Streaming Video Content Over IEEE 802.16/WiMAX Broadband Access

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Abstract
Worldwide Interoperability for Microwave Access (WiMAX) embodies the IEEE 802.16 family of standards that provide wireless broadband access to residential and commercial Internet subscribers. While other WiMAX applications exist, there is an increasing trend to employ WiMAX for last-mile Internet access to circumvent the high deployments costs and local loop distance limitations associated with wired Asymmetric Digital Subscriber Line (ADSL) connections.

We use the OPNET Modeler to simulate bandwidth intensive, delay sensitive, video traffic representative of Internet Protocol Television (IPTV) and other video-rich applications over WiMAX and ADSL. These video streams are typically encoded using MPEG-x codecs. Although marginally loss-tolerant, performance of these streams is inherently a function of available bandwidth, buffering, and delay characteristics of the underlying network. Hence, in this paper, we examine four performance factors while streaming two hours of video content to client subscribers to determine whether WiMAX can deliver access network performance comparable to ADSL for video applications.

1. Introduction
As Worldwide Interoperability for Microwave Access (WiMAX) continues to gain momentum and additional manufacturers engineer WiMAX equipment, carriers are exploring WiMAX as a last-mile alternative to their costly Asymmetric Digital Subscriber Line (ADSL) access network infrastructures. In 2007, more than hundred WiMAX carrier trials were planned worldwide. Market studies [1] have projected attractive growth rates in WiMAX subscriber base and equipment revenues, as shown in Figure 1. Furthermore, the WiMAX forum in March 2008 issued a press release [2] projecting 133 million subscribers by 2012.

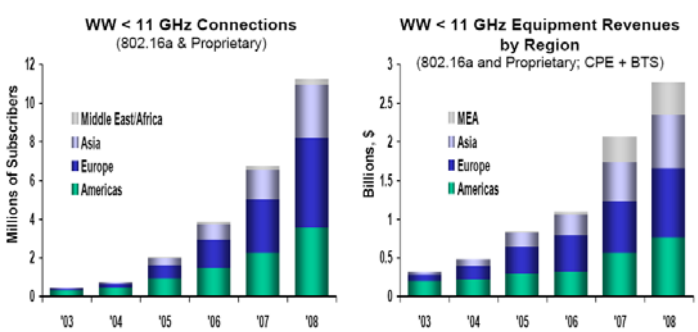


Figure 1. Broadband wireless access market growth: last mile wireless connections.

With such growth, to understand the tradeoffs of moving to WiMAX, it is desirable to quantify application performance across these dissimilar technologies using bandwidth intensive application loads such as video streaming. Given the system complexities involved in access technologies, core network infrastructure, network protocols, and video compression schemes, the scope of our study is whether WiMAX Broadband Access meets or exceeds the performance of ADSL broadband access for streaming video applications in terms of four metrics: packet loss, delay, jitter, and throughput. By experimentally characterizing the application performance over these access networks, we gain insight into the feasibility of WiMAX for fixed wireless broadband access. This effort requires a suitable application load that can sufficiently stress the network to exploit the bandwidth and delay limitations.

As the number of Internet hosts, offered services, router switching speeds, and link transmission capacities, continue to increase, multimedia rich applications such as 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 such as video on demand (VoD) and real-time video streaming. Internet Protocol Television (IPTV) technology [3], [4], [5] distributes video content over IP networks as both managed and unmanaged services. Managed services, such as IPTV and Video Conferencing, 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. Examples of unmanaged services are Google Video, IPTV, and Skype video conferencing. This study is designed around unmanaged video streaming services using an Internet topology that would serve as a lower boundary on expected video performance.

In the simulation, a two-hour interval of the Matrix III movie trace [6], [7] was streamed from an Internet video content provider to three WiMAX video client stations and one ADSL video client. The generic network topology is shown in Figure 2. Using a demanding application load representative of IPTV and other emerging video streaming services, this study compares video streaming performance of WiMAX and ADSL broadband access.

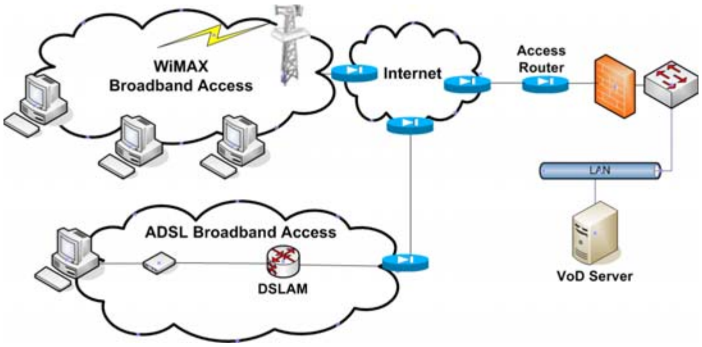


Figure 2. Simulation topology of a network with generic streaming video.

This paper is organized as follows. We present an overview of video content distribution and WiMAX in Section 2 and Section 3 respectively. The OPNET simulation model is described in Section 4. In Section 5, we convey the WiMAX specific configuration. Simulation results and performance tuning are reported in Section 6 and Section 7. In Section 8 and Section 9, related work and future work are described. Lastly, we present concluding remarks in Section 10.

2. Video Content Overview

In this Section, we give a brief overview of video content and its properties. Video content refers to the video information available from video service providers; examples include a wide range of sitcoms, newscasts, sporting events, and movies in real-time and stored video (VoD) formats. The content is structured as a sequence of video frames or images that are sent or "streamed" to the subscriber and displayed at a constant frame rate [4].

Video streaming is inherently loss-tolerant yet delay-sensitive [8], which implies that video playback on the subscriber machines may tolerate some degree of frame loss. However, 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 may be characterized by several parameters including video format, pixel color depth, coding scheme, and frame inter-arrival rate.

Video formats may range from 128 x 120 pixels (horizontal x vertical orientation) to beyond 1920 x 1080 pixels with various color depths. Common Internet video formats (YouTube) use 320 x 240 pixel resolutions while North American digital video disk (DVD) utilizes 720 x 480 and High Definition (HD) standards extend to 1920 x 1080 pixels. The higher the video frame resolution and/or pixel color depth, the larger the raw video content size.

Videos are a sequence of images displayed at a constant rate and each frame contains spatial (within) or temporal (between images) redundancy. Hence, various video coding schemes have evolved to reduce the raw video content size by exploiting this redundancy while balancing quality. These schemes include ITU H.26x and ISO MPEG-x codecs. Video frame inter-arrival rates range from 10 frames to 30 frames per second. This parameter is especially critical if network conditions can impact the frame inter-arrival rates and which, if left uncompensated, significantly degrades the video playback quality. The necessity of the client video system to playback frames at a constant rate amidst variable delays in video frame packet arrivals [8] is illustrated in Figure 3. Video frame packets inherently experience an end-to-end delay between the sender and the receiver. This delay encompasses the propagation delay and any processing and queuing delays in the intervening routers. Since queuing delays change dynamically and video packets may not necessarily traverse the same path between the VoD server and the client station, the end-to-end delay (referred to as jitter) will vary.

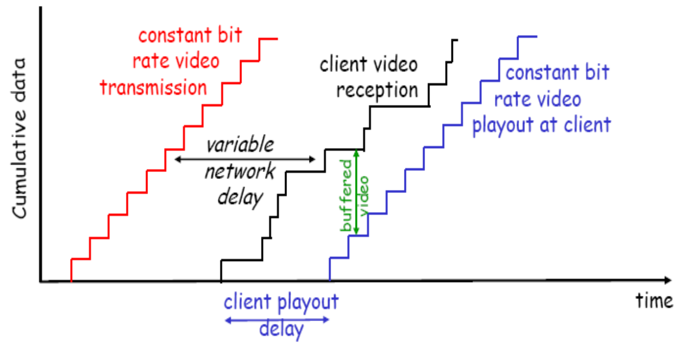


Figure 3. Buffering required at a video client.

