IE : 32 bits for each entry ;
- MBS-MAP-IE : 40 bits ;
- MBS-MAP : 28 bits ;
- MBS DATA IE : 72 bits.

The total number of overhead slots in unicast mode is equal to:

$$OV_u = 4 + \left\lceil \frac{104 + 64 + 60 \sum_{i=1}^N P_i(C) i}{slot_size(MCS_1)} \right\rceil \cdot r \quad (8)$$

and for multicast transmission of TV channel C , overhead can be calculated from the following formula:

$$OV_m = 4 + \left\lceil \frac{104 + 64 + 40}{slot_size(MCS_1)} \right\rceil \cdot r + \left\lceil \frac{28 + 72 \sum_{i=1}^N P_i(C)}{slot_size(MCS_1)} \right\rceil \cdot r \quad (9)$$

where, r is the repetition factor.

We calculate two additional variables to consider the overheads, expressed as a percentage:

$$O_u = \frac{S_t}{S_t - OV_u}, \quad O_m = \frac{S_t}{S_t - OV_m}; \quad (10)$$

where S_t denotes the maximum number of available slots.

Then we introduce auxiliary variables S_u^* and S_m^* as follows:

$$S_u^* = S_u \cdot O_u, \quad S_m^* = S_m \cdot O_m \quad (11)$$

Therefore, as suggested in [9] we can define the multicast gain for a WiMAX cell which takes into account the overhead slots as follows:

$$MG_{Cell} = \frac{S_u^* - S_m^*}{S_t} \quad (12)$$

Replacing S_t by S_{AZ} in equations (10) and (12) this leads to the following formula to calculate the *multicast gain of access links*:

$$MG_{Access} = \frac{S_u^* - S_m^*}{S_{AZ}} \quad (13)$$

B. Multicast Gain on Relay Links

In this section, we calculate the gain obtained from multicasting in relay links. Relays are organized in a tree-structured network. Therefore, we start our analysis from the lowest level of the tree (i.e., from relays that don't have any subordinate relay). We

assume relays are fixed and the MCS levels between relay links (link quality) do not change during the operation.

1) *Multicast gain on the lowest level*

Assume having an MMR network with k levels of relays. To refine our definition of multicast gain, let us concentrate on an arbitrary relay in the lowest level (e.g., $RS_{k,1}$) of the network (See Fig. 10).

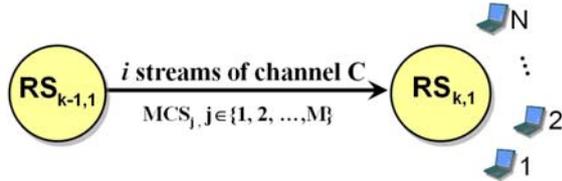


Fig. 10 – Lowest level relay links

We want to calculate the gain obtained from multicasting in the link between this relay and its superordinate relay. Here, we only consider active clients. Assume having a fixed number of N active clients at an arbitrary instant of time, i of which are watching TV channel C . If multiple unicasting is used instead of multicasting, i concurrent video streams (i instances of TV channel C) are transmitted via this link. Thus, if modulation and coding scheme $MCS_j, j \in \{1, 2, \dots, M\}$ is used, the difference between the required slots for i streams and the required slots for one stream ($i=1, \dots, N$) is equal to:

$$S_u - S_m = \sum_{i=2}^N \binom{N}{i} p^i (1-p)^{N-i} \cdot (i-1) \cdot Slots(MCS_j) \quad (14)$$

And similar to (13) the *multicast gain for a relay link* is equal to:

$$MG_{Relay} = LG(RS_{k-1,1}, RS_{k,1}) = \frac{S_u - S_m}{S_{RZ}}, \quad (15)$$

where, S_{RZ} is the total number of slots in the relay zone. Note that, MG is the gain to be expected in the long term. It is quite obvious that when the number of users that watch TV channel C , is less than two, no gain is obtained.

2) *Multicast gain on higher levels*

The downlink traffic to a specific RS consists of the traffic to the direct users of that relay and the traffic to its subordinate relays. To calculate the multicast gain on higher level links, we need to introduce the concept of sub-tree. The set of links and relays below relay $RS_{i,j}$ is called a sub-tree and denoted by $ST_{i,j}$ (see Fig. 11).

