Utilizing WiMAX Mesh Mode for Efficient IPTV Transmission

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ABSTRACT

Providing high bit-rates, WiMAX enables IPTV multicasting for several simultaneous broadcasting channels. WiMAX base stations can offer higher capacity to users with better signal quality values, and more robust but lower capacity modulations to users with worse connection quality. WiMAX Mesh mode allows user equipments to operate in ad-hoc mode, which can be used to relay IPTV channels to users with worse links to the base station and better links to relay users. Rescheduling of streaming multimedia data channels using parallel transmissions allows more users to get IPTV service from the same source and increases throughput.

Categories and Subject Descriptors

C.2 [**Computer-Communication Networks**]: Miscellaneous

General Terms

Algorithms,Design,Performance

Keywords

WiMAX, Mesh mode, IPTV, Multicasting

1. INTRODUCTION

WiMAX [1, 2, 3] offers high data transmission rates to users within the coverage of a WiMAX base-station. Cells in WiMAX networks are made up of multiple concentric cells each with a different modulation scheme used by different users according to best available signal quality. Although user equipments demand for highest data-rates, modulation techniques cannot preserve healthy communication with users beyond some specific distance to the base station [3, 4]. Other signal quality loss factors like multi-path fading, doppler spread and co-channel and adjacent channel interference also prevent usage of modulations with high data rates [5].

Potential users of an IPTV [4, 6, 7, 8] system reside mostly in urban areas that contain several physical obstacles in between the base station and the user equipments. Penetration through walls, glass, or metal is inevitable, and this limits the propagation range of WiMAX signals [5]. Although best service quality can be obtained via line-of-sight (LOS) communication, almost all users will obtain WiMAX services using non-LOS connections[9].

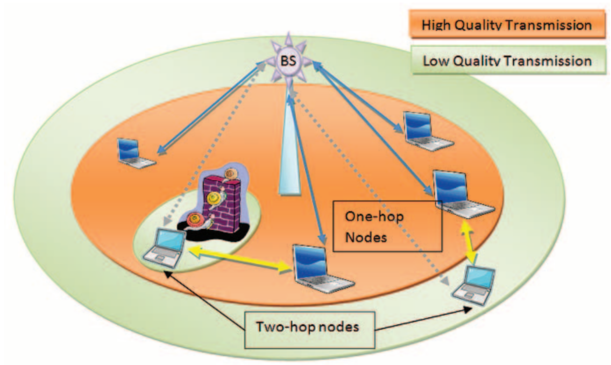

Figure 1: WiMAX Cell Structure

Multicasting has the advantage of simultaneously providing the same IPTV channels to all user nodes that demand for it. In urban areas, a user may be theoretically close enough to a base station to establish a connection with high data-rate modulation, but still not be able to obtain such a high capacity transmission. In order to obtain a time-sensitive, streaming and high bit-rate IPTV service, the user nodes with poor connection quality to the base station (identified as "two-hop nodes") may search for "one-hop nodes" around them that can provide a high quality connection by buffering the service data requested by the two-hop node and re-transmit the service in a mesh manner [10]. Relay nodes are the user equipments that have high capacity connection to the base station and can be scheduled to re-transmit data-frames for the two-hop nodes.

The relay station amendment, introduced in IEEE 802.16j, to the PMP mode can be considered as an alternative to the

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Mesh mode of WiMAX. However, it should be noted that the main aim of using mesh mode in this model is not to extend the coverage range of the network but to enable SSs who suffer bad channel conditions due to physical factors to have service via relaying. Also, the static deployment of the relay stations would not be suitable for a dynamic environment with SSs having changing traffic demands [11]. Instead, a self-organizing network operating in mesh mode would be more appropriate in adapting to a dynamic topology and balancing the traffic load [1].

In an economical perspective, instead of a model with relay stations whose prices are comparable to base stations, a model with more base stations and smaller cells which could ease the management of the network and decrease the load on one cell could be more cost-efficient.

