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CISCO

IPTV, Internet Video and Adaptive Streaming Technologies

BRKSPV-1999

Presenter Today – Ali C. Begen

- Have a Ph.D. degree from Georgia Tech
- With Cisco since 2007
    - Video and Content Platforms
    - Research & Advanced Development Group
- Works in the area of
    - Architectures for next-generation video transport and distribution over IP networks
- Interested in
    - Networked entertainment
    - Internet multimedia
    - Transport protocols
    - Content distribution
- Senior member of the IEEE and ACM
- Visit http://ali.begen.net for publications

Agenda

- Part I: IPTV
  - IPTV – Architecture, Protocols and SLAs
  - Video Transport in the Core Networks
  - Video Distribution in the Access Networks
  - Improving Viewer Quality of Experience
- Part II: Internet Video and Adaptive Streaming
  - Example Over-the-Top (OTT) Services
  - Media Delivery over the Internet
  - Adaptive Streaming over HTTP
  - Emerging Standards

First Things First
IPTV vs. IP Video

IPTV	IP Video
Managed delivery	Best-effort delivery
Emphasis on quality	Quality not guaranteed
Linear TV plus VoD	Mostly on demand
Paid service	Paid or free service

Experiences Consumers Want Now
Yet Service Providers Struggle to Deliver

Online Content on TV/STB

Intuitive Unified Navigation for All Content

Multi-screen TV Experience

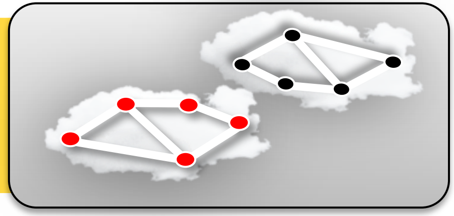
Web 2.0 Experiences on TV/STB

Support an increasing variety of services on an any device and deliver a common experience everywhere

Three Dimensions of the Problem
Content, Transport and Devices

Managed and Unmanaged Content

Managed and Unmanaged Transport



Managed and Unmanaged Devices

From Totally Best-Effort to Fully-Managed Offerings

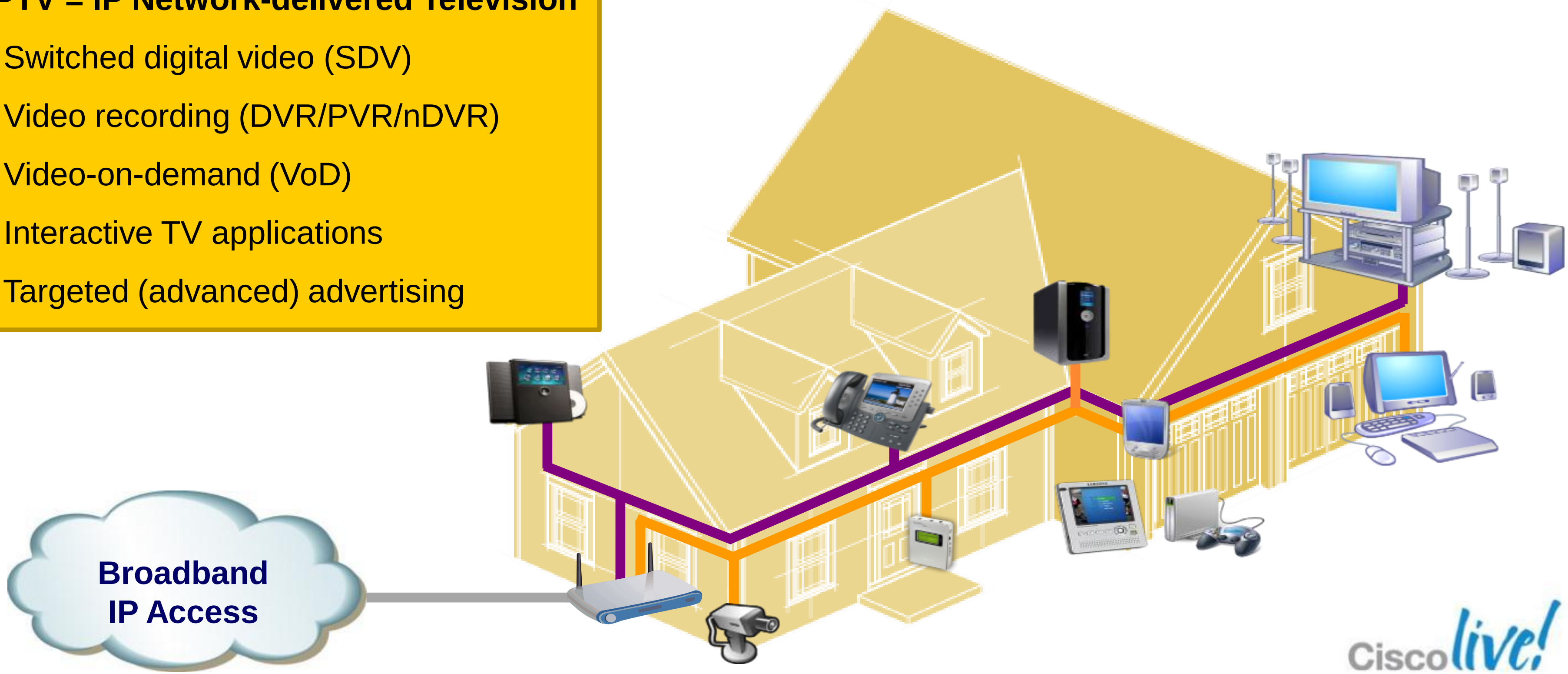
Challenge is to Provide a Solution that Covers All

Part I: IPTV

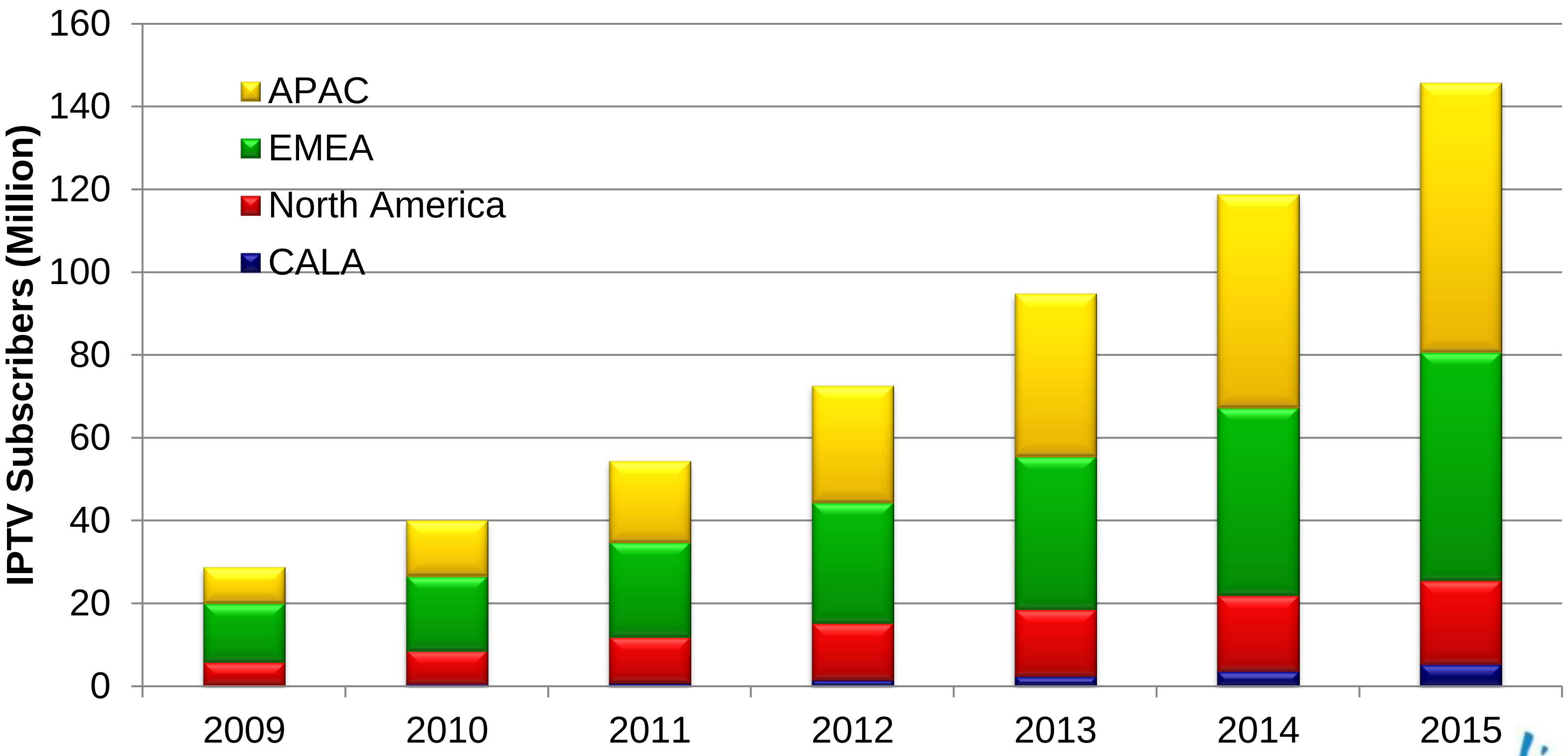
What Is IPTV?
The Fundamental Component for Connected Homes

IPTV = IP Network-delivered Television

- Switched digital video (SDV)
- Video recording (DVR/PVR/nDVR)
- Video-on-demand (VoD)
- Interactive TV applications
- Targeted (advanced) advertising



Growth for IPTV



Source: Infonetics Research, 2011

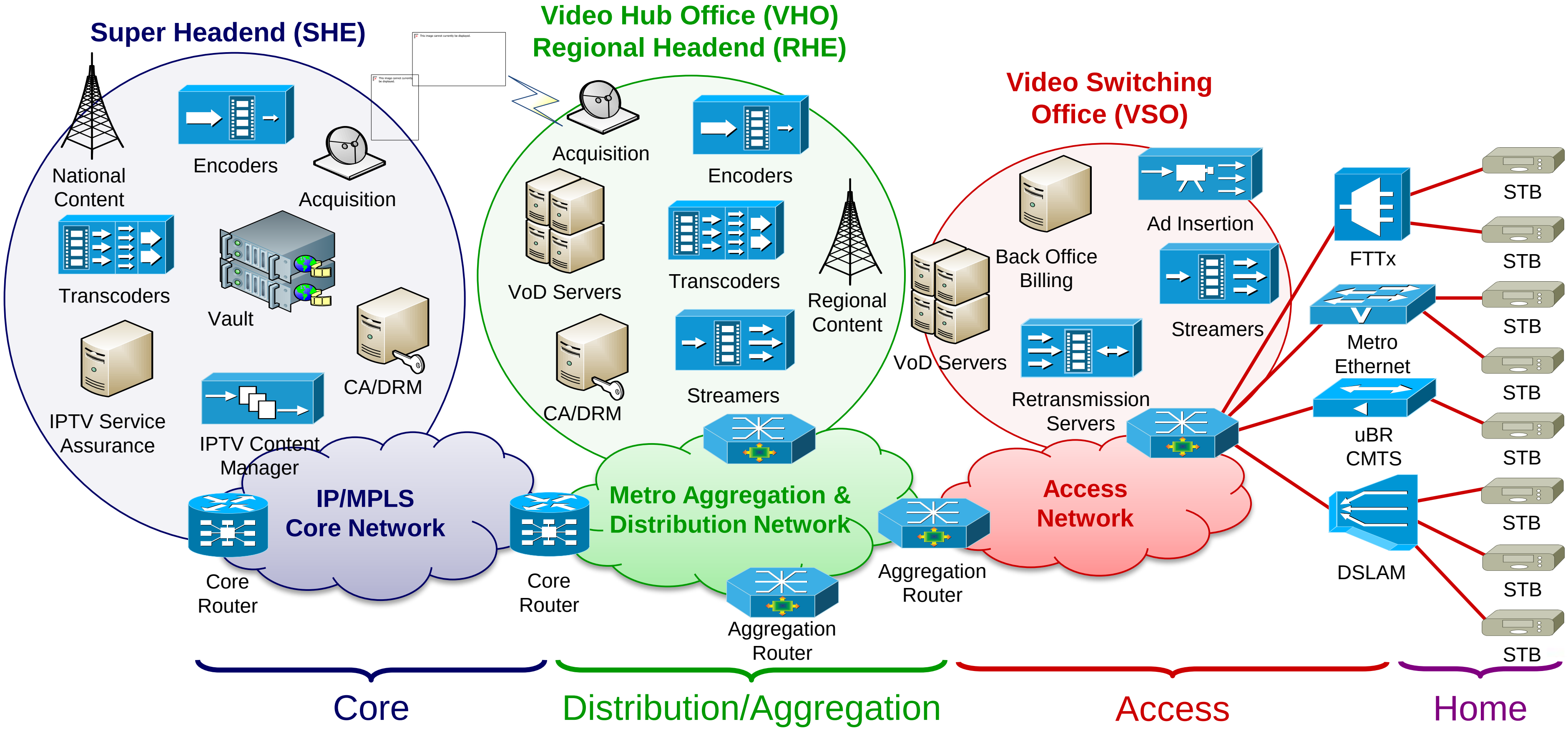
Trends Driving IPTV Adoption

- **Subscribers want more choice and control**
  - New generation grew up computer/Internet savvy
  - Customised for me – One bill, one provider, integrated services
- **Codec, access, server and CPE technologies are improving**
  - MPEG-4 AVC (H.264) improvements, new xDSL, FTTx, DOCSIS 3.0 access technologies
  - Moore's law advancements in processing and memory
- **Competition is increasing among service providers**
  - No longer limited by access
  - Traditional markets are going away, e.g., VoIP is almost free

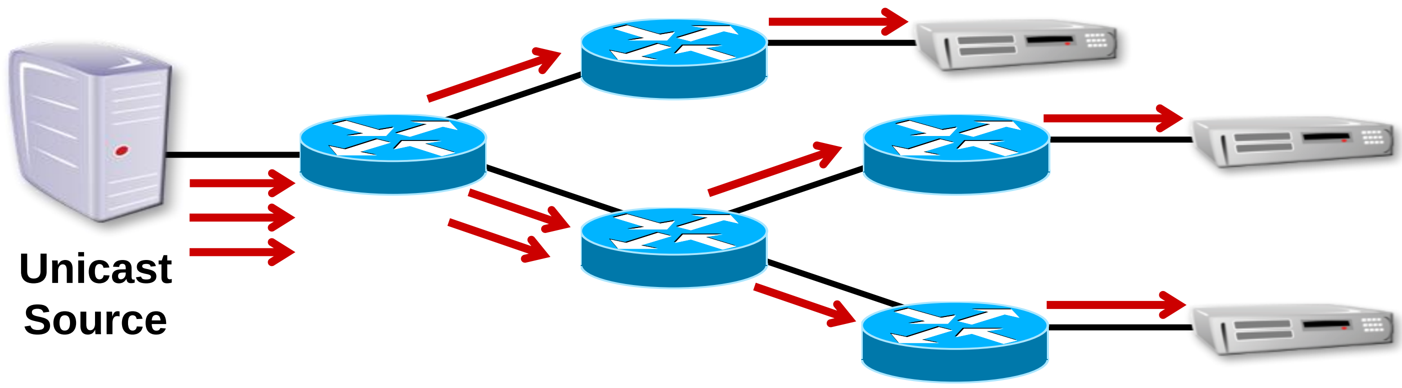
Video is driving next generation service provider network designs

