Streaming Video And Audio Content Over Mobile WiMAX Networks

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Roadmap

- Introduction
- Technological overview (video content, RTP, WiMAX)
- Design and implementation
- Validation
- Simulation results
- Project challenges
- Closing comments
- References

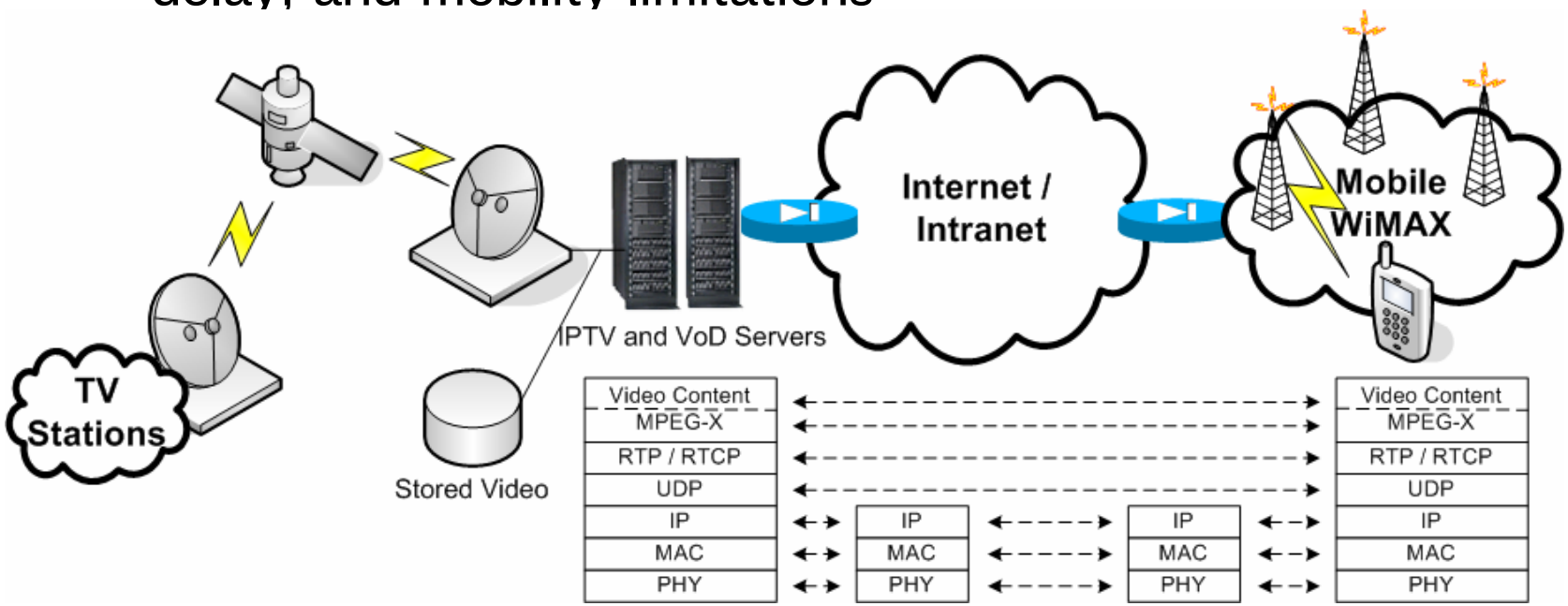
Motivation – WiMAX growth trends

- In 2007: 100+ carrier trials were planned worldwide *
- In 2008: 133M WiMAX users by 2012 **
  198% compound annual growth rate to 2012 ***
- In 2009: 460 fixed & mobile WiMAX deployments **
  800M users by 2010 *
  1.3B users to have WiMAX access by 2012 ****

* OPNETWORK 2007. www.opnet.com/opnetwork2007.
** WiMAX forum. www.wimaxforum.org/news/pressreleases.
*** Telecom Application Report 2008. www.researchandmarkets.com.
**** Intel - WiMAX Subscriber Growth. www.wimaxday.net.

Project objective

- To stream bandwidth intensive, delay sensitive, video content representative of Video on Demand services over Mobile WiMAX to exploit potential throughput, delay, and mobility limitations



Project scope

- Enhance an existing OPNET model from previous work *
  - Upgrade model from OPNET 12.0.A to 14.5.A
  - Generate and integrate audio component
  - Refine performance metrics
  - Enhance protocol stack - Real Time Protocol (RTP)
  - Design, integrate, and optimize WiMAX mobility
  - Design and characterize WiMAX MAC and PHY

  Due to stability issues after the upgrade process, an entirely new OPNET model was created for this project

RTP Real Time Protocol MAC Media Access Control PHY Physical

* W. Hrudey and Lj. Trajkovic, “Streaming Video Content Over IEEE 802.16 / WiMAX Broadband Access,'' *OPNETWORK 2008*, Washington, DC, Aug. 2008.

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Video content is ...

- digital audio and visual information from sitcoms, newscasts, sporting events, movies, etc.
- streamed from Internet Protocol TV (IPTV) and Video on Demand (VoD) services hosted in an Internet / Intranet Data Center (IDC)
- delivered to video subscribers over an IP network
- organized as frames which are then compressed and encapsulated by lower layer protocols
- characterized by video resolution, color depth, compression scheme, number of audio channels, frame rate and frame size
  - video coding schemes exploit temporal and spatial characteristics
  - various standards and codecs - ITU H.26x and ISO MPEG-x

IPTV	Internet Protocol TV	VoD	Video On Demand
IDC	Intranet Data Center	ITU	International Telecommunications Union
MPEG	Motion Pictures Experts Group		

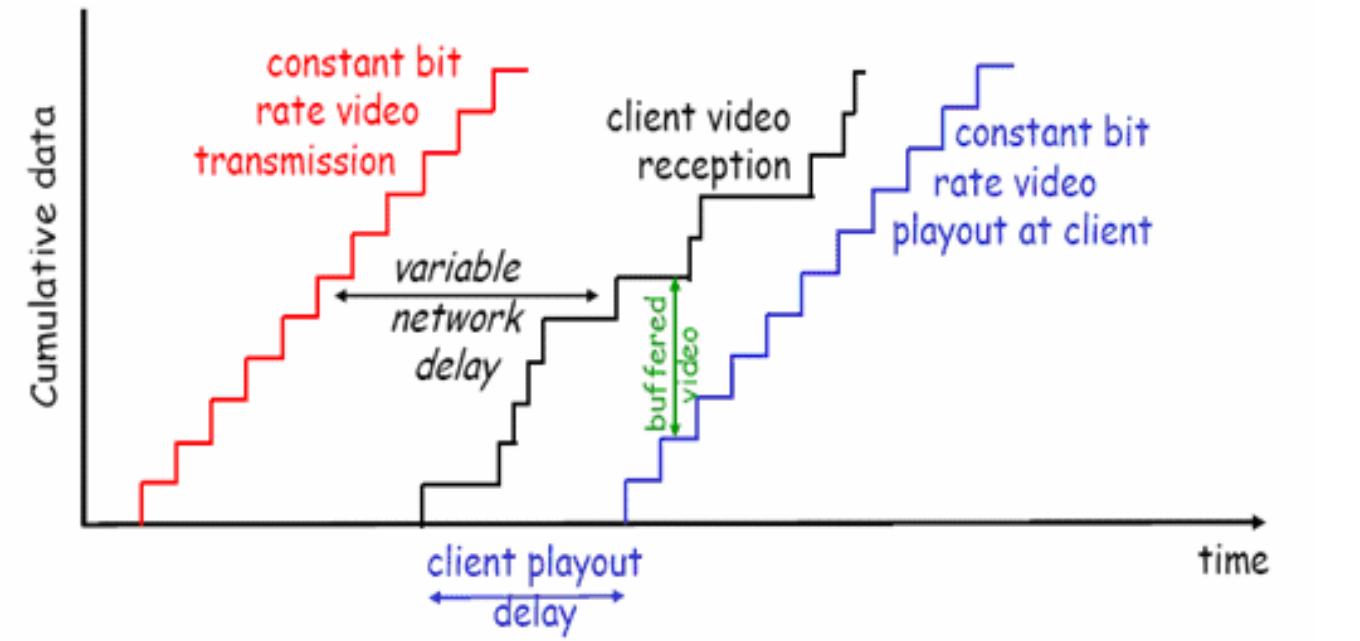
Video format examples

Format	VCD	SVCD	DVD	HDTV	DivX	RM	MOV
Resolution	352x240 352x288	480x480 480x576	720x480 720x576	1920x1080 1920x720	640x480	320x240	640x480
Video codec	MPEG-1	MPEG-2	MPEG-1 MPEG-2	MPEG-2	MPEG-4	RM	MPEG-4
Video bitrate	1.15Mbps	2Mbps	5Mbps	20Mbps	1Mbps	0.35Mbps	1Mbps
Audio codec	MP1	MP1	MP1, MP2, AC3, DTS, PCM	MP1, MP2, AC3, DTS, PCM	MP3, WMA, AAC, AC3	RM	MP3
Audio bitrate	224kbps	224kbps	448kbps	448kbps	128kbps	64kbps	128kbps

VideoHelp Forum [Online]. Available: http://www.videohelp.com/oldguides/comparison.