In addition to operating in mesh mode, using 4x4 multiple-input multiple-output antenna technology (MIMO) could provide theoretically 1 Gbps, practically around 300 Mbps bit-rates [12, 13, 14, 15]. Considering these data rates and assuming all nodes are very close to the base station to receive with best modulation, a WiMAX base station may support transmission of upto 50 distinct IPTV channels, each with 6 Mbps traffic requirement, simultaneously. If there are two-hop nodes that require relay-transmission of IPTV channels, then the channels requested by those nodes have to be retransmitted at least once. If two of the two-hop nodes request the same IPTV channel from two different relay nodes, then the channel has to be scheduled twice more in addition to the transmission made by the base station.

With a rough calculation, a worst case scenario of 20 distinct IPTV channels for the relay nodes and 15 distinct IPTV channels for two-hop nodes can be scheduled. Simulation results presented in this paper are far better than those numbers since many users will request the same IPTV channels and most of the users are expected to be directly receiving transmission from the base station. Also, spatial diversity makes parallel transmissions of multiple relay nodes possible, leaving more available time slots and thereby more IPTV channels for other nodes to transmit and receive.

In our previous work [16] we have shown that after the second hop, the latency values increase dramatically. Thus, in the proposed solution in this paper, we do not consider connections to the base station more than two hops. Although there are no limitations for the number of hops to the base station in the mesh mode operation, allowing three or more hop connections is not practical for IPTV due to its delay-sensitive nature.

The rest of this paper includes formulation of the problem and proposed solution in section II, simulation results for the proposed solution in section III and final conclusion remarks and future work at section IV.

2. IPTV OVER WIMAX

2.1 Definitions

The following terms are used in this paper:

One-Hop Nodes: Nodes that receive IPTV transmission directly from the base station and relay the IPTV transmission in favor of the two-hop nodes.

Two-Hop Nodes: Nodes that are able to connect directly to the base station but prefer to receive IPTV transmission over a one-hop node.

2.2 Node Calculator

In order to estimate the number of IPTV users that can receive transmission directly from the base station, namely one-hop nodes, and number of two-hop nodes, a worst-case calculator has been implemented. Given the modulation capacity of the base station, the calculator provides the maximum allowed number of users. A complete set of parameters are listed in Table (1).

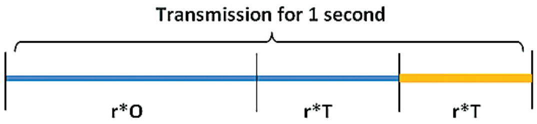

Figure 2: Node Counts For Worst-Case State

Starting with one one-hop node that consumes a fraction of a second proportional to

$$\frac{r}{C_{BS}} \tag{1}$$

while the remaining portion of the transmission second can be filled with relaying transmissions of the two-hop nodes. Iteratively incrementing the number of the one-hop nodes, up to a maximum number of the two-hop nodes can be found for each configuration.

2.2.1 *Worst-Case Problem*

The worst case occurs when all distributed scheduling has to be made sequentially, no parallel transmission from one-hop nodes to two-hop nodes is possible and all subscribers are watching different IPTV channels. In order to fit "O" distinct IPTV channels for one-hop nodes and "T" distinct IPTV channels for two-hop nodes into one second of transmission, centralized scheduling requires transmission of O+T IPTV channels. Distributed scheduling requires retransmission of the T IPTV channels. Adding up the two total scheduling requires time slots enough to serve O+$2T$ transmissions. Base station has to transmit O+T IPTV channels at a total time of

$$\frac{O+T}{O+2T} \tag{2}$$

of a second.

For a given O and T pair, the minimum bandwidth requirement at the base-station is:

$$r(O+T)\frac{O+2T}{O+T} = r(O+2T) \tag{3}$$

The minimum bandwidth requirement between one-hop and two-hop nodes is:

$$rT\frac{T}{O+2T} \tag{4}$$

The scheduling algorithm provides a centralized period for base station transmissions of O+T IPTV channels and distributed time for relay transmission of T IPTV channels. For a frame-length of F bits for each channel, a channel has to be rescheduled after every

$$F(O+2T) \tag{5}$$

Table 1: Calculation Parameters

Term	Definition
r	Traffic requirement of a TV channel in terms of *bits-per-second*.
O	Total number of one-hop nodes in the network.
T	Total number of two-hop nodes in the network.
F	Framelength of a single burst of an IPTV channel in terms of *bits*.
C_{BS}	Base station modulation capacity in terms of *bits-per-second*.
C_i	Modulation capacity of ith one-hop node in terms of *bits-per-second*, where $i \in \{1, 2, ..., O\}$. This value is equal to C_{BS} for all one-hop nodes throughout this paper.
K	Worst case duration of a frame schedule iteration.
K_s	Worst case duration of a frame schedule iteration when there is only one TV channel transmission for the entire network.
K_{su}	Worst case duration of a frame schedule iteration when there is only one TV channel transmission for the entire network and one-hop nodes relays with single modulation.