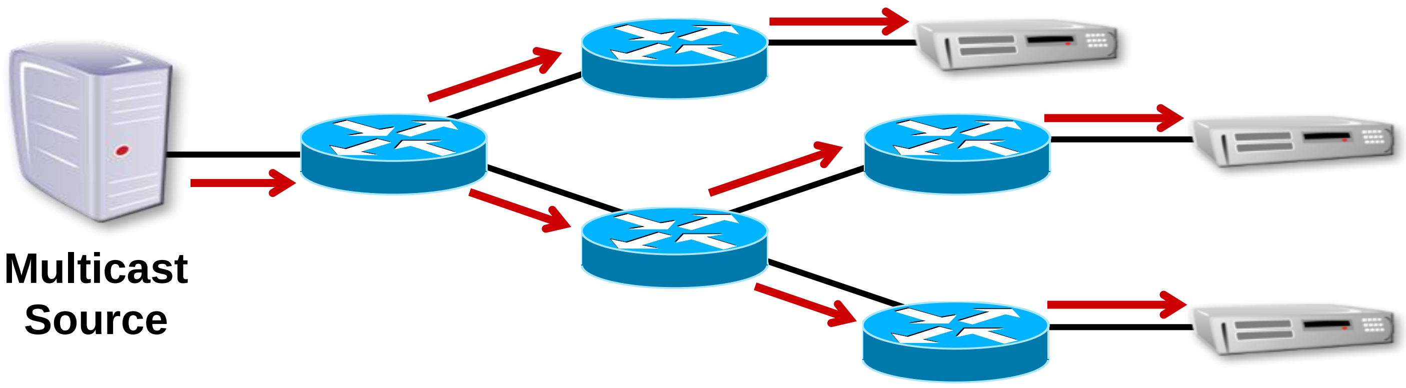
IPTV – Architecture, Protocols and SLAs

End-to-End IPTV Network Architecture



Unicast vs. Multicast





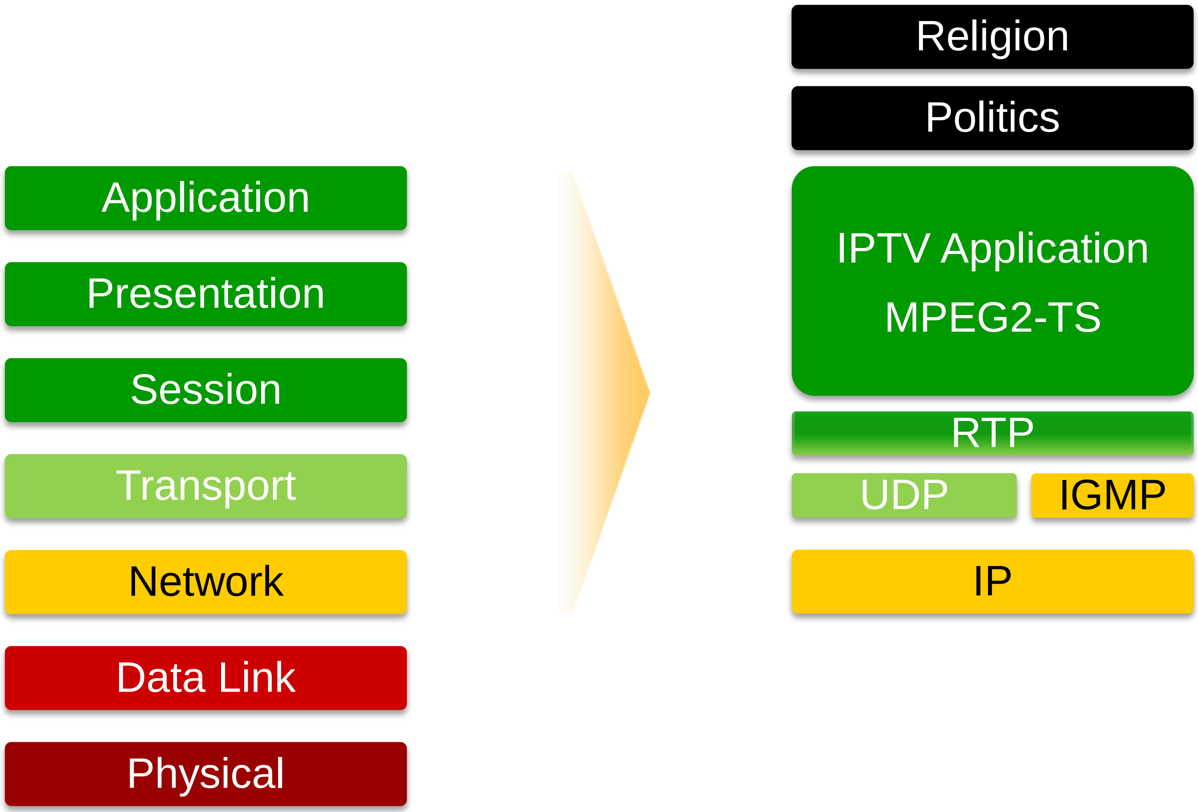
Broadcast IPTV = IP Multicast

- **Various Transports**
  - Native IP multicast, MPLS, L2, optical
- **SSM: Source-Specific Multicast (RFC 4604 and 4607)**
  - Receivers subscribe (S,G) channels to receive traffic only from source S sent to group G
  - Primarily introduced (by IETF) for IPTV-like services
- **IP Multicast Endpoints**
  - Sources: Encoder, transcoder, groomer, ad-splicer
  - Receivers: Transcoder, groomer, ad-splicer, eQAM, IP STB
- **IETF standardised**
  - Receiver-to-Router Protocols: IGMPv3 (IPv4) and MLDv2 (IPv6) with (S,G) signalling
  - Router-to-Router Protocols: PIM-SSM, IGMPv3 Proxy Routing, Snooping on HAG and L2 devices
- **Transport Challenges**
  - Packet loss, out-of-order delivery, packet duplication
  - (We cannot use TCP for IP multicast)

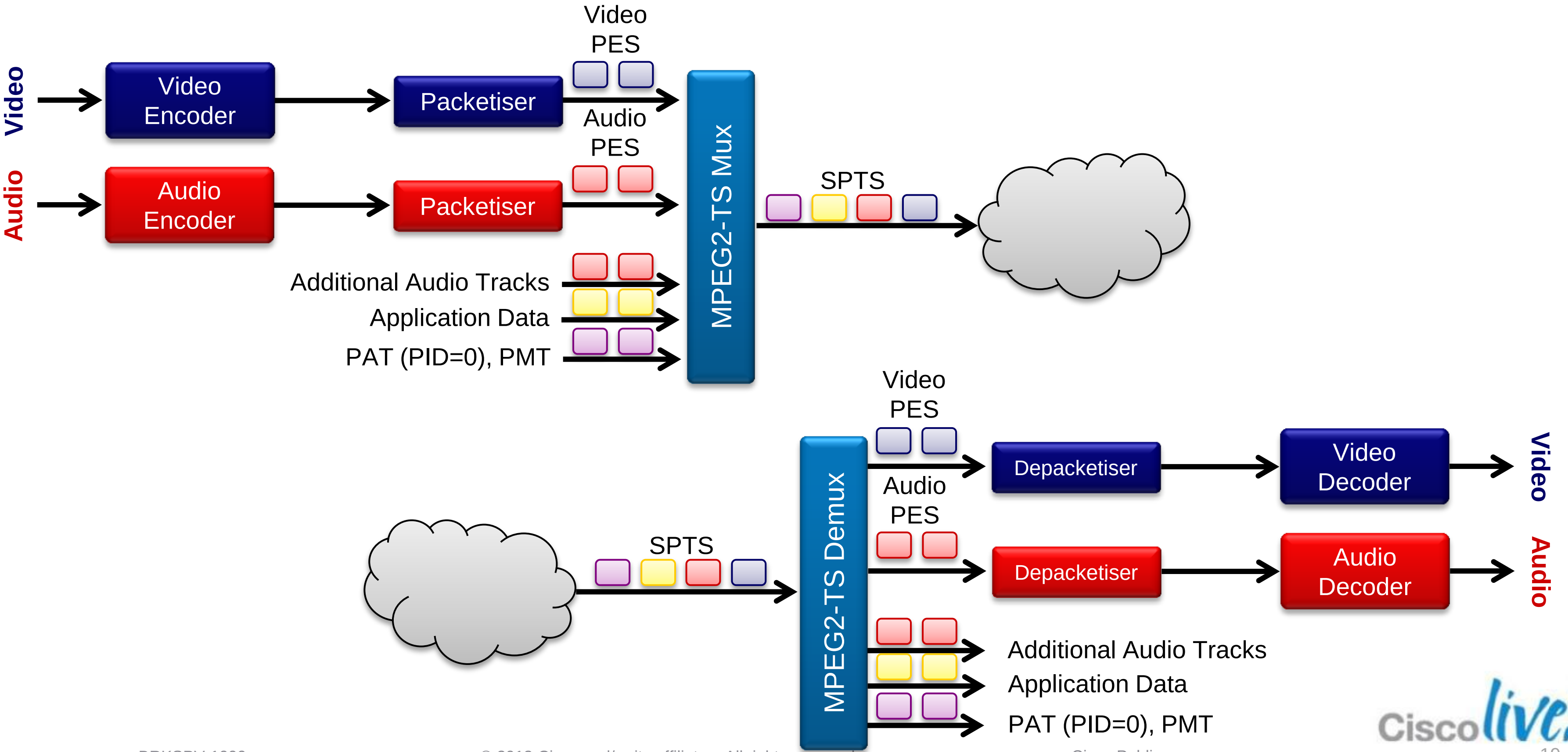
Real-Time Transport Protocol (RTP)
http://tools.ietf.org/html/rfc3550

- **Basics**
  - First specified by IETF in 1996, later updated in 2003 (RFC 3550)
  - Runs over any transport-layer protocol (Typically over UDP)
  - Runs over both unicast and multicast
  - No built-in reliability
- **Main Services**
  - Payload type identification
  - Sequence numbering
  - Timestamping
- **Extensions**
  - Basic RTP functionality uses a 12-byte header
  - RFC 5285 defines an RTP header extension mechanism
- **Control Plane – RTCP**
  - Provides minimal control and identification functionality
  - Enables a scalable monitoring functionality (Sender, receiver, extended reports)

RTP Transport of MPEG2 Transport Streams

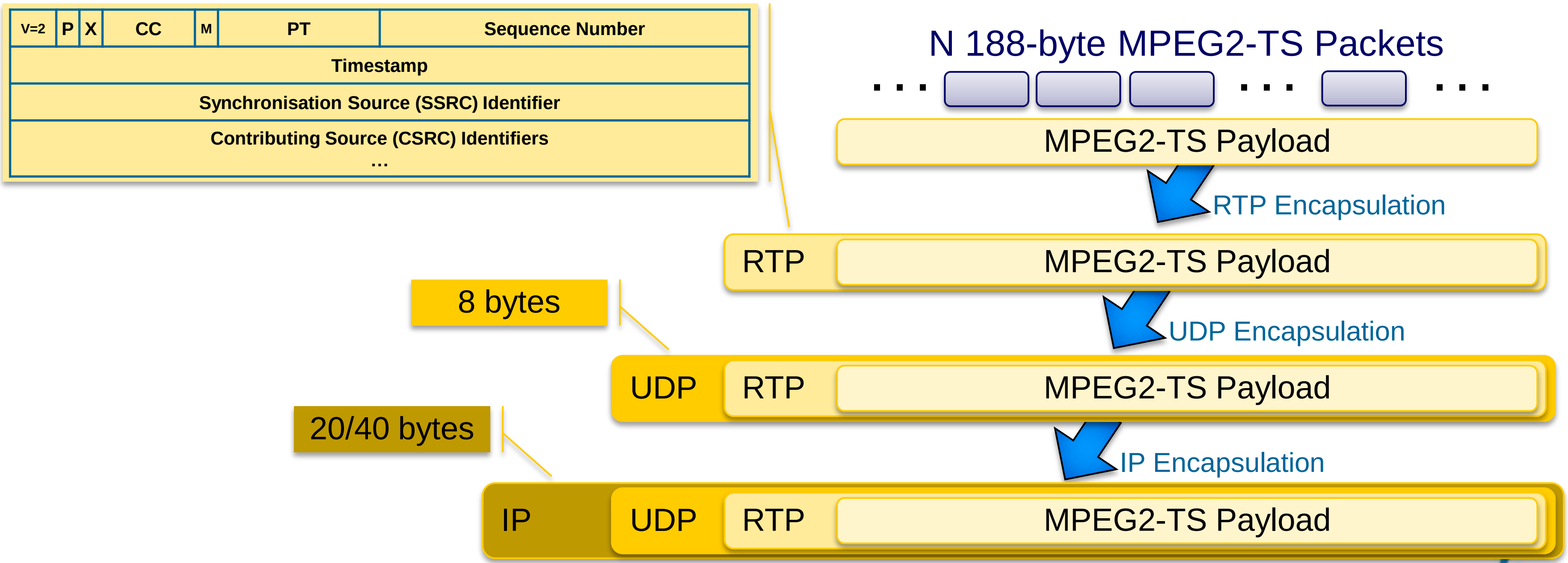


Packetisation into MPEG2 Transport Streams
Single Program Transport Streams (SPTS)



RTP Transport of MPEG2 Transport Streams

http://tools.ietf.org/html/rfc2250



Default IP header size is 20 and 40 bytes for IPv4 and IPv6, respectively

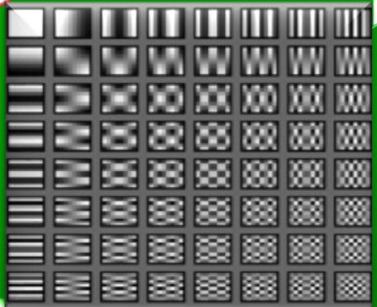
Video Headend Building Blocks

ACQUISITION

- Satellite reception
- Off-air reception
- Fibre reception
- Signal conversion

ENCODING

- MPEG-2
- MPEG-4 AVC
- Standard def.
- High definition
- Audio encoding



PROCESSING

- Transcoding
- Transrating
- Splicing
- Multiplexing
- Ad-insertion

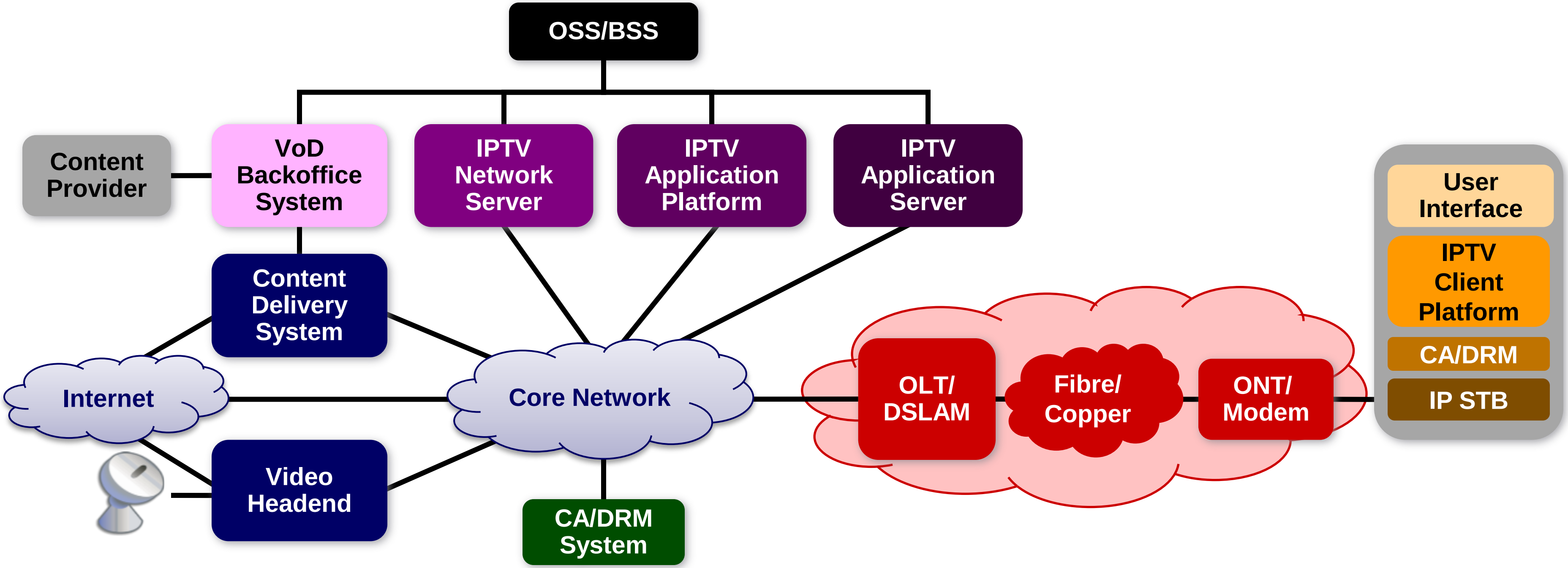
MANAGEMENT

- CAS/DRM
- Remote ops
- Metadata
- Billing
- VoD servers
- Video apps

Role of IPTV Middleware

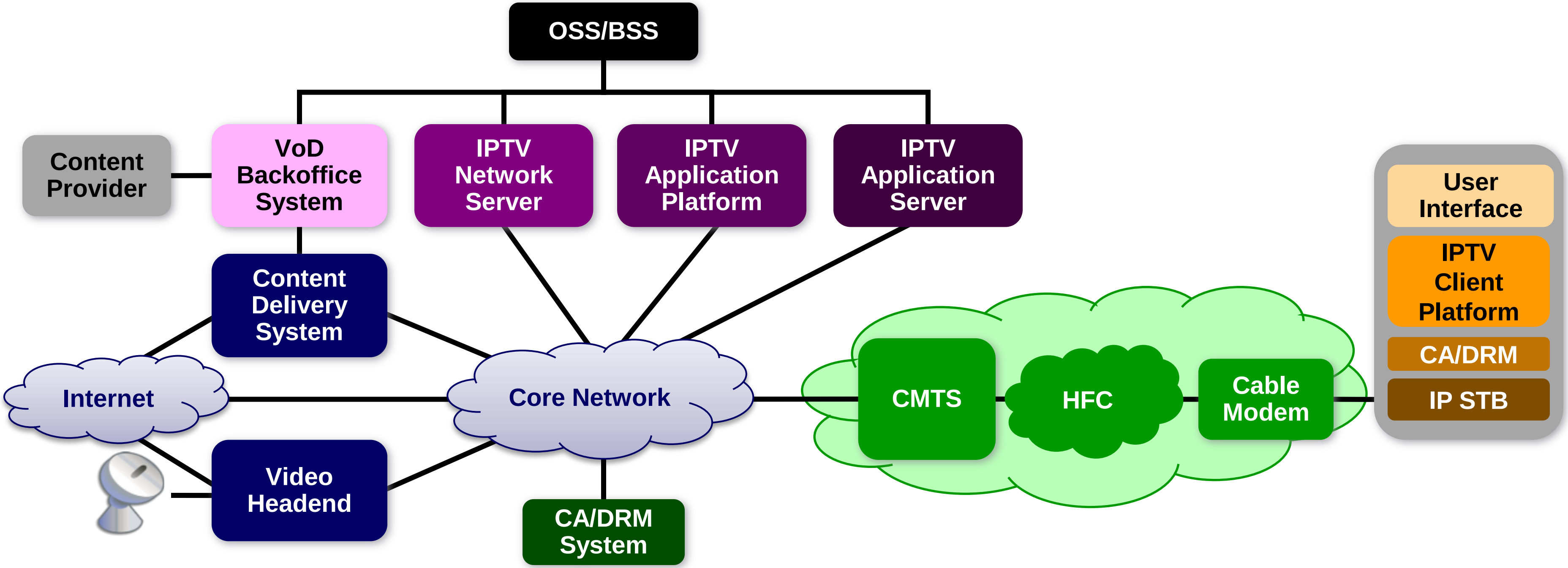
- **Middleware provides interoperability for system components**
- **Middleware enables**
  - Revenue producing IPTV services
  - Differentiation for service providers
  - Consistent and extensible consumer experience
  - Delivery of rich media to consumers
  - Compelling GUIs
- **Middleware ties together all parts of an end-to-end IPTV system**
  - EPG, content navigation
  - CAS/DRM, VoD servers, asset management, service packaging
  - EAS, STB support, network management
  - Billing, triple-play integration, subscriber management