Recall from notations, $U(ST_{i,j})$ is the number of total users in a sub-tree and is equal to the sum of the local users of $RS_{i,j}$ and the users of its subordinate relays. Assume $RS_{i,j}$ has m subordinates, therefore:

$$U(ST_{i,j}) = Ud(RS_{i,j}) + \sum_{k=1}^m U(ST_{i+1,k}) \quad (16)$$

For example, in Fig. 11:

$$U(ST_{1,1}) = Ud(RS_{1,1}) + [U(ST_{2,1}) + U(ST_{2,2})] = 4 + 3 + 5 = 12.$$

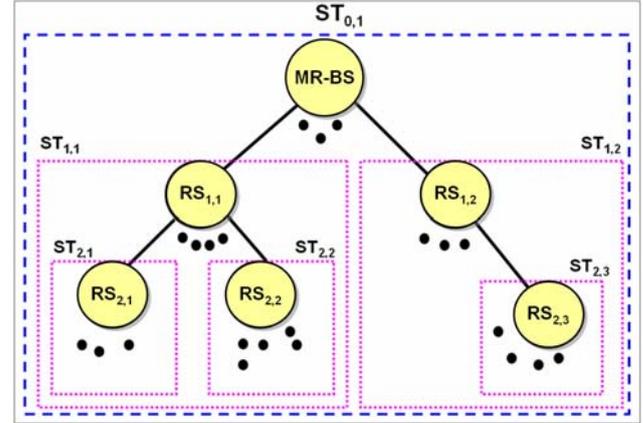


Fig. 11- Concept of sub-trees

Note that, for relays in the lowest level,

$$U(ST_{i,j}) = Ud(RS_{i,j}).$$

Therefore, *multicast gain for the link between $RS_{i,j}$ and its superordinate relay* (i.e., link $RS_{i-1,m}-RS_{i,j}$) with MCS_x is equal to:

$$LG(RS_{i-1,m}, RS_{i,j}) = \quad (17)$$

$$\frac{\sum_{k=2}^{U(ST_{i,j})} \binom{U(ST_{i,j})}{k} p^k (1-p)^{U(ST_{i,j})-k} (k-1) Slots(MCS_x)}{S_{RZ}}$$

The *multicast gain of a network* is the sum of the gains of its links plus the gains obtained from serving local subscribers [6].

Note that it is possible to restrict multicasting only to higher levels of the tree when it is not worthwhile to use multicasting in lower levels.

VI. CASE STUDIES AND NUMERICAL RESULTS

In this section, we want to discuss some numerical results based on the analytical formulae obtained in Section V.

We designed an algorithm that constructs different tree structures and calculates multicast gain for all the links as well as the total multicast gain of the tree. We implemented it by using the C++ programming language. One of the generated trees is shown in Fig. 12 and will be studied as an example. In this example, one BS and eleven relays are organized as a tree structure with three levels.

In fact, all the statements about the obtained gain and number of supported subscribers depend on the type of the workload. The mobile TV workload depends on the quality and the size of the display screen. We assume that WiMAX subscribers use PDA or mobile phones which have low display resolution and small sizes and encoding standards like QCIF (176×144) or CIF (352×288) can be used. Display

resolution directly affects bandwidth requirement for TV streams. For example, for a TV program in QCIF format with 15 frames per second, bandwidth requirement (b_c) is about 128 Kbps.

Table II summarizes the system parameters used in our analysis. Seven MCSs are assumed according to Table I. With the assumption of the DL:UL ratio of 3:1 and number of 30 subchannels the total number of slots in the downlink is equal to 510 [27]. After reducing the overhead for control parts (Preamble, FCH, DL-MAP and UL-MAP), the remaining slots are divided with the ratio of 4:3 between downlink access zone (S_{AZ}) and relay zone (S_{RZ}).