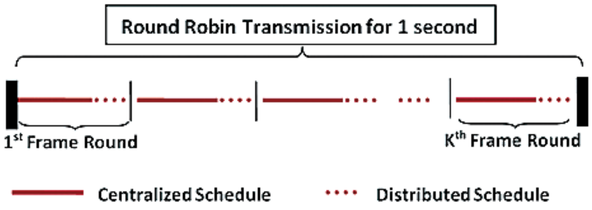

Figure 3: Round Robin Scheduling of Channel Frames

bits of transmission. In order to provide continuity of streaming media and equal priority to all users, a round-robin scheduling of requested IPTV channels can be applied.

Different modulation techniques provide different transmission durations. Base station modulation and relay modulation may or may not be the same depending on the available technology and applicability.

During centralized scheduling, each of the O+T IPTV channels require a duration of

$$\frac{1}{C_{BS}} \tag{6}$$

of a second per bit. Frame duration of each of these IPTV channels is therefore

$$F\frac{1}{C_{BS}} \tag{7}$$

of a second.

A total transmission duration of

$$(O+T)\frac{F}{C_{BS}} \tag{8}$$

of a second is required for every round of centralized frame scheduling of O+T IPTV channels.

During distributed scheduling each one of T IPTV channels may be transmitted with a different modulation. Frame duration of i^{th} node of two-hop nodes is

$$F\frac{1}{C_i}, i \in \{1, 2, ..., T\} \tag{9}$$

and a total duration of

$$F\sum_{i=1}^{T}\frac{1}{C_i} \tag{10}$$

of a second is required for each round of distributed frame scheduling of T IPTV channels.

For a single iteration of the round-robin transmissions of all IPTV channels during centralized and distributed scheduling, it takes

$$K = F(\frac{O+T}{C_{BS}} + \sum_{i=1}^{T}\frac{1}{C_i}) \tag{11}$$

of a second while a total of

$$\frac{1}{K} \tag{12}$$

round-robin frame scheduling iterations can be performed each second.

2.2.2 *Single TV Channel Transmission*

In case of multicasting, a single IPTV channel to all nodes, the problem reduces to transmitting one channel instead of O+T IPTV channels during the centralized period, and retransmitting this channel at most $\min\{O, T\}$ times in the worst case during the distributed period.

Centralized period of the k^{th} iteration of the round-robin frame schedule contains data frame of a single channel, whereas distributed period contains at most O copies of the same frame, if all two-hop nodes can receive transmission over some i^{th} one-hop one with the same modulation, $i \in \{1, 2, ...O\}$. Distributed scheduling may last more than O transmissions if any one of the two-hop nodes is using a different modulation than the rest of the two-hop nodes that receive transmission over the same one-hop node. This condition causes a worst-case condition of scheduling T copies of the same frame, each with a different relay modulation and transmission duration.

Worst case duration of a frame schedule iteration for single TV channel transmission becomes

$$K_s = F(\frac{1}{C_{BS}} + \sum_{i=1}^{T}\frac{1}{C_i}) \tag{13}$$

of a second, resulting in a total of

$$\frac{1}{K_s} \tag{14}$$

frames per second.

When transmitting a single IPTV channel using uniform modulations at each one-hop node, with the modulation capacity of i^{th} one-hop node being equal to $C_i, i \in \{1, 2, ..O\}$, the number of possible modulations are upper bounded by O, and the total frame round duration becomes

$$K_{su} = F(\frac{1}{C_{BS}} + \sum_{i=1}^{O} \frac{1}{C_i}) \tag{15}$$

of a second, resulting in a total of

$$\frac{1}{K_{su}} \tag{16}$$

channel frames per second.