Video streaming characteristics

- Video content is marginally loss tolerant yet delay sensitive



J. Kurose and K. Ross, *Computer Networking: A Top-Down Approach*, 4/e. Boston, MA: Pearson/Addison-Wesley, 2008.

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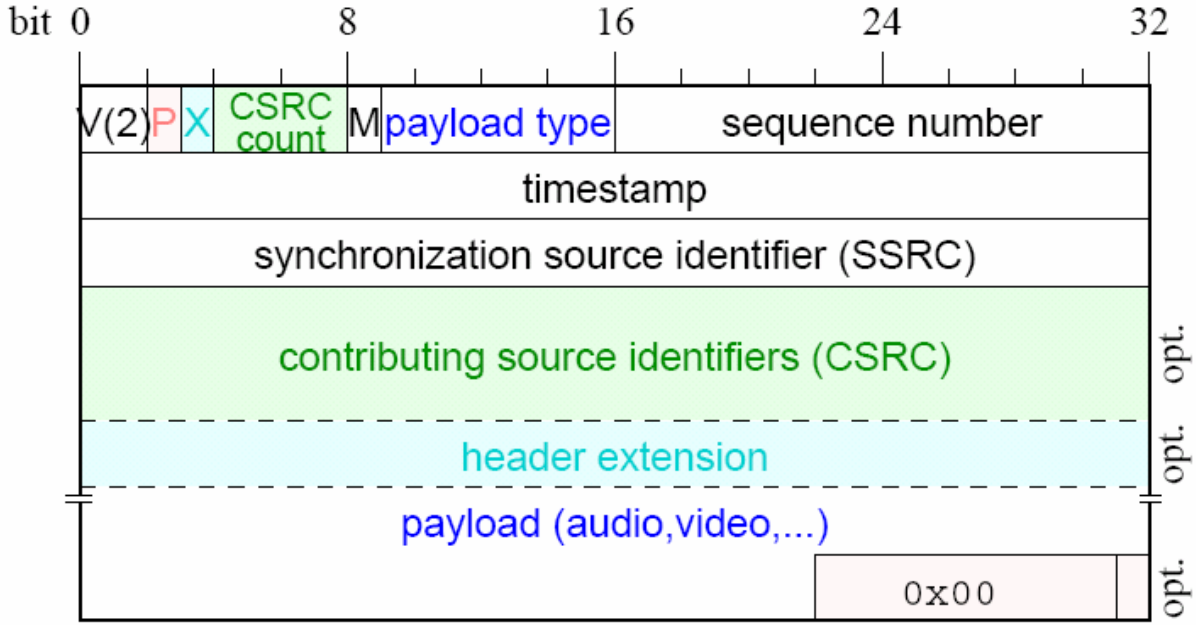
Real Time Protocol overview

RTP Real Time Protocol IP Internet Protocol

- RTP is widely used in IP video transmission systems * **



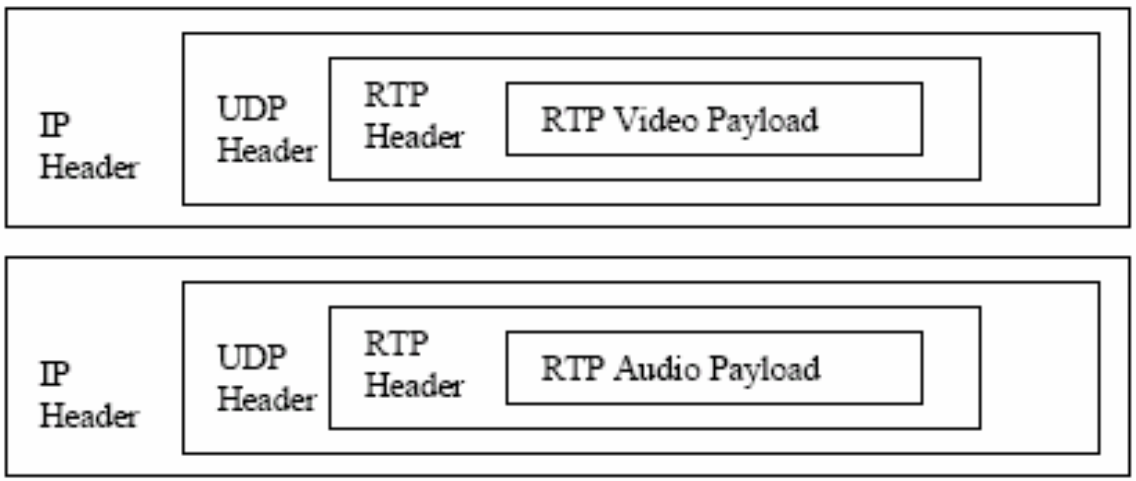
* H. Nyberg, C. Johansson, B. Olin, "A Streaming Video Traffic Model for the Mobile Access Network," IEEE VTC 2001, Sep. 2001, pp. 423 – 427.

** T. Ahmed, G. Buridant, A. Mehaoua, "Encapsulation and Marking of MPEG-4 Video Over IP Differentiated Services", Proc IEEE ISCC 2001, Sep. 2001, pp. 346 – 352.

Real Time Protocol ...

RTP Real Time Protocol UDP User Datagram Protocol IP Internet Protocol

- does not reserve bandwidth, guarantee delivery or end to end delays
- provides timestamps for jitter calculations and sequencing for packet loss and out-of-order detection
- encapsulation is only seen at the end systems



audio and video are encoded separately *

* Real time protocol RFC 3550 [Online]. Available: http://tools.ietf.org/html/rfc355

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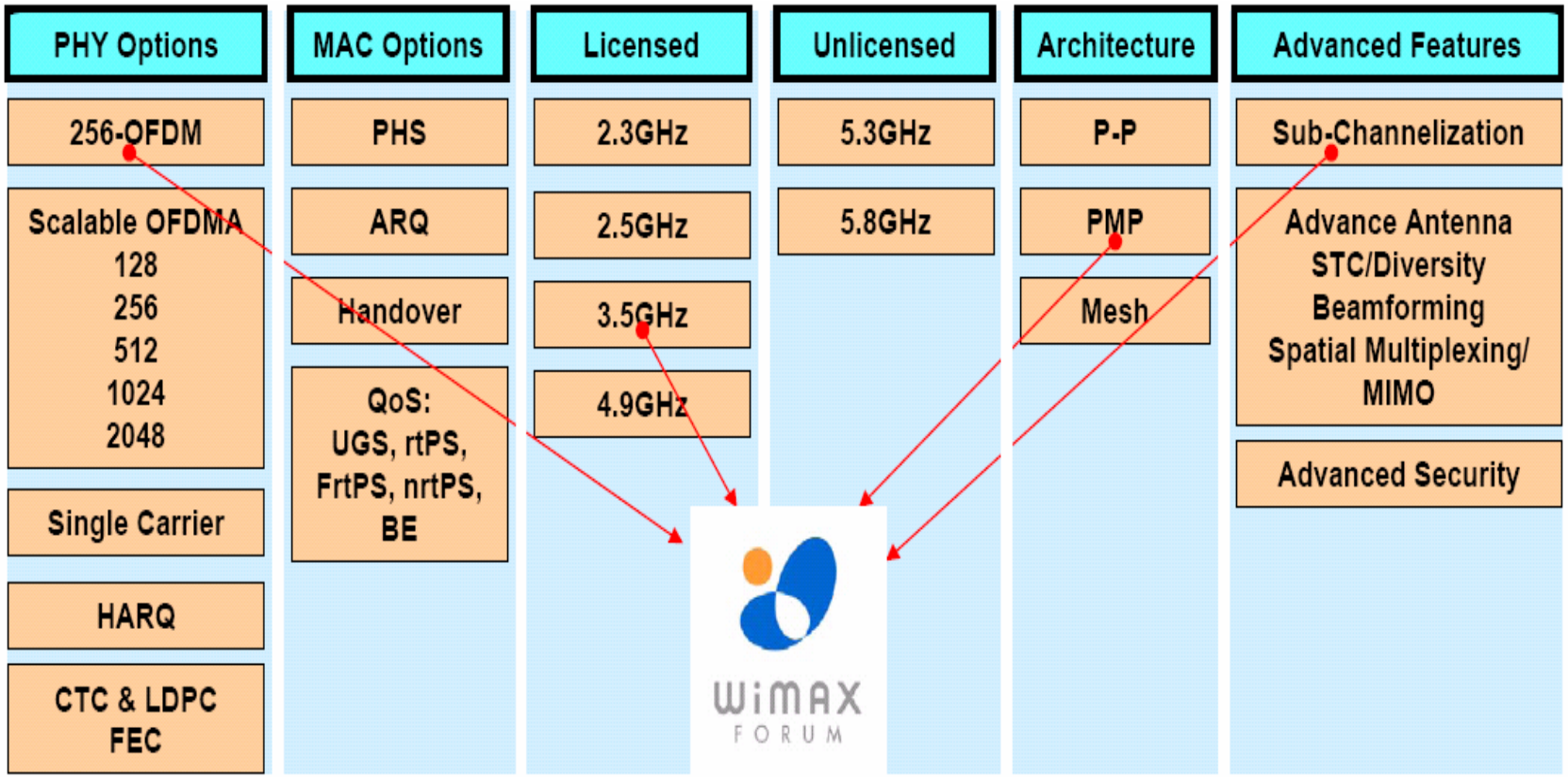
WiMAX overview

- Worldwide interoperability for microwave access
- Line of sight (LOS) and non-LOS communications
- All IP network architecture
- Point to point, point to multipoint (PMP), and mesh modes
- Connection oriented MAC layer – support for real time services
- High throughput rates
- 1.25 – 20 MHz channel bandwidths
- Mobility – with vehicular speeds up to 120 kph
- Multiple PHY access schemes: SC, OFDM, and SOFDMA
- Multiple duplexing schemes: TDD and FDD
- Advanced antenna systems (AAS): beam forming, STC, and SM

LOS	Line of Sight	NLOS	Non Line of Sight	AAS	Advanced Antenna Systems	PHY	Physical
PMP	Point to Multipoint	SC	Single Carrier	OFDM	Orthogonal Frequency Division Multiplex		
SOFDM	Scalable OFDM	TDD	Time Division Duplex	FDD	Frequency Division Duplex		