VoD services store the video content at the source location rather than generate it 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.

As shown in Figure 4, the protocol stack for streaming video services typically incorporates the Real Time Protocol (RTP) that provisions a packet structure for video and audio data above the transport layer protocol. RTP specifies an eight-byte header with protocol fields to describe the type of content being carried (MPEG-2, MPEG-4), packet sequencing, and time stamping. Since RTP lies above the transport protocol, it is deployed in the end-systems rather than in the network core. RTP does not provide mechanisms to guarantee bandwidth or packet delays [8].

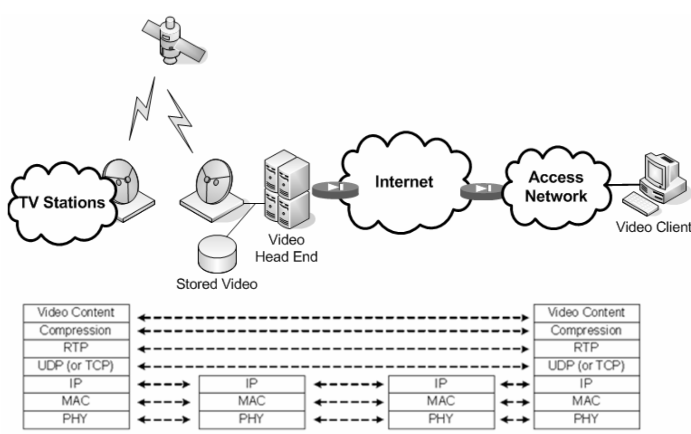


Figure 4. Topology of generic video streaming.

Typical streaming services also utilize the User Datagram Protocol (UDP) that provides best effort service without delay, loss, or bandwidth guarantees. Unlike Transmission Control Protocol (TCP), UDP is connectionless, unreliable and it does not provide flow control or congestion control. The lack of reliability and congestion control mechanisms are desirable properties in media delivery because video servers can stream their content at the native encoding rate of video content without being constrained by congestion control when a packet loss 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 lost 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 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, four performance metrics with appropriate thresholds may be used to measure video streaming performance. We can thus determine whether video clients accessing VoD services over a WiMAX access network satisfies each metric. Furthermore, these metrics enable comparisons between WIMAX and ADSL connected clients because they access the same VoD services over the same wired network infrastructure. The performance metrics are:

- *Packet 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)
  - → 10 kbps – 5 Mbps [8]

3. WiMAX Overview

In this Section, we give a brief overview of the WiMAX technology. WiMAX embodies a family of IEEE 802.16 standards (PHY and MAC layers) focused on delivering fixed, nomadic, and mobile wireless intranet/Internet access. The fixed wireless specification was formalized by IEEE in 2004 [10]. WiMAX operates in the 10–66 GHz band with line of sight (LOS) communications using the single carrier (SC) air interface. The IEEE 802.16a standard outlined non line of sight (NLOS) communications in the 2 – 11 GHz band using one of three 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 [10], [11]. Channel bandwidths range between 1.25 MHz and 20 MHz 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, and DC subcarriers. Subcarriers are then modulated using conventional digital modulation schemes with various inner code rates [10]: Binary Phase Shift Keying (BPSK), Quadrature Phase Shift Keying (QPSK), Quadrature Amplitude Modulation (QAM) (16-QAM, 64-QAM, and optional 256-QAM). Consequently, WiMAX data rates between 1.5 to 75 Mbps are achievable while ADSL access rates range from 1.5 – 9 Mbps.

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. WiMAX is able to achieve Quality of Service (QoS) by using a bandwidth request and granting scheme on the subscriber stations. This prevents the WiMAX base station from over-subscribing its available resources. Therefore, given the multiple air interfaces and adaptive transmission rates, WiMAX provides a compromise between 4G mobility and Wi-Fi throughput rates [12], as shown in Figure 5.

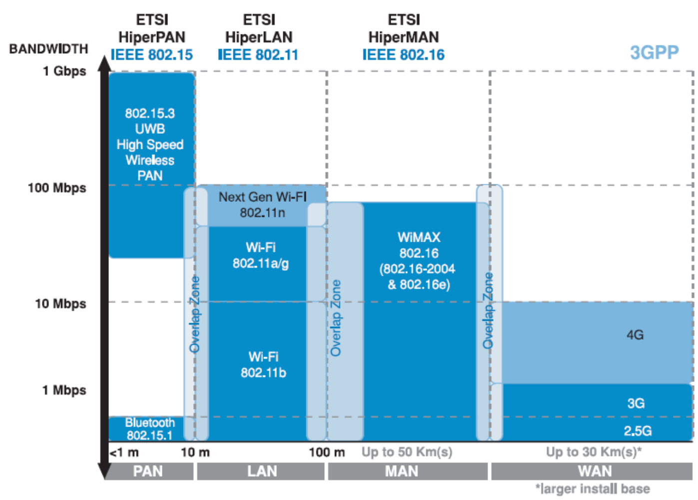


Figure 5. Variety of wireless technologies.

Cell sizes in WiMAX systems typically have radii between 7 km and 10 km. However, with favorable terrain conditions, cell radii up to 50 km are permissible [13]. Outdoor customer premise equipment (CPE) is installed at the subscriber location with an optimum orientation to the WiMAX base station in a given cell. The CPE furnishes an Ethernet connection to the subscriber home network. Figure 6 illustrates one type of subscriber connection. Alternatively, connection configurations may utilize portable WiMAX CPE where signal conditions are favorable.

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 ADSL service regions or in densely overloaded ADSL regions to attain high speed Internet access.

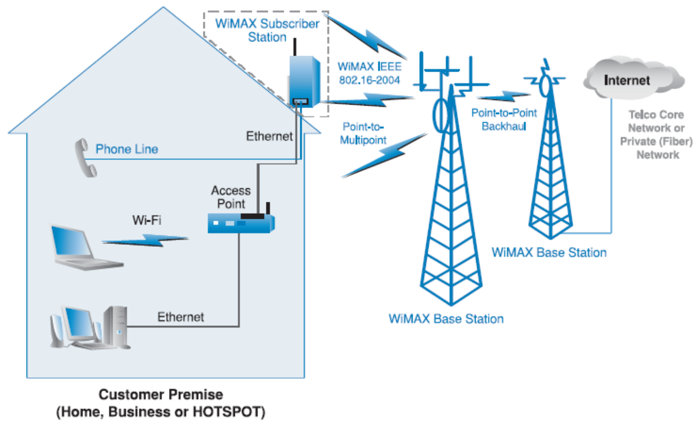


Figure 6. WiMAX client station connection.

4. An OPNET WiMAX Simulation Model

In this study, we used OPNET to develop a simulation model. OPNET Modeler simulation tool [14] 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.

A network topology shown in Figure 7, consisting of geographically separated video client and video services subnets, was employed to simulate a more realistic real world scenario. The video services subnet, shown in Figure 8, 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 100 Mbps Ethernet network behind a firewall. The firewall's outside interface connects to an access router connected to the Internet via a 45 Mbps Digital Signal 3 (DS3) Wide Area Network (WAN) link.