3. RELAY SIMULATION

3.1 Simulation Steps

The simulation engine initializes a media server that generates channel frames and sends the frames to the base station. The base station and initial numbers of one-hop and two-hop nodes are also initialized. Base station buffers the traffic frames of IPTV channels that are currently being requested by existing nodes. A transmission queue is filled with available traffic frames. These frames are then multicast sequentially by the base station to all nodes that can receive transmission directly from the base-station. After transmission of a traffic frame, the simulation time is incremented by duration of

$$1000\frac{F}{C_{BS}} milliseconds. \tag{17}$$

If the frame size is 300 Kbits long and base station modulation capacity is 300 Mbits per second, then traffic frame transmission time becomes 1 millisecond. A minimum of

$$\frac{r}{F} \tag{18}$$

frames have to be transmitted to all nodes requesting the IPTV channel. Considering a bandwidth requirement of 6 Mbits per second for each IPTV channel, and 300 Kbits frame size, at least 20 frame transmissions are required for a user to receive a continuous streaming of real-time multimedia content.

After centralized transmission by the base station is completed, all the one-hop nodes relay their buffered traffic to two-hop nodes according to a predefined slotted distributed schedule. The distributed schedule consists of two phases, *parallel slots* and *dedicated slots*. A slot is a time slice reserved for frame transmission of one or more one-hop nodes. All two-hop nodes that are in transmission range of only one one-hop node can receive their frames in a parallel slot. On the other hand, two-hop nodes that can receive signals from more than one one-hop node have to be assigned dedicated time slots to avoid collisions. Parallel slots contain a list of one-hop nodes and their re-transmission frames. An one-hop node can only send one frame at a given slot. All one-hop nodes in a parallel slot relay to their child nodes at the same time. As soon as parallel slots are over, dedicated slots start and a single one-hop node transmits a single frame to all its child nodes. When an one-hop node transmits a frame, all two-hop nodes connected to that node receive the frame if it belongs to the IPTV channel they requested.

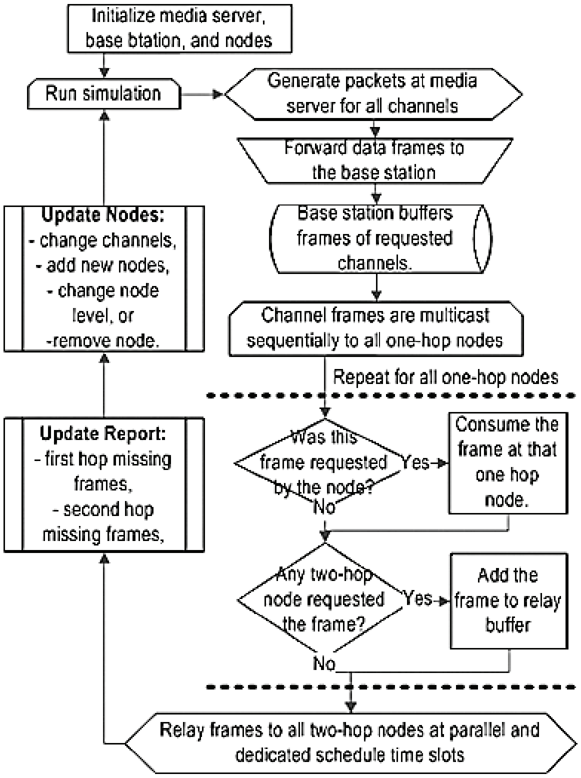

Figure 4: IPTV Over WiMAX Simulation Flow

After transmission of a slot, the simulation time is incremented by the duration of that slot, i.e. transmission time of a single channel frame. For parallel slots, time increment is performed only once regardless of the number of frames transmitted. For dedicated slots, time is incremented for all frames since one slot is consumed for one frame. If the one-hop node has a modulation capacity, (C_i), other than C_{BS} then the simulation time is incremented by actual duration of the slot, which is

$$1000\frac{F}{C_i}, milliseconds. i \in \{1, 2, ..O\}. \tag{19}$$

Simulation events are node addition, node removal, two-hop node transfer from an aborting one-hop node to another one-hop node, changing the requested IPTV channel of a node. The events are performed based on predefined probabilities over a uniform distribution. We determine whether a new node becomes a one-hop node or a two-hop node that is randomly assigned to a one-hop node probabilistically. When a one-hop node is leaving the system, the two-hop nodes that receive service from that node are transferred to another one-hop node with some probability. If no available one-hop node can be found, then those nodes are *dropped* from the system. A predefined random number of nodes change their existing IPTV channels at each step of simulation.