WiMAX system options



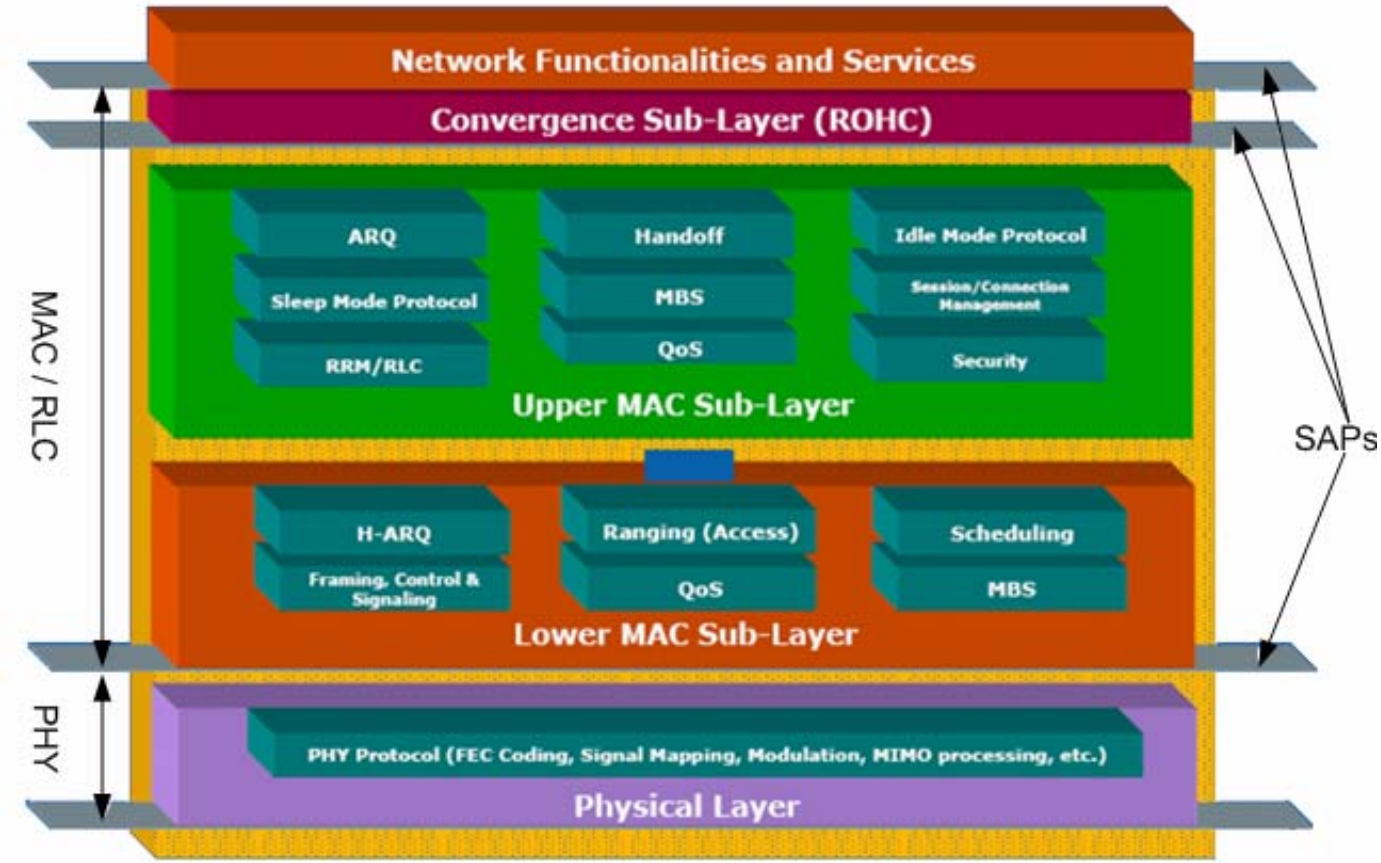
R. Golshan, Fixed and Mobile WiMAX Overview [Online]. Available: www.fujitsu.com/downloads/MICRO/fma/pdf/esc_wimax06.pdf

WiMAX standards

- IEEE 802.16 (2001)
  - 10 – 66 GHz line of sight (LOS) operations
- IEEE 802.16c (2002)
  - amended system profiles
- IEEE 802.16a (2003)
  - 2 – 11 GHz non LOS (NLOS) operations
- IEEE 802.16d-2004 (informally known as Fixed WiMAX)
  - replaced all previous releases
- IEEE 802.16e-2005 (informally known as Mobile WiMAX)
  - mobility amendment

LOS Line of Sight NLOS Non Line of Sight

WiMAX reference model



Intel – S. Ahmadi, Introduction to mobile WiMAX Radio Access Technology - PHY and MAC [Online]. Available: http://www.mat.ucsb.edu/~ggroup/ahmadiUCSB_slides_Dec7.pdf

WiMAX MAC QoS

- Service classes characterized by QoS parameters
  - UGS, rtPS, ertPS, nrtPS, and BE schedulers
  - min reserved and max sustainable data rates
  - max latency and jitter tolerance
  - traffic priorities
- Service flows (SF) are an instance of service class
  - carry unidirectional traffic
  - mobiles can have multiple service flows
  - can have unique MCS, MTU, retransmission scheme

UGS	Unsolicited Grant Service	rtPS	real-time Polling Service	ertPS	enhanced rtPS	BE	Best Effort
SF	Service Flow	MCS	Modulation and Coding Scheme	MTU	Max Transfer Unit		

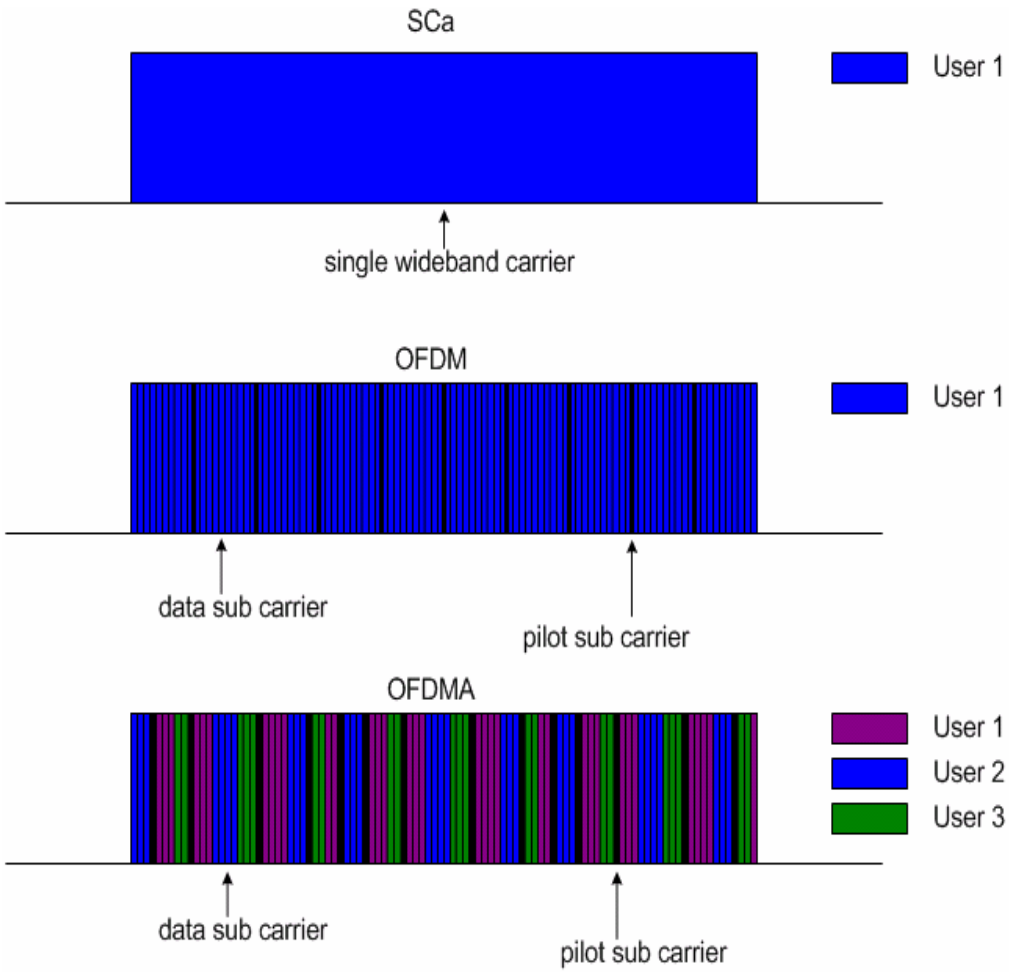
WiMAX MAC AMC

- Adaptive Modulation and Coding (AMC)
  - as channel conditions degrade, adaptively downgrade modulation to a lower order, more robust scheme

Modulation	Bits per Baud	FEC Rate	Spectral Efficiency (bps/Hz)	Receiver SNR (dB)
QPSK	2	½	1	5
		¾	1.5	8
16-QAM	4	½	2	10.5
		¾	3	14
64-QAM	6	½	3	16
		2/3	4	18
		¾	4.5	20
		5/6	5	22

* IEEE Std. 802.16e-2005: Part 16: Air interface for fixed and mobile broadband wireless access systems

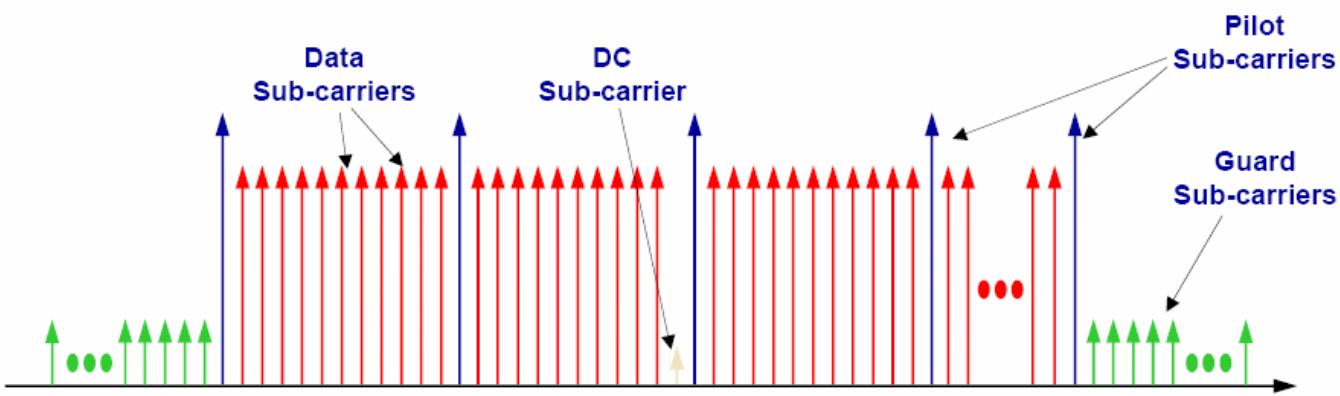
PHYsical access schemes



SC Single Carrier OFDM Orthogonal Frequency Division Multiplex SOFDM Scalable OFDM

