ENSC-835: Communication Networks

Streaming Video Content Over IEEE 802.16 / WiMAX Broadband Access

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Final Project

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1 Abstract

WiMAX (Worldwide Interoperability for Microwave Access) embodies the IEEE 802.16 family of standards which provision wireless broadband access to residential and commercial Internet subscribers. While WiMAX can also provide backhaul site-to-site connections as well as mobility, there is increasing motivation to employ WiMAX for last-mile Internet access to circumvent the high deployments costs and distance limitations associated with wired ADSL connections.

As a result, the objective of this study is to simulate bandwidth intensive, delay sensitive, video traffic representative of IPTV or other video-rich emerging applications targeted at fixed residential and commercial Internet subscribers. These video streams are typically encoded using MPEG-2 or MPEG-4 codecs and while these streams are marginally loss-tolerant, their performance is inherently a function of available link bandwidth, buffering and delay characteristics. Specifically, the study will examine various performance factors including video packet loss, end-to-end packet delay, packet jitter and throughput of several subscriber stations over WiMAX and ADSL access networks. The OPNET modeler with integrated WiMAX support has been adopted for this effort. Several video traffic sources were selected, pre-processed and imported into the model to drive the simulation.

While ADSL exhibited marginally better performance than the WiMAX video subscribers, the simulation demonstrated promising results for WiMAX in the context of all 4 performance metrics. It should be understood that the simulated performance may not necessarily be a shortcoming in the WiMAX technology but rather from overly conservative configuration parameters that may be unnecessarily handicapping the simulation including the adoption of the least QoS aware scheduling facility. With further refinement and insight into carrier specific WiMAX deployment parameters, WiMAX will likely deliver more flexible far reaching access that exceeds existing wired access technologies.

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2 Introduction

As WiMAX continues to gain momentum and more equipment manufacturers engineer WiMAX network solutions, more carriers are exploring WiMAX as a last-mile alternative to their costly ADSL access network infrastructures. As of 2007, there were more than a 100 planned WiMAX carrier trials worldwide. Market studies [10] have projected attractive growth trends in both WiMAX subscriber base as well as WiMAX equipment revenues as depicted in Figure 1.

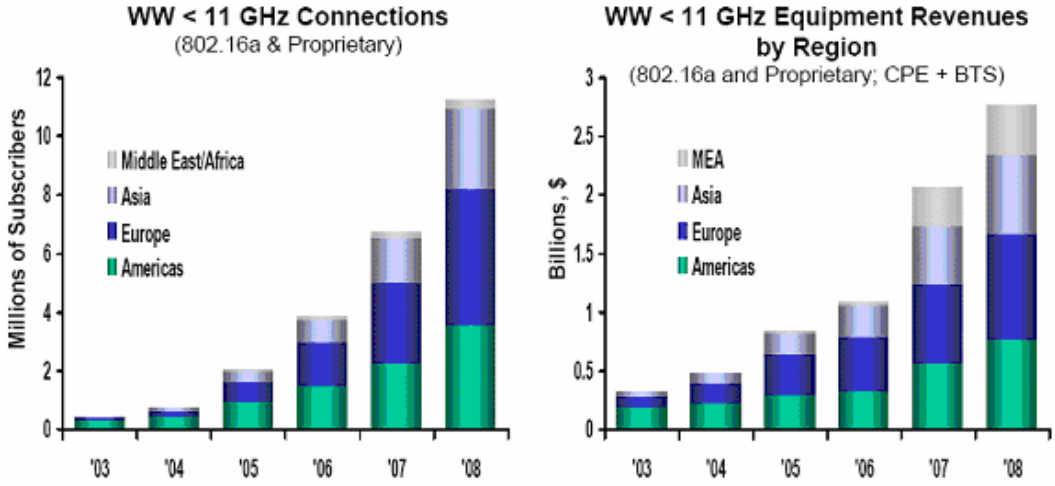

Figure 1. BWA market growth – last mile wireless connections

Additionally, in March 2008, the WiMAX forum [18] issued a press release projecting 133 million subscribers by the year 2012. With such emerging growth, it's reasonable that the technical community seek and quantify application performance across these dissimilar access technologies using a bandwidth intensive application load such as streaming video to understand any potential tradeoffs by moving to WiMAX.

Given the system complexities and variables involved in last mile access technologies, core network infrastructure, network protocols, and video compression schemes, the focus of this study will address the following question:

Can WiMAX Broadband Access meet or exceed the performance of ADSL broadband access for streaming video applications?

To address this question, the study will quantify performance by identifying four metrics to measure the resulting video transmission performance over these access networks:

- ❑ Video packet loss
- ❑ End-to-end delay

- Video packet jitter
- Throughput

By experimentally characterizing the resulting application performance over these access networks, we can gain insight into the feasibility of WiMAX for fixed wireless broadband access. This effort requires a suitable application load to which can stress the network sufficiently to exploit the bandwidth and delay limitations.

As the Internet continues to advance in the number of hosts, offered services, router switching speeds, and link transmission capacities, multimedia rich applications like video streaming are gaining wider adoption in the Internet community. Media providers are exploring new and innovative applications over core IP networks giving rise to emerging video services like Video on demand (VoD) and real-time video streaming. IPTV technology [4,7,8] distributes video content over IP networks as both managed and unmanaged services. Managed services are typically provided by carriers who have provisioned the access network and therefore have control over the resulting quality of service (QoS) to their subscribers. Unmanaged services refer to Internet services that have little control over the end-to-end performance between the subscribers and corresponding services. This study is designed around unmanaged video streaming services using an Internet topology which would serve as a lower boundary on expected video performance.

The study will incorporate actual movie video trace to drive the simulation model. Specifically, it will stream the Matrix III movie [15,16] for a 2-hour interval to three WiMAX video client stations and one ADSL video client from a video content services provider on the Internet. The generic topology is described in Figure 2.

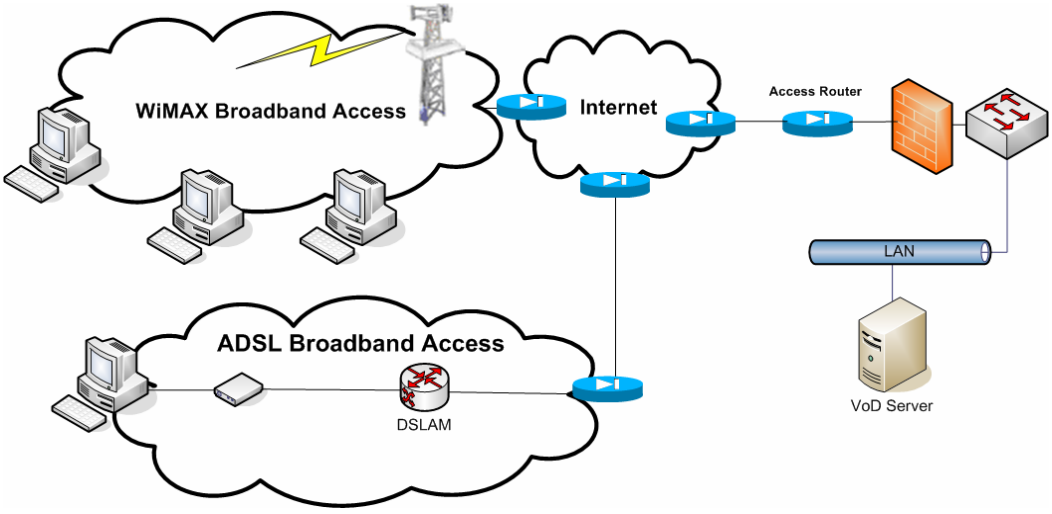

Figure 2. Generic streaming video simulation topology

In summary, using a demanding application load representative of IPTV and other emerging video streaming services, this study will compare video streaming performance over WiMAX in comparison to ADSL broadband access.

2.1 Video Content Overview

Video content refers to the video information available from video service providers; examples include a wide range from sitcoms, newscasts, sporting events, and movies in real-time and stored video (VoD) formats. The video content is organized as a sequence of video frames or images that are sent to the subscriber ("streamed") and displayed at a constant frame rate [7]:

Inherently, video streaming is loss-tolerant but delay-sensitive [14] which means video playback on the subscriber machines can tolerate some degree of frame loss but delays or variations intra-frame reception rapidly degrade the overall video playback experience. While streaming real-time video and VoD possess different transmission and buffering requirements from the network and the client video player, video content can be characterized by the following parameters:

- Video format – horizontal by vertical pixel resolution
- Pixel color depth – the number of bits/pixel to describe the color of the pixel
- Video coding scheme –reduces transmitted frame size
- Frame Inter-arrival rate –rate at which frames are received and played back

Video formats can range from 128x120 pixels to beyond 1920x1080 pixels with various color depths. Common Internet video formats (i.e. YouTube) use 320x240 pixel resolutions while North American DVD's utilize 720x480 and HD (High Definition) standards extend to 1920x1080 pixels. The higher the video frame resolution and/or pixel color depth, the larger the raw video content size.

Since videos are a sequence of images displayed at a constant rate and each frame contains spatial (within) or temporal (between images) redundancy, various video coding schemes have evolved to reduce the raw video content size by exploiting this redundancy while balancing quality.

ITU (H.26x) & ISO (MPEG-x)

Codec	Raw Data Rate	Compressed Rate
MPEG-1	30 Mbps	1.5 Mbps
MPEG-2	128 Mbps	3 – 10 Mbps
MPEG-4		< 1.024 Mbps

Video frame inter-arrival rates can range from 10 frames per second (fps) to 30 fps. This parameter can be especially critical as network conditions can impact the frame inter-arrival rates and which if left uncompensated, significantly

degrades the video playback quality. The following figure illustrates the necessity of the client video system to playback frames at a constant rate amidst variable delays in video frame packet arrivals [14].

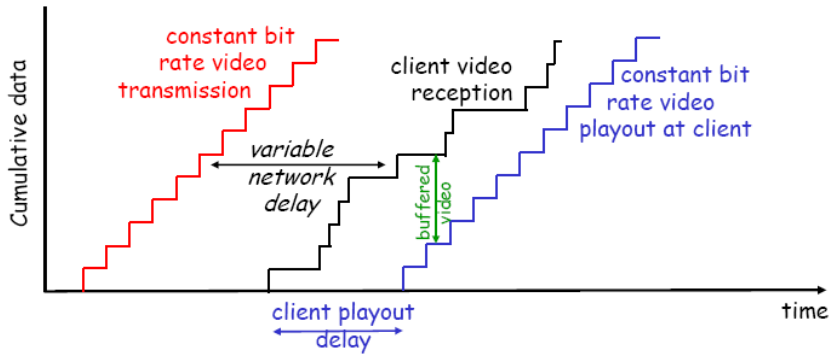

Figure 3. Video client buffering

Video frame packets inherently experience an end-to-end delay from the sender to the receiver which can be observed in Figure 3. This delay encompasses the propagation delay as well as any processing and queuing delays on the intervening routers. Since queuing delays can be dynamic in nature and video packets may not necessarily traverse the same path between the VoD server and the client station, the end-to-end delay will vary and it is referred to as jitter.

VoD services store the video content at the source location rather than being generated in real-time. Consequently, VCR functionality can be employed to facilitate functions like pause, rewind and fast forward with a minimal lag in command execution. VoD services can be either managed or unmanaged. Managed video services are typically provided by an access carrier since they have control over the provisioning of the network and therefore the resulting Quality of Service (QoS). These services may include IPTV and Video Conferencing. Unmanaged video services reflect services available on the Internet and consequently the video services provider has little control over the end-to-end communications path and the resulting performance. Google Video, IPTV and Skype video conferencing are examples of unmanaged video services.