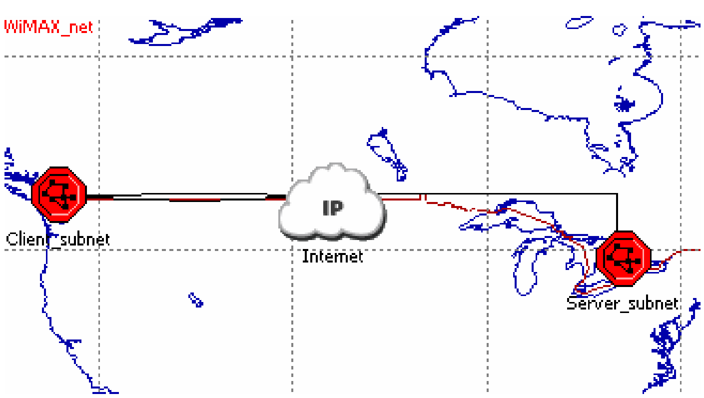


Figure 7. Topology if the simulation model network.

The video client subnet, shown in 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 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 for comparison with WiMAX stations.

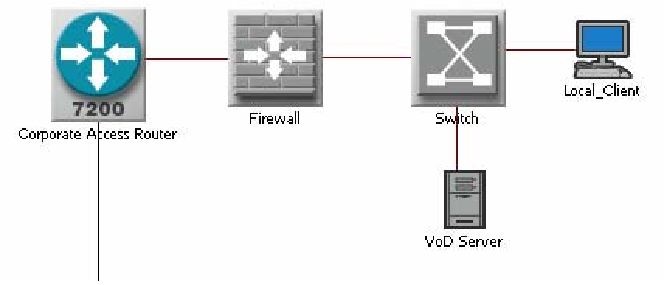


Figure 8. Video services subnet.

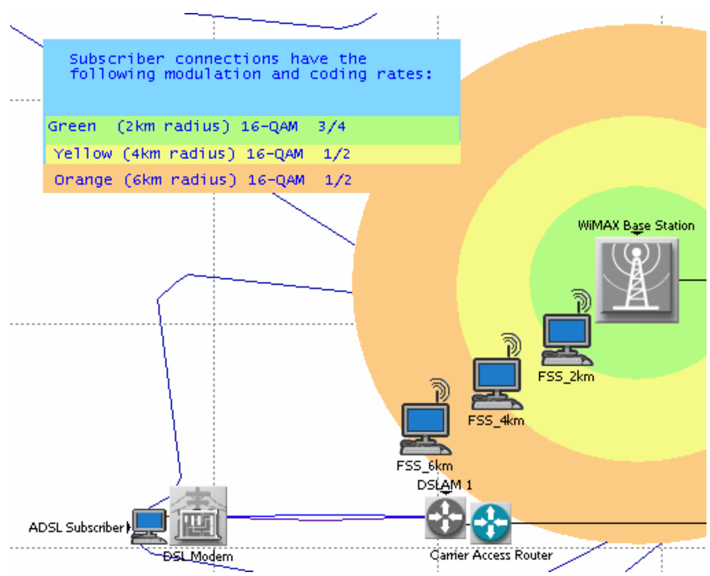


Figure 9. Simulation model of the video client subnet.

It should be noted that the Modeler provides three distinct coordinate systems to model node distances and corresponding wireline and wireless path lengths. In this model, we adopted the geocentric coordinate system using latitude and longitude. Using publicly available Global Positioning System (GPS) tools, positional information was derived based on the selected design distances for the three WiMAX stations with respect to the base station. The latitude and longitude information was then configured into each node object in the model. Both subnets are connected to the Internet via DS3 WAN circuits: the approximate distance between the two subnets is 3,342 km equivalent to approximately 13.3 ms propagation delay.

The Local Area Network (LAN) and WAN links were configured with alternating 10% and 20% utilization loads over 30 minute intervals. The Internet "cloud" was configured with a packet discard ratio of 0.001%, which results in one packet being dropped out of every 100,000 packets in the Internet. The Internet also introduces 1 ms delay in addition to the propagation delays on the WAN links. Furthermore, the scenarios also incorporate staged background traffic growth of 10% every 30-minute intervals to create intervals of increasing traffic in order to monitor video traffic performance.

The video traffic is a key aspect of the study as its inherent bandwidth intensive and delay sensitive properties will stress the access links further than most other types of application traffic. As a result, several video sources were employed in this simulation model. The first source is generated by the Modeler video conferencing application using a Constant Bit Rate (CBR) configuration, as shown in Table 1. The purpose of this traffic source, since it is not compressed, is to generate traffic with predictable characteristics that can be used to validate the model. The second traffic source is a video trace from a 10-minute MPEG-2 movie clip of Terminator 2. This traffic was obtained from Arizona State University [6], [7] and it has a high resolution format and encoding frame rate. Consequently, the mean transmission rate is 5.72 Mbps, with peak rates beyond 30 Mbps. 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 [6], [7] with a 352x288 frame resolution and an encoding rate of 25 frames per second (fps). The mean and peak rates shown in Table 1 were more realistic for modeling access network video streaming. All three video traces reflect video frames only. The corresponding audio traffic for a given video trace was insignificant compared to the video traffic [6], [7].

Parameters	Validation	T2	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 1. Characteristics of the video source.

The video traces required pre-processing before they could be imported into the OPNET Modeler. 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 shown in Figure 10. Furthermore, the incoming frame inter-arrival rate was configured to reflect the content encoding rate of 25 fps in Figure 10. The outgoing stream interarrival time remains at 0 to create a unidirectional stream.

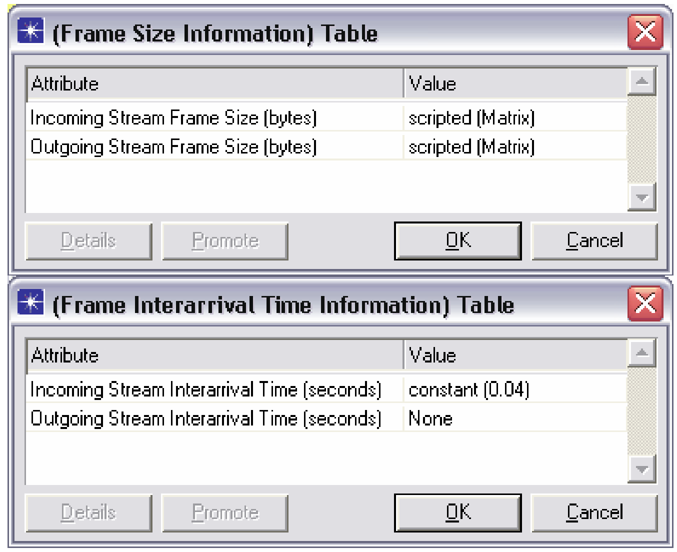


Figure 10. Frame size and interarrival time tables.

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.

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 begins and they may 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. The profile configuration for the MPEG-4 video trace is shown in Figure 11.

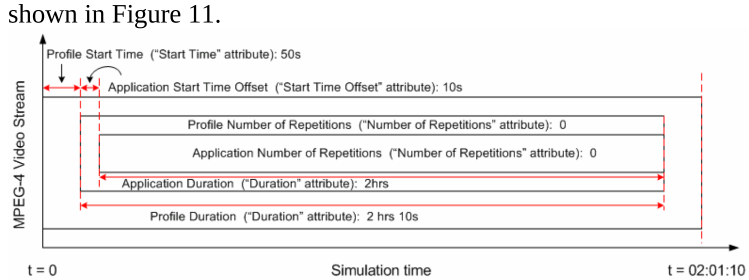


Figure 11. Profile configuration of video traffic.