Orthogonal Frequency Division Multiplex

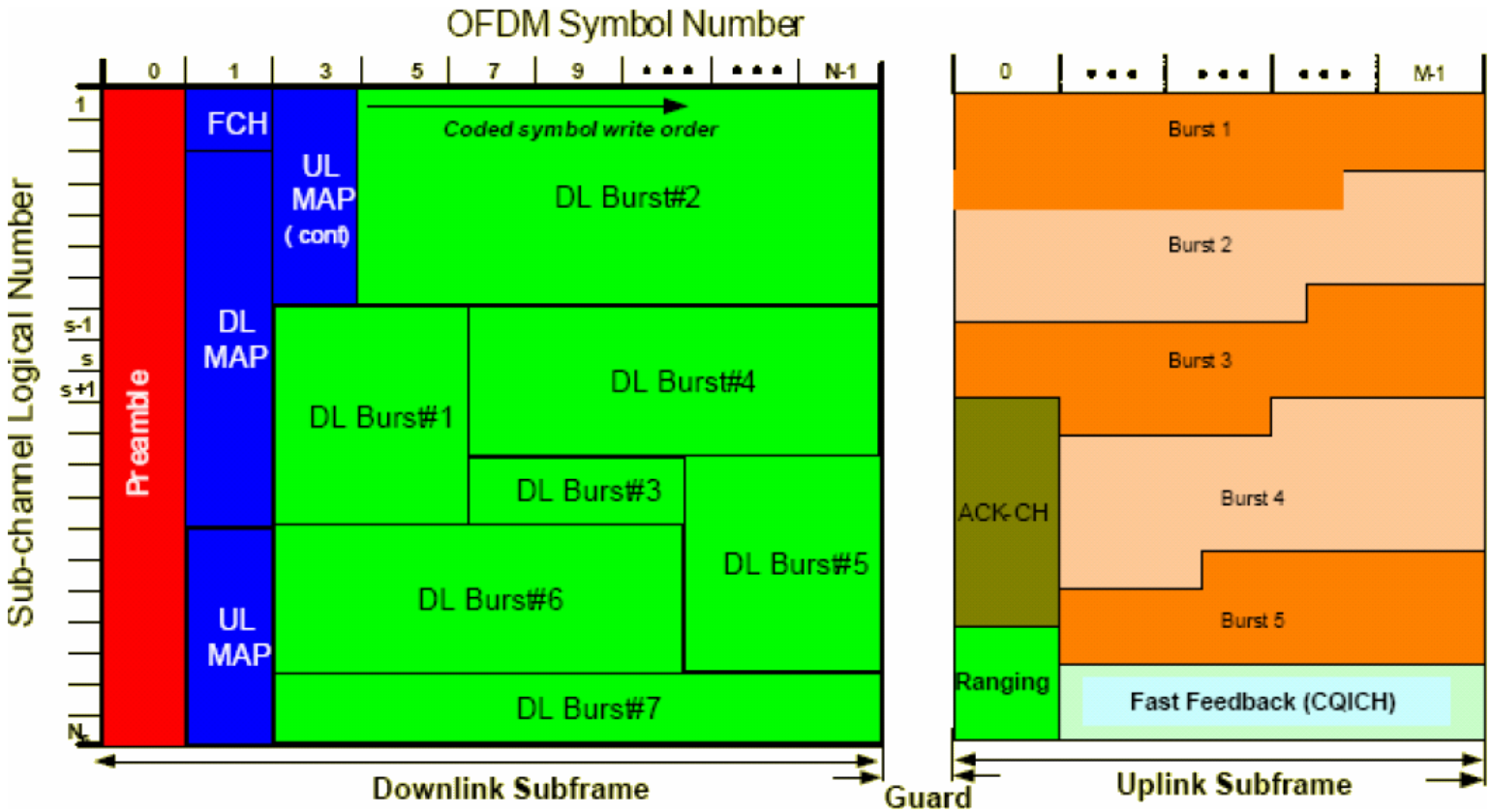
- OFDM is a multicarrier modulation scheme
  - transmits data over multiple tightly spaced orthogonal subcarriers
- Subcarrier organization
  - data subcarriers – transport of data symbols
  - pilot subcarriers – channel estimation
  - guard (null) subcarriers – spectrum shaping



R. Golshan, Fixed and Mobile WiMAX Overview [Online]. Available: www.fujitsu.com/downloads/MICRO/fma/pdf/esc_wimax06.pdf

Time division duplex (TDD) frame

OFDM Orthogonal Frequency Division Multiplex



R. Golshan, Fixed and Mobile WiMAX Overview [Online]. Available: www.fujitsu.com/downloads/MICRO/fma/pdf/esc_wimax06.pdf

Effective PHY throughput rates

Mod.	Code Rate	5 MHz Channel		10 MHz Channel	
		Downlink Rate, Mbps	Uplink Rate, Mbps	Downlink Rate, Mbps	Uplink Rate, Mbps
QPSK	1/2 CTC, 6x	0.53	0.38	1.06	0.78
	1/2 CTC, 4x	0.79	0.57	1.58	1.18
	1/2 CTC, 2x	1.58	1.14	3.17	2.35
	1/2 CTC, 1x	3.17	2.28	6.34	4.70
	3/4 CTC	4.75	3.43	9.50	7.06
16QAM	1/2 CTC	6.34	4.57	12.67	9.41
	3/4 CTC	9.50	6.85	19.01	14.11
64QAM	1/2 CTC	9.50	*6.85*	19.01	*14.11*
	2/3 CTC	12.67	*9.14*	25.34	*18.82*
	3/4 CTC	14.26	*10.28*	28.51	*21.17*
	5/6 CTC	15.84	*11.42*	31.68	*23.52*

QPSK Quadrature Phase Shift Keying QAM Quadrature Amplitude Modulation CTC Convolutional Turbo Code PHY Physical

WiMAX forum – Mobile WiMAX – Part I: A Technical Overview and Performance Evaluation

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RTP analysis

- Analyzed OPNET voice application and its interface to lower layers
  - comprised of two process models (client-client architecture)
  - uses RTP
  - uses H.323 out-of-band signaling
- Analyzed OPNET video conferencing application
  - comprised of two process models (client-client architecture)
    - video calling process model (~ 1900 lines of code)
    - video called process model (~ 1700 lines of code)
  - uses TPAL (transport adaptation layer) instead of RTP
  - uses in-band application layer handshaking instead of H.323
- Analyzed OPNET RTP module – API and process models

RTP Real Time Protocol TPAL Transport Adaptation Layer API Application Programming Interface

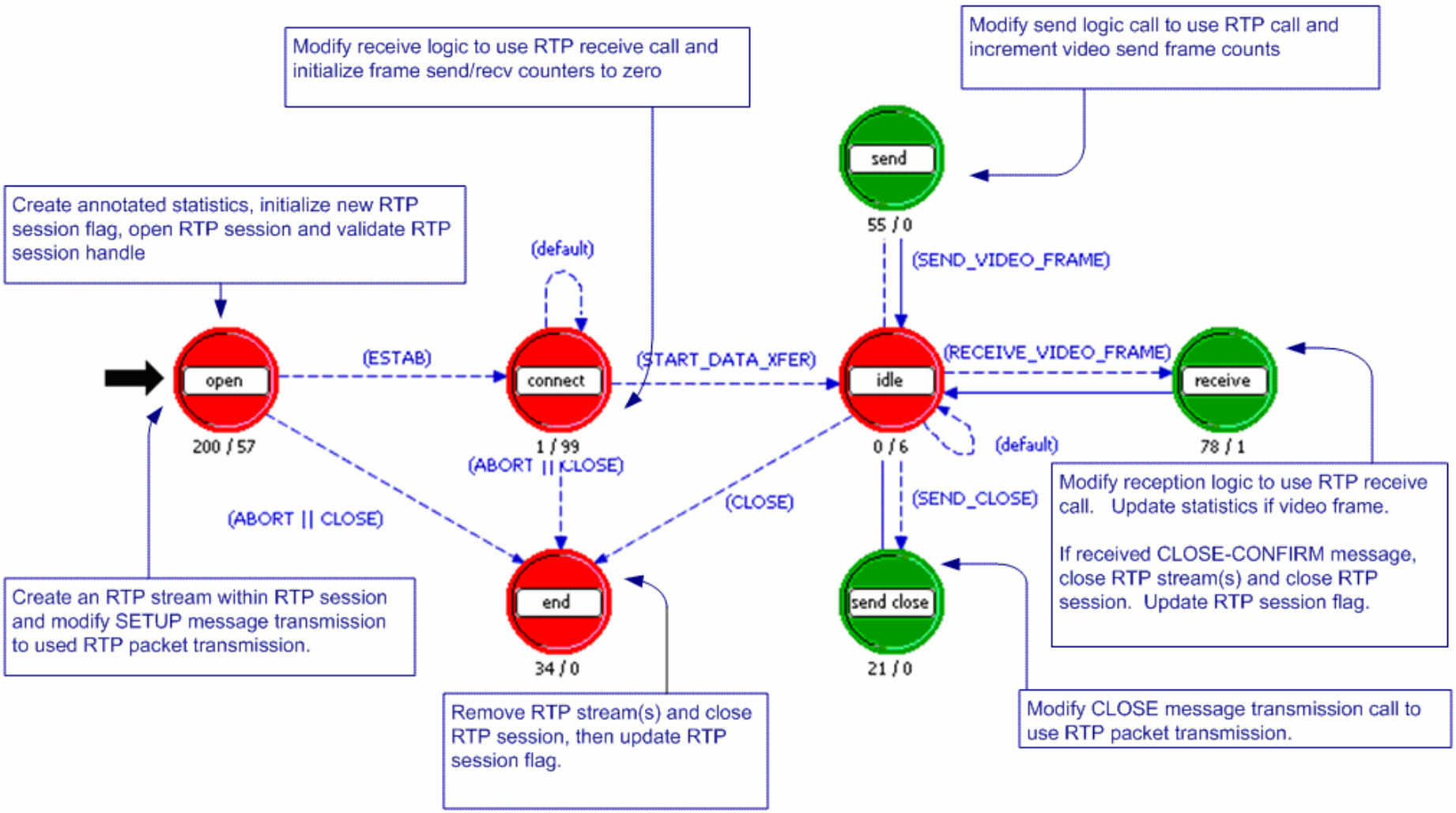
RTP design approach

- Localize changes to the OPNET video conferencing process models
- Process models define the behavior of a module by using finite state machines (FSM)
  - FSM uses states and transitions to determine appropriate action in response to a given event
  - process models comprised of ProtoC code blocks
    - state enter and exit executives
    - header, function, diagnostic, and termination blocks
- Replace existing TPAL interface with RTP