As observed in Figure 4, the protocol stack for streaming video services would typically incorporate the Real Time Protocol (RTP) which provisions a packet structure for video and audio data above the transport layer protocol. RTP specifies an 8 byte header with protocol fields to describe the type of content being carried (MPEG-2, MPEG-4, etc), packet sequencing and time stamping. Since RTP lies above the transport protocol, it runs on the end-systems rather than in the network core. Moreover, it does not provide any mechanism to guarantee bandwidth or packet delays [14].

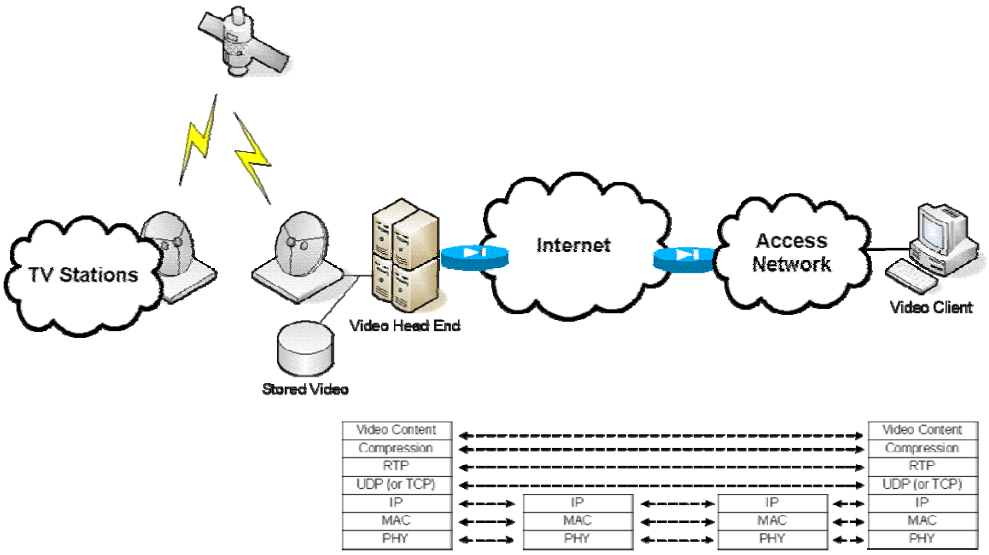

Figure 4. Generic video streaming topology

Additionally, typical streaming services utilize the User Datagram Protocol (UDP) which provides best effort service without delay, loss or bandwidth guarantees. Unlike Transmission Control Protocol (TCP), UDP is connectionless, unreliable and it does not provide any flow control or congestion control. The lack of reliability and congestion control mechanisms are actually desirable properties in media delivery so video servers can stream their content at the native encoding rate of video content without being constrained by congestion control when a dropped packet occurs. Equally undesirable is the TCP retransmission scheme given the delay sensitive nature of video applications.

UDP segments are subsequently encapsulated into unicast IP datagrams for proper addressing and routing to the video clients. IP datagrams can be dropped due to router buffer overflows or delayed due to router congestion which impacts the video client playback rate. Consequently, video clients implement a buffering scheme to smooth out the playback rate and compensate for network jitter. The primary objective is to maintain a constant playback rate that coincides with the original encoding rate. IP datagrams pass through appropriate MAC and PHY layers and then propagate through the Internet and access network to the video client subscriber. Video client stations buffer, decompress, and playback the frames at a constant rate.

By observing communications behavior between the VoD server and the video client, we can impose four performance metrics with appropriate thresholds to measure video streaming performance. Thus, we can determine whether video clients accessing VoD services over a WiMAX access network can satisfy each metric. Additionally, these metric allows us to make comparisons between WIMAX connected clients and ADSL connected clients since they access the same VoD services over the same wired network infrastructure.

The performance metrics are as follows:

- Loss – Number of Packets Dropped
  - → 1 - (# of received packets) / (# of expected packets)
  - → Avg: $< 10^{-3}$ Ideal: $< 10^{-5}$

- Delay – Average Time of Transit
  - → Processing delay + propagation delay + queuing delay
  - → Avg: < 300 ms Ideal: < 10 ms [9]

- Jitter – Variation in Packet Arrival Time
  - → Actual reception time – expected reception time
  - → Avg: < 60 ms Ideal: < 20 ms

- Throughput – Minimum End-to-End Transmission Rate
  - → Measured in bytes/sec (or bps)
  - → 10kbps – 5Mbps [14]

2.2 WiMAX Broadband Access Network Overview

WiMAX embodies a family of IEEE 802.16 standards focused on delivering fixed, nomadic and mobile wireless intranet / Internet access. The fixed wireless specification was formalized by IEEE in 2004 [12]. WiMAX operates in the 10 – 66 GHz band with line of sight (LOS) communications using the single carrier (SC) air interface. Shortly after the introduction of WiMAX, the IEEE 802.16a standard outlined non line of sight (NLOS) communications in the 2 – 11 GHz band using one of 3 air interfaces: SC, Orthogonal Frequency Division Multiplex (OFDM) and Orthogonal Frequency Division Multiple Access (OFDMA). OFDM and OFDMA enable carriers to increase their bandwidth and data capacity. This increased efficiency is achieved by spacing subcarriers very closely together without interference because subcarriers are orthogonal to each other [1,12].

While WiMAX has numerous applications including wireless backhaul links for Wi-Fi hot spots and redundant wireless Internet backup links for commercial businesses, this study focuses on WiMAX as an alternate access network technology to ADSL. It enables residential and commercial subscribers either outside DSL service regions as well as in densely overloaded DSL regions to attain high speed Internet access.

WiMAX is an all-IP infrastructure deployed in a point-to-multi-point (PMP) topology where one or more subscribers communicate with a WiMAX base station. The WiMAX standard addresses the PHY and MAC layers. Moreover, WiMAX is able to achieve Quality of Service (QoS) by using a bandwidth request and granting scheme on the subscriber stations. This facility prevents the

WiMAX base station from over-subscribing its available resources. Consequently, WiMAX is ideal for delay sensitive video applications.

Given the multiple air interfaces and adaptive throughput rates, WiMAX provides a compromise between 4G mobility and Wi-Fi throughput rates [11] as described in Figure 5.

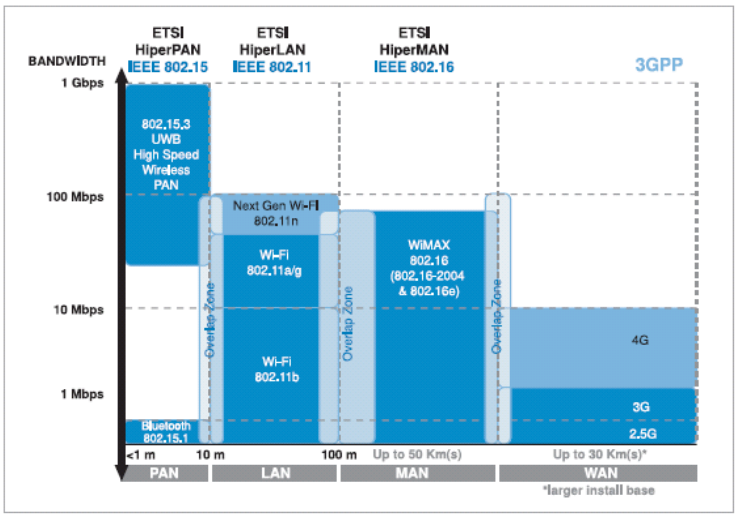

Figure 5. Wireless technologies

WiMAX cell radii between 7 and 10 km are typical. However, with favorable terrain conditions, cell radii up to 50 km are permissible [2].

In terms of a typical subscriber access connection, WiMAX outdoor customer premise equipment (CPE) is installed at the subscriber location with an optimum orientation to the WiMAX base station. The WiMAX CPE furnishes an Ethernet connection to the subscriber home network accordingly. Figure 6 illustrates one type of subscriber connection.

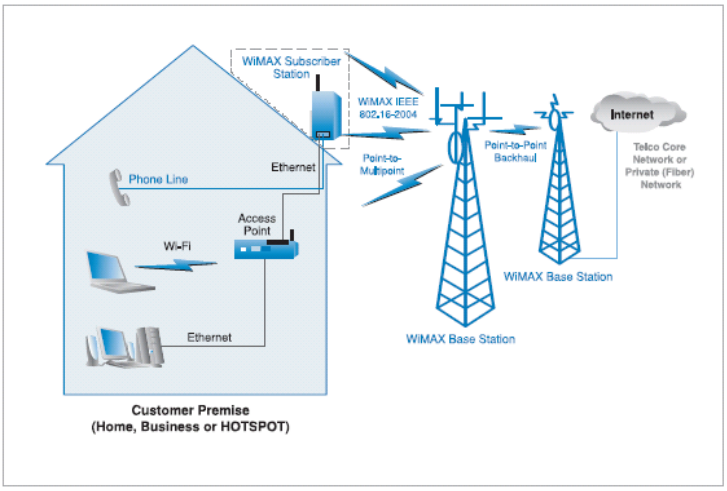

Figure 6. WiMAX network topology

Alternate connection configurations may utilize portable WiMAX CPE where signal conditions with the base station are favorable.

WiMAX channel bandwidths can range between 1.25 MHz and 20MHz in the 2 – 11 GHz band. With OFDM, the number of subcarriers scales linearly with the channel bandwidth. Within a given channel bandwidth, subcarriers are allocated as:

- Null subcarriers
- Data subcarriers
- Pilot subcarriers
- DC subcarriers

Subcarriers are then modulated using conventional digital modulation schemes using various inner code rates [12]:

- BPSK
- QPSK
- 16-QAM
- 64-QAM
- 256-QAM (optional)

Consequently, data rates between 1.5 to 75 Mbps are achievable. Alternatively, ADSL access rates range from 1.5 – 9 Mbps.

3 Simulation Model

In order to answer the question posed in this study, the OPNET Modeler simulation tool was selected as the tool of choice given its widespread adoption in both commercial and military domains. Moreover, the OPNET Modeler included native support for both ADSL and WiMAX component technologies.

3.1 Development Environment

3.1.1 Hardware

A Toshiba Tecra S2 laptop computer with the following hardware was utilized in this study:

- Intel Pentium M processor 1.86 GHz
- 1 GB RAM
- 80 GB HDD

3.1.2 Software

The following software was utilized in this study:

- ❑ OPNET Modeler 12.0.A PL5 (Build 4523)
- ❑ OPNET WiMAX models (models_12.0.A_22-Jul-2007-WiMAX_win32.exe)
- ❑ Microsoft Visual Studio .NET 2003 (Version 7.1.3088)
- ❑ Microsoft Windows XP SP2

3.1.3 Model Limitations

The following technological features were not available in the video traces or supported in the Modeler:

- ❑ WiMAX adaptive burst profiles (AMC) [13]
- ❑ WiMAX power management [13]
- ❑ RTP encapsulation for the Modeler video conferencing application
- ❑ Video traces do not model audio component [15,16]

3.2 Network Topology

To make the study more realistic and representative of a real world scenario, a network topology consisting of geographically separated video client and video services subnets was derived.