Table II. PARAMETER SETTING

Parameter	Value
Channel bandwidth	10 MHz
Permutation mode	PUSC
Number of subcarriers	1024
Data subcarriers	720
Cyclic prefix	1/8
Subcarrier spacing (f)	1094 KHz
Useful symbol time ($T_b=1/f$)	91.41 μ s
Guard time ($T_g=T_b/8$)	11.41 μ s
OFDMA symbol duration ($T_s=T_b+T_g$)	102.82 μ s
Frame duration	5 ms
OFDMA symbols per frame	48
Data OFDMA symbols per frame	44
Number of subchannels	30
DL:UL ratio	3:1
Video format of TV channel	QCIF(176 \times 144)-15 fps
Bandwidth (data rate) requirement for TV	128 Kbps

Taking advantage of Payload Header Suppression (PHS), upper layer overheads (RTP/UDP/IP) are significantly reduced and therefore, this overhead is not considered in the capacity evaluation.

A. Effect of Client Distribution on Multicast Gain

To evaluate the effect of client distribution, 130 clients are distributed among the relay nodes and BS. Any active client can watch channel C with the probability p and watch other channels with probability $(1-p)$. Since the bandwidth is shared among the subscribers, in comparison with wired access technologies (e.g., xDSL), the number of served clients is much lower. Three different cases are studied:

Case 1: Equal distribution of users among access nodes (10 clients per each node).

Case 2: Unequal distribution of users, (according to Fig. 12 (a)); called ‘Unequal 1’ in Fig. 14(a).

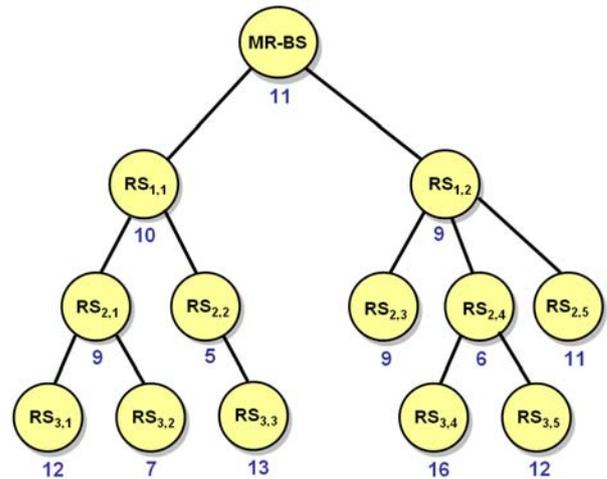
Case 3: Unequal distribution of users, (according to Fig. 12 (b)); called ‘Unequal 2’ in Fig. 14(a).

We vary the watching probability (channel popularity) of the channel C from a rarely watched channel ($p=0.001$)

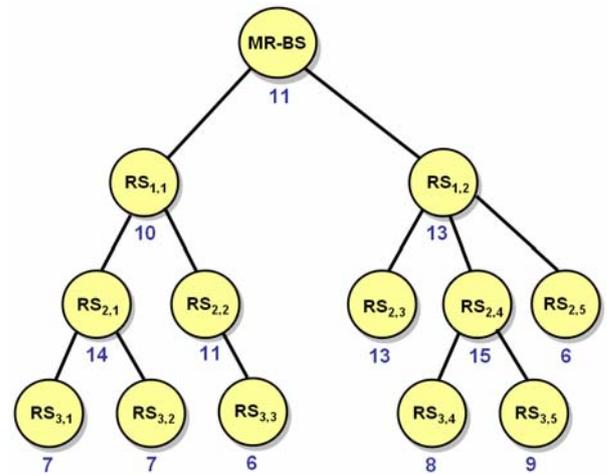
to a popular channel ($p=0.1$). 64QAM 3/4 MCS is assumed for all relay links. The results are shown in Fig. 14(a).

Note that in case 1, the total number of 50 users are distributed in level 3 and 50 users are distributed in level 2 relays (10 users per relay). In case 2, however, the number of level 3 users is increased to 60; but the number of level 2 users is lower than in case 1 (40 users). In case 3, more users are shifted toward level 2 relays and less users (in comparison with other cases) remain for level 3 relays.

As can be concluded from Fig. 14(a), the lowest gain is obtained for case 3, when there are less users in the lower level relays (i.e., $RS_{3,i}$). Since lower level relays have more impact on obtained multicast gain, the total gain would be higher in case 2. Also, it can be seen from the figure that for channels with watching probability less than 0.01, no considerable gain is obtained. We repeated the test for numerous other types of trees and different user distributions and obtained similar results. Therefore, the multicast gain in a given tree depends not only on the distribution of users but also on the density of users in each level.