Simulation iterates by collecting statistics about rate of frames that did not arrive within an expected time. For example, if 20 frames are expected within one second and only 18 could be scheduled, then there are two frames delayed for that node. While a delay-intolerant configuration allows a small number of nodes to be served successfully, allowing delays not exceeding ∼100 milliseconds [17] between two consecutive channel frames also results in continuous reception of IPTV service by the users. Tolerating such delays results in many more users to be serviced both on the one-hop and the two-hop regions compared to non-delay configurations. Considering 300Mbps base station modulation capacity and 6 Mbps channel traffic, it is possible to fit at most 50 distinct IPTV channels concurrently if *no-delay* is desired. Allowing inter-frame delays up to 100 milliseconds results in more than 150 IPTV channels to be transmitted from a single WiMAX base station to a group of one-hop and two-hop nodes.

3.2 Simulation Setup

IPTV over WiMAX simulation provides an estimation of runtime service configuration. Some of the configuration parameters are used to evaluate the probability of an event to happen during simulation. Other parameters define the system settings for IPTV simulation.

The set of configuration parameters are listed in Table 2. *Channel Count* is the total number of available distinct IPTV channels that a user may be requesting from. *Channel Bandwidth* is the r parameter given in Table 1, indicating the bit rate of each IPTV channel. *Frame Length* is the F parameter given Table 1, corresponding to bit length of each frame burst of a channel. *Simulation Duration* is the length of network operation in minutes. *One-Hop* and *Two-Hop Node Counts* define initial number of one-hop and two-hop nodes, respectively. *Probability of a New Node* defines the probability of a new node to join the system every second. Similarly, *Probability of Leaving* defines the probability for an existing node to leave the system. When a one-hop node leaves the system, each one of its two-hop nodes are transferred to another one-hop node with the value defined in *Probability of Finding Transfer Node.* Probability of whether a new node being added to the network will be a two-hop node is defined with the *Probability of Two-Hop Connection* configuration parameter. At any second of the simulation, the nodes change their current IPTV channel with a probability value defined by *Probability of Changing Channel* parameter. For a two-hop node, decision of hearing multiple one-hop nodes at the same time is evaluated according to the value of *Probability of Hearing Multiple One-Hop Nodes* parameter, in which condition the two-hop node requires a dedicated time slot for the relay.

The simulation is executed for the specified duration, making runtime modifications to the network by adding, removing, or transferring nodes, changing channels of existing nodes, and reporting frame miss rates and inter-frame delays.

3.3 Simulation Results

WiMAX is capable of serving the users with different modulations based on their link quality. The system always attempts to use a higher capacity modulation as long as it is available. Diminishing communication quality and increasing bit error rate results in lower capacity modulation, if not completely disconnected. Although QPSK, 16-QAM, 64-QAM, 256-QAM are capable of carrying multiple IPTV channels, practical bit-rates of these modulations are not enough to serve an urban area IPTV-WiMAX cell.

The raw bit-rate R_b for each modulation can be calculated according to the following formula from the standard [**?**]:

$$R_b = \frac{N_{used}.b_m.c_r}{T_s} \tag{20}$$

where N_{used} is the number of active subcarriers used in the FFT (pilot and data subcarriers), b_m is the number of bits per modulation symbol, c_r is the coding rate and T_s is the total bit duration.

Imposing the MIMO's multiple streaming property into the previous equation, the raw bit rate R_b becomes:

$$R_b = \frac{N_{used}.b_m.c_r}{T_s}.R_{stc} \tag{21}$$

where R_{stc} is the space time coding rate due to MIMO antenna system.