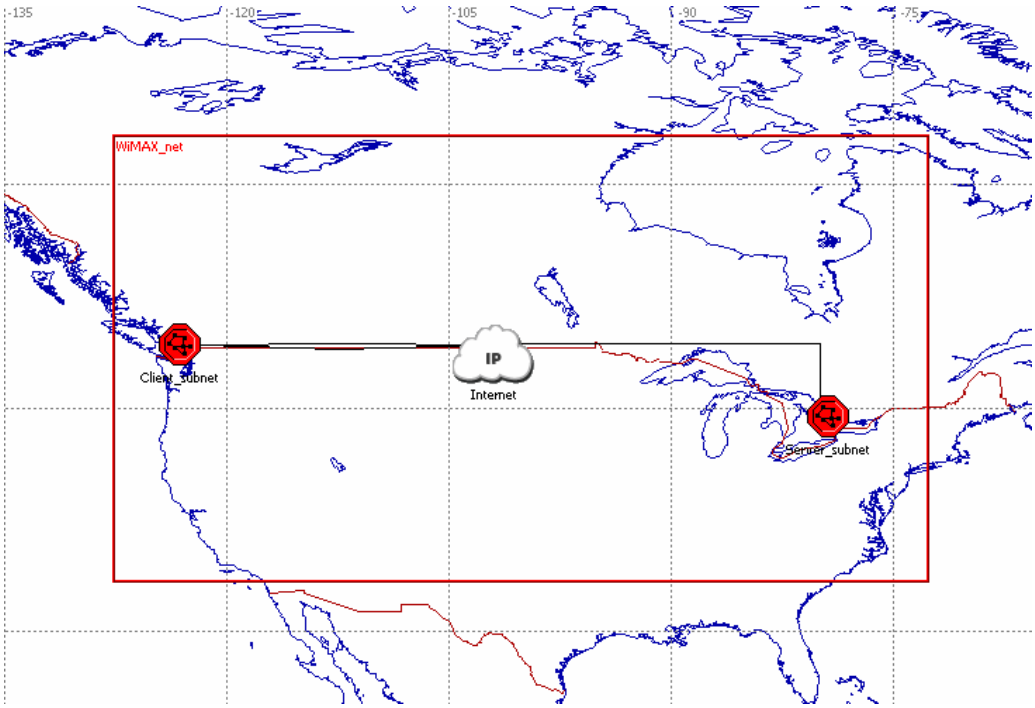

Figure 7. Simulation model network topology

The video services subnet is located in Toronto and it provisions a VoD server capable of streaming stored video content to video clients on request. This subnet reflects a basic corporate architecture where the video server resides on a 100Mbps IP network behind a firewall. The firewall's outside interface connects to an access router which is connected to the Internet via a 45 Mbps DS3 WAN link.

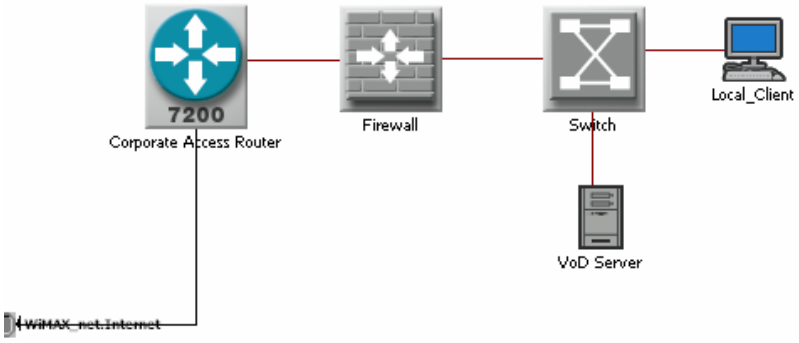

Figure 8. Video services subnet

Additionally, the local video client was utilized for initial troubleshooting and traffic validation purposes; however it was not used in the formal simulation scenarios.

The video client subnet (see Figure 9) is located in Vancouver and encompasses four video client stations that will access the same VoD services from Toronto. In this subnet, three fixed wireless WiMAX stations are located 2, 4, and 6 km from the WiMAX base station. The base station is subsequently connected to the Internet via a DS3 WAN link. The fourth video client is an ADSL station located 5 km from the carrier's central office and serves as the baseline reference to which WiMAX stations will be compared against.

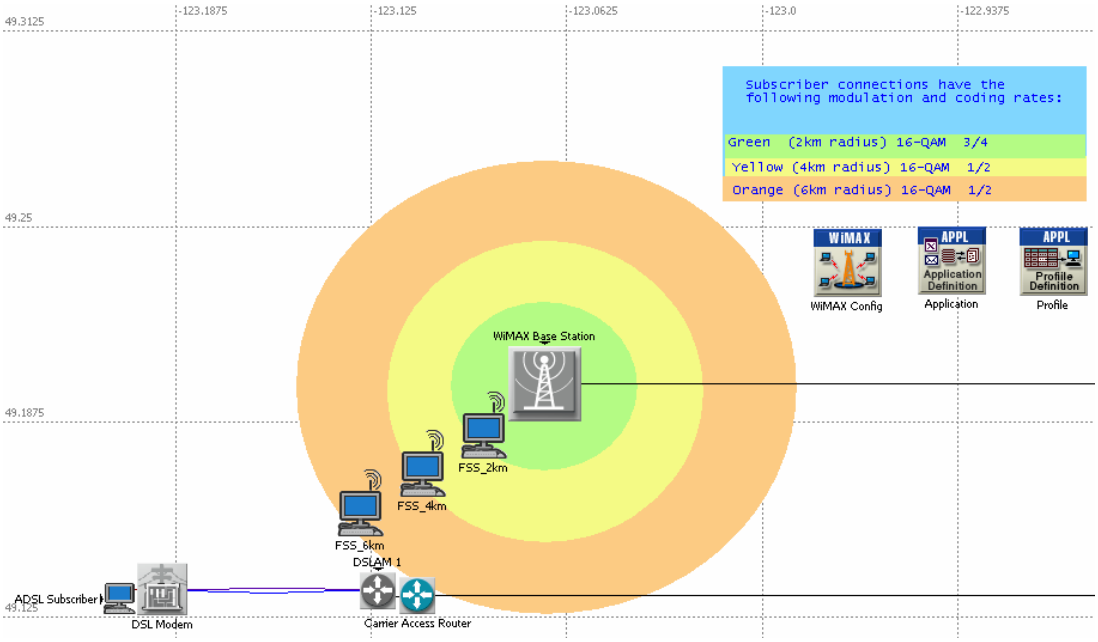

Figure 9. Simulation model video client subnet

It should be noted that the Modeler provides three different coordinate systems to model node distances and corresponding wireline and wireless path lengths. The geocentric coordinate system using latitudes and longitudes was adopted in this model and can be observed on the grid lines in Figure 9. Using publicly available Global Positioning System (GPS) tools, positional information was derived based upon the stated design distances for the three WiMAX stations from the base station. These latitude and longitudes were then configured into each node object in the model.

Additionally, the IP subnets and corresponding network node addresses configured in the model are described in Table 1 below.

Node	Network	Address	Gateway
FSS_2km	192.0.0.0 / 24	192.0.0.1	192.0.0.254
FSS_4km	192.0.0.0 / 24	192.0.0.2	192.0.0.254
FSS_6km	192.0.0.0 / 24	192.0.0.3	192.0.0.254
ADSL_Subscriber	192.0.1.0 / 24	192.0.1.1	192.0.1.254
Local_client	10.0.2.0 / 24	10.0.2.100	10.0.2.254
VoD Server	10.0.2.0 / 24	10.0.2.1	10.0.2.254

Table 1 Node Addressing Scheme

Both subnets are connected to the Internet via DS3 WAN circuits. The approximate distance between the two subnets is 3342 km which equates to approximately 13.3 ms propagation delay. The LAN and WAN links were configured with alternating 10 and 20% utilization loads over 30 minute intervals.

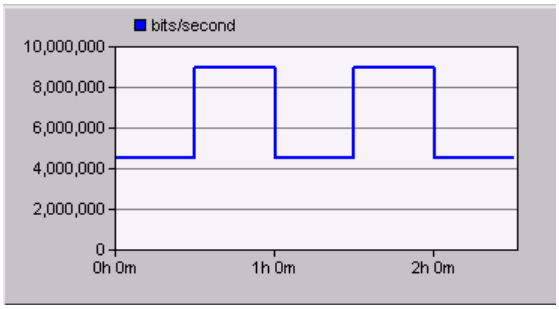

Figure 10. WAN link

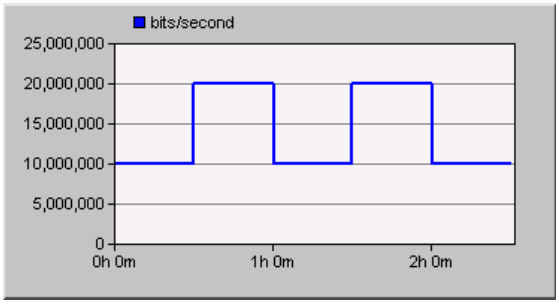

Figure 11. LAN link

Moreover, the Internet "cloud" was configured with a packet discard ratio of 0.001% which results in one packet out of every 100,000 packets is dropped in the Internet. The Internet also introduces 1 ms delay in addition the propagation delays noted on the WAN links.

The simulation scenarios also incorporate staged background traffic growth of 10% every 30 minute intervals to create escalating time intervals of increasing traffic to which video traffic performance may be monitored.

3.3 Video Traffic

The video traffic is a key aspect of the study as its inherent bandwidth intensive, delay sensitive properties will stress the access links to a much further extent that most other types of application traffic.

As a result, several video sources were employed to drive this simulation model. The first source is generated by the Modeler video conferencing application using a Constant Bit Rate (CBR) configuration as detailed below in Table 1. The purpose of this traffic source, since is not compressed, is to generate traffic with predictable characteristics which can be used to validate the model.

The second traffic source is an actual video trace from a 10 minute MPEG-2 movie clip of Terminator 2. This traffic was obtained from Arizona State University [15,16] and it has a high resolution format and encoding frame rate. Consequently, the mean transmission rate is 5.72 Mbps with peak rates beyond 30Mbps. Given the capacity available on both access links, this video source performed very poorly.

The third traffic source was a 2-hour MPEG-4 Matrix III movie trace [15,16] which utilized a 352x288 frame format resolution and a 25 fps encoding rate. The mean and peak rates outlined in table were much more realistic for modeling access network video streaming.

Parameters	Validation Traffic	Terminator 2	Matrix III
Resolution	128x120	1280x720	352x288
Codec	<none>	MPEG-2	MPEG-4 Part 2
Frame Compression Ratio	1	58.001	47.682
Min Frame Size (Bytes)	17280	627	8
Max Frame Size (Bytes)	17280	127036	36450
Mean Frame Size (Bytes)	17280	23833.792	3189.068
Display Pattern	N/A	IBBPBBPBBPBB	IBBPBBPBBPBB
Transmission Pattern	N/A	IPBBPBBPBBIB	IPBBPBBPBBIB
Group of Picture Size	N/A	12	12
Frame Rate (frames/sec)	**1**	**30**	**25**
Number of Frames	7,200	324,000	180,000
Peak Rate (Mbps)	0.138	30.488	7.290
Mean Rate (Mbps)	**0.138**	**5.720**	**0.637**

Table 2 Video Source Characteristics

It should be noted that all three video traces reflect video frames only. The corresponding audio traffic for a given video trace is deemed insignificant in relation to the video traffic [15,16].

The video traces required pre-processing before they could be imported into the Modeler. The appendix includes tables of the trace formats. Essentially the traces were sorted into codec sequence and then the frame sizes were extracted and converted from bits to bytes. After processing, the trace files were imported into the Modeler video conferencing frame size configuration as a scripted file. Additionally, the incoming frame inter-arrival rate was configured to reflect the content encoding rate. The resulting unidirectional video stream was subsequently mapped to a Type of Service (ToS) value that would be later mapped to a WiMAX service flow.

Next, the Modeler profile node was configured to reflect the newly defined applications (validation video conferencing application, MPEG-2 movie, MPEG-4 movie). The Modeler profile represents a simulation schedule of various applications. Within a simulation scenario, profiles are deployed to video clients and the VoD server is configured to support the appropriate application services. Profiles can be configured to start at a specific time after the simulation starts and they can also repeat a number of times with constant or variable inter-profile repetition times. Within a profile, applications can be configured serially or in parallel with similar offset and inter-repetition times. Figure 12 details the profile configurations for MPEG-2 and MPEG-4 video traces.