(a) More users in lower-level relays



(b) More users in higher-level relays

Fig. 12 – Unequal distribution of users (Numbers at RSs: number of served subscribers)

B. Effect of Link Capacity on Multicast Gain

To analyze and evaluate the effect of link capacity on multicast gain, the watching probability is varied from a rarely watched channel to a popular channel and the multicast gain for different MCSs is calculated. Users are distributed among access stations according to Fig 12 (a). The result for different links is depicted in Fig. 14(b). A special case is also investigated (curve *Different* in Fig. 14(b)) in which the relay links of the first level (links between MR-BS and its subordinate relays) are assumed to use 64-QAM 3/4, Level 2 links use 16-QAM 3/4 and Level 3 links use QPSK 3/4 to transmit data. Note that, since we are not discussing blocking probability of requests, users are distributed in such a way that all the links have enough capacity for the transmission of multiple unicasting.

Here, multicast gain is a way to quantify the motivation of using multicasting. It can be argued from the figure, for the links with lower capacity, more motivation exists to use multicasting. To have an idea of why gain is higher in the links with lower data rates, see Fig. 13. In this figure, two relay links with different qualities are compared. 18 slots can be saved when one uses multicasting in the upper link (QPSK 3/4), while in the lower link only 6 slots are saved.

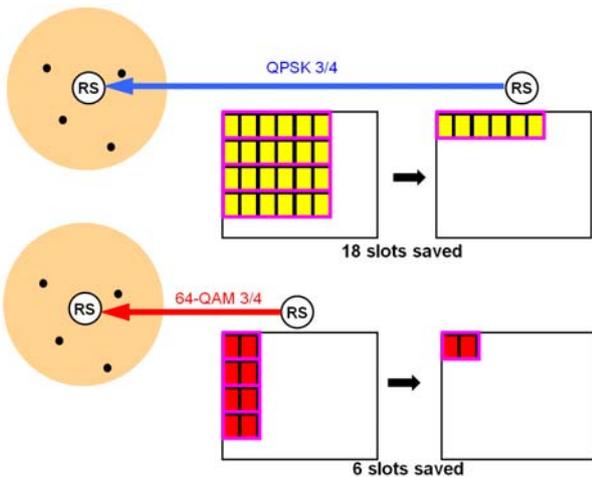


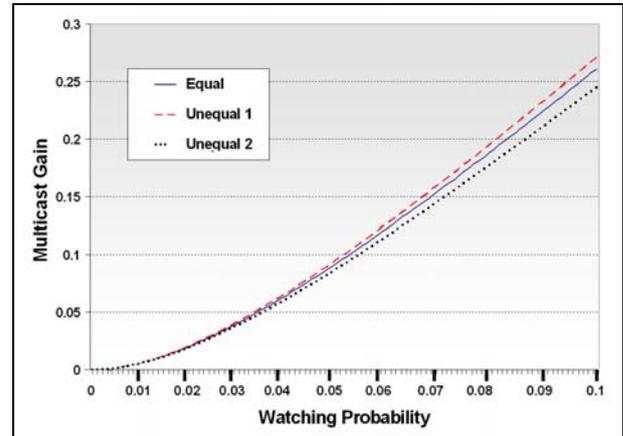
Fig. 13 – Efficiency of multicasting in different relay links (Transmission in relay zone)

C. Effect of Number of Clients on Multicast Gain

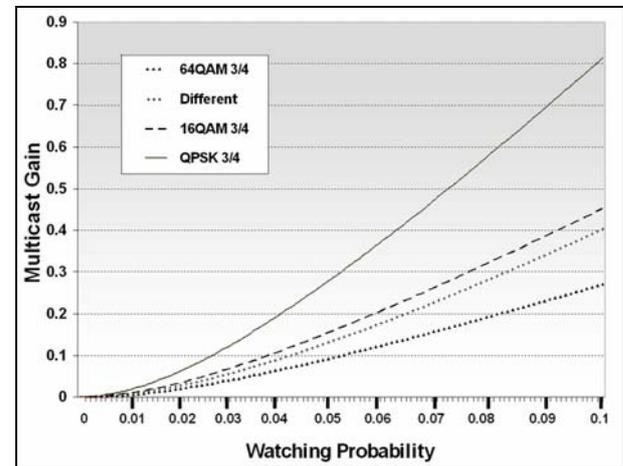
To evaluate the impact of number of clients, we calculated multicast gain for different number of users that are equally distributed on relays and MR-BS (3, 6, 9, 12, 15). The watching probability varies from 0 to 0.1. We assume all relay links use 64-QAM 3/4 modulation.