FSM Finite State Machine TPAL Transport Adaptation Layer RTP Real Time Protocol

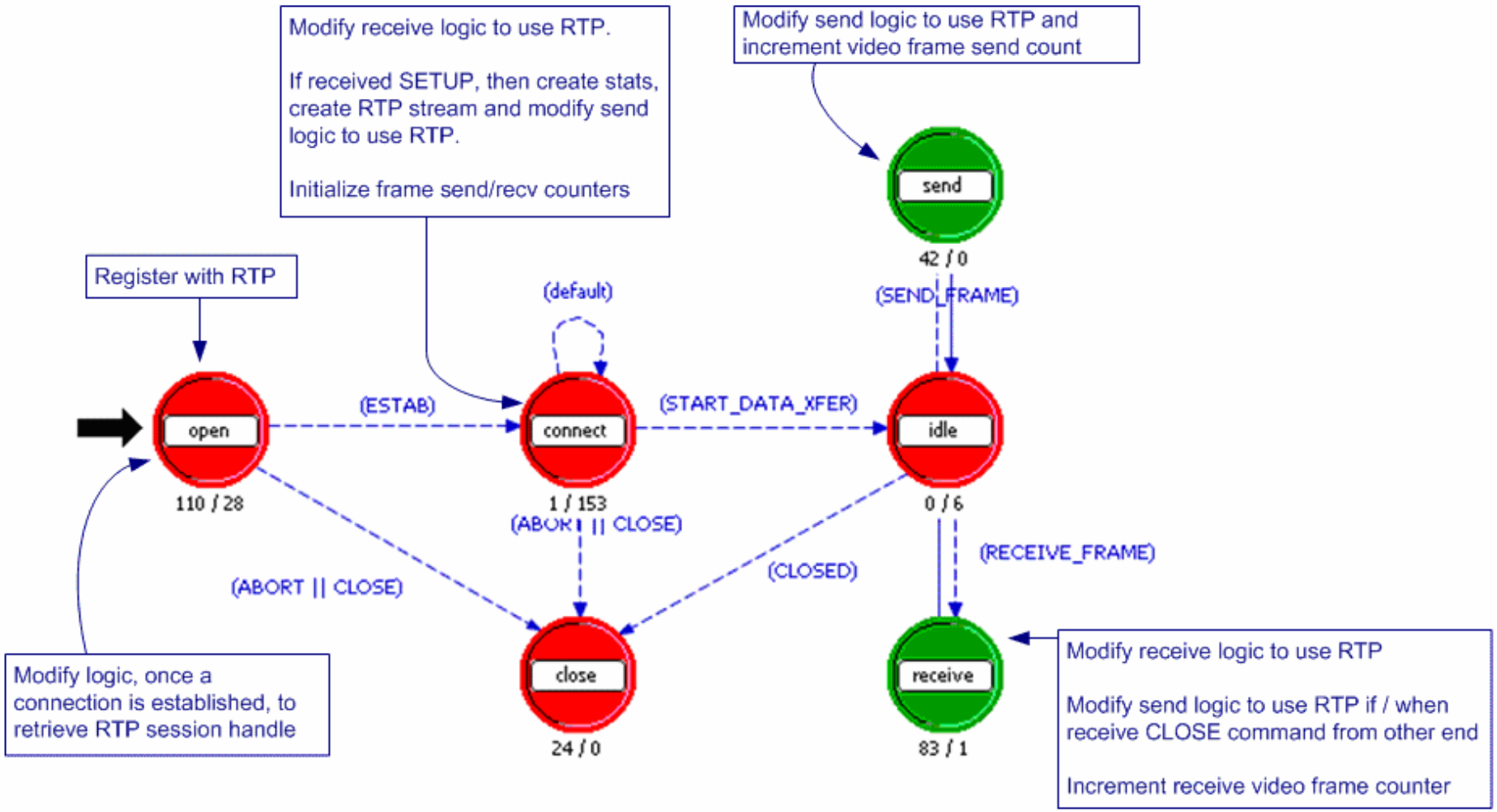
Video calling process model

RTP Real Time Protocol



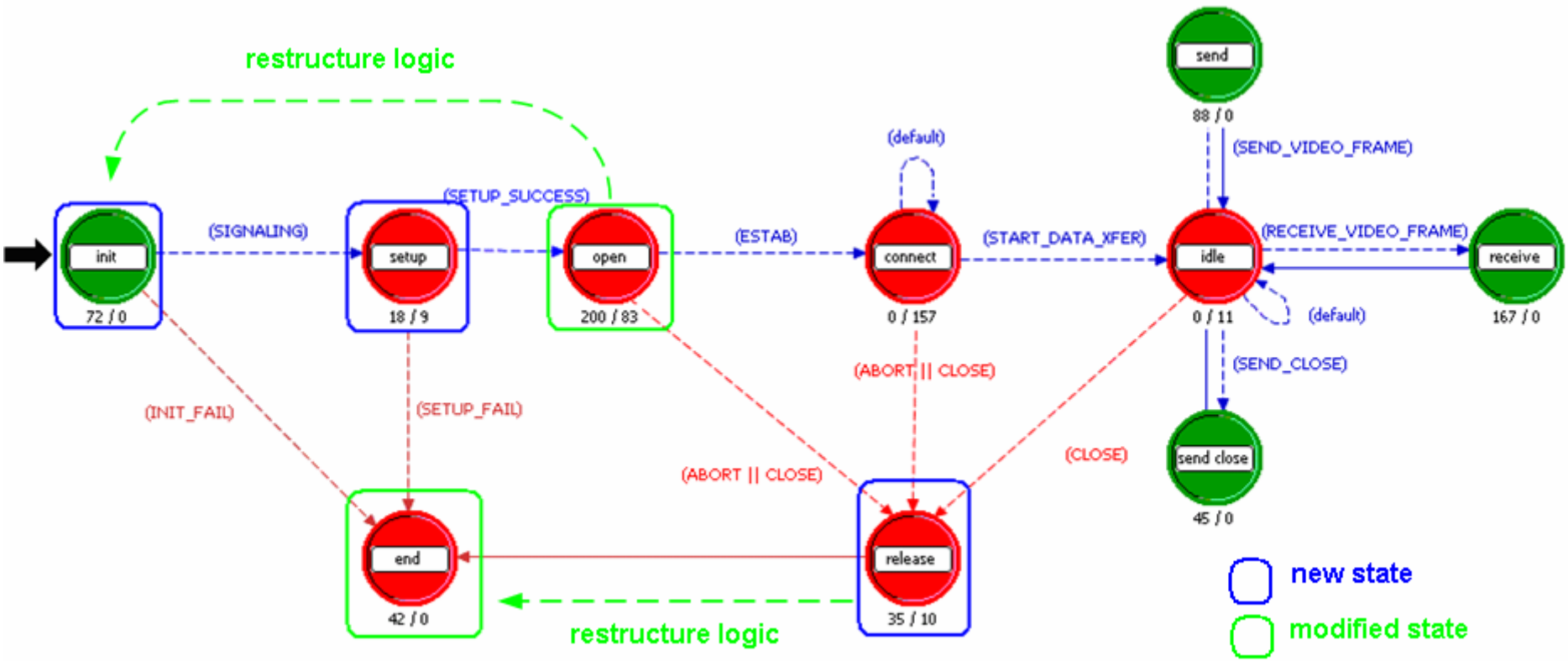
Video called process model

RTP Real Time Protocol



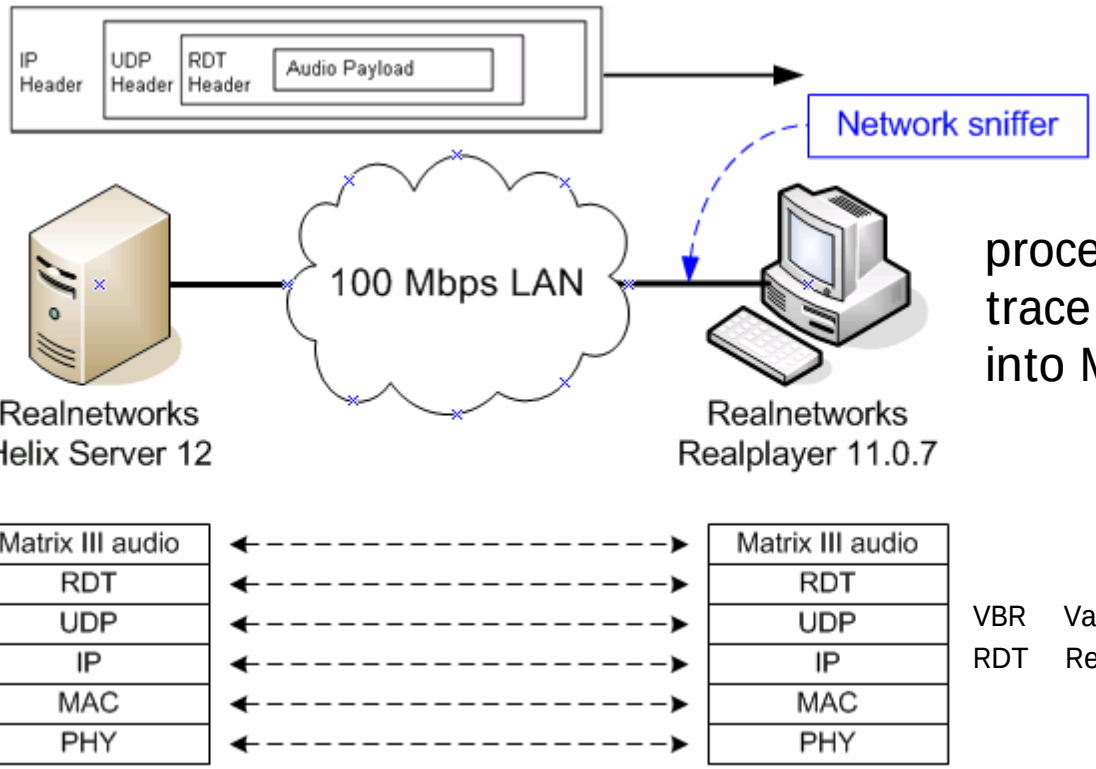
RTP calling model design revisited

RTP Real Time Protocol



Audio streaming component

- Extract soundtrack from Matrix III into VBR format
- Stream audio to client while capturing network trace