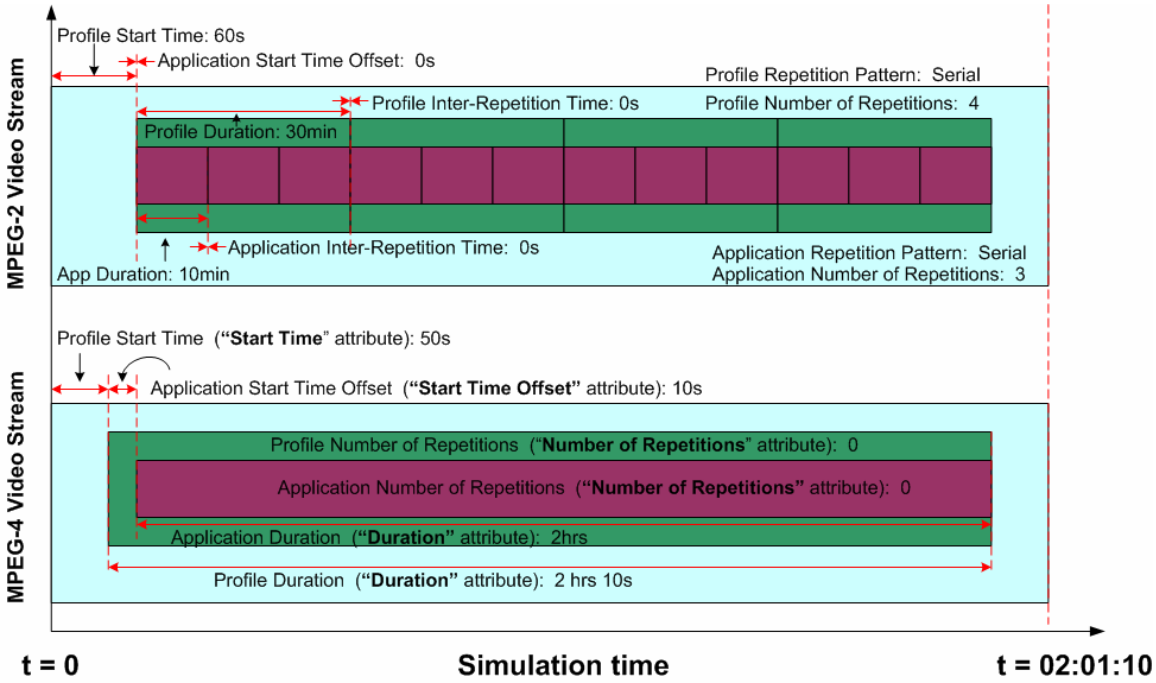

Figure 12. Video traffic profile configuration

3.4 WiMAX Configuration

The WiMAX specific configuration involved the following areas:

- ❑ Service Class / Service Flows
- ❑ MAC scheduler
- ❑ Burst profiles
- ❑ Air Interface
- ❑ Operating Frequency
- ❑ Channel bandwidth and subcarrier allocation
- ❑ Transmit power
- ❑ Pathloss model

In WiMAX, a service class captures the QoS requirements of service flows where service flows represent traffic flows between the base station and the subscriber stations. Service flows from the base station to the subscriber station are termed downlink flows; service flows from the subscriber station to base station are termed uplink flows. For a given service class, the key parameters are minimum sustainable data rate, which is minimum guaranteed over the air (OTA) rate, as well as the media access control (MAC) scheduler type.

The MAC scheduling facility allows WiMAX to provide QoS capabilities, thereby supporting delay sensitive traffic like voice and video services. There are four scheduler types:

- UGS (ungranted service)
- rtPS (real time polling service)
- nrtPS (non real-time polling service)
- BE (best effort)

The available bandwidth resources are allocated to UGS first, then to rtPS and nrtPS flows. Lastly, any remaining resources are then assigned to BE flows.

For the purposes of this study, one service class was created for the downlink using BE scheduling and 3.0 Mbps minimum sustainable data rate. Another service class was created using BE scheduling and 640 kbps minimum sustainable data rate. Subsequently, the base station and WiMAX subscriber stations were configured to map the uplink and down link service flows to a specific ToS setting that was configured during the application node configuration. Moreover, each service flow (uplink and downlink) can be configured with specific burst profile. For this study, the uplink channel was assumed to have similar properties to the down channel so for a given WiMAX station, the same burst profile was used on both the uplink and downlink service flows.

The legend in Figure 9 details the modulation and coding rate (burst profile) for each WiMAX station. Since the Modeler did not support adaptive burst profiles, WiMAX client stations were manually configured with more robust modulation/coding schemes with increased distance from the base station. Table 3 details the available coding rates for a given modulation scheme as well as the minimum signal to noise ratio (SNR).

Modulation	Coding	Information Bits/symbol/Hz	Required SNR (dB)
QPSK	1/2	1	9.4
	3/4	1.5	11.2
16-QAM	1/2	2	16.4
	3/4	3	18.2
64-QAM	2/3	4	22.7
	3/4	4.5	24.4

Table 3 Modulation / coding rates

Initially 64-QAM scheme was configured for the 2 km fixed subscriber station (FSS), but the SNR at 2 km from the base station was below acceptable levels and the resulting performance was poor. Consequently, a more robust scheme was configured at the expense of lower transmission efficiency.

The air interface or PHY layer access was configured to utilize OFDM on a 2.5 GHz base frequency using a 5 MHz channel bandwidth which provisions 512 subcarriers allocated in the following manner in Table 4:

Frequency Division		
	DL Zone	UL Zone
Number of Null Subcarriers - Lower Edge	46	52
Number of Null Subcarriers - Upper Edge	45	51
Number of Data Subcarriers	360	272
Number of Subchannels	15	17

Table 4 PHY layer frame division pattern

The WiMAX client station transmit power was configured to use 33 dBm (2 watts) of transmit power over the 5MHz channel bandwidth using 14 dBi gain antennas. The base station transmit power was configured to 35.8 dBm (3.8 watts) with 15 dBi gain antenna.

Finally, for the purposes of this study, it was important to factor pathloss into the performance of our WiMAX clients, so a fixed suburban (Erceg) model was employed with a conservative terrain model which accounted for mostly flat terrain with light tree densities.

3.5 ADSL Configuration

The ADSL configuration employed in this model was representative of an "enhanced" subscriber package with a 3.0Mbps downlink channel and a 640 kbps uplink channel. The modeled distance between the subscriber and the central office was 5 km.

3.6 Simulation Scenarios

The following simulation scenarios were created over the course of this project. The scenarios can be categorized as either validation-oriented for either incoming or outgoing traffic for a given access network or MPEG-4 video streaming scenarios. As described in Figure 13, scenarios 9 to 15 reflect various base station buffer sizes and simulation time combinations.

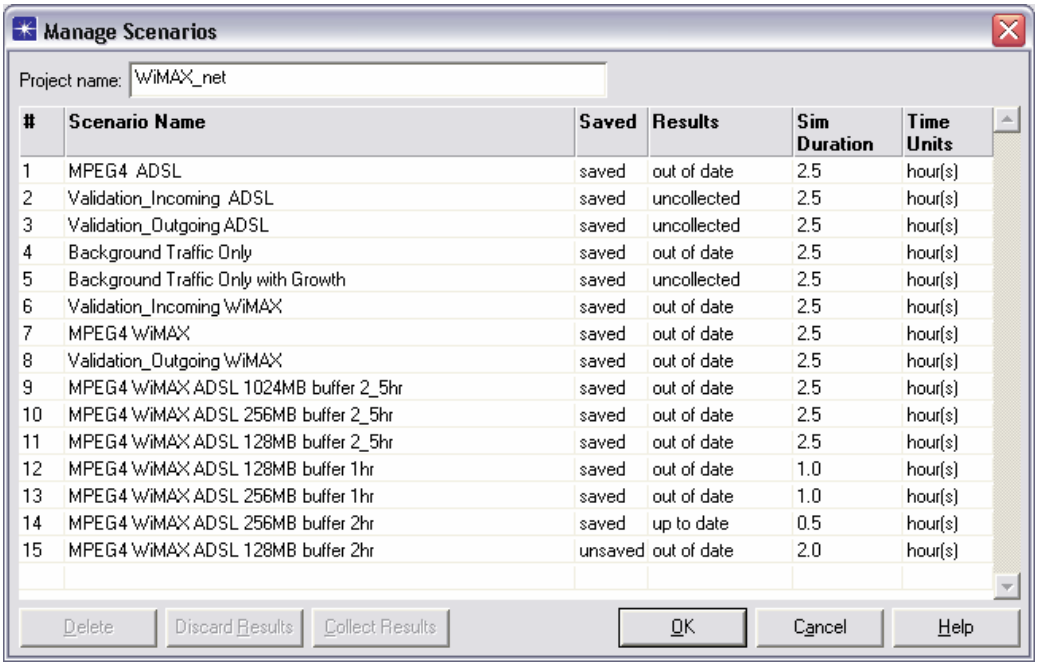

Figure 13. Modeler scenarios

3.7 Model Validation

There were various stages of model validation throughout the implementation stages of this project. Most importantly, the DES log was invaluable in detecting many (but not all) errors as noted in Figure 14.

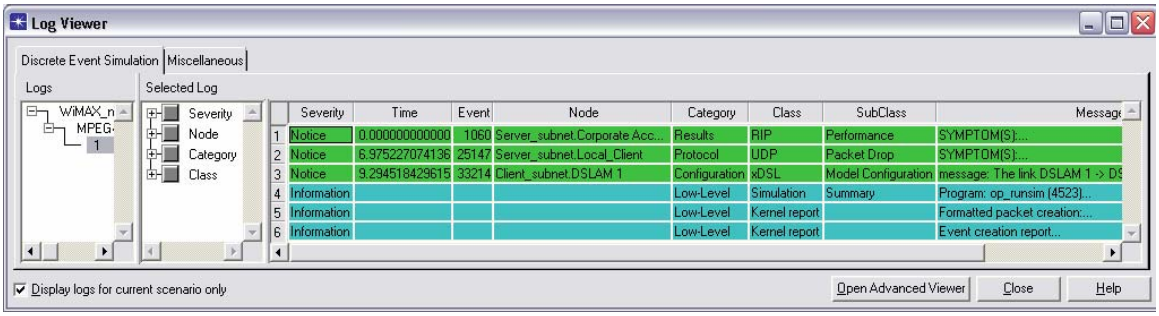

Figure 14. Modeler DES log

The model was initially validated by incorporating a reference video client station connected to the same 100BaseTX switch as the VoD server. This scheme facilitated initial model implementation stages to overcome routing issues, WiMAX service class connection mapping, etc. Once the model stabilized with end-to-end traffic being observed on all client stations, more rigorous end-to-end validation tests to the remote clients were created to ensure the model was implemented correctly.

Consequently, for the validation phase, two video conferencing scenarios were separately configured in the Modeler to generate predictable amounts of unidirectional CBR traffic which could then be validated on the remote end accordingly. The first application generated incoming traffic to the WiMAX and ADSL client stations using the following characteristics noted in Table 5.

Generic Video Conferencing Application					
Resolution	Color Depth (bits/pixel)	Frame Size (Bytes)	Frame Size (bits)	Frame Rate	Throughput (bps)
128x120	9	17280	138240	1	138,240

Table 5 Video conferencing stream details

Using a constant frame size of 17280 bytes, this configuration generated video frames at a rate of 1 fps which equates to 17280 bytes/sec. A profile was configured to stream this CBR video traffic for 2 hours and it was subsequently deployed to the client stations. The simulation results, as reported on the individual stations were in alignment with the predicted results. Specifically, Figure 15 shows all four video clients receiving the video stream at a rate close to 1 packet/sec on average. Figure 16 shows all four video clients receiving the video stream at a rate close to 17280 bytes/sec which further validates the model implementation.