5. WiMAX Configuration

WiMAX service classes capture 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 called downlink flows while service flows from the subscriber station to base station are called uplink flows. For a given service class, the key parameters are minimum sustainable data rate (minimum guaranteed over the air (OTA) rate) and the media access control (MAC) scheduler type, which enables WiMAX to provide QoS capabilities, thereby supporting delay sensitive traffic such as voice and video services. There are four scheduler types: UGS (ungranted service), rtPS (real time polling service), nrtPS (non real time polling service), and 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, we created one service class 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 as shown in Figure 12.

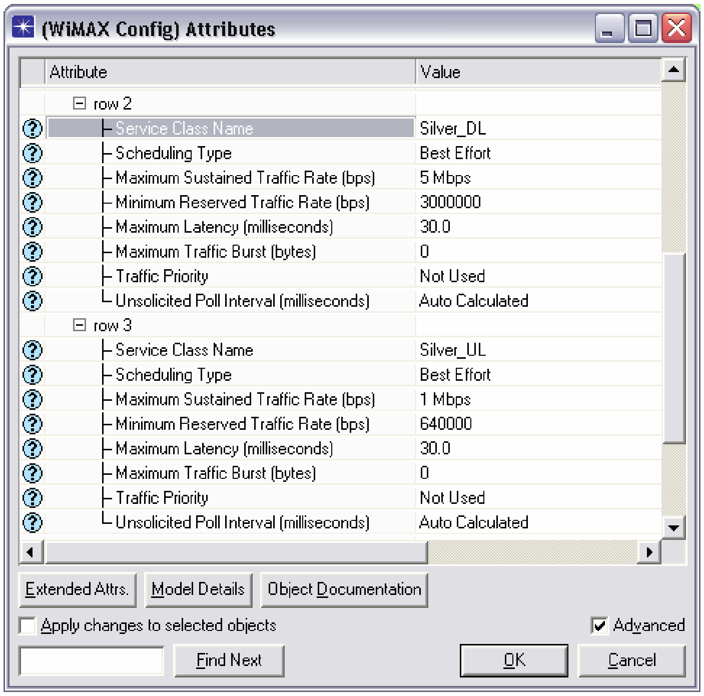


Figure 12. WiMAX service class configuration.

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 profiles. For this study, we assumed that the uplink channel has similar properties to the down channel and, hence, for a given WiMAX station, the same burst profile was used on both the uplink and downlink service flows.

The modulation and coding rate (burst profile) for each WiMAX station are shown in Figure 9. Since the OPNET Modeler did not support adaptive burst profiles [15], WiMAX client stations were manually configured with more robust modulation/coding schemes with increased distance from the base station. The available coding rates for a given modulation scheme and the minimum signal to noise ratio (SNR) [13] are listed in Table 2.

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 2. Modulation/coding rates.

Initially, 64-QAM scheme was configured for the 2 km fixed subscriber station (FSS). However, 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 2km FSS modulation and coding rates for both uplink and downlink service flows are shown in Figure 13.

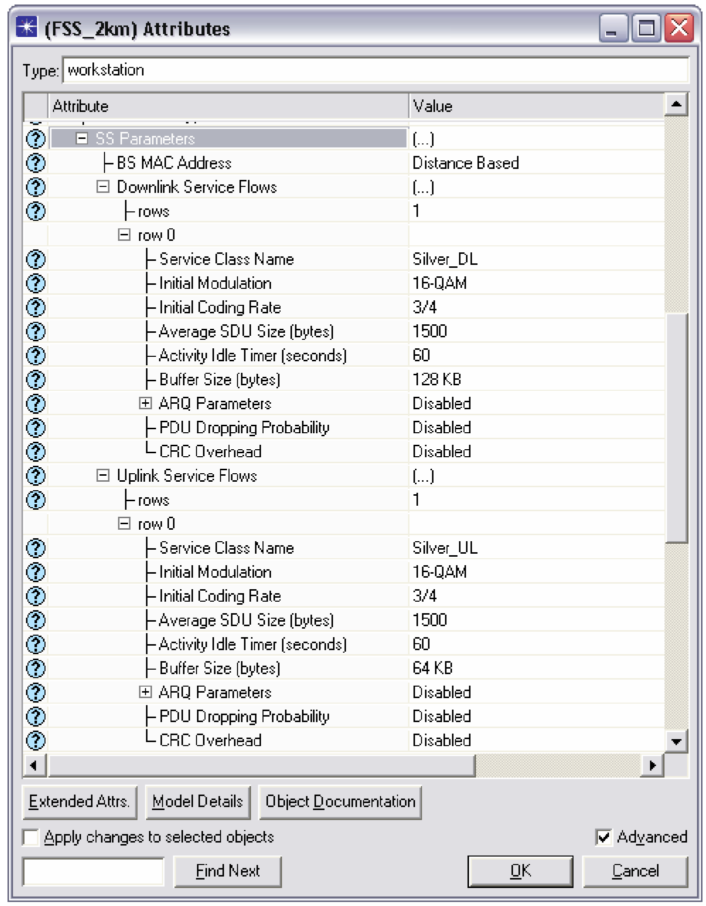


Figure 13. FSS service flow modulation and coding rates.

The air interface or physical (PHY) layer access was configured to utilize OFDM over a 2.5 GHz base frequency using a 5 MHz channel bandwidth that provisions 512 subcarriers allocated in the manner shown in Table 3. The 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. Moreover, a fixed suburban (Erceg) pathloss model was employed with a conservative terrain model that accounted for mostly flat terrain with light tree densities.

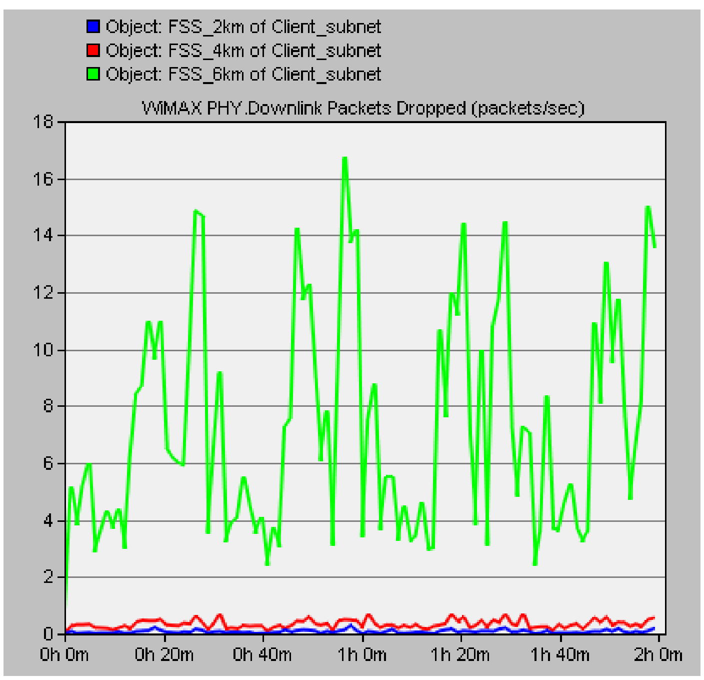
Frequency Division		
	DL Zone	UL Zone
Number of Null Subcarriers - Lower Edge	46	52
Number of Null Subcarriers - Upper Edge	45	51
Number of Data Subcarriers	360	272
Number of Subchannels	15	17

Table 3. PHY layer frame division pattern.