The results are shown in Fig. 14(c). It clearly makes sense that the more clients in the network, the higher the multicast gain would be; because then it is more probable that two or more clients watch the same channel simultaneously. Similarly, in all cases, for the channels

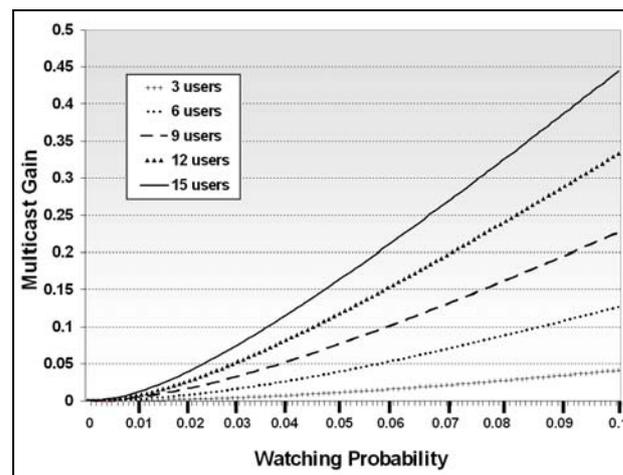
with watching probability less than 0.01, multicast gain is insignificant.



(a) Effect of user distribution on multicast gain



(b) Effect of link capacity (quality) on multicast gain



(c) Effect of number of clients on multicast gain

Fig. 14- Numerical results for multicast gain on relay links

D. Effect of Tree Structure on Multicast Gain

To evaluate the effect of tree structure in the obtained multicast gain for a given number of users, we investigate the following tree structures generated by our algorithm.

- 1) *Tree1*: The tree structure of figure 7
- 2) *Tree2*: The tree structure of figure 12
- 3) *Tree3*: Binary tree with 3 levels (15 nodes in total)

The total number of 120 users is distributed among the nodes in each tree. Such that, for the case of Tree1, 10 users are served by each node (RS or MR-BS). In Tree2, there are 12 users in the coverage range of MR-BS, and each relay station serves 9 users ($12+9*12=120$). Finally, in the binary tree, i.e. Tree3, 8 users are served per node. All the relay links are assumed to use 64QAM 3/4 MCS. We calculated multicast gain for three different channels: A popular channel ($p=0.1$), a normal channel ($p=0.05$) and an unpopular channel ($p=0.01$). The results are shown in Fig. 15. As can be concluded from the figure, for the same number of users in the tree, the highest gain is obtained for Tree3 in which there are eight relays in the lowest level (e.g., relays 3 hops away from MR-BS). In Tree2, there are five relays in level 3 and therefore, the multicast gain is higher than for Tree 1 in which only two relays are in the lowest level. In addition, the gain is directly related to the popularity of the TV channel. For all the cases, the multicast gain is considerable for a popular channel. Also, irrespective the structure of the tree, for unpopular channels multicasting is not efficient.

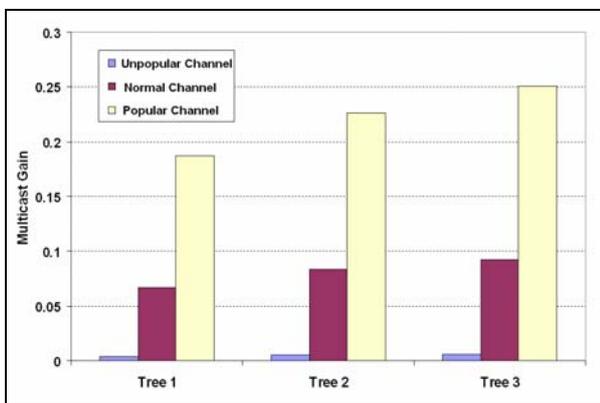


Fig. 15- Multicast gain for different tree structures

E. Multicast Gain on Access Links

To calculate multicast gain in access links, we need the approximated area of each MCS region. Table I shows the required SNR for each MCS region. The maximum distance between a subscriber (with a given SNR) and its access station is calculated from (1). The area fractions are calculated according to (2). Regarding to what we discussed about using most robust MCS in multicast sessions in Section V.A, we assume:

$$Slots(WorstCondition) = Slots(MCS_1).$$

Fig.16 shows the multicast gain obtained in an access link with 25 subscribers. Watching probability varies from 0.001 to 0.1. As depicted in the figure, having 25

subscribers, for the channels with watching probability less than 0.058, multicasting is not efficient and using multiple unicasted flows outperforms multicasting in terms of number of slots. Note that if the watching probability is high enough, even for two subscribers, multicast is more efficient.

Finally, we can conclude that the potential advantage of multicast vs. unicast in an MMR network depends on:

- Tree structure (number of levels and branches);
- Watching probabilities of channels;
- Number of users at access stations;
- Distribution of users at access stations;
- Density of users at different levels;
- MCS of the relay links;
- Bandwidth requirement (b_c) to transmit the desired channel.

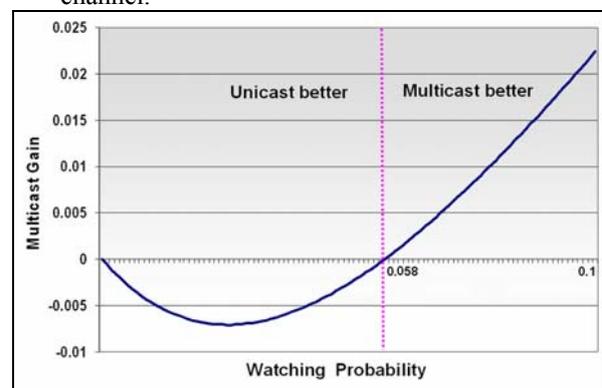


Fig. 16- Multicast gain on access link

VII. CONCLUSION

Multicast can reduce the steady state bandwidth requirement on network links in TV distribution systems from one stream per viewer to one stream per TV channel. An interesting feature of WiMAX is support of multicast using MBS. In addition, many other capabilities like, QoS support, wide coverage range, high bandwidth, power saving mode (necessary for handheld devices) and mobility support, makes WiMAX a good candidate to be used as an IPTV access network. We introduced a performance criterion, the multicast gain, to compare multicast and unicast efficiency in terms of required slots. Based on this new measure, we analyzed the benefits of multicasting in tree-structured MMR networks on IEEE 802.16j basis, and proposed analytical methods to calculate multicast gain in relay and access links. We evaluated our formulae in a case study for different scenarios and discussed the effects of number of users, link qualities, user density and user distribution on multicast gain. Among others, we obtained the highly interesting and unexpected result that for some scenarios unicast is able to outperform multicast.

REFERENCES

- [1] G. O’Driscoll: Next Generation IPTV Services and Technologies, John Wiley & Sons, 2008.
- [2] L. Nuaymi, WiMAX: Technology for Broadband Wireless Access, John Wiley & Sons, New York, NY, USA, 2007.