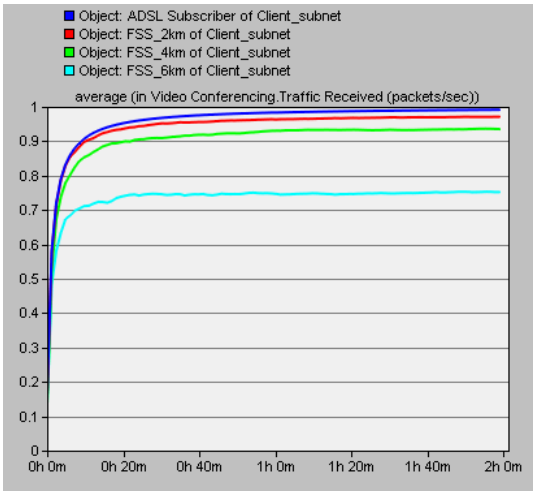

Figure 15. Received pkts/sec

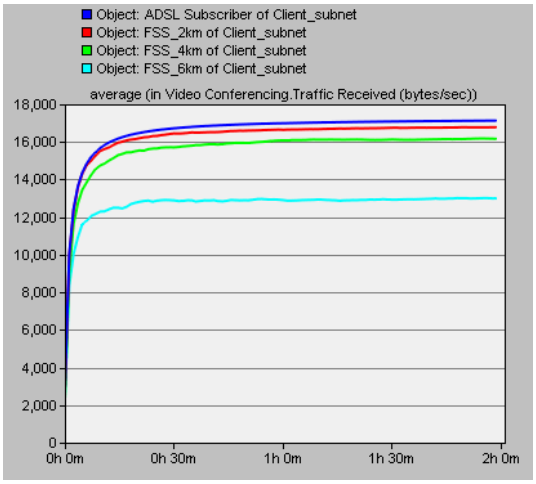

Figure 16. Received bytes/sec

Additionally, another validation scenario was created to test the outgoing traffic from the client stations which utilized a similar application/profile configuration as above. The results described in Figure 17 and Figure 18 below measure up with our predicted values. It should be noted that all four curves in both plots lay on top of each other, hence only one colored curve is evident in the figures.

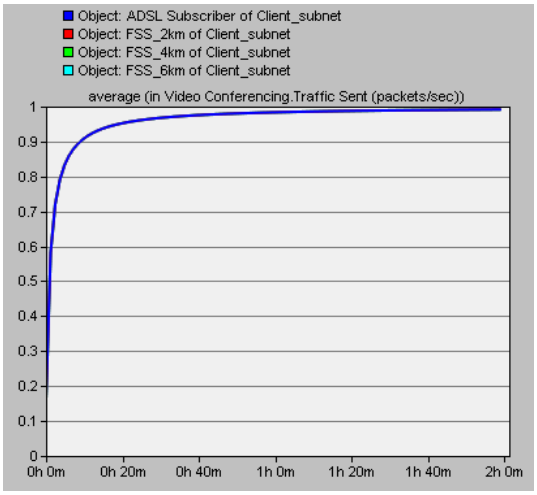

Figure 17. Sent pkts/sec

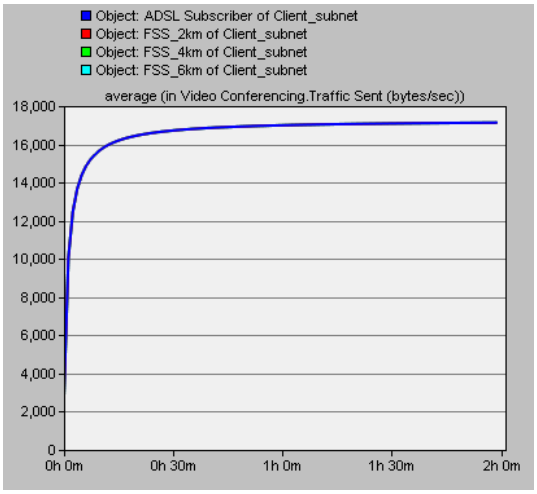

Figure 18. Sent bytes/sec

4 Results

As noted earlier, the MPEG-2 video stream performed poorly since its mean and peak throughput rates were well beyond the capacity available on both downlink access links. Consequently the MPEG-2 video content was abandoned and the simulation focused on the MPEG-4 video content. Specifically, the reported simulation results reflect the streaming of the 2 hour MPEG-4 video content to the four video subscribers. Actual simulation times ranged from 2 to 8 hours for a given scenario depending on whether incremental background traffic growth was enabled.

4.1 MPEG-4 Video Stream

4.1.1 WiMAX Link Characteristics

The following PHY layer statistics provide insight into the performance of the WiMAX access network. Figure 19 details the dropped packet rates by the PHY layer for the three WiMAX stations. The 6 km WiMAX station (green curve) exhibits a much higher drop rate than the 2 km and 4 km stations over the 2 hour interval. Figure 20 details the downlink SNR for the three WiMAX stations. Note that the 6 km station reports a downlink SNR that is below the necessary

minimum level for 16-QAM with ½ coding (see Table 3). This low SNR for the 6 km station is a major contributor to the high drop rate accordingly.

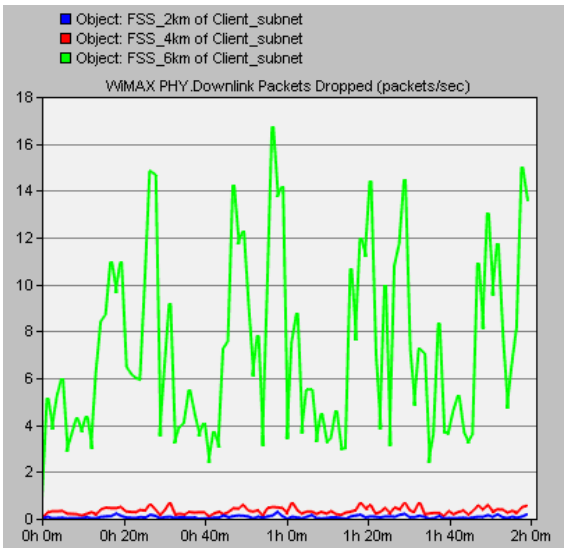

Figure 19. Downlink Dropped pkts/sec

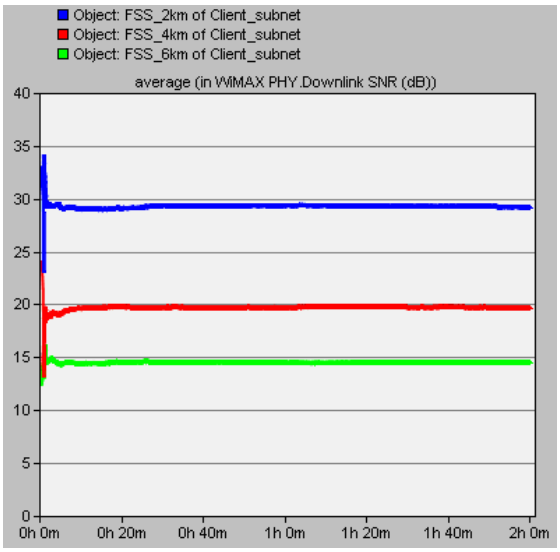

Figure 20. Downlink SNR

The downlink Block Error Rate (BLER) for the 2 km and 4 km WiMAX stations are indicated in Figure 21. The 4 km station is expected to reflect a higher BLER given that it is twice as far from the base station than the 2 km station. Figure 22 displays a BLER two orders of magnitude higher than the 4 km WiMAX station.

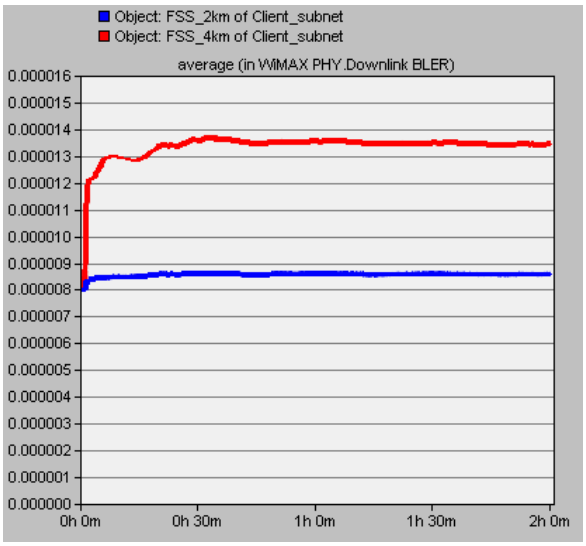

Figure 21. Downlink BLER

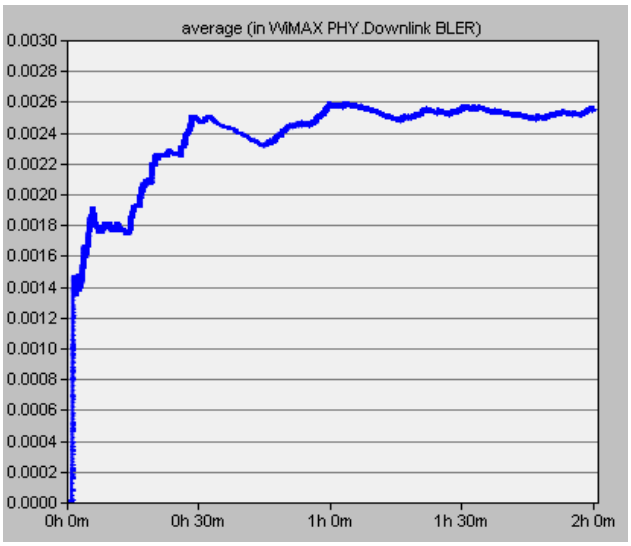

Figure 22. Downlink BLER

It is understood that the lower the SNR for a given station, the higher BLER which is consistent with our simulation results.

4.1.2 Video Packet Loss

The following figures show the resulting video packet loss observed on all four video clients. Since the Modeler does not provide a video application layer loss statistic, the loss in Figure 23 is represented as the curve deviation from the 25 packets/sec position on the vertical axis. All four curves are averaged over the 2 hour movie duration. The blue ADSL client curve approaches a received packet rate that matches the VoD sending rate of 25 packets/sec. The WiMAX stations exhibit a deviation from the encoding rate with more pronounced degradation as the subscriber to base station distance increases.

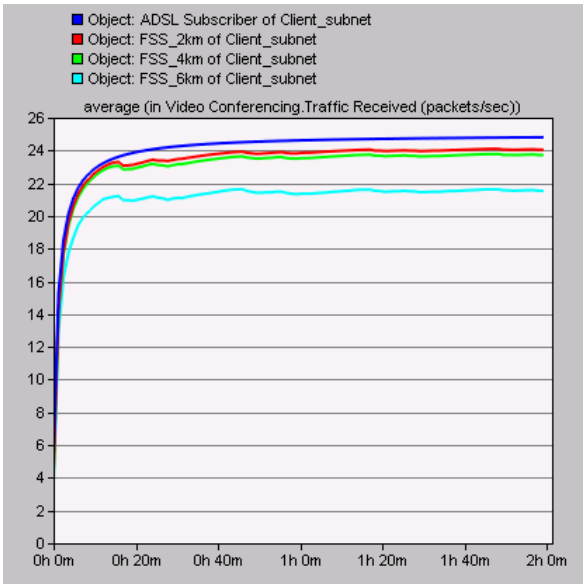

Figure 23. Received video packets/sec

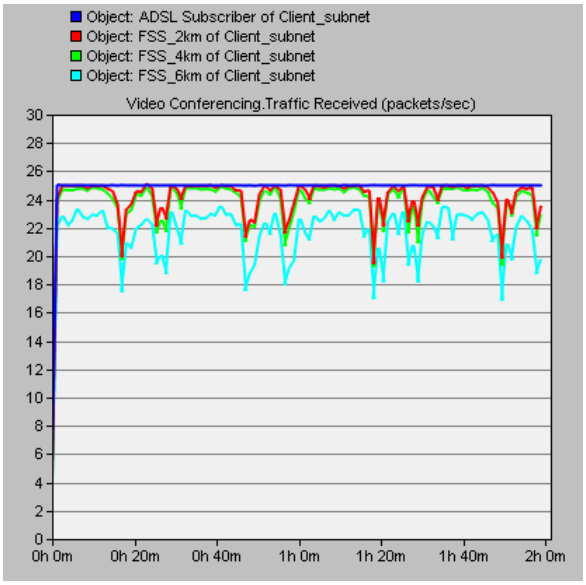

Figure 24. Received video packets/sec

Figure 24 reports the same video packet loss using instantaneous values.