Telco IPTV System Reference Architecture



IP Content and Delivery over Fibre/xDSL Access

Cable IPTV System Reference Architecture



IP Content and Delivery over DOCSIS (VDOC)

Efficiency Gains From IPTV in Cable Delivery

Variable Bitrate

- VBR provides a bandwidth savings of 40-60%
- IPTV is the best choice for narrowcast statmux and AVC statmux

Switched Video

- Switching is the way to offer unlimited channels
- IPTV provides built-in switching functionality

Advanced Coding

- AVC provides a bandwidth savings of 50% over MPEG2
- IPTV solves the problem of slow channel change

QAM Sharing

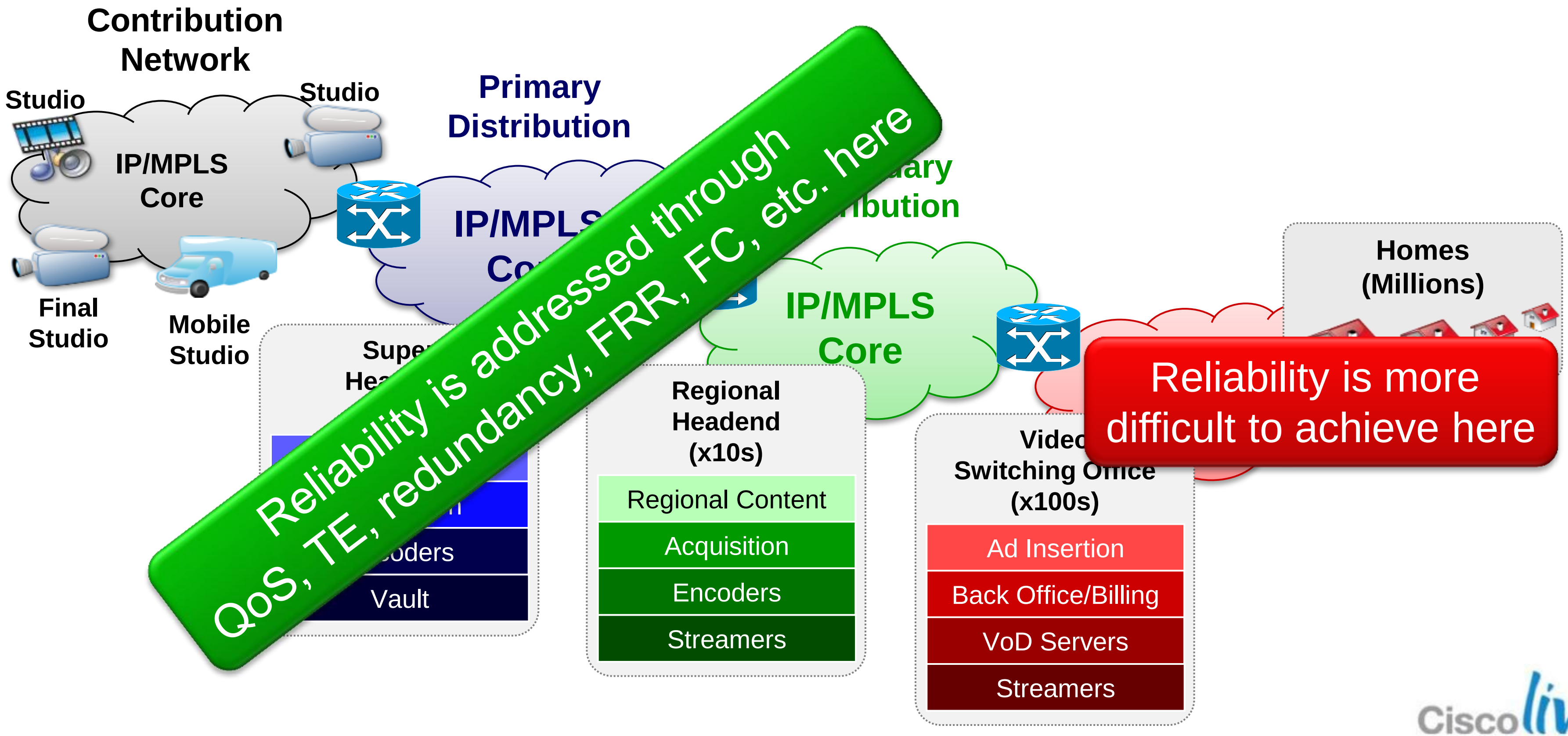
- Convergence provides further bandwidth savings
- We can share QAMs for VoD and SDV as well as for video and DOCSIS

Types of Video Services

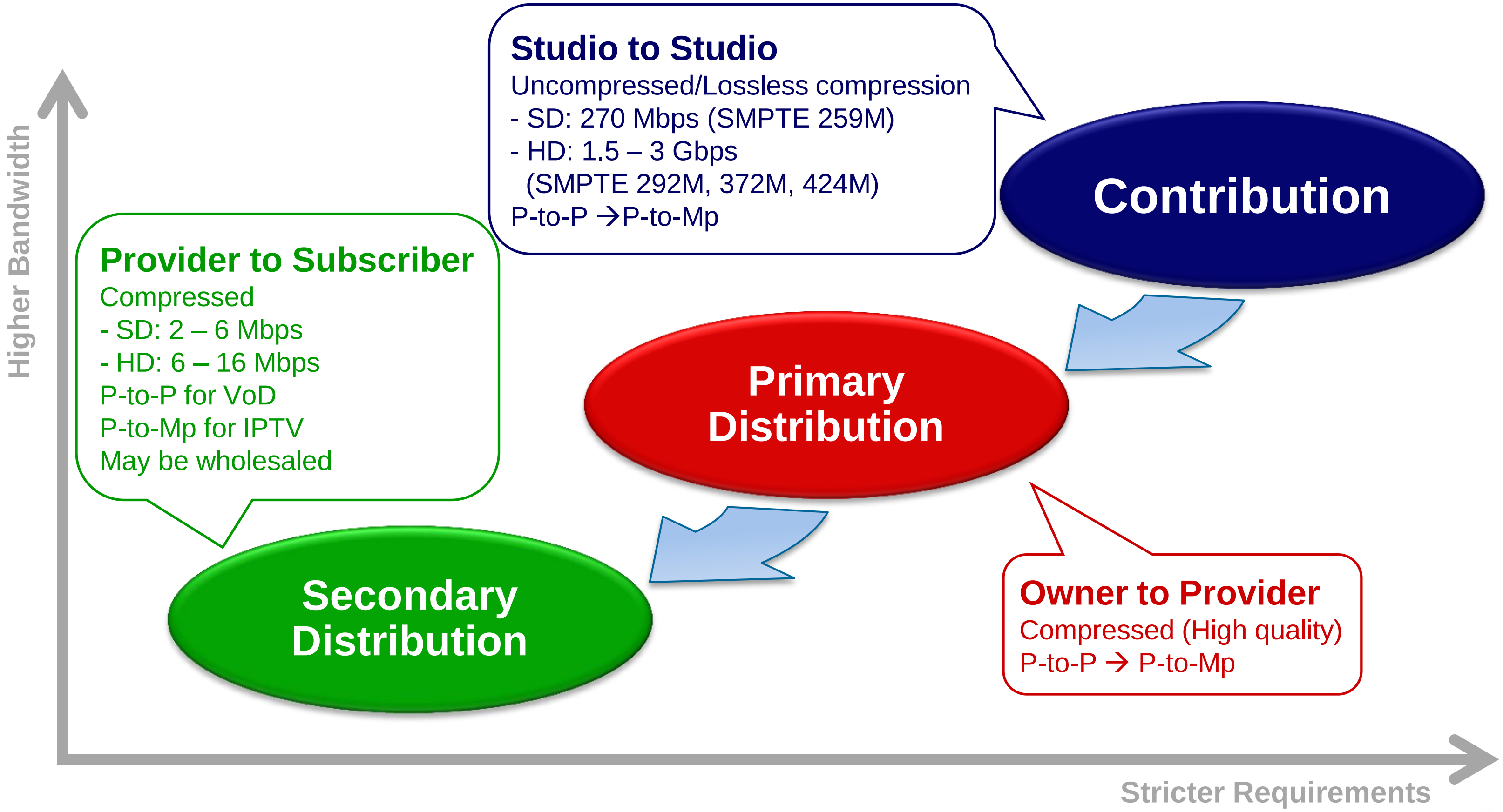
- **Transport (Contribution and Primary Distribution)**
- **IPTV /CATV (Secondary Distribution)**
  - IP multicast distribution from centralised super headends
    - Driving enhanced multicast features and functions
- **VoD (Secondary Distribution)**
  - Distributed architecture for better scalability
  - Non-real-time content distribution to caches
- **Enterprise**
  - mVPN based
  - Driving enhanced multicast features and functions
- **Over-the-Top (e.g., Hulu, Apple TV, Netflix)**
  - Adaptive streaming methods are quickly becoming ubiquitous

IPTV *must* Deliver Entertainment-Caliber Video

Tolerance is One Visible Artifact per Movie



Taxonomy of Video Service Providers



Digital Video Bandwidths

Uncompressed Digital Video	
SDTV (480i CCIR 601 over SD-SDI SMPTE 259M)	165.9 – 270 Mbps
HDTV (1080i or 720p over HD-SDI SMPTE 292M)	1.485 Gbps
HDTV (1080p over Dual Link HD-SDI SMPTE 372M or 3G-SDI SMPTE 424M)	2.970 Gbps
MPEG-2 Compressed Video	
SDTV Broadcast (3.75 Mbps for Cable VoD)	3 – 6 Mbps
HDTV Broadcast (19.3 Mbps for ATSC DTV)	12 – 20 Mbps
SDTV Production (Contribution – 4:2:2 I-frame only)	18 – 50 Mbps
SDTV Production (Contribution – 4:2:2)	20 – 30 Mbps
HDTV Production (Contribution – 4:2:2)	34 – 60 Mbps
JPEG-2000 HDTV Production (Contribution – 4:4:4 I-frame only)	150 - 300 Mbps
MPEG-4 AVC / H.264 Compressed Video	
SDTV Broadcast (~50% less than MPEG-2)	1.5 – 3 Mbps
HDTV Broadcast (1080i)	6 – 9 Mbps

Video SLA Requirements

- **Throughput**
  - Addressed through capacity planning and QoS (i.e., Diffserv)
- **Delay/Jitter**
  - Controlled with QoS
  - Absorbed by de-jittering buffer at IP STB
    - We desire to minimise jitter buffer size to improve responsivity
    - Jitter originating in the core is rather insignificant
- **Packet Loss**
  - Controlling loss is the main challenge
- **Service Availability**
  - Proportion of time for which the specified throughput is available within the bounds of the defined delay and loss

Video Transport in the Core Networks

Four Primary Causes for Packet Loss

- **Excess Delay**
  - Renders media packets essentially lost beyond an acceptable bound
  - Can be prevented with appropriate QoS (i.e., Diffserv)
- **Congestion**
  - Considered as a catastrophic case, i.e., fundamental failure of service
  - Must be prevented with appropriate QoS and admission control
- **PHY-Layer Errors**
  - Apply to core and access – Occurrence in core is far less
  - Considered insignificant compared to losses due to network failures
- **Network Reconvergence Events**
  - Occur at different scales based on topology, components and traffic
  - Can be eliminated with high availability (HA) techniques

What are the Core Impairment Contributors?

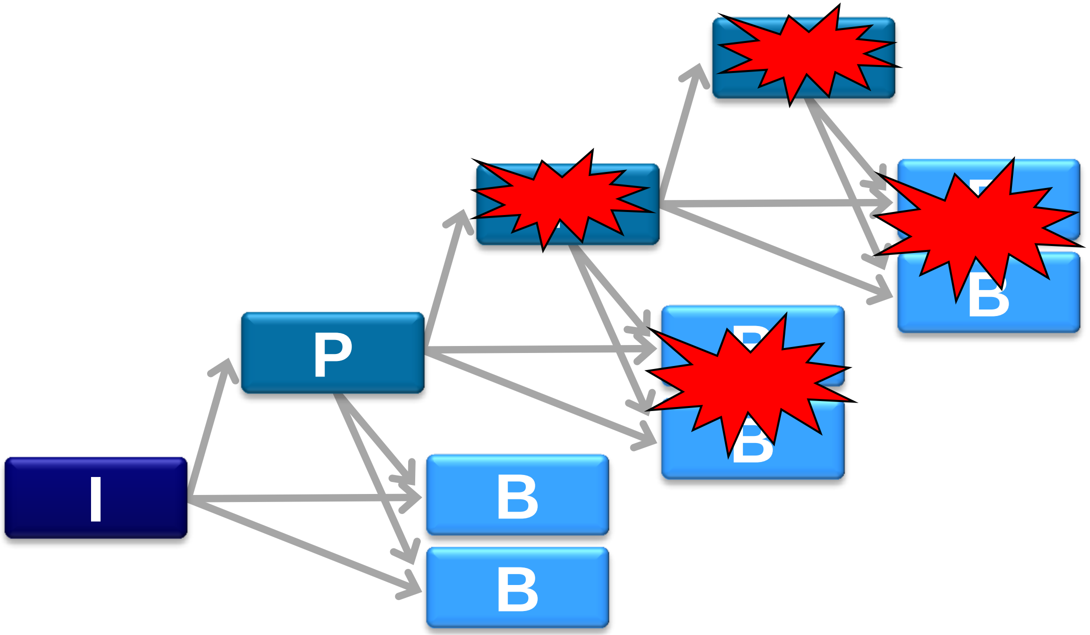
	Impairment Rate
Trunk failures	.0010 /2h
Hardware failures	.0003 /2h
Software failures	.0012 /2h
Non-stop forwarding (NSF) and Stateful switch-over (SSO) help here	
Software upgrades (Maintenance)	.0037 /2h
Modular code (IOS-XR) helps here	
Total	.0062 /2h (One every two weeks)

Note that average mean time between errors on a DSL line is in the order of minutes when no protection is applied

Back of envelope calculations across several SPs show mean time between core failures affecting video is > 100 hours

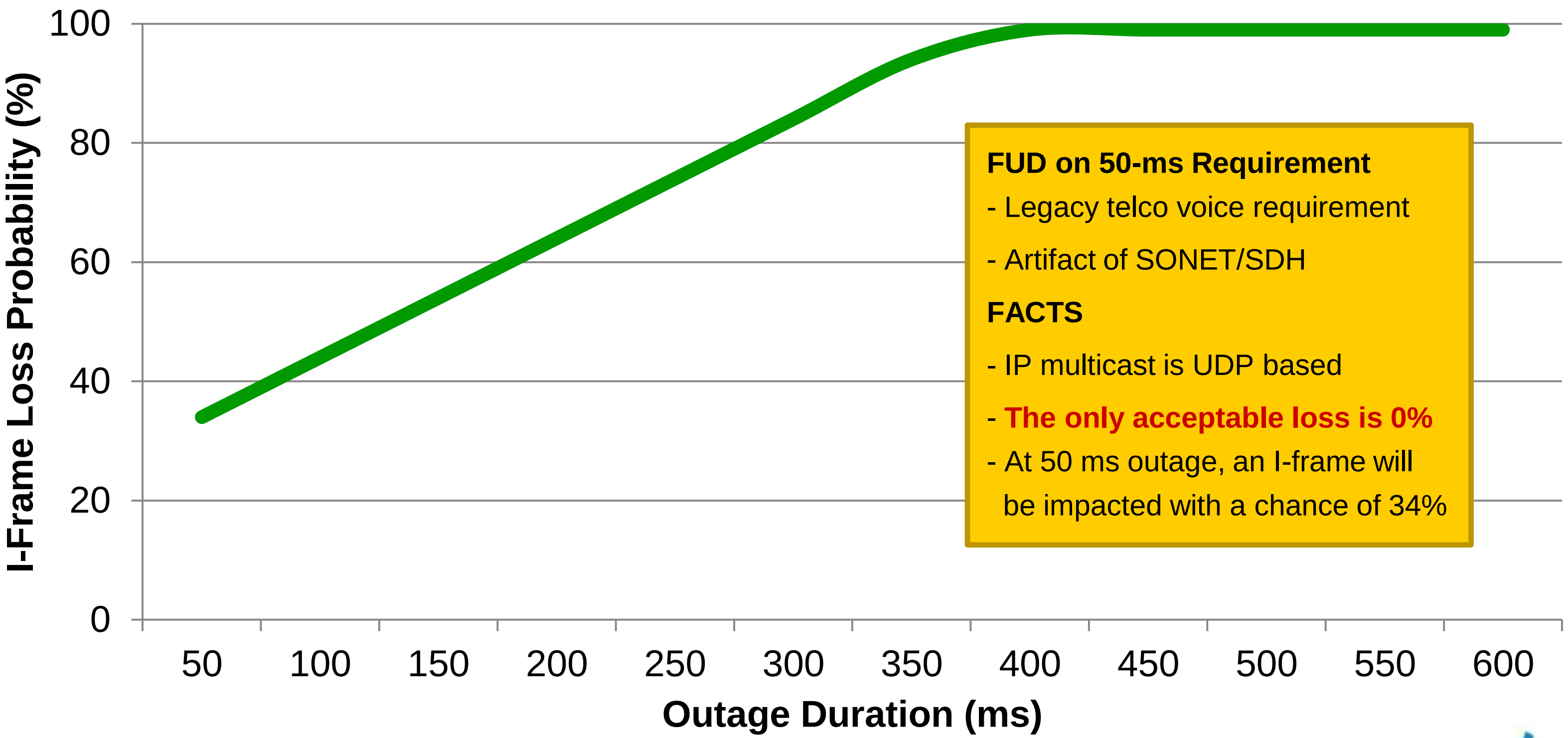
Source: Data from industry standards, customers and assumptions