- [3] IEEE 802.16j-2009 Standard for Local and Metropolitan Area Networks Part 16: Air Interface for Broadband Wireless Access Systems Amendment 1: Multiple Relay Specification.
- [4] K. Etemad and L. Wang, "Multicast Broadcast Multimedia Services in Mobile WiMAX Networks," *IEEE Commun. Mag.*, vol. 47, no. 10, pp. 84–91, Oct. 2009.
- [5] A. Abdollahpouri and B.E. Wolfinger, "Decision Support for the Usage of Multicast versus Unicast in Broadband TV Networks," AICT 2010, Barcelona, Spain, May 2010.
- [6] A. Abdollahpouri, B.E. Wolfinger, and J. Lai, "Unicast versus Multicast for Live TV Delivery in Networks with Tree Topology," WWIC 2010, Lulea, Sweden, June 2010.
- [7] J. Aaltonen, J. Karvo, and S. Aalto, "Multicasting vs. Unicasting in Mobile Communication Systems," In Proc. WoWMoM'02, 2002.
- [8] A. Phonphoem and L. Suchaisri, "Performance Analysis and Comparison between Multicast and Unicast over Infrastructure Wireless LAN," AINTEC 2006.
- [9] A. Abdollahpouri and B. E. Wolfinger "New Measures for Multicast Gain and Their Application to IPTV Delivery in WiMAX based Access Networks," IFIP/IEEE Wireless and Mobile Networking Conference (WMNC2011), October 26-28, Toulouse, France, 2011.
- [10] A. Abdollahpouri and B. E. Wolfinger "On the Efficiency of Multicasting for IPTV Delivery over IEEE 802.16j Networks," International Symposium on Performance Evaluation of Computer and Telecommunication Systems, SPECTS 2011, June 7 - 30, The Hague, Netherlands, 2011.
- [11] L. Erwu, W. Dongyao, L. Jimin, Sh. Gang, and J. Shan, "Performance Evaluation of Bandwidth Allocation in 802.16j Mobile Multi-hop Relay Networks," in Proc. IEEE VTC 2007-Spring, April 2007.
- [12] H. Zeng and C. Zhu, "System-Level Modeling and Performance Evaluation of Multi-hop 802.16j Systems," IWCMC 2008, Crete Island, Greece, August 2008.
- [13] C. H. Cho, K. T. Kim, and H. Y. Youn, "Mobile Multi-hop Relay System using AMC for Multicast Broadcast Service over Mobile WiMAX," in Proc. WTS, Pomona, CA, pp. 46–52, Apr. 2008.
- [14] I. Güvenc, U. C. Kozat, M.-R. Jeong, F. Watanabe, and C.-C. Chong, "Reliable Multicast and Broadcast Services in Relay-based Emergency Communications," *IEEE Wireless Commun.*, Vol. 15, no. 3, pp. 40–47, 2008.
- [15] W.-H. Kuo and J.-F. Lee, "Multicast Recipient Maximization in IEEE 802.16j WiMAX Relay Networks," *IEEE Transactions on Vehicular Technology*, Vol. 9, no. 1, pp. 335–343, 2010.
- [16] S. Deb, V. Mhatre, and V. Ramaiyan, "WiMAX Relay Networks: Opportunistic Scheduling to Exploit Multiuser Diversity and Frequency Selectivity," *ACM MOBICOM*, Sept. 2008.
- [17] D. Ghosh, A. Gupta, and P. Mohapatra, "Adaptive Scheduling of Prioritized Traffic in IEEE 802.16j Wireless Networks," *IEEE WiMob*, 2009.
- [18] B. Lin, P. Ho, L. Xie, and X. Shen, "Optimal Relay Station Placement in IEEE 802.16j Networks," *Proc. Int'l Conf. Wireless Comm. and Mobile Computing (IWCMC '07)*, pp. 25-30, Aug. 2007.
- [19] C.-Y. Yang, C.-C. Chou, and H.-Y. Wei, "Synchronous Multicast and Broadcast Service in Multi-rate IEEE 802.16j WiMAX Relay Network," *Wireless Networks*, Vol. 17, no. 8, pp. 1795-1807, 2011.
- [20] T. Qiu, Z. Ge, S. Lee, J. Wang, Q. Zhao, and J. Xu, "Modeling Channel Popularity Dynamics in a Large IPTV

System," SIGMETRICS/Performance'09, Seattle, WA, USA, 2009.

- [21] <http://www.att.com/u-verse> (last visited: May 2011)
- [22] <http://www.Telekom.de/Entertain> (last visited: May 2011)
- [23] Mobile WiMAX- Part I: A Technical Overview and Performance Evaluation White Paper.
- [24] S. W. Peters and R. W. Heath Jr., "The Future of WiMAX: Multihop Relaying with IEEE 802.16j," *IEEE Commun. Mag.*, Vol. 47, no. 1, pp. 104–111, Jan. 2009.
- [25] L. Yang et al., "Synchronous MBS Transmission for Macro Diversity in MR Networks," June 2007. http://www.ieee802.org/16/relay/contrib/C80216j-07_206r2.pdf
- [26] A. Saichev, Y. Malevergne, and D. Sornette: *Theory of Zipf's Law and Beyond*, Springer, 2009.
- [27] C. So-In, R. Jain, and A. Al-Tamimi, "Capacity Evaluation for IEEE 802.16e Mobile WiMAX," *Journal of Comp. Systems, Networks, and Comm.*, April 2010.



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