Using 2048 OFMDA (which has 1728 active subcarriers) with a 40 Mhz bandwidth together with 4x4 MIMO antenna system, assuming that this quadruple throughput (i.e R_{stc}=4), highest bit-rates that can be achieved for various modulation and coding rate combinations are given in Table 3 [12, 15, **?**].

Table 3: Raw Bit-Rates for WiMAX (40 Mhz, 2048 OFDMA, 4x4 MIMO)

Modulation	c_r	R_b (Mbps)
BPSK	1/2	∼ 75
QPSK	1/2	∼ 150
QPSK	3/4	∼ 224
16-QAM	1/2	∼ 299
16-QAM	3/4	∼ 449
64-QAM	1/2	∼ 399
64-QAM	2/3	∼ 532
64-QAM	3/4	∼ 673
64-QAM	5/6	∼ 748
256-QAM	1/2	∼ 532
256-QAM	3/4	∼ 898
256-QAM	5/6	∼ 997

Considering the fact that the practical data rate for highest capacity modulation(i.e. 256-QAM modulation with 56 coding rate) is ∼300 Mbps while the theoretical raw bit-rate is around 1 Gbps, the practical data rates for other modulations are expected to be reduced in the same ratio with a rough calculation. Assuming that the practical data rates are ∼30% of the theoretical raw bit-rates, the data rates of BPSK and QPSK modulations are calculated as 24 Mbps, 48 Mbps and 72 Mbps for BPSK modulation with 1/2 coding rate and QPSK modulation with 1/2 and 3/4 coding rates, respectively. According to these calculated values, even using highest data rate modulation and coding rate among these two(i.e. QPSK modulation with 3/4 coding rate) only 12 IPTV channels could be supported without any relay. As a result, BPSK and QPSK modulations seem practically insufficient for one-hop IPTV transmissions in PMP mode with, let aside a two-hop relay mode. Therefore, instead of single transmission with low capacity modulations such as BPSK and QPSK, relaying with higher capacity modulation techniques such as 256-QAM can be used to serve more IPTV channels.

Simulations of three hours length and 100 repetitions have been performed using link capacity of 300 Mbps (MIMO)

Table 2: Configuration Parameters

Parameter	Value	Description
Channel Count	1000	Number of IPTV channels.
Channel Bandwidth	6 Mbps	r (Table 1).
Frame Length	300 Kbits	F (Table 1).
Simulation Duration	180 min	Simulation length in minutes.
One-Hop Nodes	100	Initial number of one-hop nodes.
Two-Hop Nodes	50	Initial number of two-hop nodes.
Probability of a New Node	0.03	Probability of joining a new node, each second.
Probability of Leaving	0.03	Probability of a node to leave, each second.
Probability of Finding a Transfer Node	0.10	Two-hop nodes are transferred to another one-hop node according to this value, if existing one-hop node leaves the network.
Probability of Two-Hop Connection	0.30	Probability of a new node to request relay.
Probability of Changing Channel	0.06	Nodes change their current IPTV channels with this probability every second.
Probability of Collision At Two-Hop Nodes	0.10	Two-hop nodes receive signals from multiple one-hop nodes with this probability.

Table 4: Utilization

One-Hop Nodes	Two-Hop Nodes				
	10	30	50	70	90
10	47.8%	52.2%	56.6%	63.2%	75.1%
30	50.6%	61.4%	76.4%	84.5%	92.1%
50	72.8%	80.8%	89.7%	94.0%	97.3%
70	89.1%	95.5%	97.4%	98.9%	99.4%
90	96.3%	98.3%	99.9%	99.7%	99.9%

for cases with varying number of one hop and two hop nodes. Utilization of the air-link depends on the number of one-hop and two-hop nodes. As shown in Figure 5, up to 70x10, 50x50 or 30x70 one-hop and two-hop node combinations may operate as an under-utilized air-link. More nodes will cause fully-utilized network, still usable with reasonable inter-frame delay values. The initial number of one-hop nodes are assumed to be twice the number of two-hop nodes which are 100 and 50, respectively for each simulation iteration.