Unequal Importance of Video Packets
A Simple MPEG Video Group of Pictures (GoP)



MPEG Frame Impact from Packet Loss

GoP Size: 500 ms (I:P:B = 7:3:1)



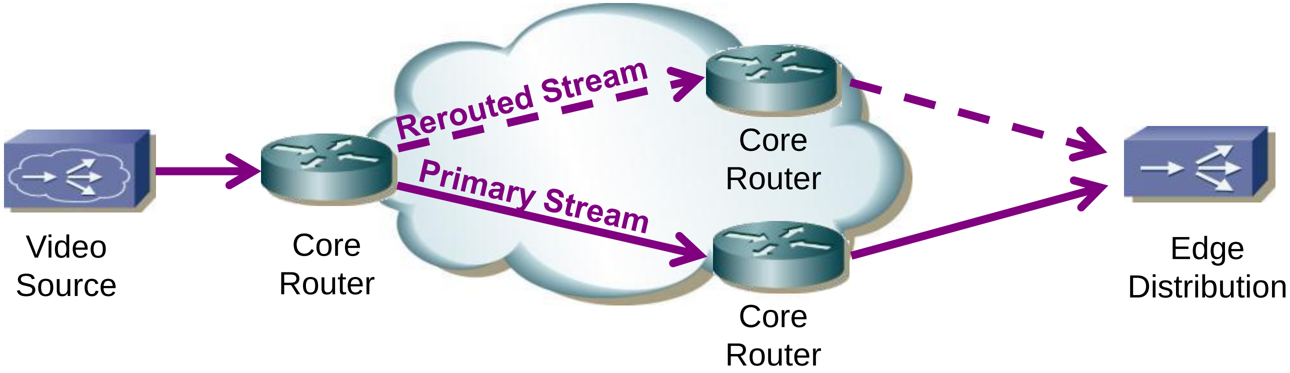
FUD on 50-ms Requirement

- Legacy telco voice requirement
- Artifact of SONET/SDH

FACTS

- IP multicast is UDP based
- **The only acceptable loss is 0%**
- At 50 ms outage, an I-frame will be impacted with a chance of 34%

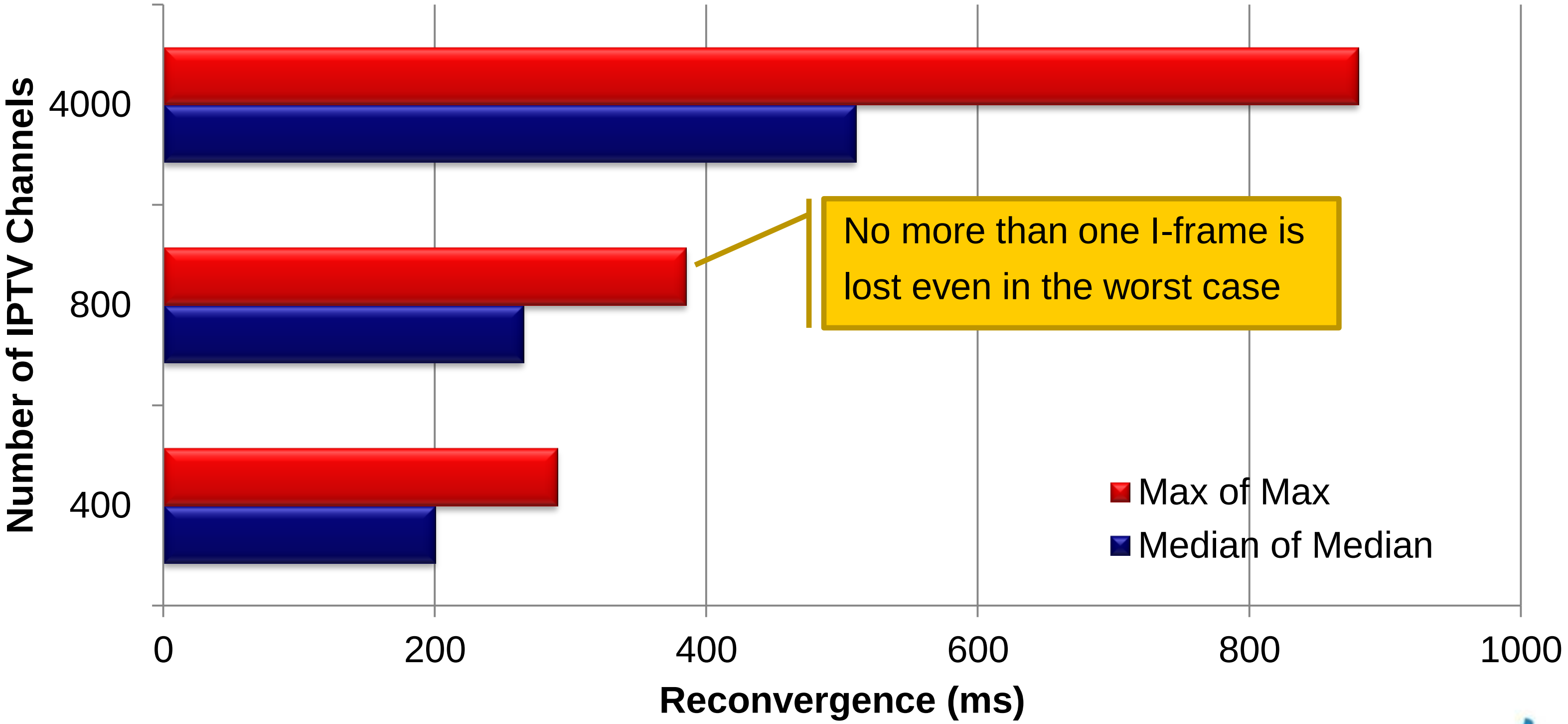
Fast Convergence or Fast Reroute



- Network reconverges (reroutes) on a network (link or node) failure
- Fast Convergence (FC) – Fast Reroute (FRR)
  - ✓ Lowest bandwidth requirements in working and failure cases
  - ✓ Lowest solution cost and complexity
  - ! Requires fast converging network to minimise visible impact of loss
  - ✗ Is NOT hitless – Loss of connectivity before connectivity is restored

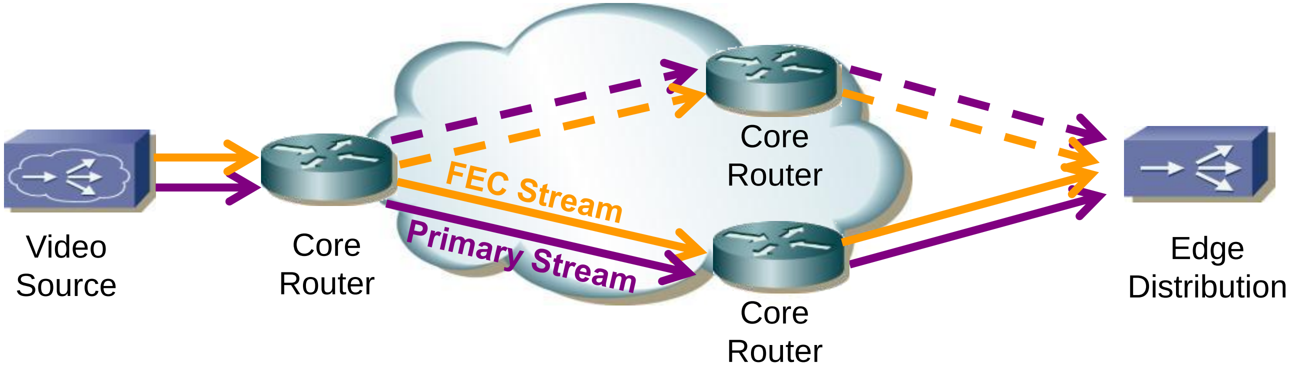
Multicast (SSM) Fast Convergence on CRS-1

Convergence Time Following A Failure



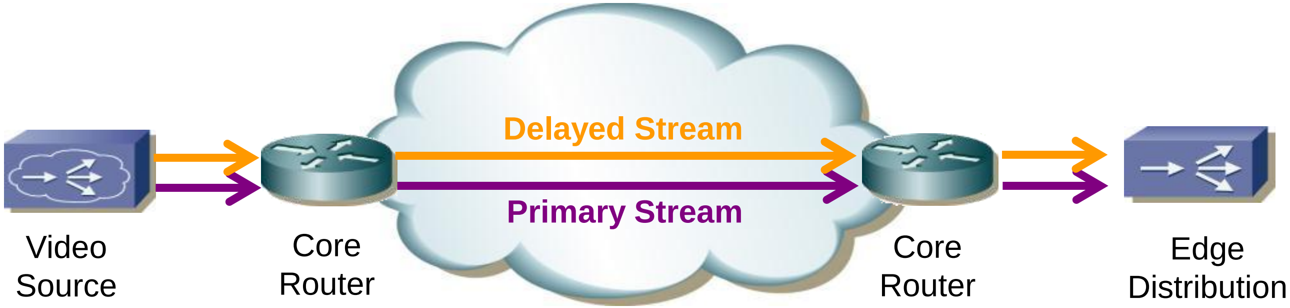
Tested with 2500 IGP prefixes and 250k BGP routes

Forward Error Correction (FEC)



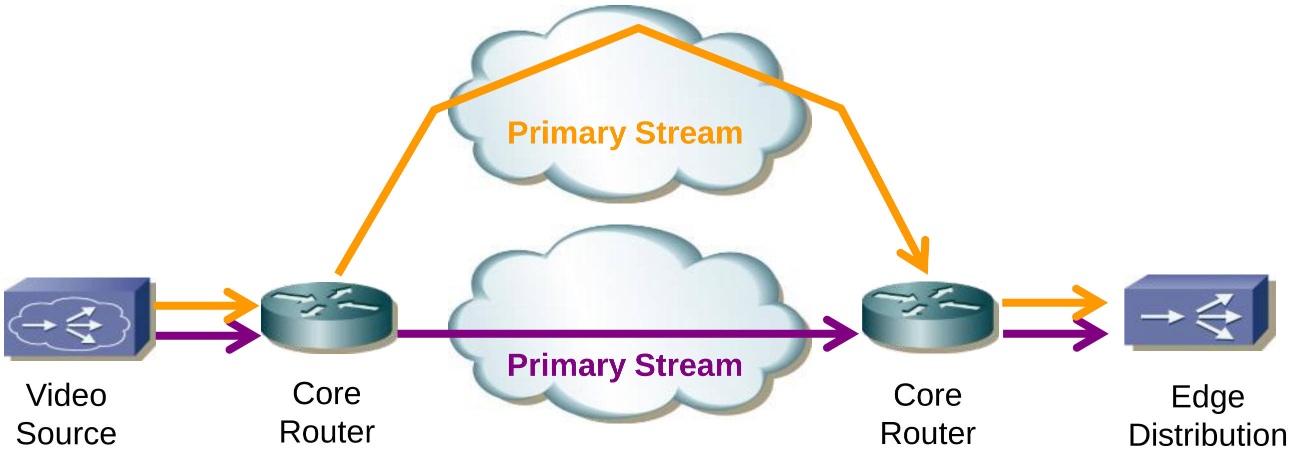
- FEC adds redundancy to the source data to allow to detect and repair losses
- FEC
  - ✓ Is hitless from loss due to core network failures if loss can be constrained
  - ✓ Does not require path diversity – Works for all topologies
  - ! Requires fast converging network to minimise FEC overhead
  - ✗ Incurs delay – Longer outages require larger overhead or larger block sizes (More delay)

Temporal Diversity (Redundancy)



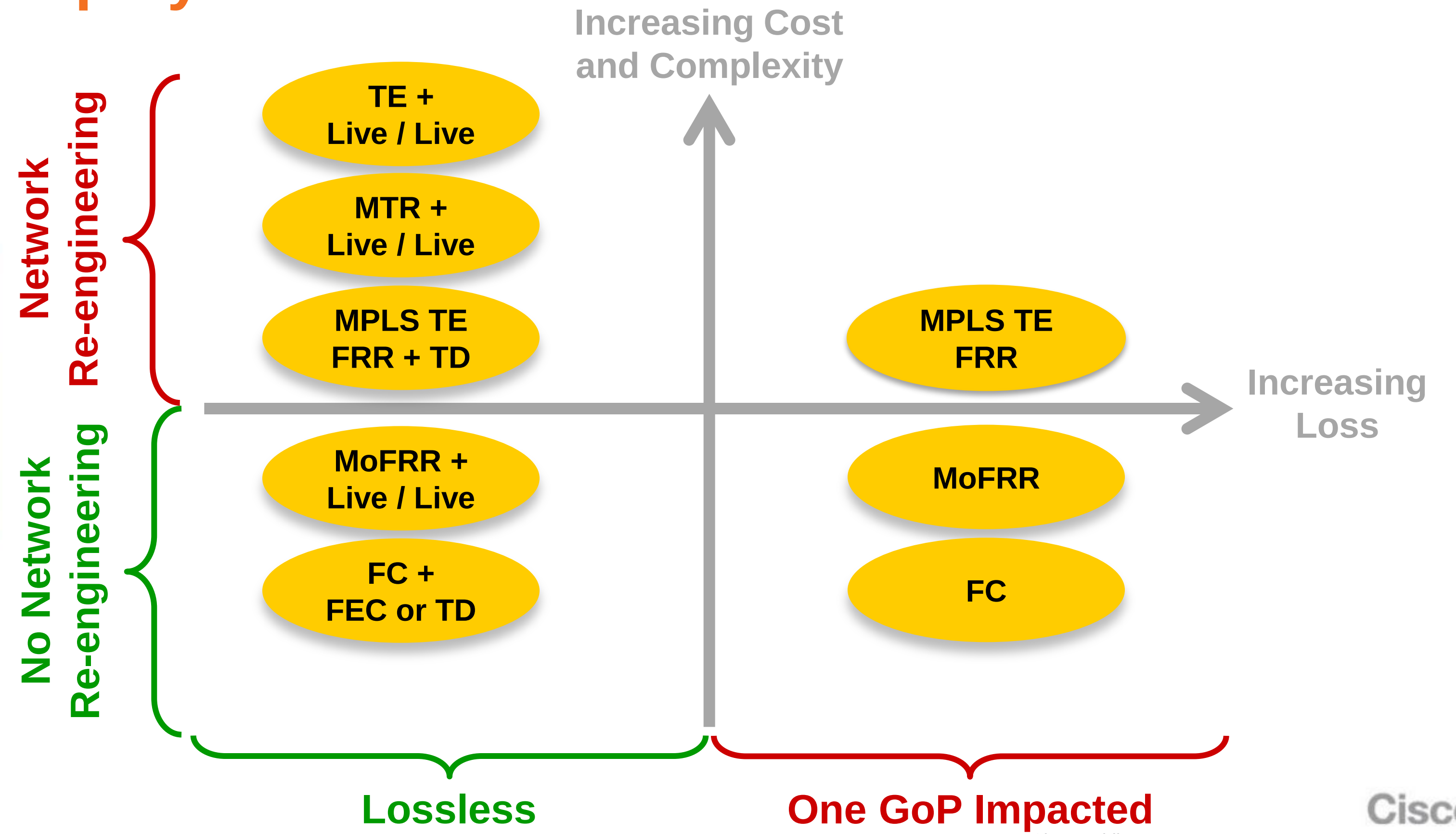
- Let Q (ms) denote the max outage duration that is intended to be repaired
- Packets are transmitted twice, each separated by Q-ms delay
- Temporal diversity
  - ✓ Is hitless from loss due to core network failures if loss can be constrained
  - ✓ Does not require path diversity – Works for all topologies
  - ! Requires fast converging network to minimise Q
  - ✗ Introduces 100% overhead and Q-ms delay