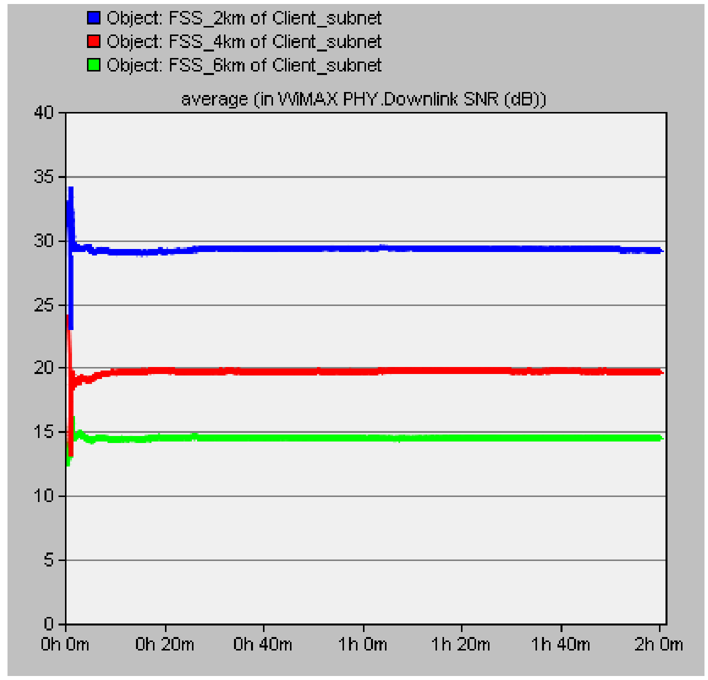
The ADSL configuration employed in this model illustrated an "enhanced" subscriber package with a 3.0 Mbps downlink channel and a 640 kbps uplink channel. The modeled distance between the subscriber and the central office was 5 km.

6. Simulation Results: packet loss, delay, and delay jitter

All simulations lasted 2 hrs. The captured PHY layer statistics provide insight into the performance of the WiMAX access network. The dropped packet rates by the PHY layer for the three WiMAX stations are shown in Figure 14(a). The 6 km WiMAX station (green curve) exhibits a much higher loss rate than the 2 km and 4 km stations over the 2-hour interval. The downlink SNR for the three WiMAX stations is shown in Figure 14(b). Note that the 6 km station exhibits a downlink SNR that is below the necessary minimum level for 16-QAM with ½ coding (shown in Table 2). This low SNR for the 6 km station is a major contributor to the high packet loss rate.



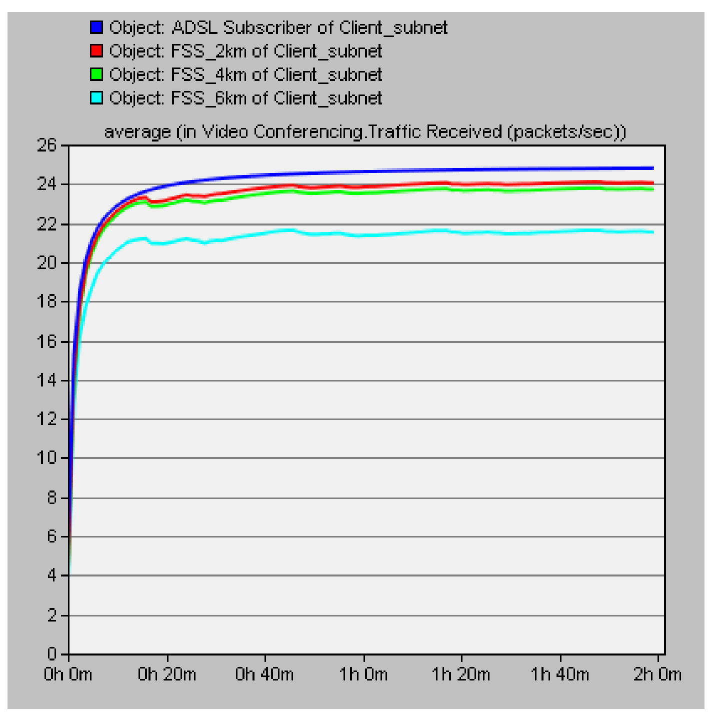
(a)



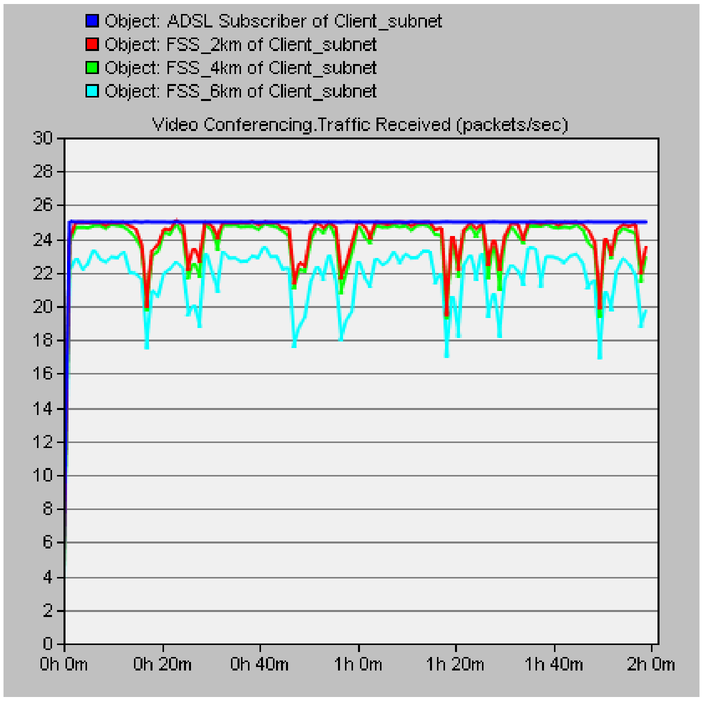
(b)

Figure 14. PHY layer: (a) lost packets and (b) SNR.

The resulting video packet loss was observed on all four video clients. The OPNET Modeler does not provide a video application layer loss statistic and, hence, the loss shown in Figure 15 is represented as the curve deviation from the 25 packets/sec position on the vertical axis. All four curves are averaged across the 2-hour movie duration. The ADSL client curve (top) 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.



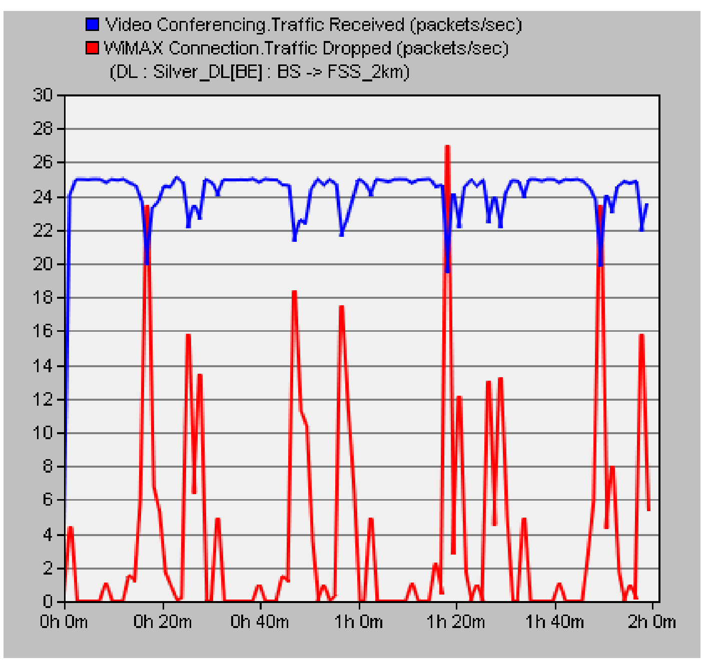
(a)