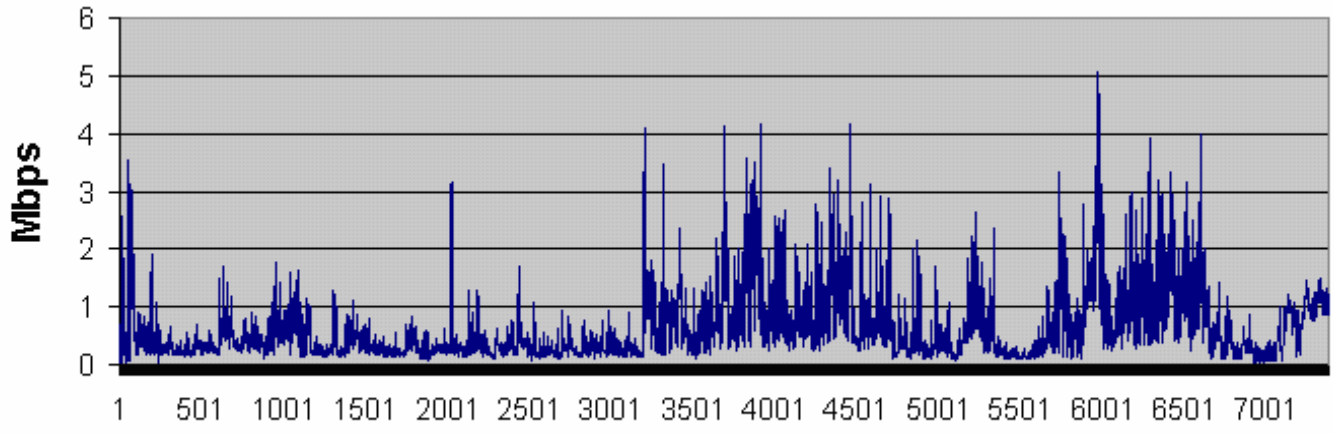


testbed

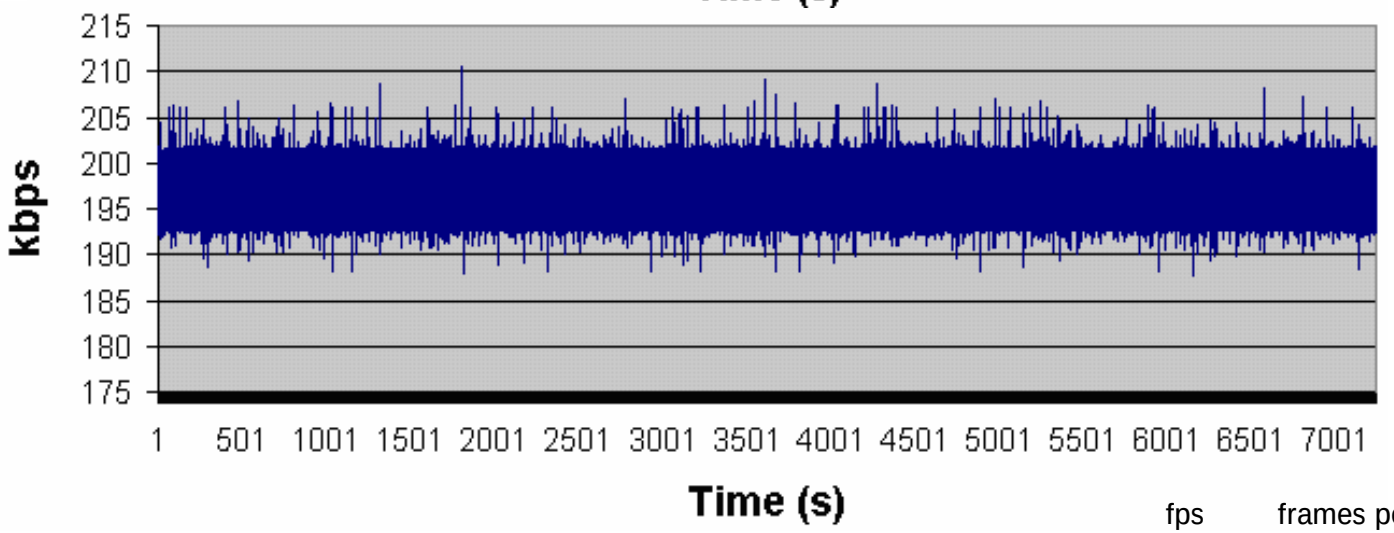
process network trace and import into Modeler

VBR Variable Bit Rate
RDT RealNetworks Data Transport

Matrix III video content traffic load



Video
25 fps



Audio
21.6 fps

fps frames per second

Performance metrics

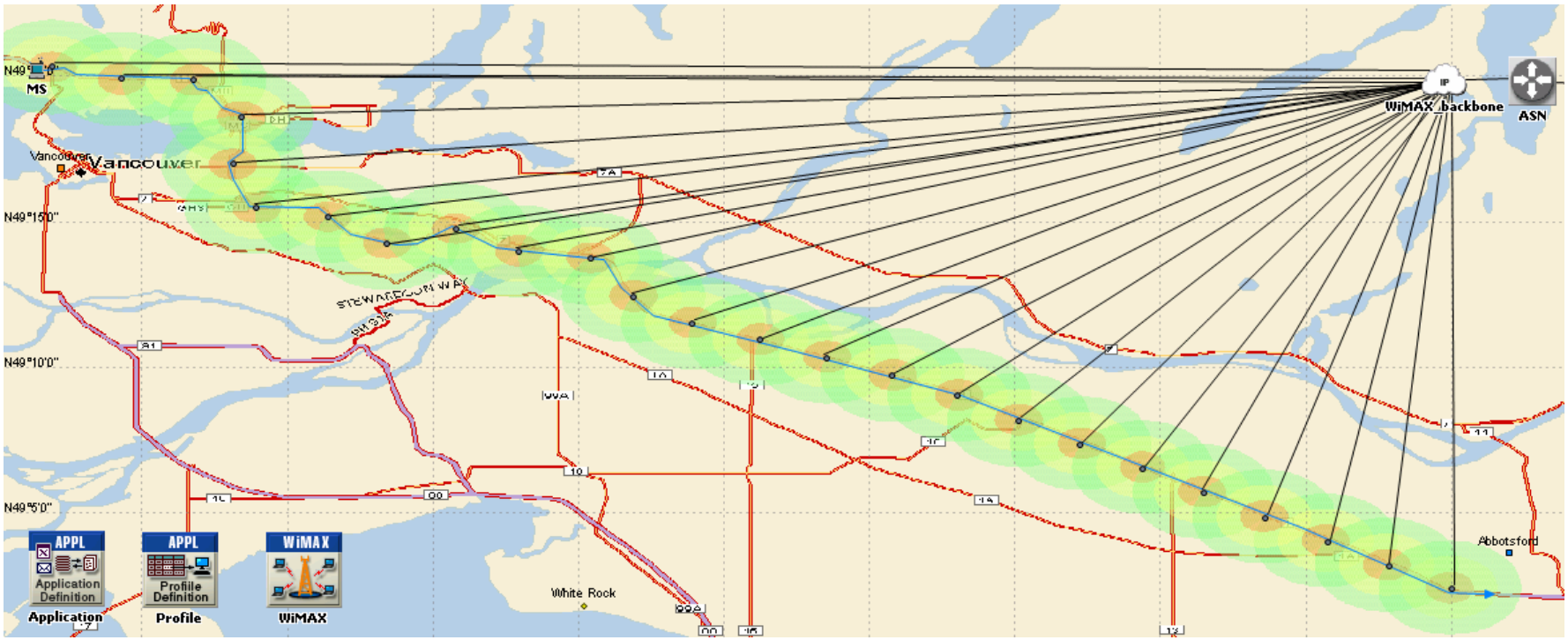
- Packet loss ratio: # of lost packets to total packets
  - target: < 10^{-3}
- Delay: average time of transit
  - processing + propagation + queuing delays
  - target: < 400 ms
- Jitter: variation in packet arrival time
  - actual reception time – expected reception time
  - target: < 50 ms
- Throughput: minimum end-to-end peak transmission rate
  - video stream: 5.1 Mbps
  - audio stream: 0.211 Mbps

WiMAX mobility

- Mobile station (MS) travels 50 km/h for 74 km trip

Delorme StreetAtlas 2007

WiMAX network topology design



Mobility design details

- Twenty five base sites (BS) located across 75 km
  - BS-BS spacing of 3.0 km
- Vehicular pathloss + multipath channel fading model
- Multiple cascading scanning interval definitions
  - scanning thresholds: 5 dB, 2 dB, 0 dB
  - as SNR degrades, scanning interval increases
- ASN architecture for L2 / L3 handover
- Frequency reuse scheme of one
  - each BS uses different subchannel to subcarrier mapping to minimize co-channel interface (CCI)

CCI Co-Channel Interference BS Base Site SNR Signal to Noise Ratio ASN Access Service Network

MAC design parameters

- Two service classes: Silver_DL / Silver_UL
  - rtPS scheduler
  - min reserved data rate: 1.0 / 0.384 Mbps
  - max sustained data rate: 6.0 / 1.5 Mbps
- Streaming video traffic mapped to ToS code
- Service flows (SF) configured in each direction
  - each SF is mapped to the same ToS code
- Base station SF buffer set to 256 KB

MAC Media Access Control rtPS real-time Polling System ToS Type of Service SF Service Flow

PHY design parameters

PHY	Physical	SOFDMA	Scalable Orthogonal Frequency Division Multiplex			TDD	Time Division Duplex		
DL	Downlink	UL	Uplink	PUSC	Partially Used Sub Carriers	MS	Mobile Station	BS	Base Station

- Operating frequency: 3.5 GHz
- SOFDMA access scheme
- Time division duplex (TDD)
  - DL/UL ratio 3:1
- Distributed PUSC subchannelization scheme
- MS transmit power / antenna gain: 27 dBm / 5 dBi *
- MS antenna height: 1.5 m
- BS transmit power: 43 dBm ** / 15 dBi
- BS antenna height: 32 m

* RedMAX 4C RPM [Online]. Available: www.redlinecommunications.com.