Spatial (Path) Diversity – Live/Live



- Two streams are sent over diverse paths in the core
- Spatial diversity
  - ✓ Introduces no delay if the paths have equal propagation delays
  - ✗ Requires network-level techniques to ensure spatial diversity
  - ✗ Incurs 100% overhead
    - May not be an issue where redundant capacity is normally provisioned
    - E.g., dual-plane core networks

Toward Lossless IPTV Transport
Deployment Scenarios



Towards Lossless IPTV Transport
Reading

“Toward lossless video transport,”
IEEE Internet Computing, Nov./Dec. 2011

“Designing a reliable IPTV network,”
IEEE Internet Computing, May/June 2009

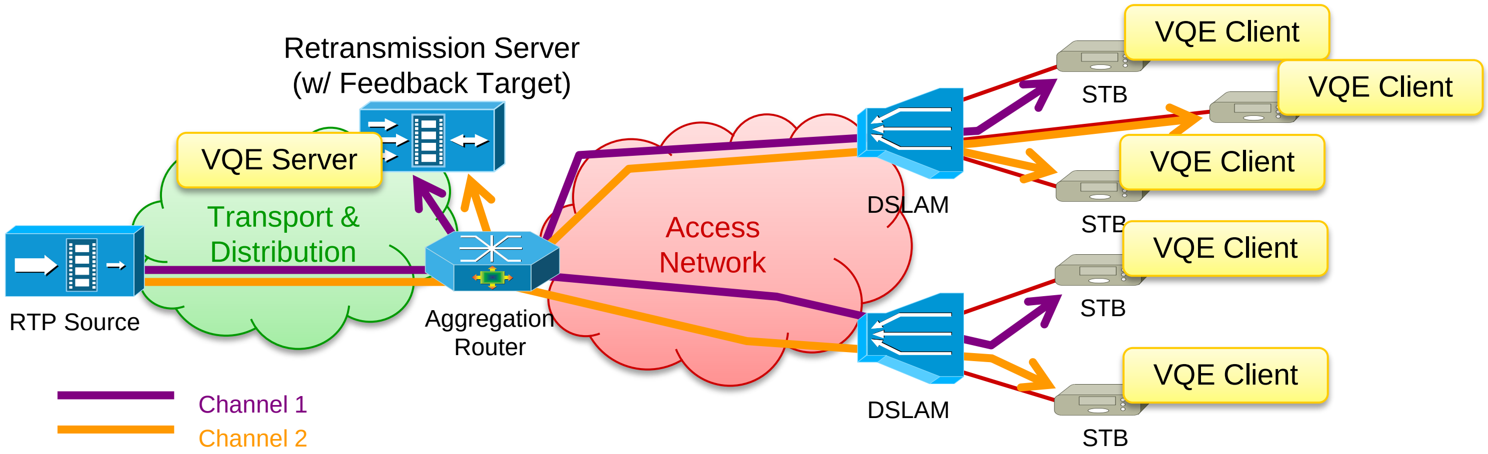
Video Distribution in the Access Networks

VQE – A Unified QoE Solution

Glitch-Free Audiovisual Quality, Short and Consistent Zapping

- **IPTV viewers have two criteria to judge their service**
  - Artifact-free audiovisual quality
    - Loss may be correlated in spatial and/or temporal domain, must be recovered quickly
    - Loss-repair methods must be multicast friendly
  - Short and consistent zapping times
    - Compression and encryption used in digital TV increase the zapping times
    - Multicasting in IPTV increases the zapping times
- **Service providers need a scalable unified solution that**
  - Is standards-based and interoperable with their infrastructure
  - Enables versatility, quick deployment and visibility into the network
  - Extends the service coverage area, and keeps CapEx and OpEx low

A Simplified Model

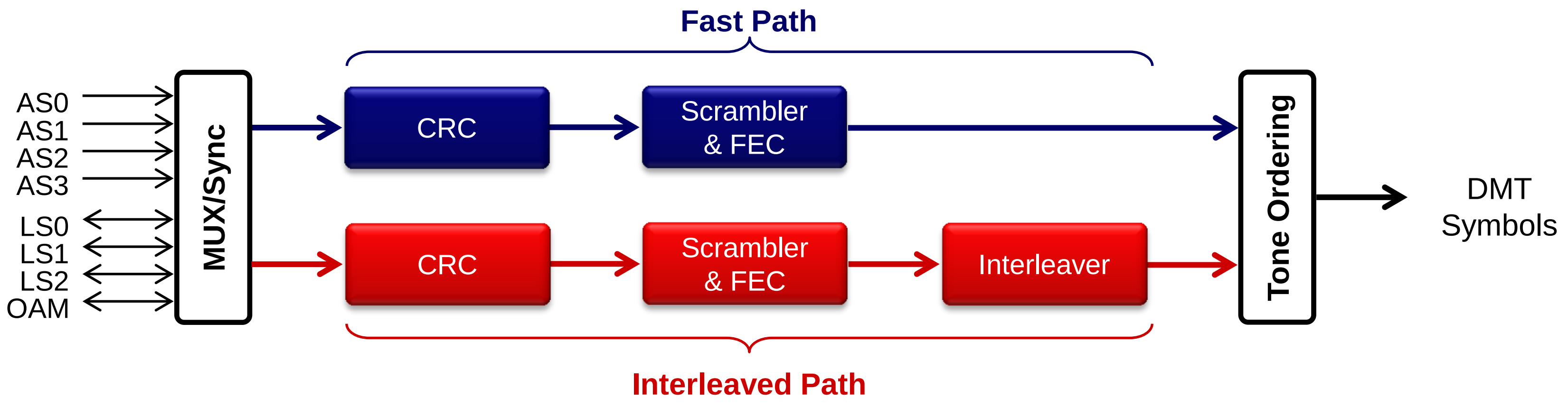


- **Each TV channel is served in a unique (SSM) multicast session**
  - IP STBs join the respective multicast session for the desired TV channel
  - Retransmission servers join all multicast sessions
- **Unicast feedback from IP STBs are collected by the feedback target**
  - NACK messages reporting missing packets, rapid channel change requests
  - RTCP receiver and extended reports reporting reception quality

Impairments in xDSL Networks

- **Twisted pair is subject to**
  - Signal attenuation: Use shorter loops
  - Cross talk: Use Trellis Coding and RS-based FEC
  - Impulse noise: Use RS-based FEC with interleaving
- **There are three types of DSL impulse noise**
  - REIN: Short burst of noises (< 1 ms)
  - PEIN: Individual impulse noise (> 1 ms, < 10 ms)
  - SHINE: Individual impulse noise (> 10 ms)
- **We observe different noise characteristics**
  - Among different SP networks
  - Among different loops in the same SP network

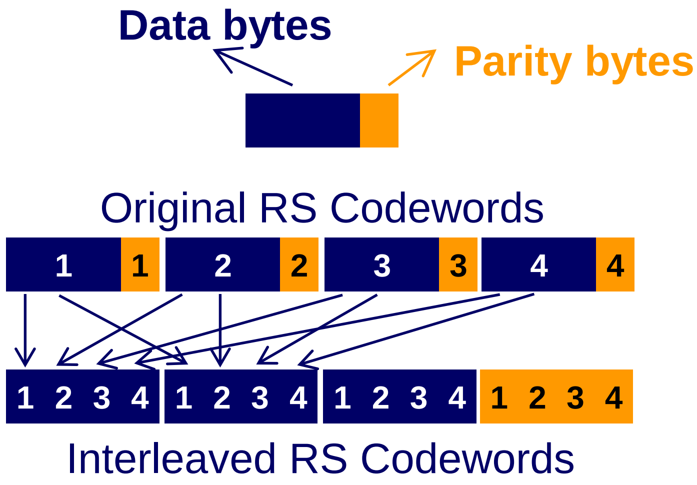
ADSL Transmitter Reference Model
ITU-T Recommendation G.992.1



ADSL and ADSL2+ Configurations

	ADSL	ADSL2+
Data bytes per RS codeword, K	239 bytes	69 bytes
Parity bytes per RS codeword, R	16 bytes	10 bytes
Correctable byte errors per RS codeword, T = R / 2	8 bytes	5 bytes
Total bytes per RS codeword, N = K + R	255 bytes	79 bytes
# of RS codewords per DMT symbol, 1/S	1	11
DMT duration, t	250 us	250 us
Line data rate, LDR = N / S / t	8.0 Mbps	27.4 Mbps
Net data rate, NDR = LDR x K / N	7.5 Mbps	24 Mbps
Interleaver depth, D	32	352
Size of required memory, B = (N–1) x (D–1)	7874 bytes	27378 bytes
Interleaving delay, ID = B / LDR	7.87 ms	7.97 ms
Block size (Protection period), PP = N x D / LDR	8.16 ms	8.10 ms
Correctable error burst length, BL = D x T	256 bytes	1760 bytes
Impulse noise protection, INP = floor(BL / (N / S))	1	2

Example: Interleaving of RS Codewords

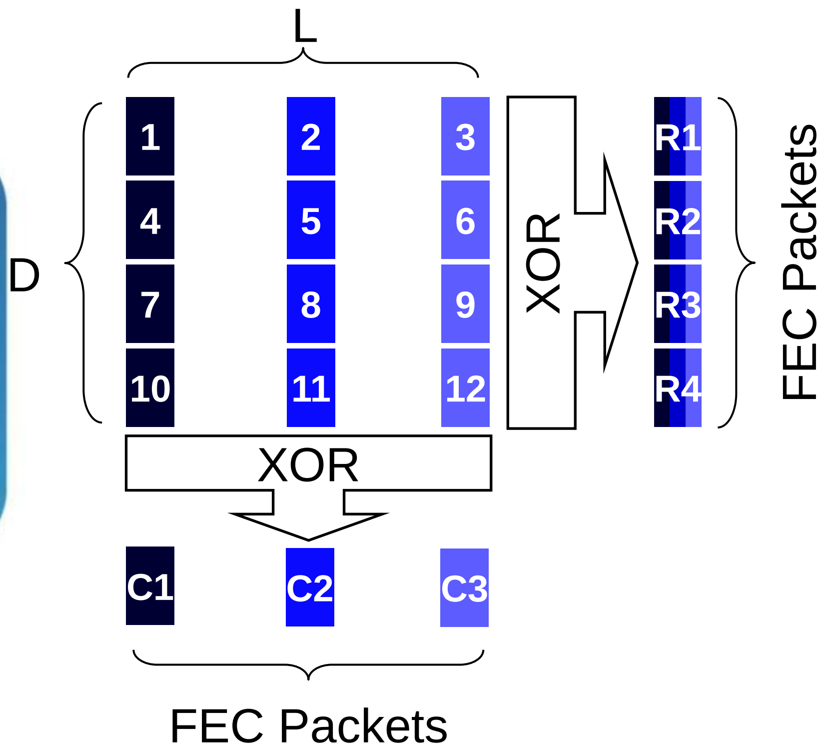


- Interleaving
  - ✓ Spreads a bursty error among multiple codewords
  - ✓ Allows the decoder to repair the error with fewer parity bytes
  - ✗ Introduces delay
  - ✗ Renders the whole block useless upon a decoding failure

Fast vs. Interleaved Path

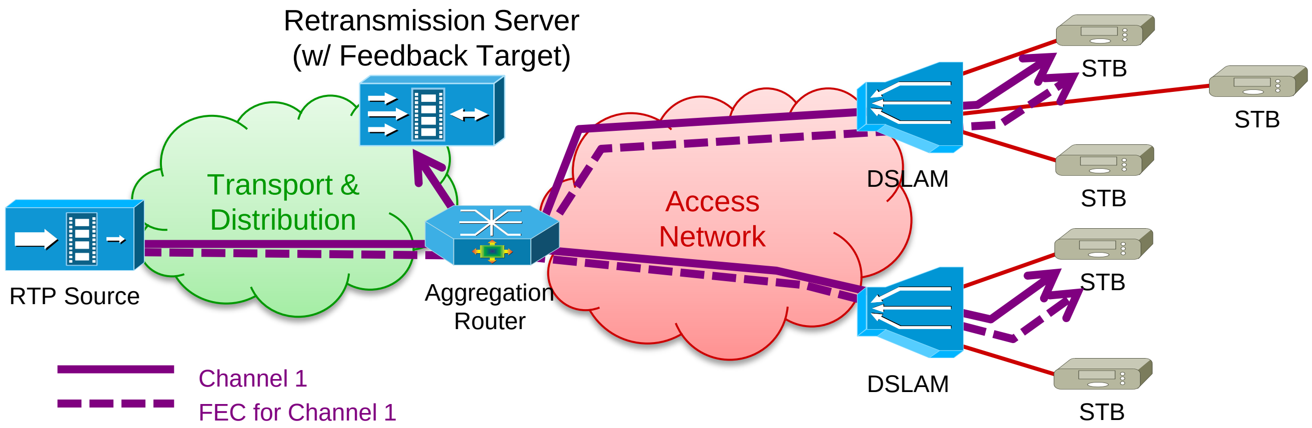
- **Assumptions**
  - One impulse noise arrives every 15 seconds
  - 2% of these impulses cause an error
- **Conditional Probability of (DMT error | There is an error)**
  - 85% probability for one DMT in error
  - 12% probability for two DMTs in error
  - 3% probability for three or more DMTs in error
- **Fast Path**
  - ADSL/ADSL2+: One (maybe two) IP packet loss in every 750 seconds
- **Interleaved Path (Interleaving delay: 8 ms)**
  - ADSL: Up to 7 IP packet losses (at the net rate) in every 5000 seconds
  - ADSL2+: Up to 19 IP packet losses in every 25000 seconds

First-Line of Defence in Loss Repair
1-D/2-D Parity Forward Error Correction



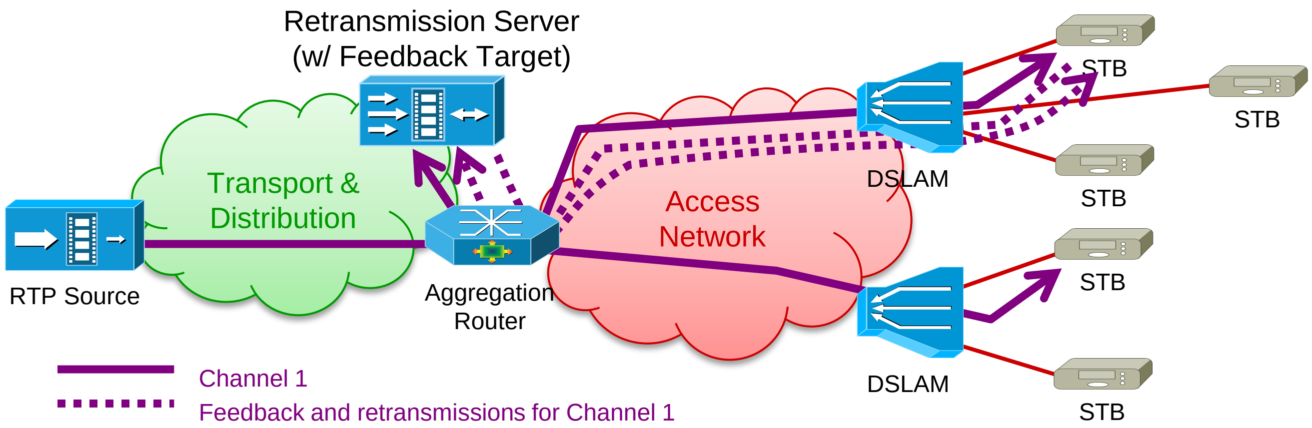
- **Source Block Size: D x L**
- **1-D Column FEC (for Bursty Losses)**
  - Each column produces a single packet
  - Overhead = 1 / D
  - L-packet duration should be larger than the (target) burst duration
- **1-D Row FEC (for Random Losses)**
  - Each row produces a single packet
  - Overhead = 1 / L
- **2-D Column + Row FEC**
  - Overhead = (D+L)/(DxL)

First-Line of Defence in Loss Repair
1-D/2-D Parity Forward Error Correction



- **Each TV channel may be associated with one or more FEC streams**
  - FEC streams may have different repair capabilities
  - IP STBs may join the respective multicast sessions to receive FEC stream(s)
- **General Remarks**
  - ✓ FEC scales extremely well with upfront planning, easily repairs spatially correlated losses
  - × Longer outages require larger overhead or larger block sizes (More delay)
  - × FEC requires encoding/decoding operations