In order to understand the why the video packet loss on the WiMAX stations is significant, further exploration and characterization was necessary. Figure 25 captures the 2 km WiMAX station video packet drop rate along with the MAC layer drop rate statistic from the base station. It is evident that the MAC layer on the base station is dropping a significant number of frames. This information prompted further investigation and it was found that the base station queue size of 128 KB was being overrun as indicated in Figure 26. This behavior is largely in part due to the variable sized MPEG-4 video frames.

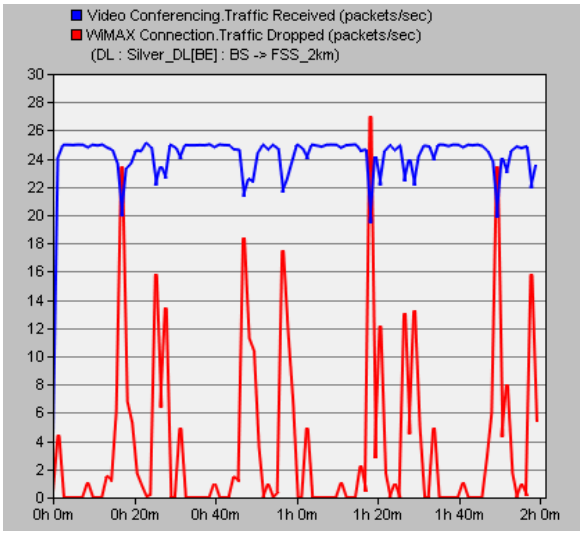

Figure 25. Received and dropped pkts/sec

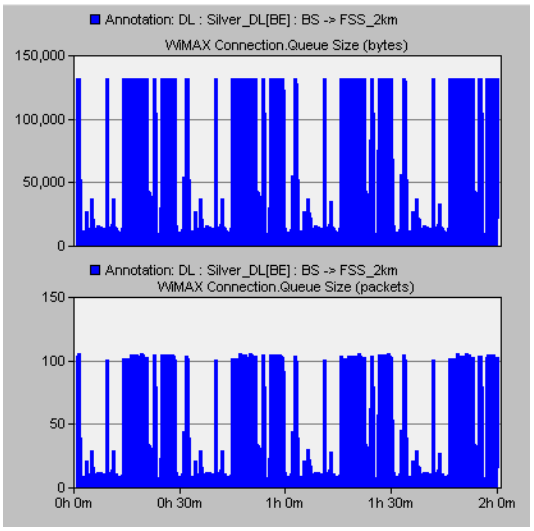

Figure 26. Base station DL queue

Similarly, Figure 27 – 30 exhibit similar behavior with the 4 km and 6 km WiMAX stations.

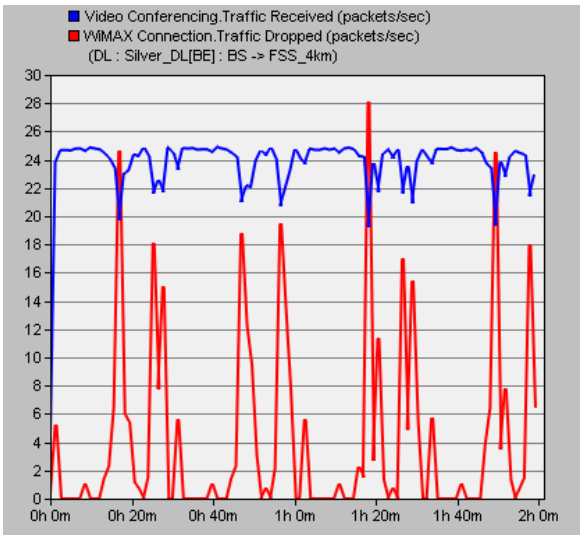

Figure 27. Received and dropped pkts/sec

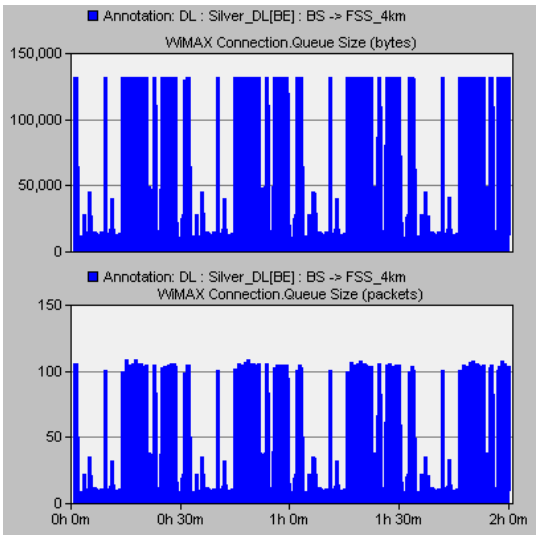

Figure 28. Base station DL queue

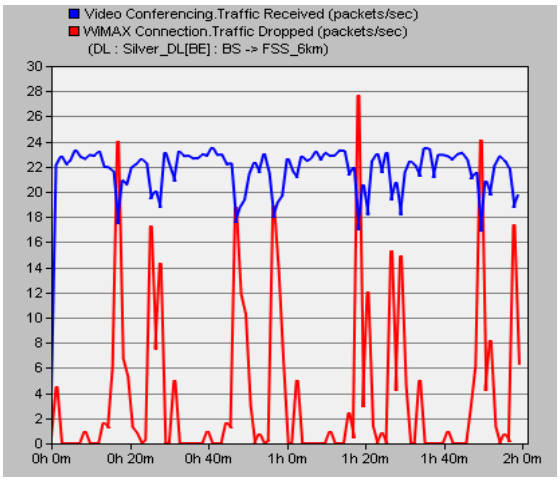

Figure 29. Received and dropped pkts/sec

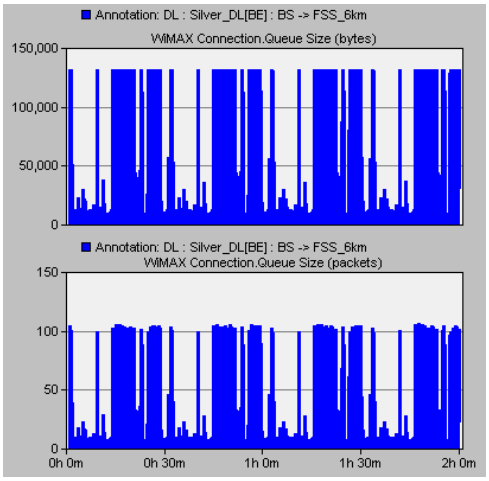

Figure 30. Base station DL queue

4.1.3 Delay

The end-to-end delay measured in the simulation run is detailed in Figure 31. The four video client curves are averaged across the 2 hour movie. From the results we can see that the ADSL client approaches the ideal delay of 10 ms or less. All three WiMAX client station curves closely tracked each other while exhibiting a damping effect that appears to settle around 90 ms towards the end of the movie.

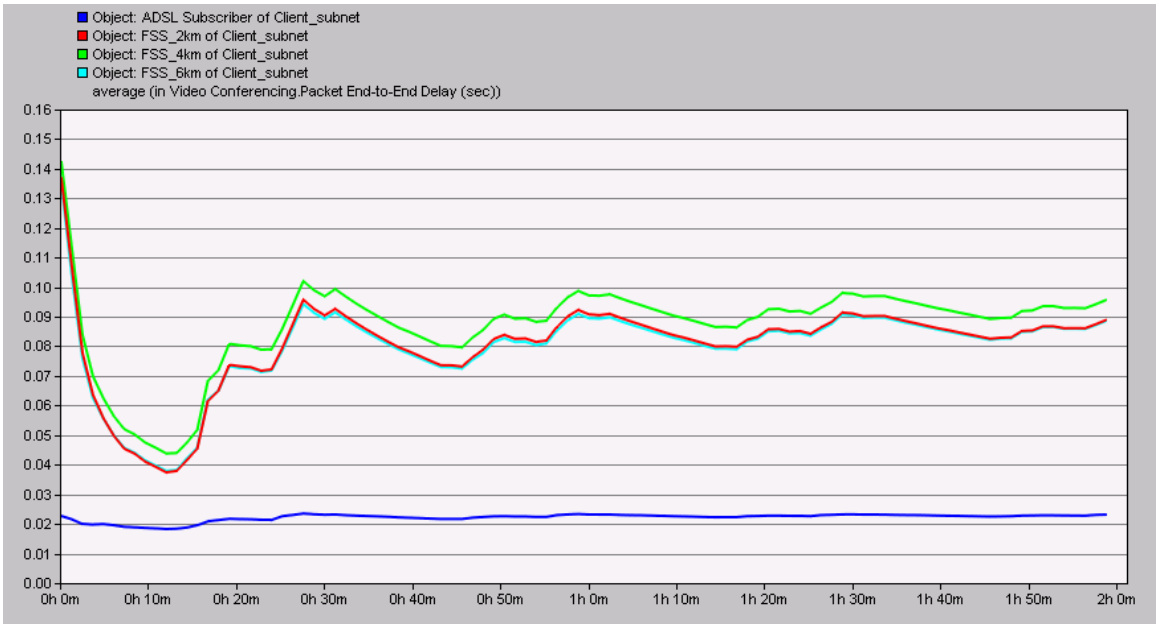

Figure 31. End-to-end packet delay

4.1.4 Jitter

The video packet jitter measured in the simulation run is detailed in Figure 32. The four video client curves are averaged across the 2 hour movie. From the results we can see that the ADSL client performed better than ideal value of 20 ms. The WiMAX client station curves closely tracked each other for the movie duration with a jitter on the order of 25 ms which also approached the ideal value.

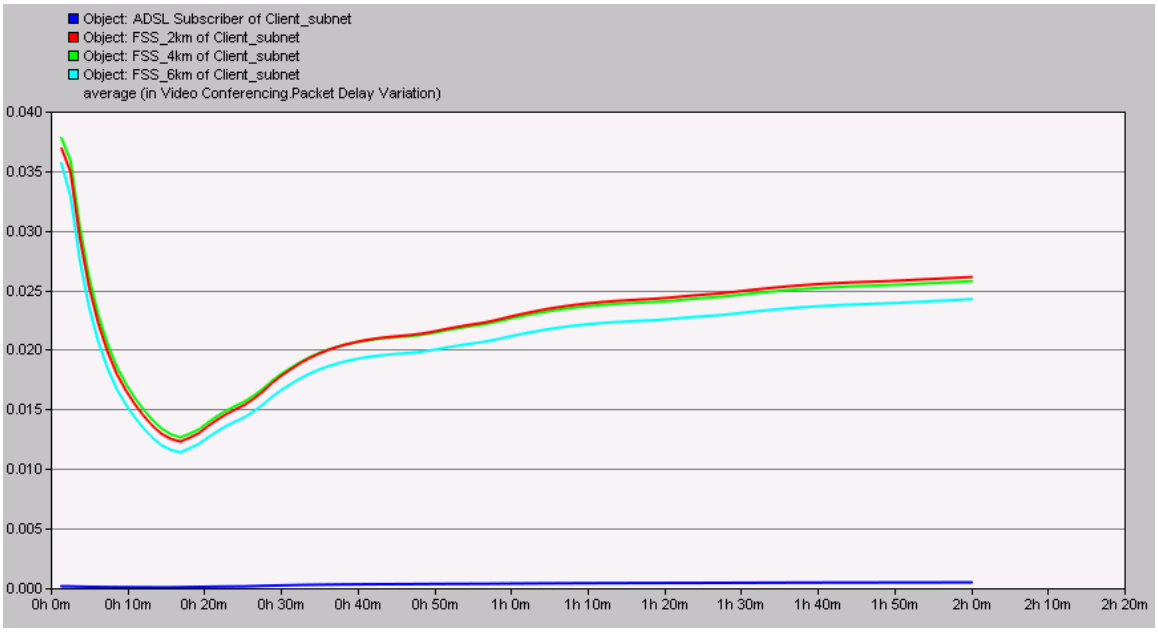

Figure 32. Video packet jitter

4.1.5 Throughput

The throughput measured in the simulation run is detailed in Figure 33. The four video client curves are averaged across the 2 hour movie. All four client curves tracked each other as expected. The observed throughputs ranged from 0.40 Mbps to 0.72 Mbps which falls within specified metric and corresponds to the mean traffic rate for the MPEG-4 content in Table 2.