Node changes occur according to the probability parameters given in Table 2. The results of the simulation in terms of average value of inter-frame delays between all consecutive frame pairs of all IPTV channels are reported in Table 6. Figures 7 and 8 show distribution of inter-frame delay values for first hop and second hop transmissions respectively, for various number of one-hop and two-hop nodes. During 3 hours of simulations for initial network topologies consisting of 10 one-hop nodes and 50 two-hop nodes; 50 one-hop nodes and 30 two-hop nodes; and finally 90 one-hop nodes and 50 two-hop nodes, distribution of the percentage of frames with inter-frame delays are provided in Table 5.

Heavy traffic loads are observed for all three configurations. According to Table 2, given 6 Mbps channel bandwidth and 300 Kbits frame length, the total number of frames per second required by each TV channel is calculated as 20 frames per second meaning that each frame contains transmission of 50 milliseconds. Although inter-frame delays up to 100 milliseconds cannot be realized by human eye, we consider it to be safer to treat delay values up to 50 milliseconds as tolerable [17].

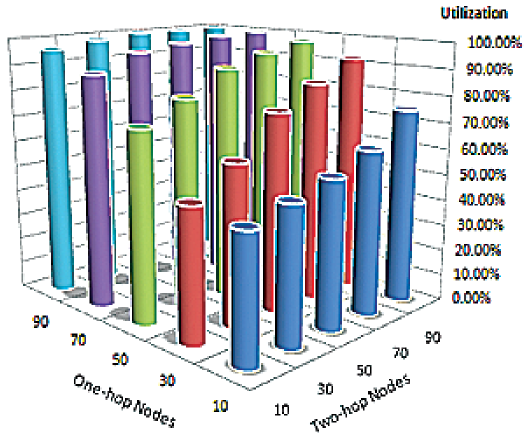

Figure 5: Utilization of Air-link

Table 6: Average Inter-frame Delay in Milliseconds, Values Shown As:(one hop delay / two hop delay)

One-Hop Nodes	Two-Hop Nodes				
	10	30	50	70	90
10	3/4	2/18	9/15	16/29	22/44
30	1/14	8/10	15/22	20/33	29/49
50	8/8	16/19	27/34	33/46	42/61
70	19/19	27/31	37/44	49/61	60/77
90	34/33	41/45	57/63	63/74	80/95

Based on these observations, 84% of the frames in the first hop and 63% of the frames in the second hop are transmitted without any inter-frame delay while about 15% of the frames in the first hop and 34% of the frames in the second hop are tolerably delayed for the network topology with initially 10 one-hop and 50 two-hop nodes.

Table 5: Percentage Distribution of Delayed Frames ([One hop Nodes | Two hop Nodes] vs Delay (msec))

	For One Hop Nodes					
	No Delay	Below 20	20-50	50-100	100-125	Over 125
10 | 50	84.85	12.78	2.37	0	0	0
50 | 30	52.44	28.29	19.03	0.24	0	0
90 | 50	51.86	4.48	16.35	27.05	0.26	0
	For Two Hop Nodes					
	No Delay	Below 20	20-50	50-100	100-125	Over 125
10 | 50	63.46	26.32	8.3	1.74	0.18	0
50 | 30	47.9	25.88	25.44	0.4	0.35	0.03
90 | 50	54.84	2.94	12.46	28.88	0.28	0.6