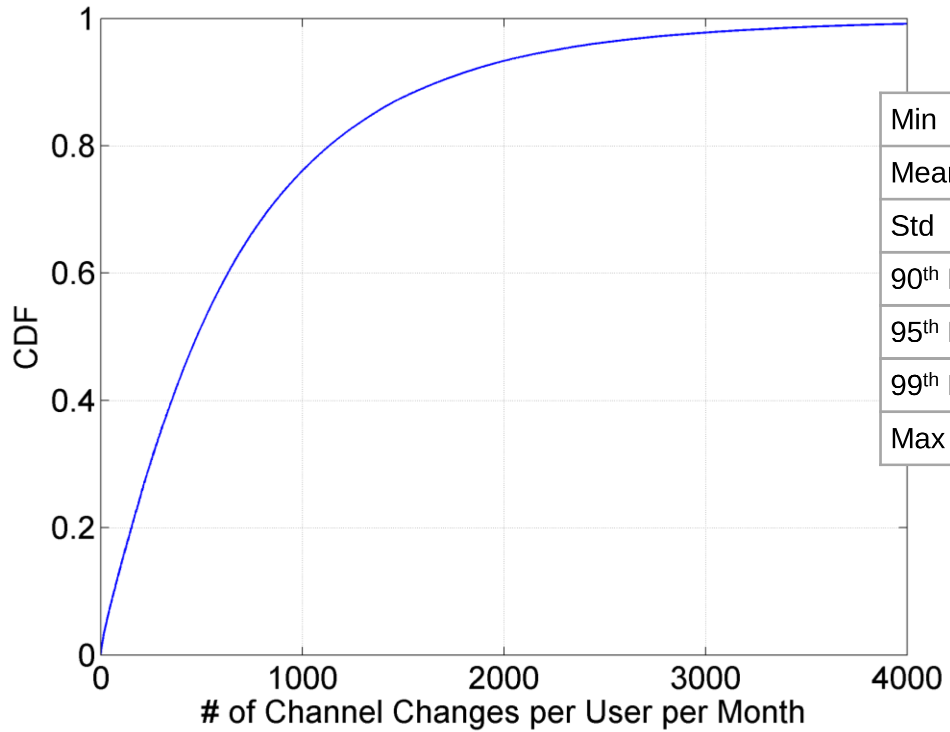
Second-Line of Defence in Loss Repair
RTP Retransmissions



- **There is a (logical) feedback target for each TV channel on the retransmission server**
  - If optional FEC cannot repair missing packets, IP STB sends an RTCP NACK to report missing packets
  - Retransmission server pulls the requested packets out of the cache and retransmits them
- **General Remarks**
  - ✓ Retransmission recovers only the lost packets, so no bandwidth is wasted
  - ✗ Retransmission adds a delay of destination-to-source-to-destination
- **Protocol suite comprises RFCs 3550, 4585, 4588 and 5760**

Improving Viewer Quality of Experience

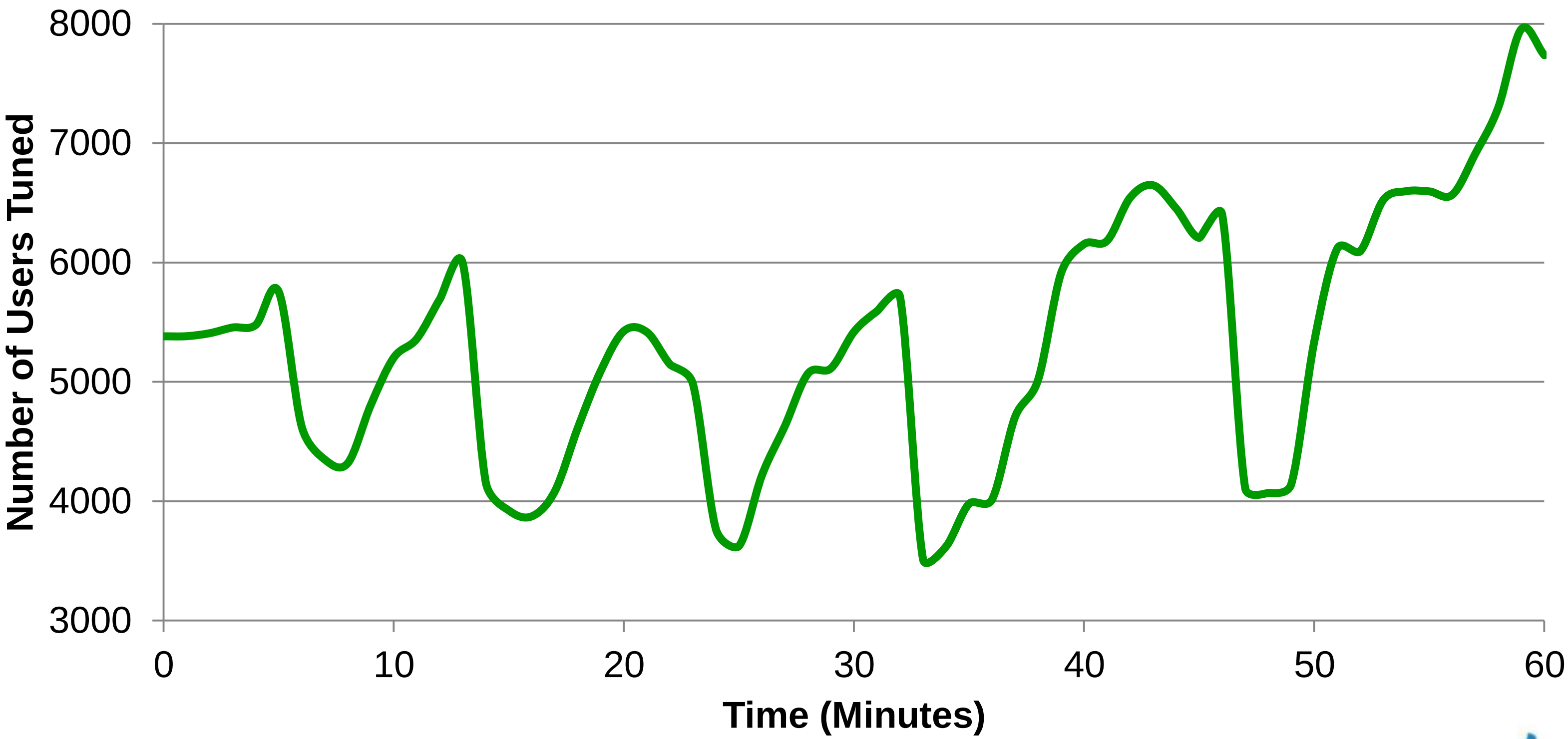
TV Viewers Love Zapping
Results are Based on 227K+ Users in NA



Min	1
Mean	726
Std	814
90th Percentile	1672
95th Percentile	2250
99th Percentile	3798
Max	24186

Zappings are Correlated in Temporal Domain

On a Sunday between 8:00 – 9:00 PM



Delay Elements in Multicast MPEG2-TS Video

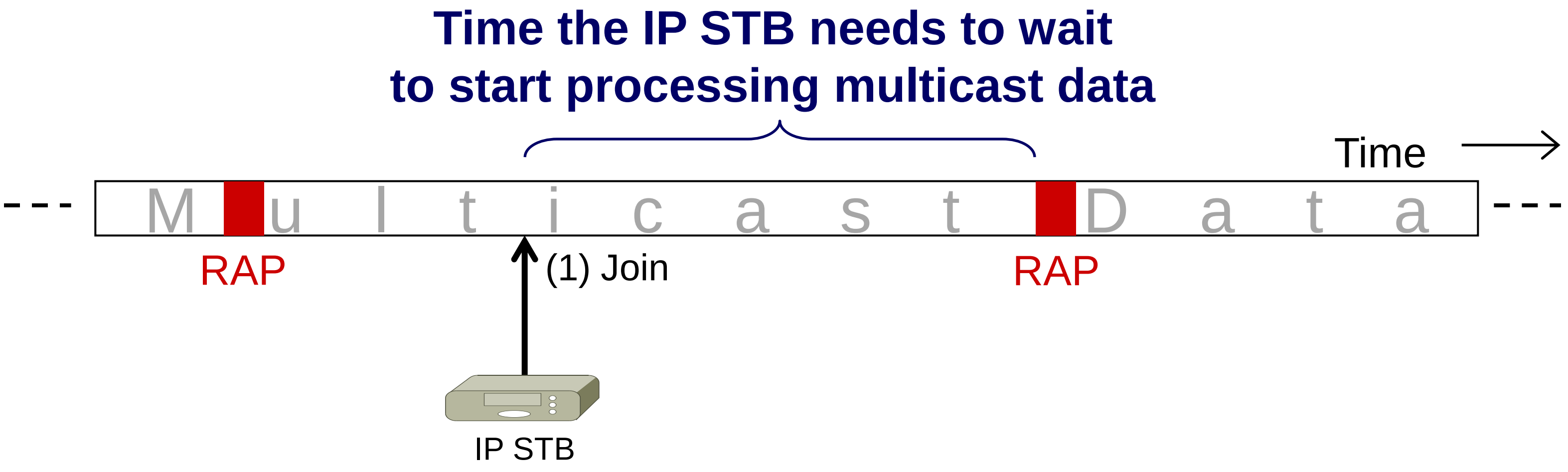
- **Multicast Switching Delay**
  - IGMP joins and leaves
  - Route establishment (Generally well-bounded)
- **Reference Information Latency**
  - PSI (PAT/CAT/PMT) acquisition delay
  - CAS (ECM) delay
  - RAP acquisition delay
- **Buffering Delays**
  - Loss-repair, de-jittering, application buffering
  - MPEG decoder buffering

Reference information latency and buffering delays are more critical in MPEG-based AV applications

Typical Zapping Times on DSL IPTV

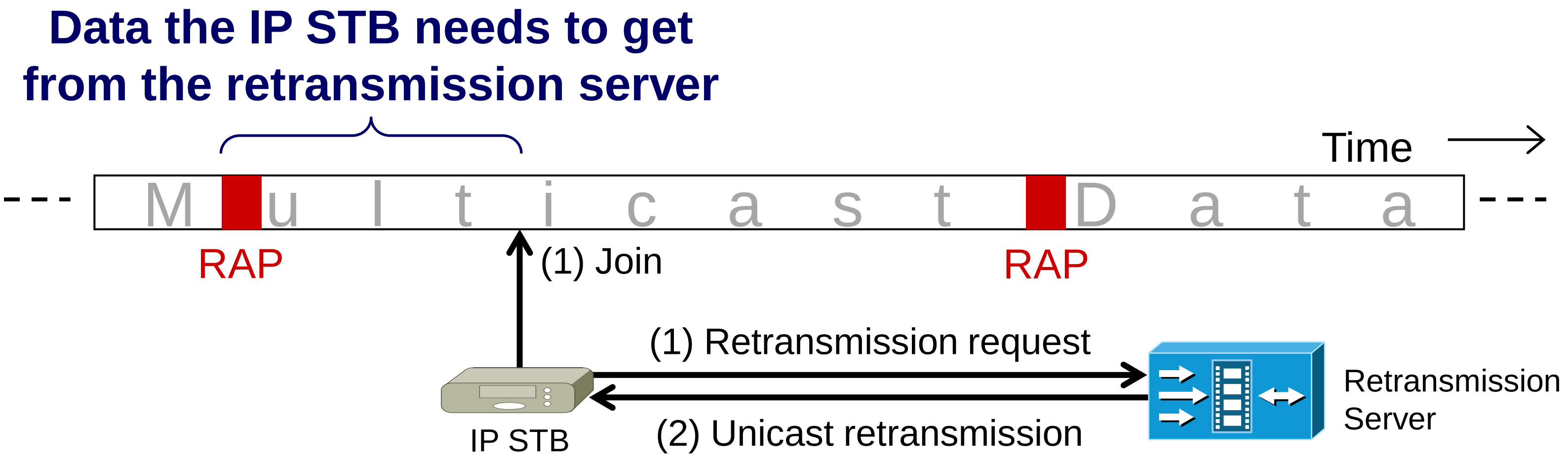
	Unit Time	Total Time
IP STB sends IGMP Leave	< 100 ms	
IP STB sends IGMP Join	< 100 ms	
DSLAM gets IGMP Leave	< 100 ms	
DSLAM gets IGMP Join	< 100 ms	~ 200 ms
DSLAM switches streams	50 ms	~ 250 ms
Latency on DSL line	~ 10 ms	~ 260 ms
IP STB receives PAT/PMT	~ 150 ms	~ 400 ms
Buffering		
De-jittering buffer	~ 150 ms	~ 550 ms
Wait for CA	< 50 ms	~ 600 ms
Wait for I-frame	0 – 3 s	0.5 – 3.5 s
MPEG decoding buffer	1 – 2 s	1.5 – 5.5 s
Decoding	**< 50 ms**	**1.5 – 5.5 s**

A Typical Multicast Join



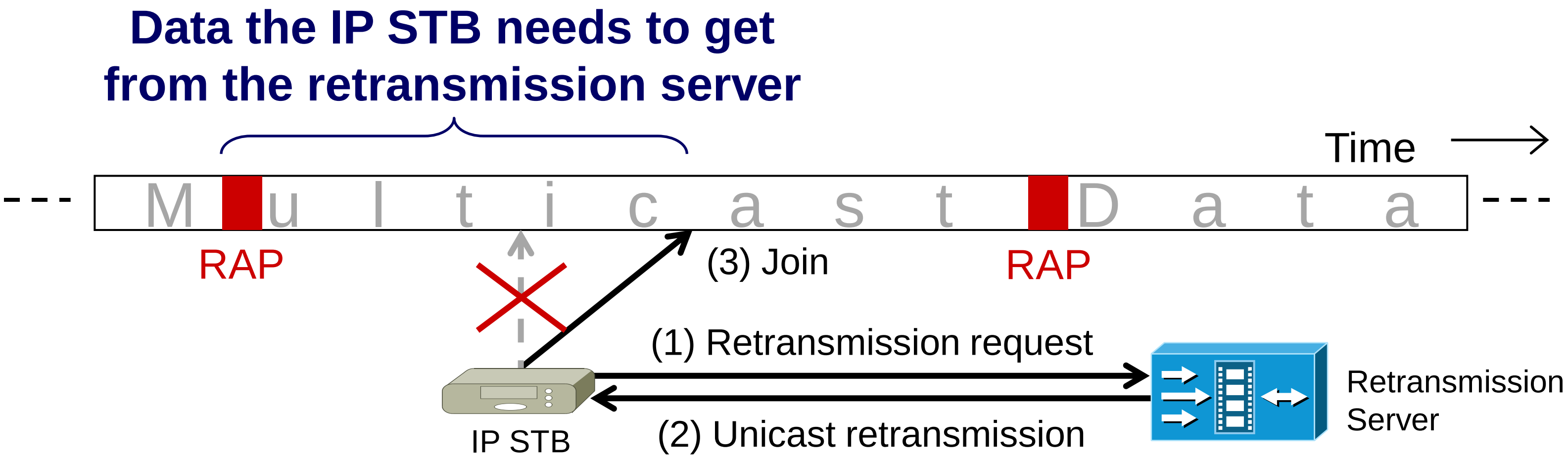
RAPs might be far away from each other
RAP data might be large in size and non-contiguous

Concurrent Multicast Join and Retransmission



If the residual bandwidth remaining from the multicast stream is small, retransmission may not be able to provide any acceleration

Retransmission Followed by Multicast Join



More data are retransmitted due to deferred multicast join
However, IP STB ultimately achieves a faster acquisition

Proposed Solution
Unicast-Based Rapid Acquisition

- **IP STB says to the retransmission server:**

  "I have no synch with the stream. Send me a repair burst that will get me back on the track with the multicast session"

- **Retransmission server**

  Parses data from earlier in the stream and bursts faster than real time

  Coordinates the time for multicast join and ending the burst

- **This solution uses the existing toolkit for repairing packet losses**

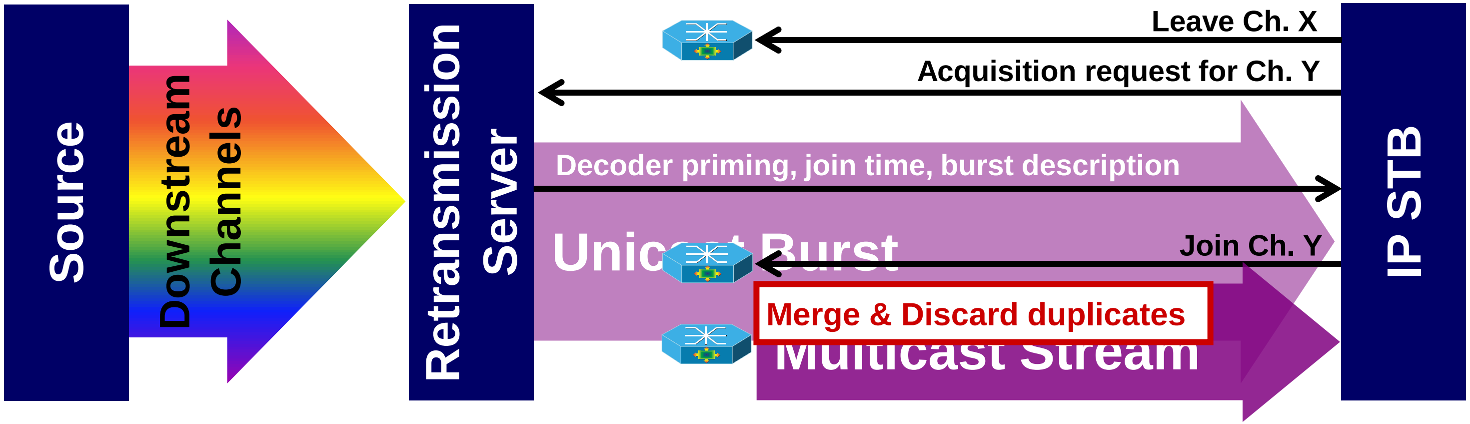
  RFC 3550 (RTP/RTCP)

  RFC 4585 (RTP AVPF)

  RFC 4588 (RTP Retransmissions)