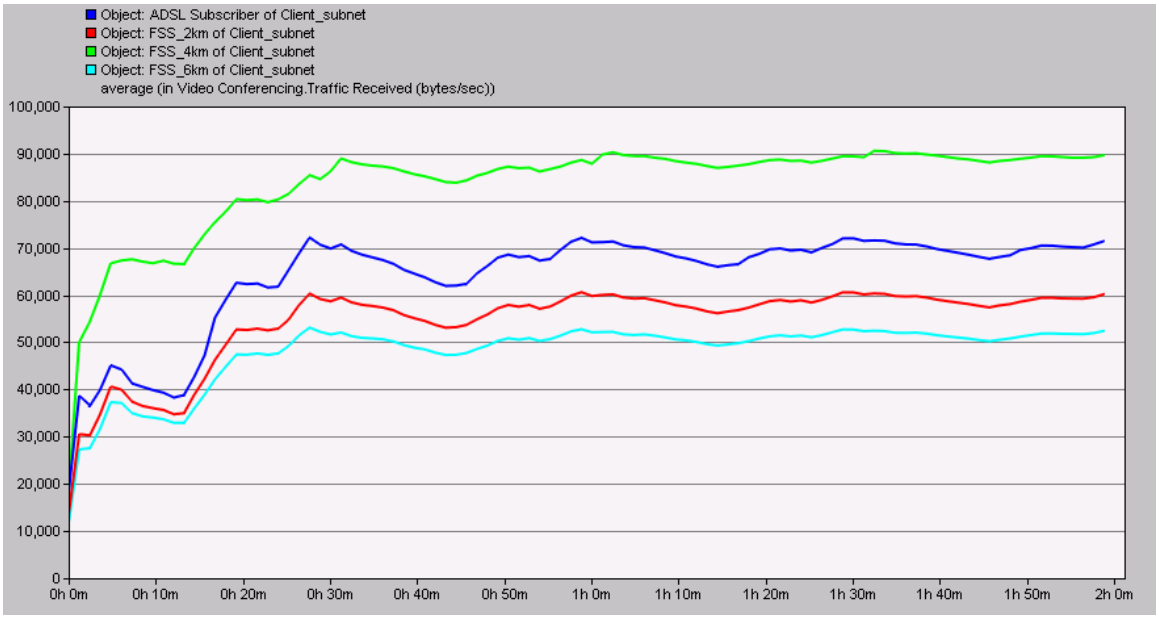

Figure 33. Minimum throughput

4.1.6 Video Server

The model was configured to stream video content to all four video clients using the MPEG-4 video content described in Table 2. Specifically, the movie was encoded at a rate of 25 fps. Since each video frame is encapsulated into its own video packet, the VoD server is expected to send out unicast video packets at a rate of 25 packets/sec for each client. Figure 34 confirms the expected behavior accordingly.

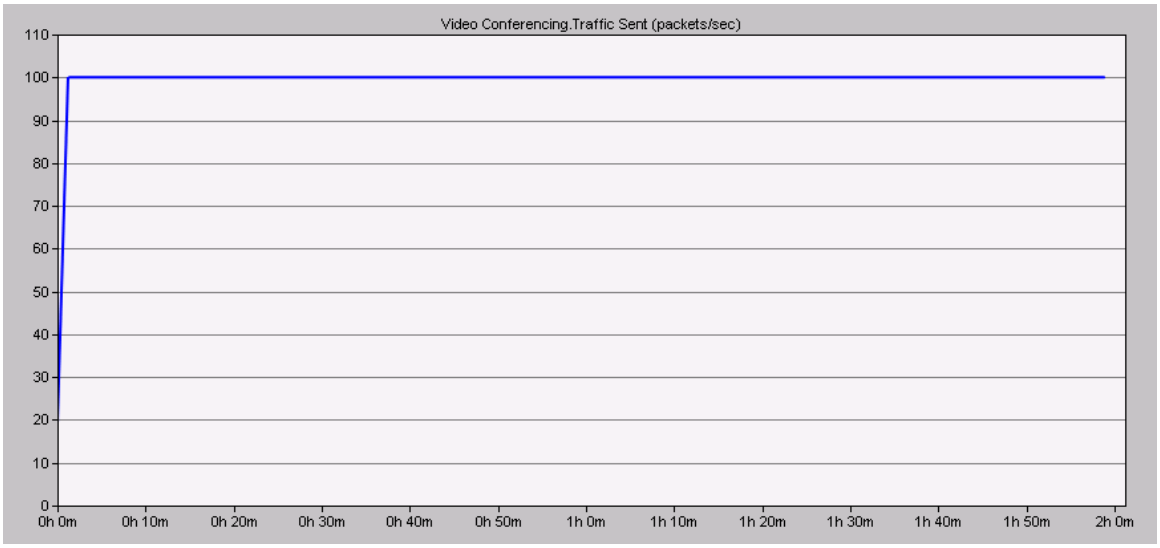

Figure 34. Video server packets/sec

4.2 Performance Tuning

After considering the performance reported in Video Packet Loss section, additional base station buffer size tuning was conducted to explore its impact on dropped packet rate statistic and ultimately the video packet loss statistic. Various queue sizes ranging from the default value of 64 KB to 1024 KB were simulated and analyzed. It was evident that 1024 KB buffer resolved the over run condition and resulted in a MAC packet drop rate of zero. Figure 35 demonstrates much improved performance of the 2 km and 4 km WiMAX stations. While the 6 km station continued to exhibit unacceptably high packet loss rates, this was primarily due resulting SNR that was below the minimum level required for the configured modulation / coding scheme. Figure 36 describes the same loss performance using instantaneous values.

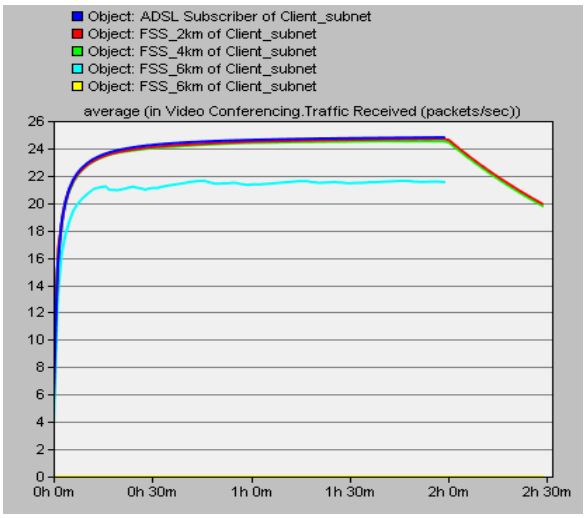

Figure 35. Received Video packets/sec (average)

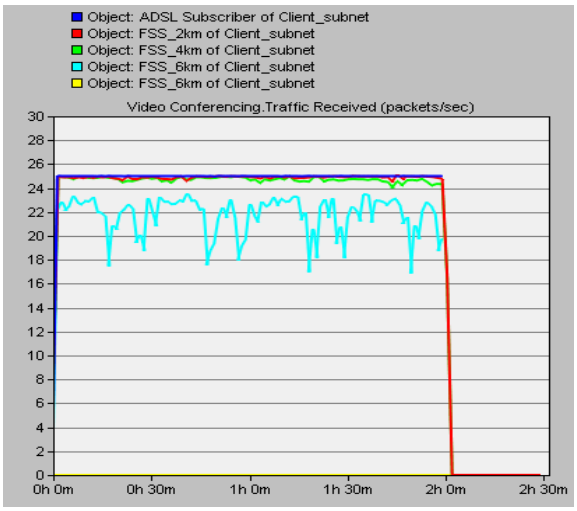

Figure 36. Received Video packets/sec (instantaneous)

With further examination of the 2 km WiMAX station, Figure 37 confirms the received video packet rate closely tracks the original encoding and transmission rate. Further, it also details the zero dropped packet rate which aligns with Figure 38 which confirms the base station connection queue size never reaches its capacity of 1024 KB.

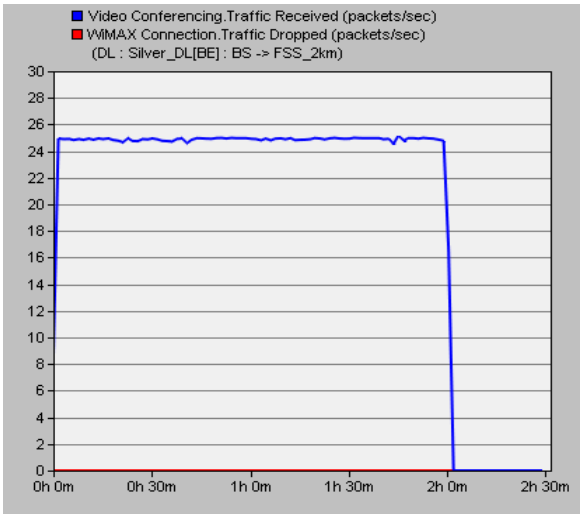

Figure 37. Received/Dropped Video packets/sec

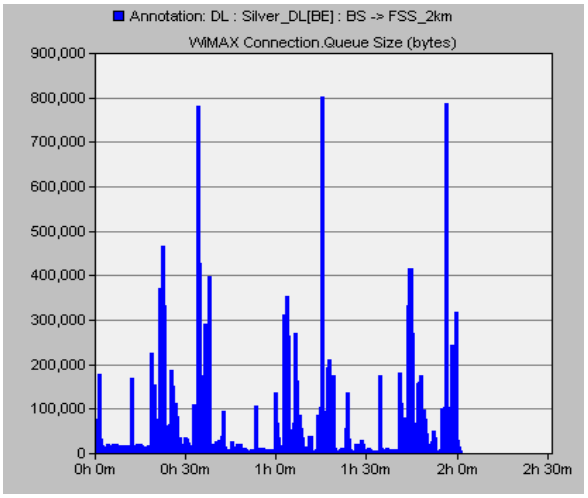

Figure 38. Base station queue size (inst.)

5 Related Work

Various related efforts have explored WiMAX in the context of real-time and stored video applications. A novel proposal for WiMAX as a wireless broadband solution for telemedicine applications [2] explored the key fundamentals of WiMAX to provide real-time imaging and audio/video information of local and remote patient data as well as from ambulance services. Real-time video services could be used to provision crucial patient health information from hospital destined ambulances. The simulations were conducted in Matlab.

Another research effort [4] presented WiMAX fundamentals as a broadband access solution to support IPTV services framework. The paper discusses the considerations associated with delivery video services while minimizing video and audio quality degradation. In addition, it presented some key transceiver design considerations at the PHY layer. However, no simulations were conducted in this effort.