** RedMAX 4C SC-1000 Mobile WiMAX Base Station [Online]. Available: www.redlinecommunications.com.

PHY design characterization matrix

PHY Physical STC Space Time Coding MIMO Multiple Input Multiple Output SISO Single Input Single Output
ARQ Automatic Repeat Request HARQ Hybrid ARQ

Channel Bandwidth (MHz)	Frame Duration (ms)	Advanced Antenna Systems	ARQ scheme
5	2	none (SISO)	none
			ARQ / HARQ
		STC 2x1 MIMO	none
			ARQ / HARQ
	20	none (SISO)	none
			ARQ / HARQ
		STC 2x1 MIMO	none
			ARQ / HARQ
7	2	none (SISO)	none
			ARQ / HARQ
		STC 2x1 MIMO	none
			ARQ / HARQ
	20	none (SISO)	none
			ARQ / HARQ
		STC 2x1 MIMO	none
			ARQ / HARQ
10	2	none (SISO)	none
			ARQ / HARQ
		STC 2x1 MIMO	none
			ARQ / HARQ
	20	none (SISO)	none
			ARQ / HARQ
		STC 2x1 MIMO	none
			ARQ / HARQ

Channel bandwidth OFDM design

OFDM Orthogonal Frequency Division Multiplex OFDMA Orthogonal Frequency Division Multiple Access
DL Downlink UL Uplink

System Parameters		Values		
System channel bandwidth in MHz		5	7	10
Sampling factor [n]		1.12	1.14	1.12
Sampling frequency in MHz [Fs]		5.60	8.00	11.20
Sample time (ns) [1 / F_s]		178.6	125.0	89.3
FFT Size (N_{FFT})		512	1024	1024
Sub carrier frequency spacing (kHz)		10.94	7.81	10.94
Useful symbol time (µs) [T_b]		91.4	128.0	91.4
Guard time (µs) [T_g]		11.4	16.0	11.4
OFDMA symbol duration (µs) [T_s]		102.9	144.0	102.9
Frame duration (ms)		5	5	5
Number of OFDMA symbols		48	34	48
DL	Null subcarriers left	46	92	92
	Null subcarriers right	46	92	92
	Data subcarriers	360	720	720
	Pilot subcarriers	60	120	120
	Subchannels	15	30	30
	Data subcarriers / subchannel	24	24	24
UL	Null subcarriers left	52	92	92
	Null subcarriers right	52	92	92
	Data subcarriers	272	560	560
	Pilot subcarriers	136	280	280
	Subchannels	17	35	35
	Data subcarriers / subchannel	16	16	16

Adaptive Modulation and Coding

DL Downlink UL Uplink BER Bit Error Ratio SNR Signal to Noise Ratio

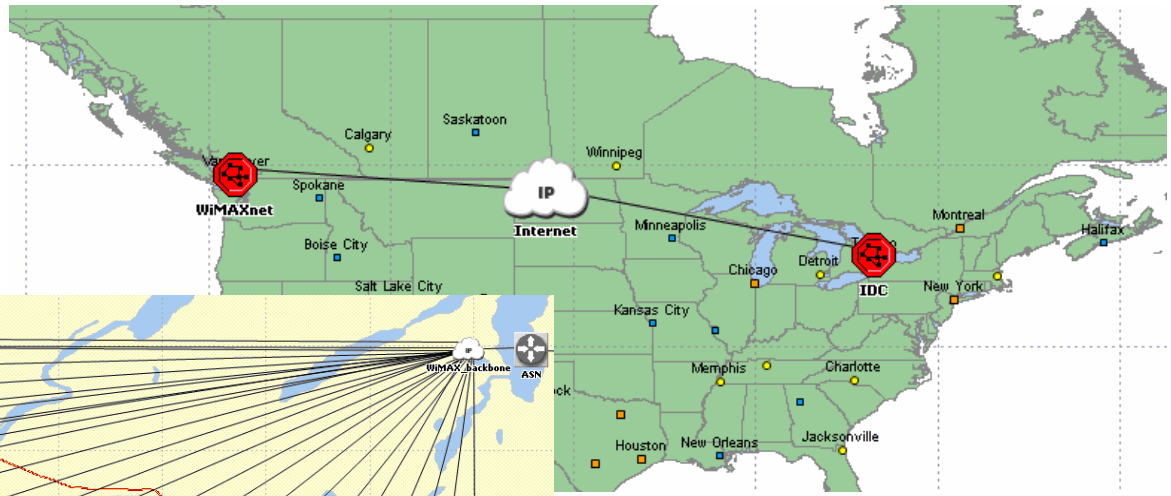
- Same configuration for UL and DL
- Entry thresholds reflect receiver SNR *
- Modulation curves approach BER of 0 for SNR

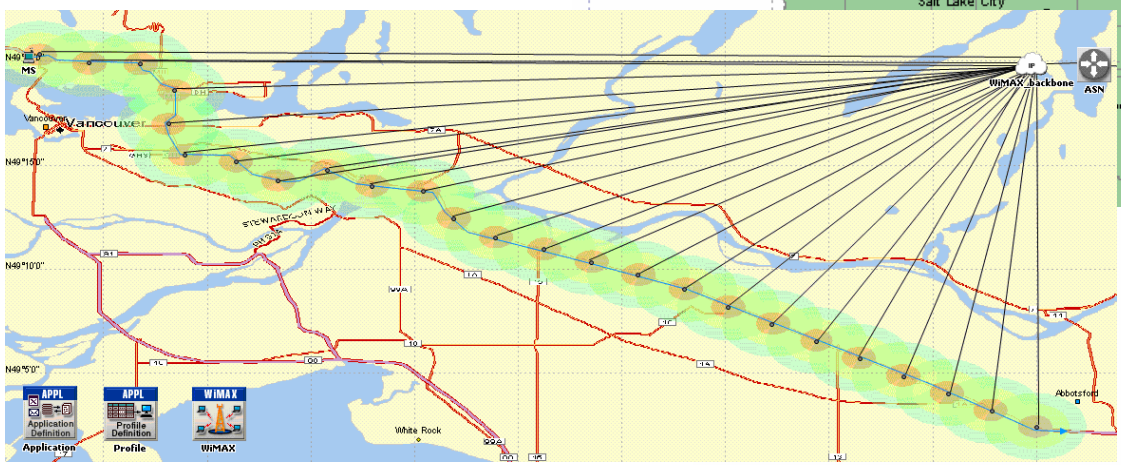
Mandatory Exit Threshold (dB)	Minimum Entry Threshold (dB)	Modulation and Coding
-20.0	5.0	QPSK 1/2
7.9	8.0	QPSK 3/4
10.4	10.5	16-QAM 1/2
13.5	14.0	16-QAM 3/4
15.9	16.0	64-QAM 1/2
17.9	18.0	64-QAM 2/3
19.9	20.0	64-QAM 3/4
21.9	22.0	64-QAM 5/6

* IEEE Std. 802.16e-2005: Part 16: Air interface for fixed and mobile broadband wireless access systems

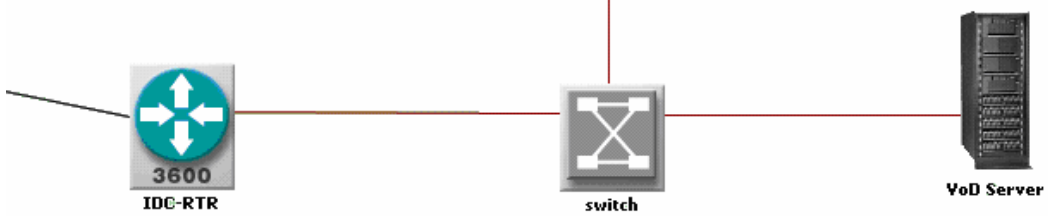
Model topology

WiMAX subnet





VoD IDC



VoD Video On Demand IDC Intranet Data Center

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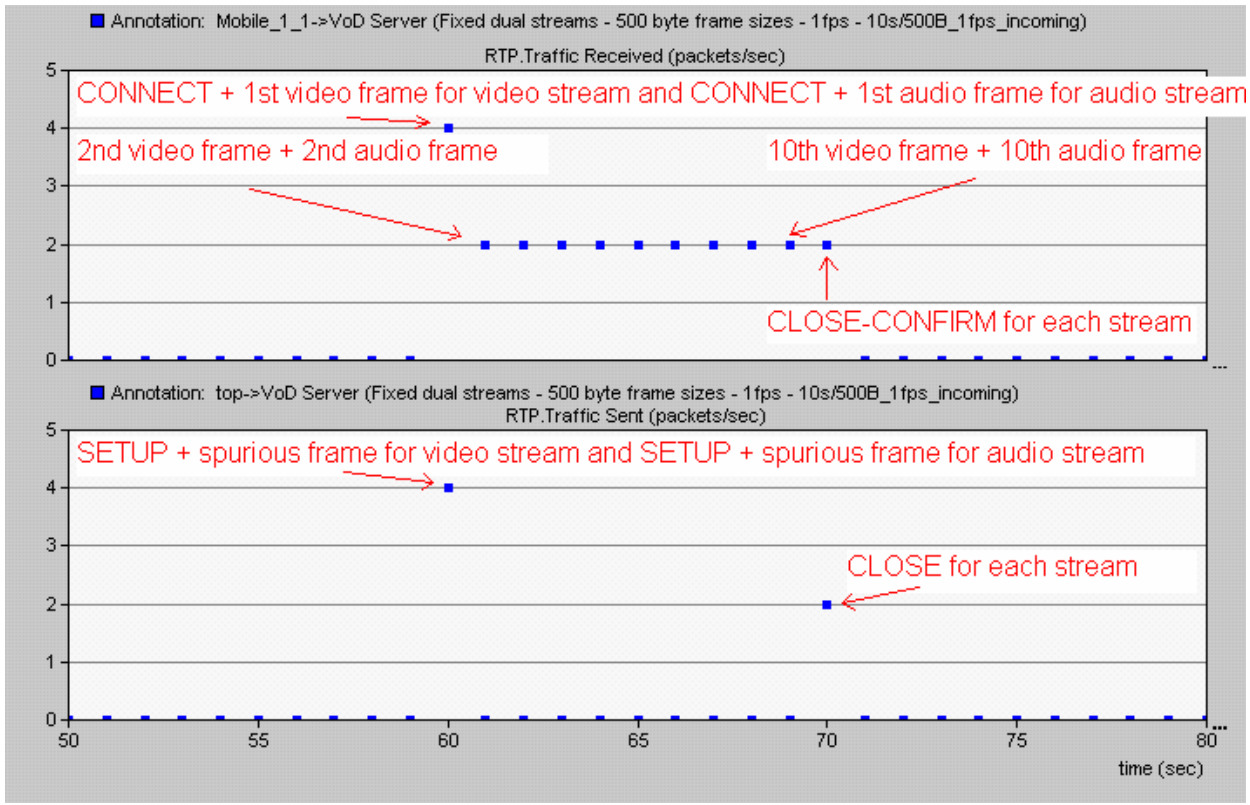
RTP - isolated streaming test

RTP Real Time Protocol fps frames per second MS Mobile Station

- Video content streamed for 10 seconds using two streams
- Each stream uses 500 byte packets at 1 frame per second (fps)