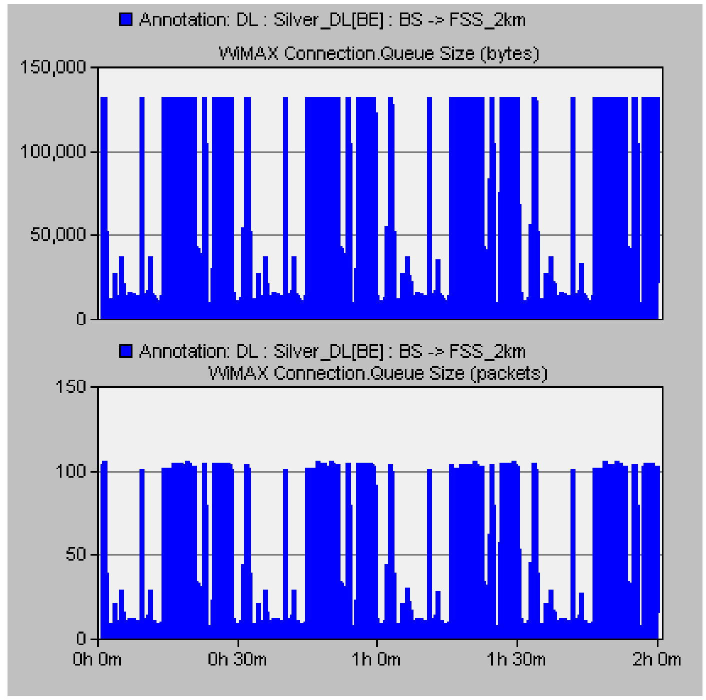
(b)

Figure 15. Received packets/sec: (a) average and (b) instantaneous values.

We further explored and characterized the packet loss in order to understand the significant video packet loss in the WiMAX stations. The 2 km WiMAX station video packet loss rate along with the MAC layer drop rate statistic from the base station is shown in Figure 16(a). The MAC layer in the base station is losing a significant number of frames because the base station buffer of 128 KB was being filled, as indicated in Figure 16(b). This behavior is in part due to the variable sized MPEG-4 video frames. Similar behavior was observed with the 4 km and 6 km WiMAX stations.



(a)



(b)

Figure 16. Downlink performance: (a) 2 km station received and lost packets/sec and (b) base station downlink queue.

The simulated end-to-end delay is shown in Figure 17. The four video client curves are averaged across the 2-hour movie. These results indicate that the ADSL client approaches the ideal delay of 10 ms. 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.

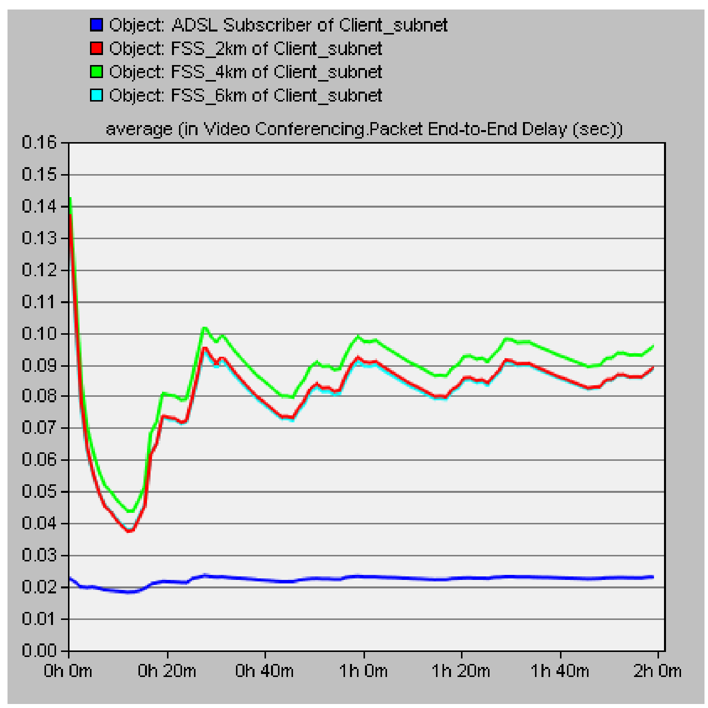
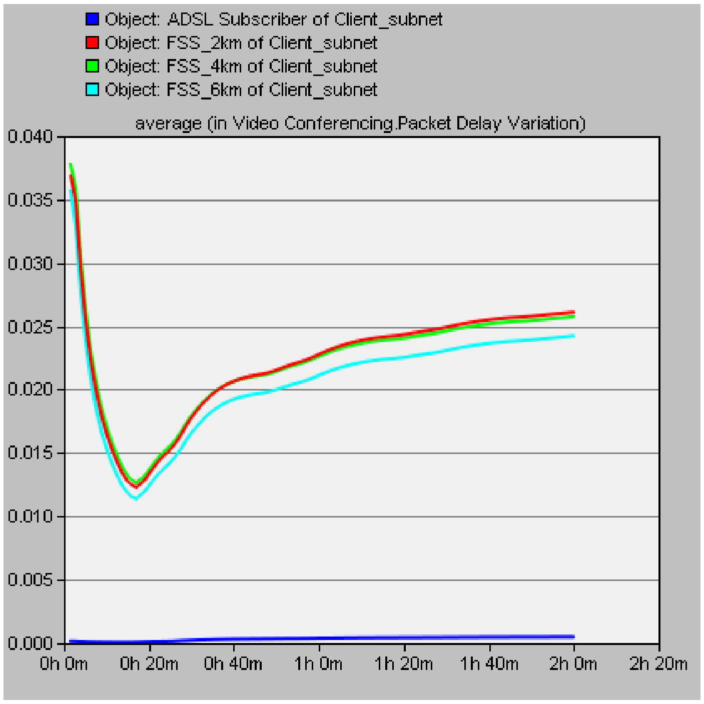
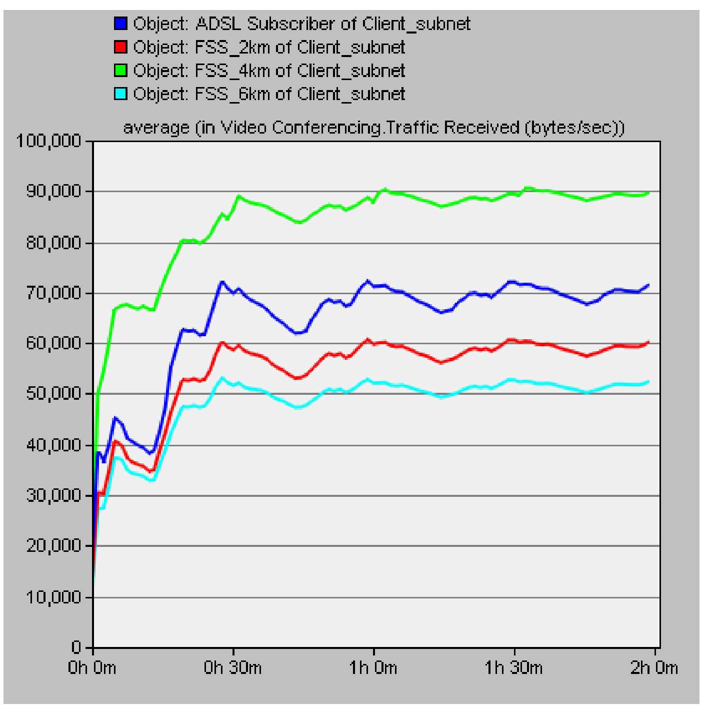


Figure 17. End-to-end packet delay: (a) average and (b) instantaneous values.