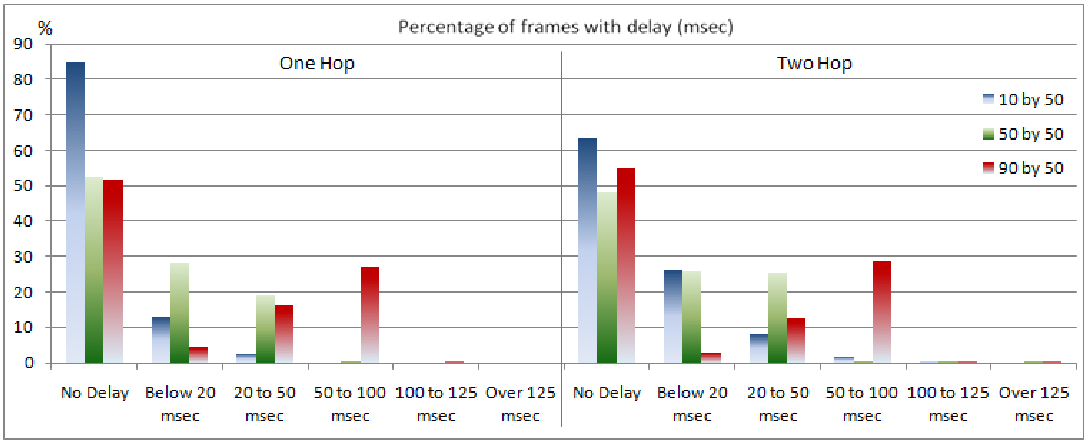

Figure 6: Percentage Distribution of Delayed Frames (One hop Nodes by Two hop Nodes vs Delay (msec))

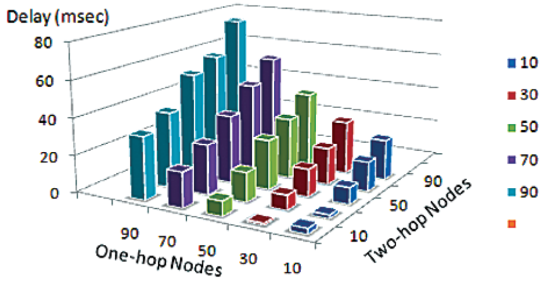

Figure 7: Average Inter-Frame Delays at One-hop

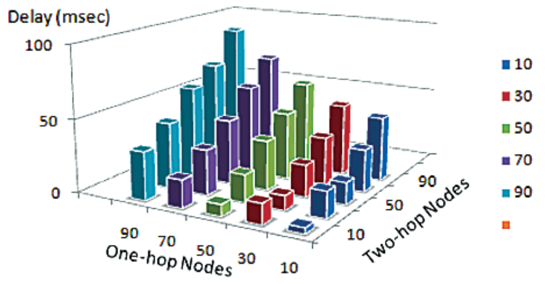

Figure 8: Average Inter-Frame Delays at Two-hop

In case of 50 one-hop nodes and 30 two-hop nodes, 52% of the frames in the first hop and 47% of the frames in the second hop are observed to have no delay while 47% of the frames in the first hop and 51% of the frames in the second hop are tolerably delayed.

For the initial network configuration of 90 one-hop nodes and 50 two-hop nodes, 51% of the frames in the first hop and 54% of the frames in the second hop are transmitted without any delays while 27% of the frames in the first hop and 29% of the frames in the second hop are delayed intolerably.

4. CONCLUSION

In this paper, a WiMAX solution based on mesh mode operation is proposed for efficient IPTV distribution. Instead of multicasting all IPTV channels with more robust but less spectral efficient modulation such as QPSK using PMP mode, utilizing mesh mode operation and relaying enables us to use less robust but more spectral efficient modulations such as 256-QAM and as a result our solution could serve more IPTV channels compared to single multicasting in PMP mode. Although there are alternative relaying methods such as IEEE 802.16j-WiMAX with relay stations operating in PMP mode, WiMAX mesh mode operation has the advantage of adaptability to changing traffic requirements and dynamic topology.

Based on the simulation results presented in this paper, IPTV over WiMAX mesh mode supports a wide range of multiple users to receive dedicated transmissions via an one-hop node if not directly from the base station. For the simulation with base station transmission capacity of 300 Mbps and 1000 available IPTV channels, it is possible to generate a schedule for 50 directly connected nodes and 30 indirectly connected nodes with reasonable inter-frame delays.

If total number of one-hop nodes and two-hop nodes are below 120, the network utilization is below 1.00. This fact leads to higher number of nodes to be supported in an urban area with many signal propagation problems and relay requirements. For IPTV channels requiring higher bandwidths the modulation capacities need to increase. Otherwise, some users will demand more capacity, causing others to receive poor quality of service.

As a future work, the number of dedicated time slots can be further decreased by implementing a parallelism algorithm that distributes the time slots of one-hop nodes that can cause collisions at two-hop nodes to distinct parallel slots. Since channel modeling is not an issue of this simulation, the relay nodes are randomly assigned to two hop nodes, which assumes (and can be replaced by) a predefined signal propagation model such as Rayleigh, or Rician, etc., based on the demands of practical use.

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