Similarly, other researchers [7] proposed a framework for IPTV services over WiMAX, citing the associated complexities and challenges. The framework details an IPTV services topology to distribute VoD content to WiMAX subscribers. While this paper did not present any simulations, it outlined the WiMAX MAC and PHY layers and their role sustaining a video content load.

There has also been effort exploring the performance of scalable video streaming over mobile WiMAX stations using feedback control [6]. Researchers evaluated MAC layer performance by scaling video content over multiple connections based on feedback of the available transmission bandwidth.

A distinctive research effort [5] empirically characterized a WiMAX access link using a test bed instead of a simulation model. The paper described the test bed topology and hardware configuration to which various generic TCP and UDP loads were utilized. The researchers observed the link performance as a function of station power and distance for eight different modulation/coding schemes.

6 Future Work

The work conducted in this project analyzed the performance of WiMAX broadband access to existing ADSL broadband access in terms of a bandwidth intensive, delay sensitive video streaming load representative of emerging Internet video services.

In order to keep the project scope within the duration of this course, certain key assumptions were made accordingly. These assumptions include:

- Station transmit power
- Station antenna gain
- Pathloss model and corresponding flat, low density tree terrain
- Carrier operating frequency and channel bandwidth
- WiMAX MAC scheduling type
- WiMAX Service class throughput rates
- WiMAX multi-path model disablement
- WiMAX fixed station configuration only (mobility disabled)

Consequently, to increase the accuracy of this model, future efforts could revisit these design parameters and further characterize their impact on the system performance through isolated scenarios.

Moreover, the generic OPNET video conferencing application used in this model can not be configured to utilize Real Time Protocol (RTP) encapsulation without customized code. This effort would more accurately model the actual protocol overhead associated with video streaming services. In addition, efforts could be allocated to the incorporation of audio data to make the model more realistic as the current video traces do not account for audio content.

Lastly, research into refining the stated performance metric thresholds would facilitate more realistic analysis.

7 Conclusion

This study has explored the technical details and performance of WiMAX broadband access technology. The focus of the study was to address whether WiMAX access technology could provide comparable network performance to ADSL for streaming video applications. As a result, the study has utilized the OPNET Modeler to design and characterize the performance of streaming a 2 hour MPEG-4 movie to both WiMAX and ADSL video subscribers. Four performance metrics were identified to evaluate video performance over the access networks.

The validation scenarios confirmed the overall design of the study was implemented successfully in the Modeler. While the initial efforts to incorporate MPEG-2 video content proved to perform poorly and was consequently abandoned, the MPEG-4 video source exhibited a more realistic traffic load given the bandwidth considerations of access networks.

From the simulation results, while ADSL exhibited behavior that approached the ideal values for the performance metrics, WiMAX demonstrated promising behavior still well within the bounds of the defined metrics. Initial MPEG-4 content simulation runs exhibited significant packet loss. However, with further tuning, a configuration was derived that demonstrated packet loss that was more comensurate of the ADSL video client station.

In conclusion, this study was successful in addressing its stated objective. Overall, the OPNET Modeler has provisioned a suitable environment to design and characterize WiMAX networks.

It should be noted that various factors likely understated the performance of the WiMAX access link including the adoption of the least-QoS aware base station scheduler as well as various WiMAX PHY parameters that were assigned conservative values given the lack of available deployment data from carriers. Additionally, the streaming video content was modeled as unicast traffic; multicast video traffic would yield better performance.

With further research and refinement as well as upgrading to the latest Modeler release, the simulation model can be enhanced to reflect more realistic field deployments.

8 References

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9 APPENDICES

9.1 Acronyms

ADSL	Asymmetric Digital Subscriber Line
AMC	Adaptive Modulation and Coding
BS	Base Station
BE	Best Effort
BPSK	Binary Phase Shift Keying
CBR	Constant Bit Rate
CPE	Customer Premise Equipment
DL	Downlink
DSL	Digital Subscriber Line
EIRP	Effective Isotropic Radiated Power
ETSI	European Telecommunications Standards Institute
FPS	Frames Per Second
GPS	Global Positioning System
HiperMAN	High Performance Metropolitan Area Network
IETF	Internet Engineering Task Force
LAN	Local Area Network
LOS	Line of Sight
MAC	Media Access Control
MAN	Metropolitan Area Network
MPEG	Motion Picture Experts Group
NAP	Network Access Provider
NLOS	Non Line-of-Sight
nrtPS	Non-Real-Time Polling Service
OFDM	Orthogonal Frequency Division Multiplex
OFDMA	Orthogonal Frequency Division Multiple Access
OTA	Over the Air
PHY	Physical Layer
PMP	Point-to-Multi-Point
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RTP	Real Time Protocol
rtPS	Real-Time Polling Service
SC	Single Carrier
SNR	Signal to Noise Ratio
SS	Subscriber Station
TCP	Transmission Control Protocol
ToS	Type of Service
UDP	User Datagram Protocol
UGS	Unsolicited Grant Service

UL	Uplink
VoD	Video on Demand
WAN	Wide Area Network
Wi-Fi	Wireless Fidelity
WiMAX	Worldwide Interoperability for Microwave Access

9.2 Terminator 2 Video Trace Details

The Terminator 2 trace data was obtained online [15,16] and reflects a single layer MPEG-2 stream with the following characteristics:

- Compression: MPEG-2
- Variable Bit Rate
- High Definition resolution: 1280x720p
- Frame rate: 30 fps
- Number of frames: 18,000 frames
- Duration: 10 minutes
- GoP Size: 12
- Post processed trace file: T2.csv

Table 1 displays the first 30 frames of the trace in display sequence. Given the frame rate of 30 fps, the table reflects one second of video frame details.

Index	Time	Type	Size (bits)	Size (bytes)	PSNR-Y (dB)	PSNR-U (dB)	PSNR-V (dB)
0	0.0000	I	360552	45069	44.89	0	0
1	0.0333	B	66672	8334	44.43	0	0
2	0.0667	B	67224	8403	44.27	0	0
3	0.1000	P	122504	15313	43.87	0	0
4	0.1333	B	71912	8989	44.24	0	0
5	0.1667	B	80360	10045	44.01	0	0
6	0.2000	P	125688	15711	43.72	0	0
7	0.2333	B	74008	9251	44.19	0	0
8	0.2667	B	73552	9194	44.12	0	0
9	0.3000	P	135552	16944	43.68	0	0
10	0.3333	B	74184	9273	44.53	0	0
11	0.3667	B	68816	8602	44.63	0	0
12	0.4000	I	362608	45326	44.92	0	0
13	0.4333	B	65512	8189	44.52	0	0
14	0.4667	B	67584	8448	44.34	0	0
15	0.5000	P	120368	15046	43.9	0	0
16	0.5333	B	73816	9227	44.25	0	0
17	0.5667	B	72464	9058	44.26	0	0
18	0.6000	P	123744	15468	43.87	0	0
19	0.6333	B	69896	8737	44.38	0	0
20	0.6667	B	68432	8554	44.28	0	0
21	0.7000	P	121384	15173	43.87	0	0
22	0.7333	B	69920	8740	44.84	0	0
23	0.7667	B	64560	8070	44.89	0	0
24	0.8000	I	340064	42508	45.22	0	0
25	0.8333	B	64120	8015	44.76	0	0
26	0.8667	B	64264	8033	44.61	0	0
27	0.9000	P	126288	15786	44.16	0	0
28	0.9333	B	66592	8324	44.61	0	0
29	0.9667	B	66400	8300	44.51	0	0

Table 1 Terminator II video stream details

9.3 Matrix III Video Trace Details

The Matrix III trace data was obtained online [15,16] and possess the following characteristics:

- Compression: MPEG-4 Part 2 Advanced Simple Profile
- Variable Bit Rate
- CIF resolution: 352x288
- Frame rate: 25 fps
- Number of frames: 18,000 frames
- Duration: 123 minutes
- GoP Size: 12
- Post processed trace file: Matrix.csv

Table 2 displays the first 25 frames of the trace in display sequence. Given the frame rate of 25 fps, the table reflects one second of video frame detail

Index	Time	Type	Size (bits)	Size (bytes)	PSNR-Y (dB)	PSNR-U (dB)	PSNR-V (dB)
0	0.00	I	8808	1101	67.9535	52.3873	52.3878
1	0.04	B	64	8	67.9535	52.3868	52.3887
2	0.08	B	64	8	67.9535	52.39	52.39
3	0.12	P	456	57	67.9535	52.3868	52.3887
4	0.16	B	64	8	67.9535	52.3873	52.3878
5	0.20	B	64	8	67.9535	52.3905	52.3914
6	0.24	P	456	57	67.9535	52.3868	52.39
7	0.28	B	64	8	67.9535	52.3873	52.3905
8	0.32	B	64	8	67.9535	52.3905	52.3909
9	0.36	P	456	57	67.9535	52.3868	52.3887
10	0.40	B	3232	404	67.9535	52.3873	52.39
11	0.44	B	3232	404	67.9535	52.3891	52.3909
12	0.48	I	8808	1101	67.9535	52.3882	52.3891
13	0.52	B	64	8	67.9535	52.3887	52.3909
14	0.56	B	64	8	67.9535	52.3905	52.3909
15	0.60	P	456	57	67.9535	52.3868	52.3891
16	0.64	B	64	8	67.9535	52.3873	52.3909
17	0.68	B	64	8	67.9535	52.39	52.39
18	0.72	P	456	57	67.9535	52.3868	52.3887
19	0.76	B	64	8	67.9535	52.3873	52.3878
20	0.80	B	64	8	67.9535	52.3905	52.3914
21	0.84	P	456	57	67.9535	52.3868	52.39
22	0.88	B	3232	404	67.9535	52.3873	52.3905
23	0.92	B	3232	404	67.9535	52.3905	52.3909
24	0.96	I	8808	1101	67.9535	52.3868	52.3887

Table 2 Matrix III video stream details

9.4 Challenges

Various challenges have surfaced throughout this project. Initially, the development platform presented some challanges in terms of setting up a standalone Windows environment including Modeler versions and integration with Visual Studio .NET 2003.

However, these challenges were shadowed by the significant learning required to configure some of the more intricate features relating to the WiMAX module and to a lesser degree in importing video traces. While the WiMAX module is provisionsed with a user guide [13], it does not delve into low level configuration details and inter-parameter relationships. Moreover, the lack of any local OPNET gurus or an active Internet OPNET newsgroup to consult upon for configuration problems amplified these challenges and extended the overall project lifecycle.

Additionally, the modeler frequently generated no simulation data for one or all of the video clients when changing seeimingly unrelated WiMAX parameters on a different video client station. In fact the initial simulation design targeted a 2.5 hour interval however numerious runs resulted in the 6 km station reporting no results at all. Yet if the same simulation was run for 1 hour or less, complete results were obtained. After extended simulation runs with incomplete results, a 2 hour interval set of results was achieved across all scenarios.

At least one issue experienced was formally recognized by OPNET as a software defect and a corresponding Software Problem Report (SPR)-113276 was created. Another defect relating to the lack of a suitable statistic in the video conferencing application to track lost application-layer packets already existed under SPR-82429.

The WiMAX real-time polling system (rtPS) scheduling facility was very finicky to configure. I was not able to get all three WiMAX stations to receive the 138 kbps validation traffic load using this MAC scheduler type. This traffic load is much less demanding in relation to the 0.632 Mbps MPEG-4 video stream so given the bandwidth request/grant allocation scheme, I would expect that it should be easier to get the validation stream configuration working if the behavior was attributed to bandwidth resource contention. Ultimately, the model utilized the BE scheme which delivers the least QoS out of the WiMAX scheduling types so the simulation results will understate the performance if deployments use higher QoS schemes.

Finally, learning WiMAX fundamentals within the duration of this project to drive the design of this simulation model proved to be challenging given the breadth and depth of this technology [12].