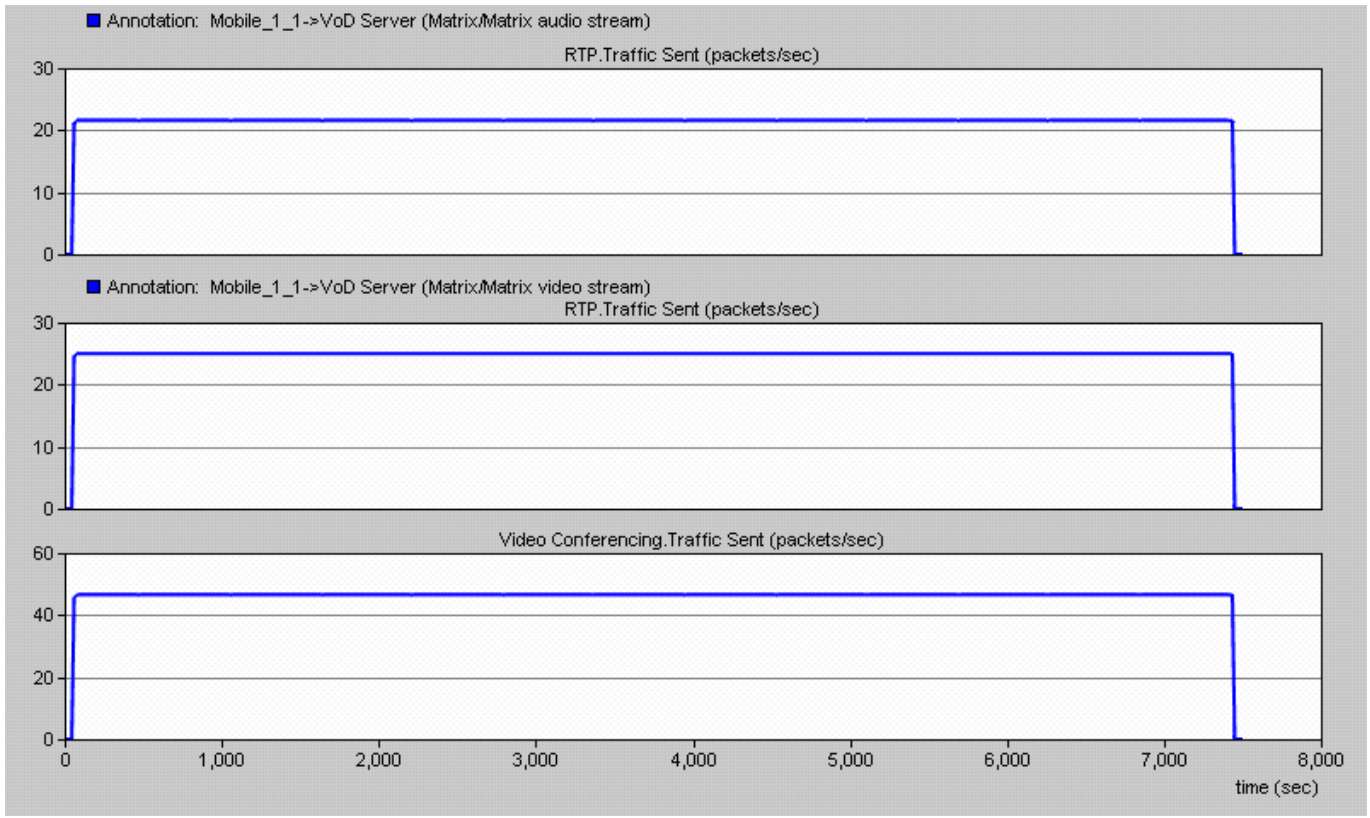


MS received RTP packet rate statistics

RTP - Matrix III streaming test

RTP Real Time Protocol fps frames per second MS Mobile Station

- Video On Demand server – packet rate statistics over time



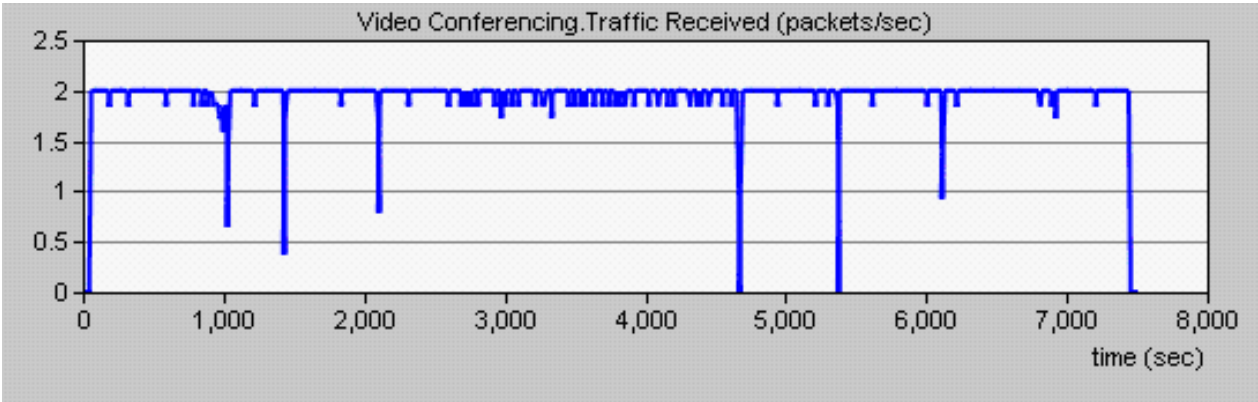
audio
21.6 fps

video
25 fps

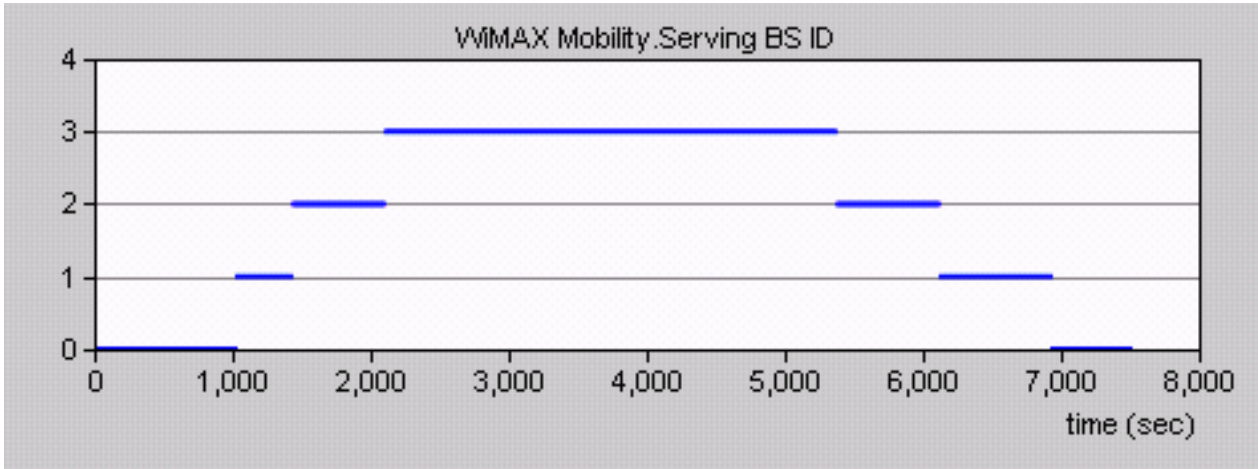
~ 47 fps

WiMAX mobility – handover test

- Streaming packet rate over time



- Handover between four sites over time



Roadmap

- Introduction
- Technological overview (video content, RTP, WiMAX)
- Design and implementation
- Validation
- Simulation results
- Project challenges
- Closing comments
- References

Simulation results

Channel Bandwidth (MHz)	Frame Duration (ms)	AAS	ARQ scheme	PLR	Delay (ms)	Jitter (ms)	Rank
5	5	none (SISO)	none	3.13E-02	50.9	0.0051	
			ARQ / HARQ	6.88E-04	53.9	0.0330	2
		STC 2x1 MIMO	none	5.69E-03	51.0	0.0055	
			ARQ / HARQ	6.88E-04	52.4	0.0200	1
	20	none (SISO)	none	3.16E-02	58.7	0.0120	
			ARQ / HARQ	7.44E-04	67.0	0.2650	
		STC 2x1 MIMO	none	5.67E-02	58.4	0.0125	
			ARQ / HARQ	7.34E-04	61.5	0.0934	3
7	5	none (SISO)	none	2.64E-02	50.4	0.0030	
			ARQ / HARQ	6.88E-04	52.7	0.0195	2
		STC 2x1 MIMO	none	2.14E-03	50.5	0.0031	
			ARQ / HARQ	6.85E-04	51.3	0.0118	1
	20	none (SISO)	none	2.67E-02	57.9	0.0100	
			ARQ / HARQ	7.36E-04	64.9	0.1750	
		STC 2x1 MIMO	none	2.15E-03	57.9	0.0090	
			ARQ / HARQ	7.23E-04	59.2	0.0480	3
10	5	none (SISO)	none	4.08E-02	49.9	0.0014	
			ARQ / HARQ	6.89E-04	52.7	0.0210	2
		STC 2x1 MIMO	none	7.68E-03	49.8	0.0014	
			ARQ / HARQ	**6.82E-04**	**50.9**	**0.0112**	1
	20	none (SISO)	none	4.19E-02	57.7	0.0105	
			ARQ / HARQ	7.46E-04	68.1	0.2580	
		STC 2x1 MIMO	none	8.07E-03	57.7	0.0095	
			ARQ / HARQ	7.28E-04	60.2	0.0770	3

Roadmap

- Introduction
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- Simulation details – results finalized in early June
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Challenges

RTP Real Time Protocol L2 Layer 2 L3 Layer 3

- RTP
  - no relevant internal design documentation
  - various internal modeler bugs
  - troubleshooting multiple streams issue
    - simulator internals very complex
- Mobility
  - unacceptable packet loss with MobileIP
  - ASN configuration for L2 / L3 handoff
  - MS forced disconnects from BS
- Limited technical support available for advanced Modeler modifications and configurations
  - modeler HARQ bug - SPR-127241
  - upgraded again from 14.5.A to 15.0.1 – bug still present

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Closing comments

- To date, the project has been ...
  - rewarding
  - diversified - broad range of enhancements
  - time intensive
- All enhancements were successfully completed
- Results are very encouraging
  - 50 % of the scenarios met or exceeded the specified performance measures
  - ARQ / HARQ and MIMO provided significant performance improvements

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Questions