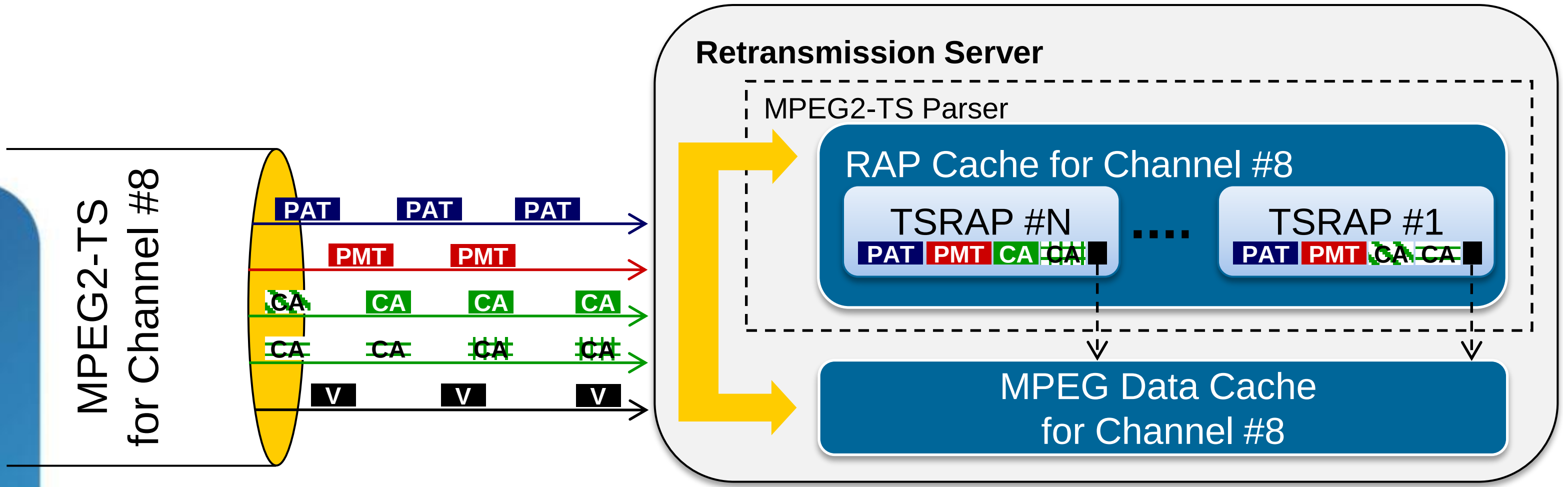
  RFC 5760 (RTCP Extensions for SSM)

Unicast-Based Rapid Acquisition
http://tools.ietf.org/html/rfc6285



How to Prime the MPEG Decoder?

http://tools.ietf.org/html/draft-begen-avt-rtp-mpeg2ts-preamble

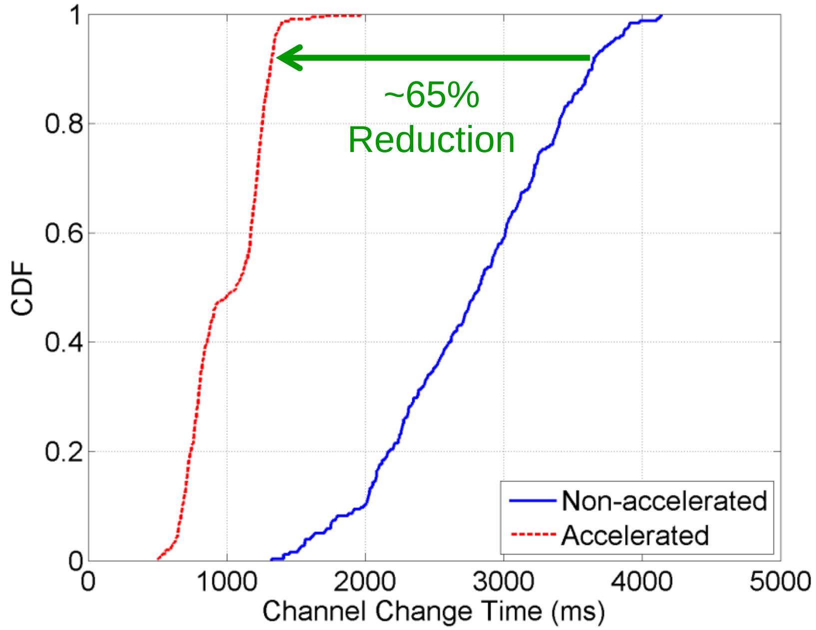


- Transport Stream Random Access Point (TSRAP) may include
  - PAT: Program Association Table, PMT: Program Map Table
  - PCR: Program Clock Reference used to initialise the decoder and STB clocks
  - SEQ: Sequence Header (MPEG2 video)
  - SPS: Sequence Parameter Set (H.264 video), PPS: Picture Parameter Set (H.264 video)
  - ECM: Entitlement Control Messages

Experimental Setup

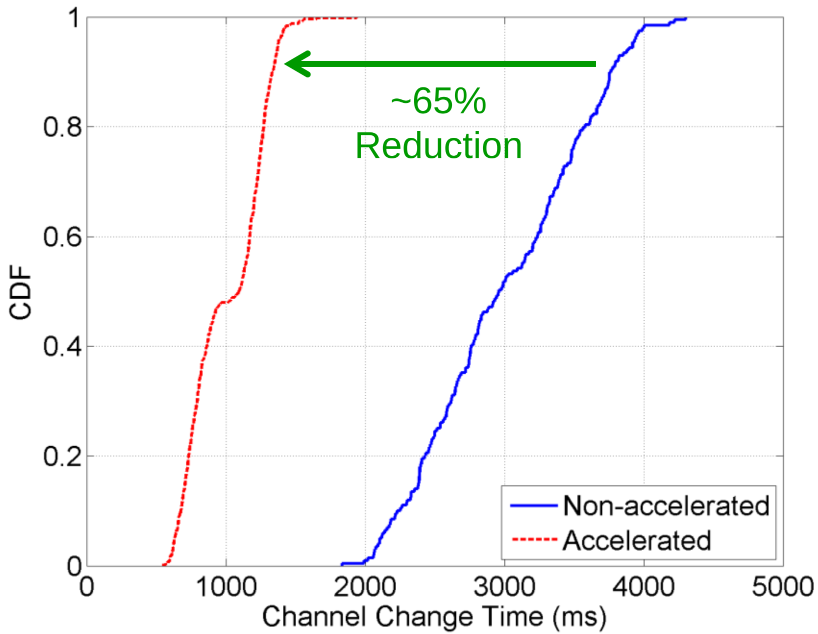
- **Comparison**
  - One IP STB with non-accelerated channel changes
  - One IP STB with accelerated channel changes
- **Video Streams**
  - Encoded with AVC at 2 Mbps and 30 fps
    - One stream with 15 frames per GoP (Short-GoP)
    - One stream with 60 frames per GoP (Long-GoP)
- **Transport**
  - 1356-byte RTP packets (7 TS packets plus RTP/UDP/IPv4 headers)
  - 20% additional bandwidth consumption for bursting
  - 500 ms loss-repair buffer in each IP STB

Short-GoP Results



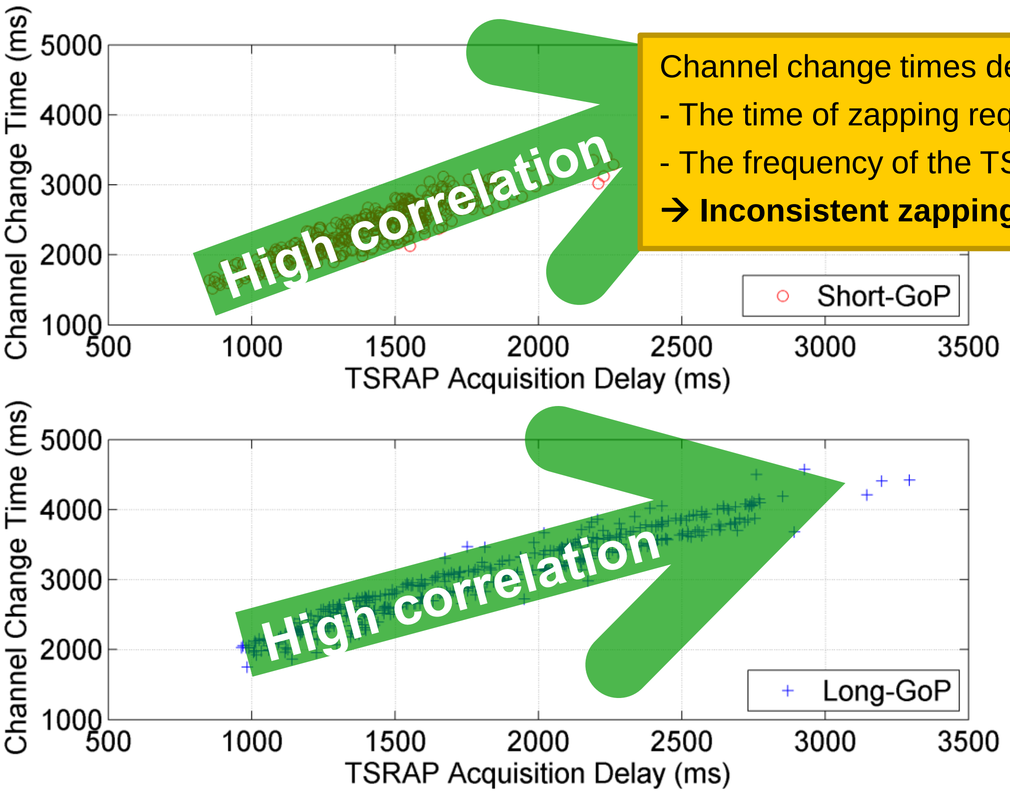
	Min	Mean	Std	95th	99th	Max
Non-accelerated	1323	2785	645	3788	4101	4140
Accelerated	501	1009	260	1345	1457	1965

Long-GoP Results



	Min	Mean	Std	95th	99th	Max
Non-accelerated	1831	3005	575	3920	4201	4300
Accelerated	536	1013	265	1377	1521	1937

When Acceleration is Disabled



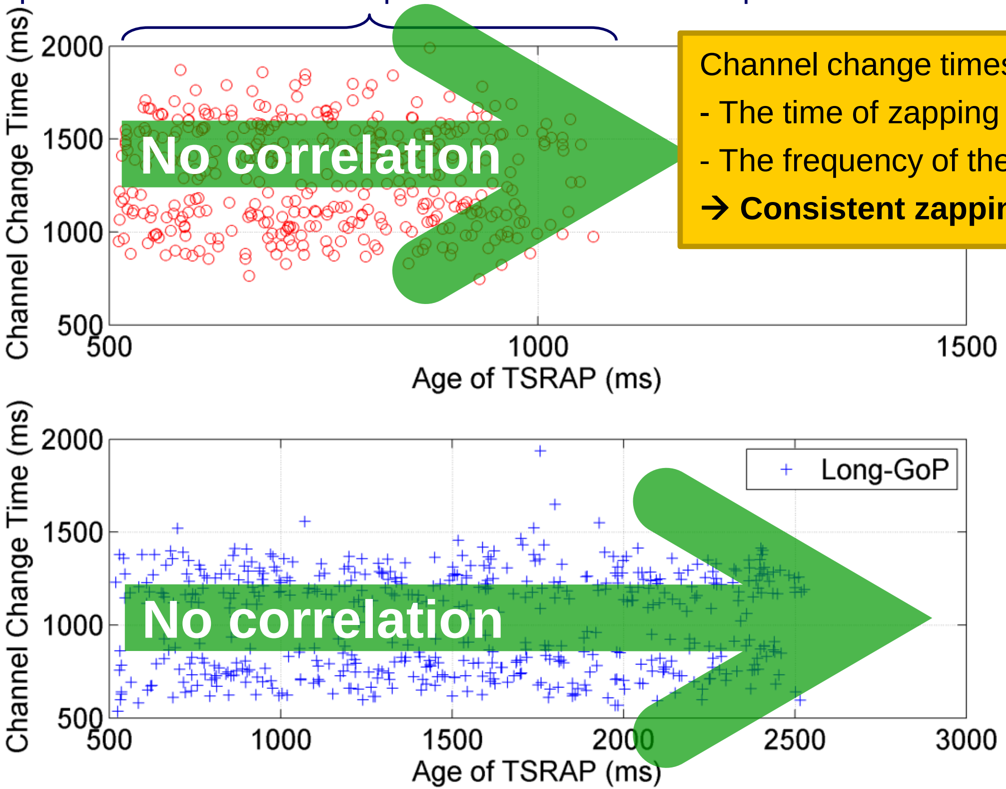
Channel change times depend on
- The time of zapping request
- The frequency of the TSRAP points

→ **Inconsistent zapping times**

TSRAP Acquisition Delay: Time for IP STB to receive all TS-related information

When Acceleration is Enabled

Loss-repair buffer size → Loss-repair buffer size + TSRAP period



Channel change times **DO NOT** depend on
- The time of zapping request
- The frequency of the TSRAP points

→ **Consistent zapping times**

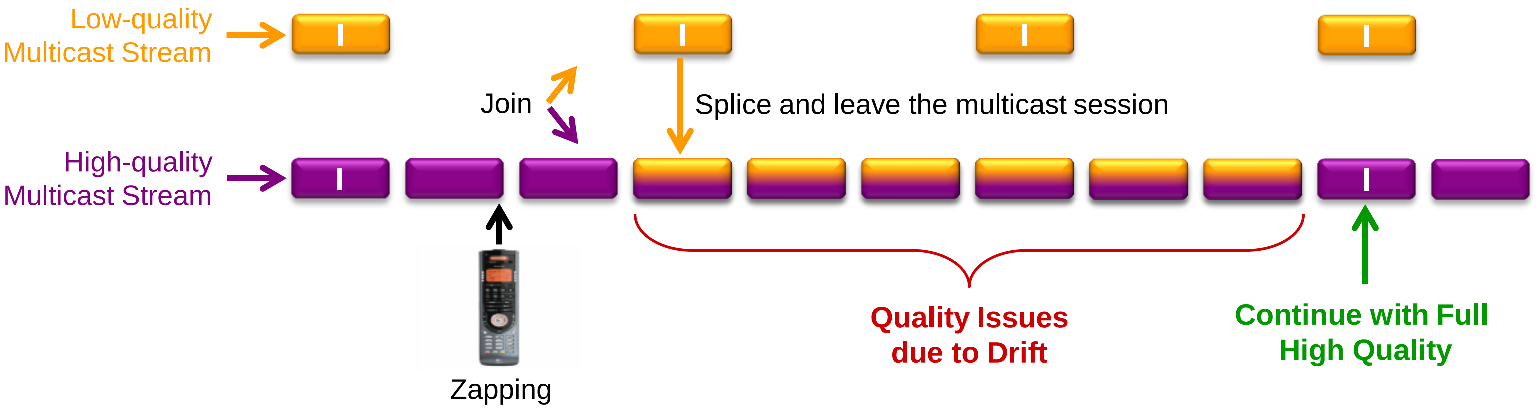
Age of TSRAP: Denotes how far TSRAP is behind multicast session when the burst starts

Unicast-Based Rapid Acquisition
Reading

"Scaling server-based channel-change acceleration to millions of IPTV subscribers," Packet Video Wksp. 2012

"Reducing channel-change times with the real-time transport protocol," IEEE Internet Computing, May/June 2009

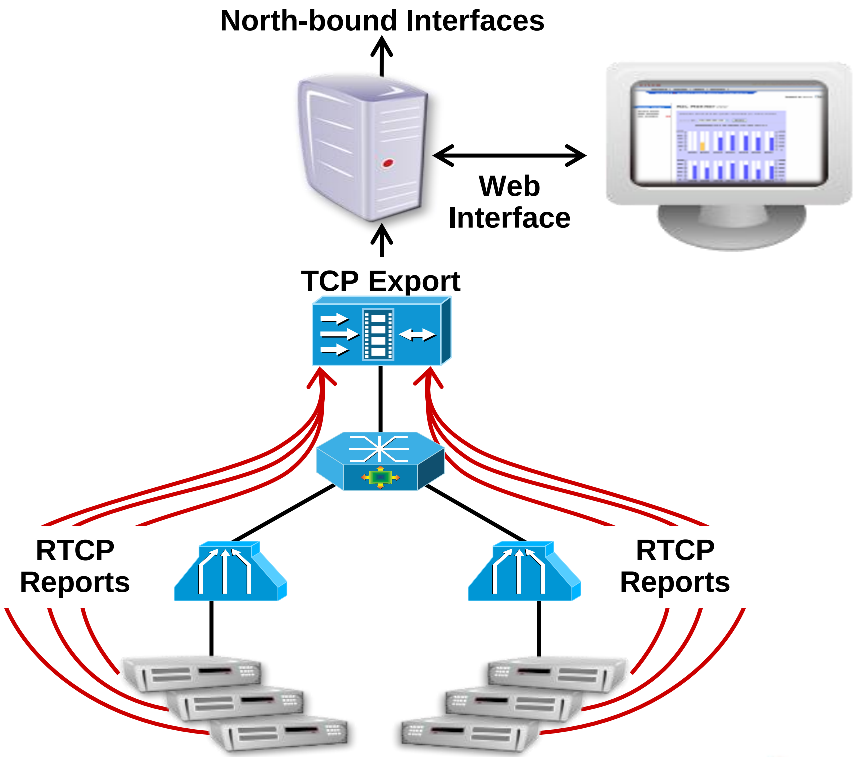
Companion-Stream Approach
The Basic Idea