The video packet jitter and throughput measured in the simulation run are shown in Figure 18 (a) and Figure 18 (b), respectively. The four video client curves are averaged across the 2-hour movie. These results shown in Figure 18(a) indicate 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 of the order of 25 ms, which also approached the ideal value. All four client curves shown in Figure 18(b) tracked each other as expected. Note that the 4 km station surpassed the ADSL station throughput when measured in bytes/sec. The observed throughput, ranging from 0.40 Mbps to 0.72 Mbps, falls within specified metric and corresponds to the mean traffic rate for the MPEG-4 content listed in Table 1.



(a)



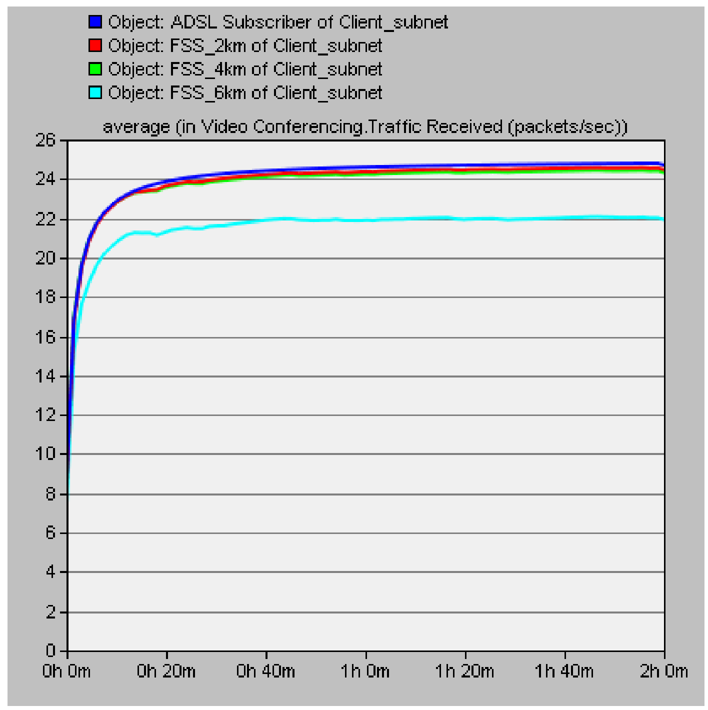
(b)

Figure 18. (a) Video packet jitter and (b) minimum throughput.

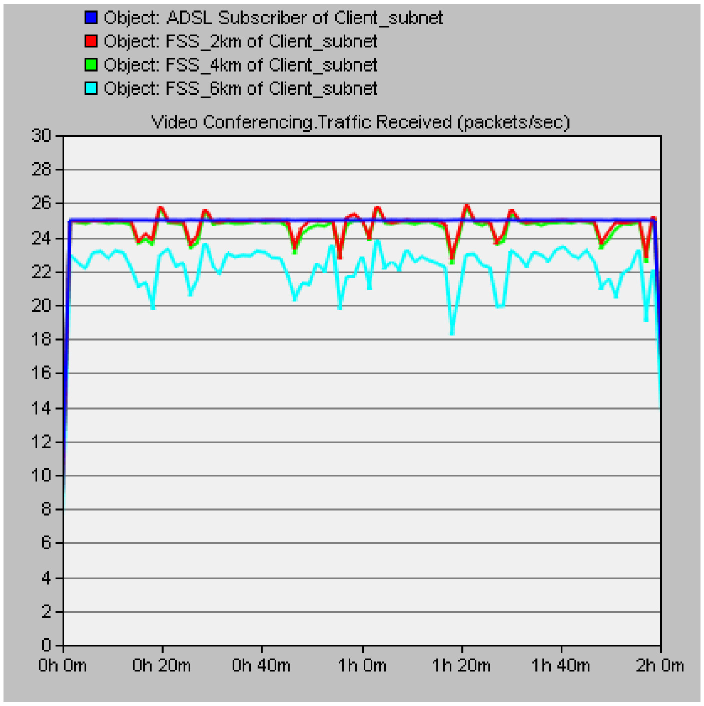
7. Performance Tuning: optimizing buffer size

After considering the performance reported in Section 6, we conducted additional tuning of the base station buffer size to explore its impact on packet loss rate statistic and, ultimately, the video packet loss statistic. Various queue sizes ranging from the default value of 64 KB to 1,024 KB were employed. It was evident that 1,024 KB buffer resolved the buffer overflow and resulted in zero MAC packet loss rate. The improved performance of the 2 km and 4 km WiMAX stations is shown in Figure 19(a). The 6 km station continued to exhibit unacceptably high packet loss rates, primarily due to the SNR that was below the minimum level required for the configured modulation / coding scheme. The same loss performance using instantaneous values is shown in Figure 19(b).

Further examination of the 2 km WiMAX station reveals that the received video packet rate closely tracks the original encoding and transmission rate, as shown in Figure 20(a). Figure 20(b) shows that the base station connection queue size never reaches the buffer capacity of 1,024 KB.

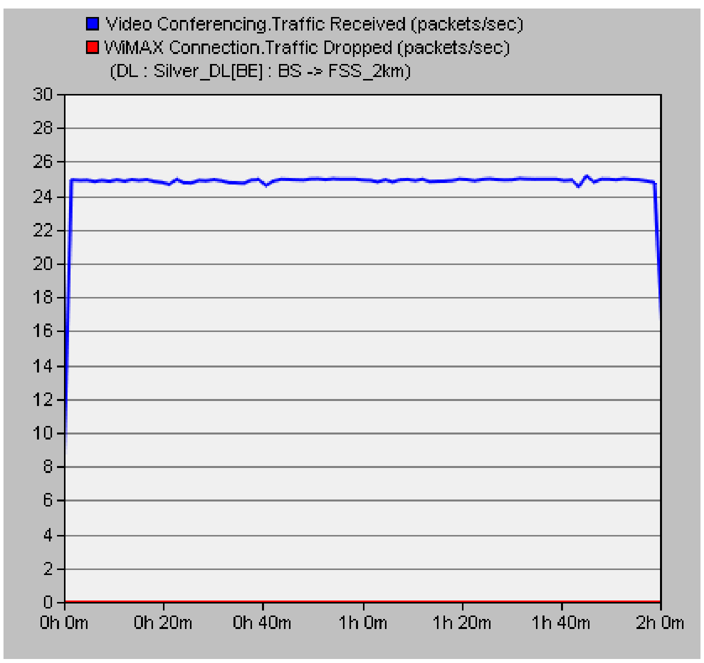


(a)

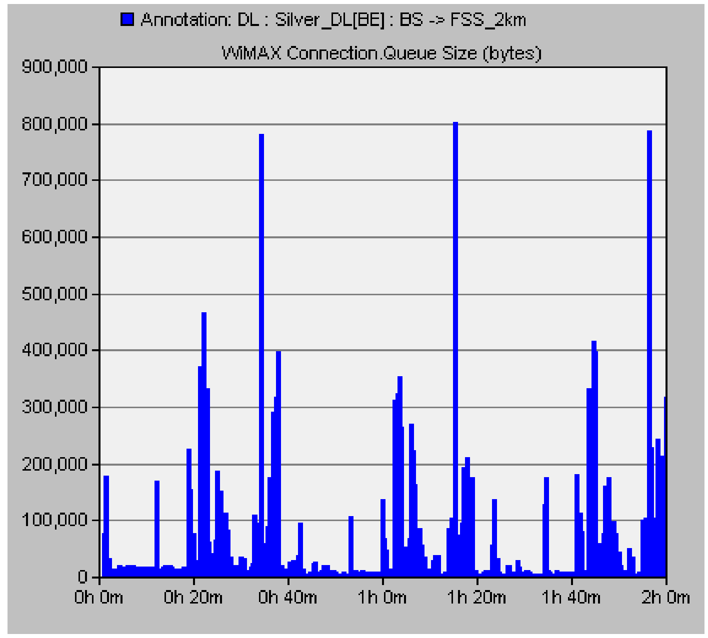


(b)

Figure 19. Received packets/sec: (a) average and (b) instantaneous values.



(a)



(b)

Figure 20.Downlink performance: (a) 2 km station received and dropped packets/sec and (b) base station downlink queue.

8. 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 [13] explored the key fundamentals of WiMAX to provide real-time imaging and audio/video information of local and remote patient data from ambulance services. Real-time video services could be used to provision crucial patient health information from hospital destined ambulances. The analysis was conducted using MATLAB. Another research effort [3] presented WiMAX fundamentals as a broadband access solution to support IPTV services framework. The authors discussed the considerations associated with delivery video services while minimizing video and audio quality degradation. Furthermore, they presented some key transceiver design considerations at the PHY layer. However, no simulations were conducted. Similarly, a framework for IPTV services over WiMAX was proposed [4] citing the associated complexities and challenges. The framework describes an IPTV services topology to distribute VoD content to WiMAX subscribers. While the authors did not present simulation results, they 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 [16]. Researchers evaluated MAC layer performance by scaling video content over multiple connections based on feedback of the available transmission bandwidth.

A distinctive research effort [17] 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 utilizing various generic TCP and UDP loads. The researchers evaluated the link performance as a function of station power and distance for eight static modulation/coding schemes.

9. Future Work

In this project, we analyzed the performance of WiMAX broadband access and compared it to existing ADSL broadband access in terms of a bandwidth intensive, delay sensitive video streaming load representative of emerging Internet video services. The project scope was limited to certain assumptions that included:

- station transmit power and station antenna gain
- pathloss model: 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

Future models could revisit these design parameters and further characterize their impact on the system performance. Furthermore, the generic OPNET video conferencing application used in this model could not be configured to utilize Real Time Protocol (RTP) encapsulation without customized code. This configuration would more accurately model the actual protocol overhead associated with video streaming services. The current video traces do not account for audio content and, hence, incorporating audio data would make the model more realistic. Lastly, refining the stated performance metric thresholds would lead to more realistic analysis.

10. Conclusion

This study explored the technical details and performance of WiMAX broadband access technology. Its aim was to address whether WiMAX access technology for streaming video applications could provide comparable network performance to ADSL. The OPNET Modeler was used to design and characterize the performance of streaming a 2-hour MPEG-4 movie to WiMAX and ADSL video subscribers using four performance metrics.

The simulation results indicated that, while ADSL exhibited behavior that approached the ideal values for the performance metrics, WiMAX demonstrated promising behavior within the bounds of the defined metrics. Initial MPEG-4 content simulation runs exhibited significant packet loss. However, with fine tuning, a configuration was designed that demonstrated packet loss that was more comparable to the ADSL video client station. Various factors possibly understated the performance of the WiMAX access link, including the adoption of the least-QoS aware base station scheduler and various WiMAX PHY parameters that were assigned conservative values given the lack of available deployment data from carriers. Furthermore, the streaming video content was modeled as unicast traffic while multicast video traffic may have yielded better performance.

References

[1] M. LaBrecque, WiMAX introduction [Online]. Available: http://www.wimaxforum.org/technology/downloads (Feb. 2008).

[2] WiMAX forum [Online]. Available: http://www.wimaxforum.org/news/pr/ (Apr. 2008).

[3] F. Retnasothie, M. Ozdemir, T. Yucek, H. Celebi, J. Zhang, and R. Muththaiah, “Wireless IPTV over WiMAX: challenges and applications,” *Proc. IEEE WAMICON 2006*, Clearwater, FL, Dec. 2006, pp. 1–5.

[4] I. Uilecan, C. Zhou, and G. Atkin, “Framework for delivering IPTV services over WiMAX wireless networks,” *Proc. IEEE EIT 2007*, Chicago, IL, May 2007, pp. 470–475.

[5] J. She, F. Hou, P. Ho, and L. Xie, “IPTV over WiMAX key success factors, challenges, and solutions,” *IEEE Communications Magazine*, vol. 45, no. 8, pp. 87–93, Aug. 2007.

[6] G. Auwera, P. David, and M. Reisslein. Traffic characteristics of H.264/AVC variable bit rate video. [Online]. Available: http://trace.eas.asu.edu/h264/index.html (Mar. 2008).

[7] G. Auwera, P. David, and M. Reisslein, Traffic and quality characterization of single-layer video streams encoded with the H.264/MPEG-4 advanced video coding standard and scalable video coding extension [Online]. Available: http://trace.eas.asu.edu/h264/index.html (Mar. 2008).

[8] J. Kurose and K. Ross, *Computer Networking: A Top-Down Approach*, 4/e. Boston, MA: Pearson/Addison-Wesley, 2008, p. 590, p. 612, and p. 624.

[9] V. Markovski, F. Xue, and Lj. Trajkovic, “Simulation and analysis of packet loss in video transfers using User Datagram Protocol,” *The Journal of Supercomputing*, vol. 20, no. 2, pp. 175–196, Sept. 2001.

[10] IEEE Std. 802.16-2004: Part 16: Air interface for fixed broadband wireless access systems [Online]. Available: http://standards.ieee.org/getieee802/802.16.html (Feb. 2008).

[11] M. Chatterjee, S. Sengupta, and S. Ganguly, “Feedback-Based real-time streaming over WiMax,” *IEEE Wireless Communications Magazine*, vol. 14, no. 1, pp. 64–71, Feb. 2007.

[12] Intel, Understanding Wi-Fi and WiMAX as metro-access solutions [Online]. Available: http://www.rclient.com/PDFs/IntelPaper.pdf (Feb. 2008).

[13] D. Niyato, E. Hossain, and J. Diamond, “IEEE802.16/WiMAX-Based broadband wireless access and its application for telemedicine / e-health services,” *IEEE Wireless Communications Magazine*, vol. 14, no.1, pp. 72–83, Feb. 2007.

[14] OPNET Modeler software [Online]. Available: http://www.opnet.com/products/modeler/home.html (June 2008).

[15] OPNET WiMAX (802.16e) model user guide [Online]. Available http://www.opnet.com/WiMAX_Academic (March 2008).

[16] H. Juan, H. Huang, C. Huang, and T. Chiang, “Scalable video streaming over mobile WiMAX,” *Proc. ISCAS 2007*, New Orleans, Louisiana, May 2007, pp. 3463–3466.

[17] F. Yousaf, K. Daniel, and C. Wietfeld, “Performance evaluation of IEEE 802.16 WiMAX link with respect to higher layer protocols,” *Proc. IEEE ISWCS 2007*, Trondheim, Norway, Oct. 2007, pp. 180–184.