VQE QoS/QoE Monitoring

Tools to Isolate and Pinpoint the Problematic Locations

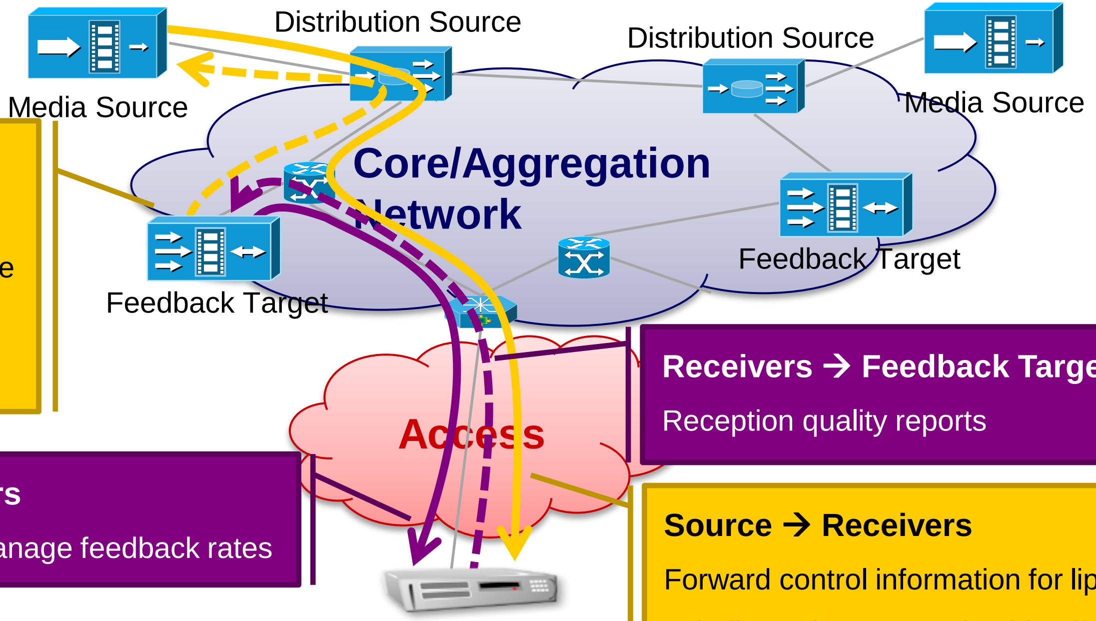
- VQE-S collects RTCP reports and outputs them to the management application
- Management application
  - Collects raw data from exporter
  - Organises database
  - Conducts data analysis, trends
  - Create alerts
- Management application supports standards-based north-bound interfaces
- Reports and analysis can be granular to
  - Regions, edge routers
  - DSLAMs, access lines
  - Home gateways
  - Set-tops
- Set-tops can support RTCP reporting and TR-069 (or TR-135) concurrently



RTCP Sender/Receiver/Extended Reports

- **RTCP Sender Reports provide info on data sent recently**
  - Wallclock time and the corresponding RTP timestamp
  - Total number of packets/bytes sent
- **RTCP Receiver Reports summarise the reception quality**
  - Timestamp of (and delay from) the last received sender report
  - Highest sequence number seen so far
  - Number and fraction of the lost RTP packets
  - Estimate of the interarrival jitter
- **RTCP Extended Reports (XR) provide**
  - Detailed transport-level stats
  - Application-specific information about RTP transport

Four RTCP Flows, Two RTCP Loops



Feedback Targets → Source

Reception quality reports reporting quality of the path from source to the feedback target and summarising reception quality for receivers

Receivers → Feedback Target

Reception quality reports

Feedback Target → Receivers

Forward control information to manage feedback rates

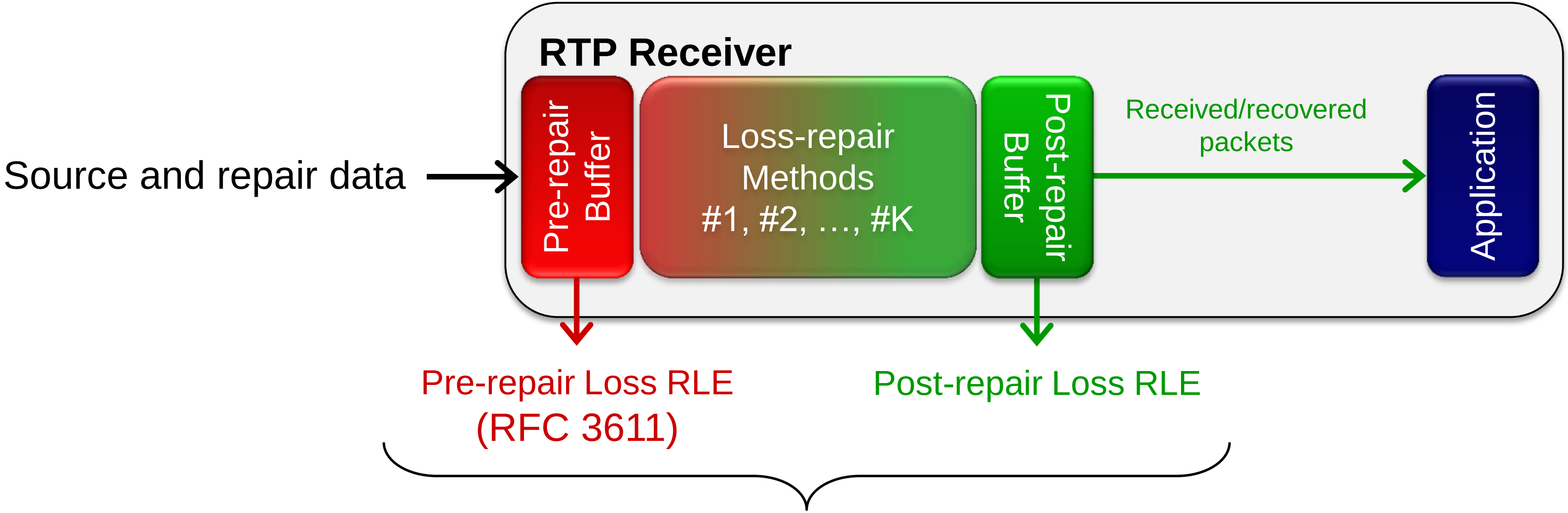
Source → Receivers

Forward control information for lip-synchronisation, to indicate liveness and to identify the source

RTCP XR Framework

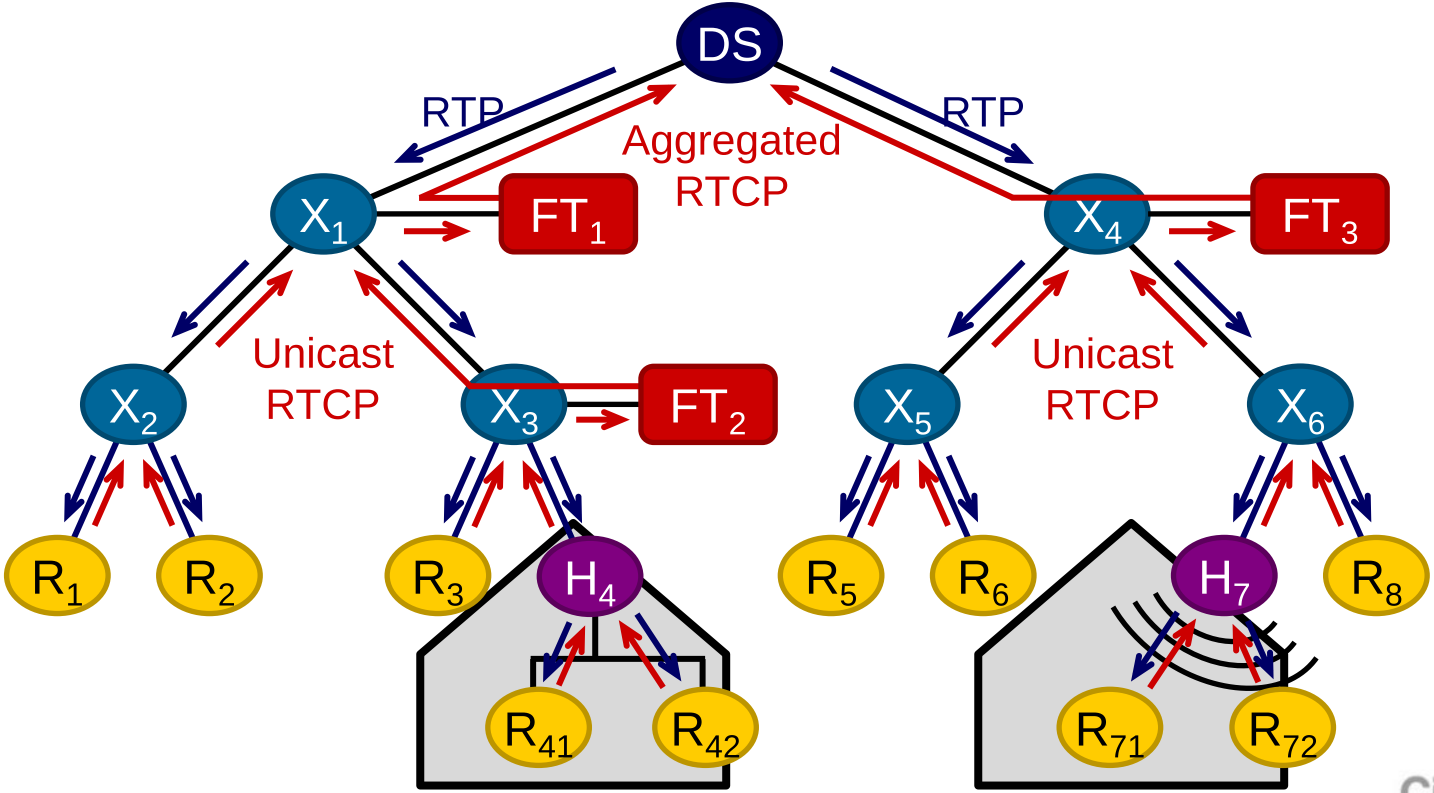
- **Provides several advantages over traditional and proprietary monitoring solutions**
- **Easily extensible to report on**
  - Packet-level loss events/patterns, mean time between losses, loss durations, etc.
    - Correlation engines identify, characterise and isolate the problems
  - Audiovisual reception quality
  - Effectiveness of the loss-repair methods
    - Loss-repair methods can be adapted depending on the network conditions
  - Effectiveness of channel change acceleration

RTCP XR Example: Loss RLE Reports
http://tools.ietf.org/html/rfc5725



The difference tells us the aggregated performance of the loss-repair methods

Fault Isolation through Network Tomography
Monitoring Viewer QoE with No Human Assistance



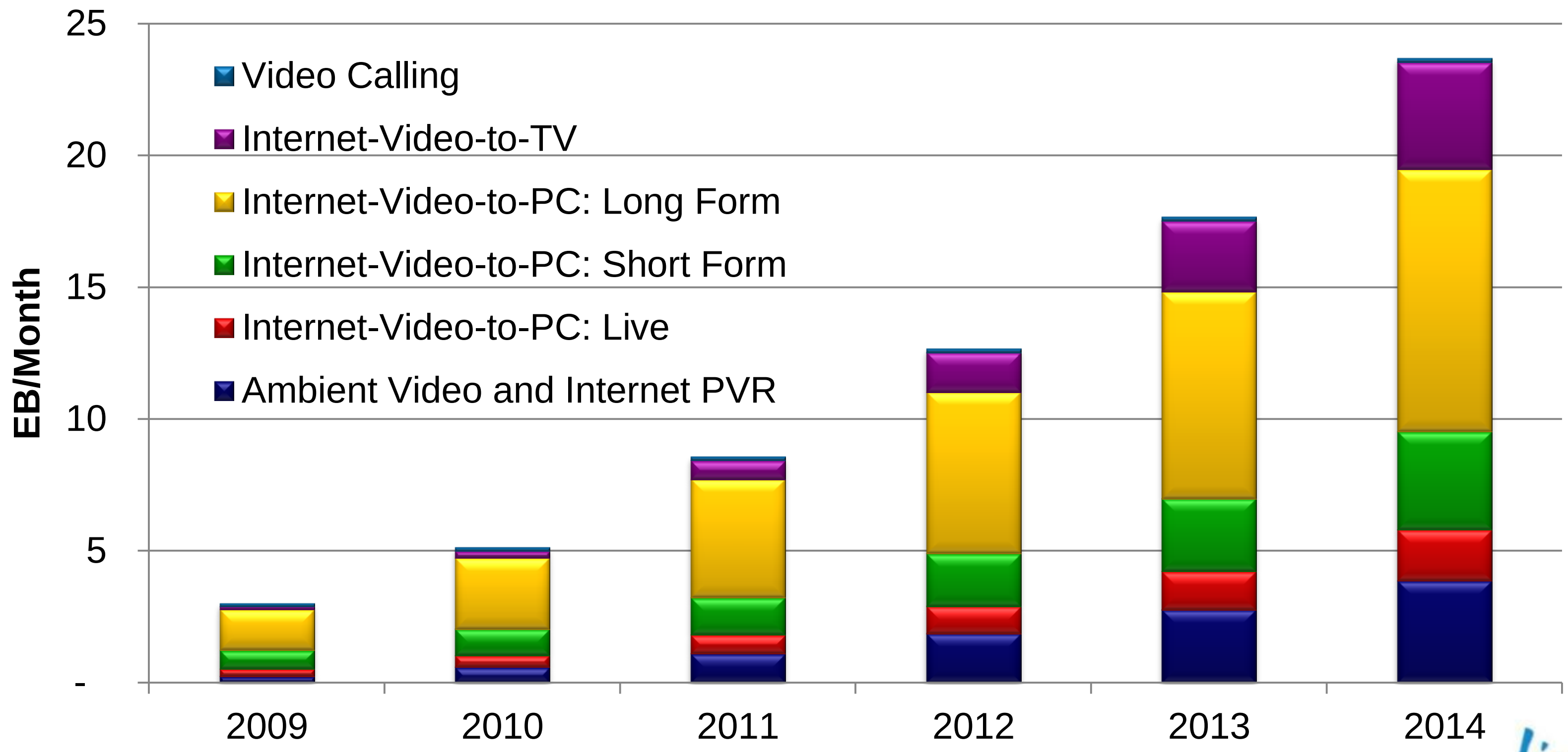
Fault Isolation through Network Tomography
Reading

"On the scalability of RTCP-based network tomography for IPTV services," IEEE CCNC 2010

"On the use of RTP for monitoring and fault isolation in IPTV," IEEE Network, Mar./Apr. 2010

Part II: Internet Video and Adaptive Streaming

Consumer Internet Video Composition



Source: http://ciscovni.com, EB: 1e18 bytes

Internet Video Essentials

Reach	• Reach all connected devices
Scale	• Enable live and on-demand delivery to the mass market
Quality of Experience	• Provide TV-like consistent rich viewer experience
Business	• Enable revenue generation thru paid content, subscriptions, targeted advertising, etc.
Regulatory	• Satisfy regulations such as captioning, ratings and parental control

Example Over-the-Top (OTT) Services

The Lines are *Blurring* between TV and the Web

AT&T U-verse – US

Verizon FlexView – US

ABC TV – Australia

TiViBu – Turkey

Amazon – US

Onet – Poland

HBO GO

Delivery of TV Content to IP-Enabled Devices

- Subscribers can watch HBO content via the Internet or 3G (only in the US)

  First launched in Feb. 2010 with Verizon FiOS

  Later expanded to AT&T U-Verse, DirecTV, DISH Network, Suddenlink, WOW!, Comcast Xfinity, Time Warner Cable (Beta available for Cox, Harvard, etc.)

  Content includes more than 1,400 titles, every episode of every season of HBO series

http://www.hbogo.com/

Netflix

Content

Over 100K titles (DVD)

Shipped 1 billionth DVD in 02/07

Shipped 2 billionth DVD in 04/09

Revenue

$905M in Q3 2012

$3.2B in 2011 and $2.1B in 2010

Streaming Subscribers

25.1M in the US by Q3 2012 (4.3M elsewhere)

[8.6M DVD subscribers in the US]

Competitors

Hulu Plus, Amazon Prime, TV Everywhere

Difficulties

ISP data caps (Most notably in Canada)

ISP/CDN throughput limitations

Big Data at Netflix

Ratings: 4M/day

Searches: 3M/day

Plays: 30M/day

2B hours streamed in Q4 2011, 3B hours in Q3 2012

Plans

Unlimited streaming (only) for $7.99 (US and Canada)

[Supported by over 450 devices]

1 DVD out at-a-time for $7.99 (US)

Blu-rays for an additional $2 per month (US)

Hulu

- **Summary**
  - Available in the US and Japan
  - Ad-supported subscription service business model
    - 2M Hulu Plus subscribers in 2012
  - Revenue of $420M (2011), $263M (2010), $108M (2009) and $25M (2008)
- **Content**
  - Catch-up TV (30000+ episodes)
  - 900+ movies
  - 350+ content partners
  - Encoded at 480, 700, 1000, 2500 and 3200 Kbps
- **Devices**
  - Primarily PC and Mac
  - Smartphones and tables (only w/ Hulu Plus)
  - Internet-connected TV (only w/ Hulu Plus)

BBC iPlayer
Available (Almost) Globally

- Statistics for September 2011

  Total Requests

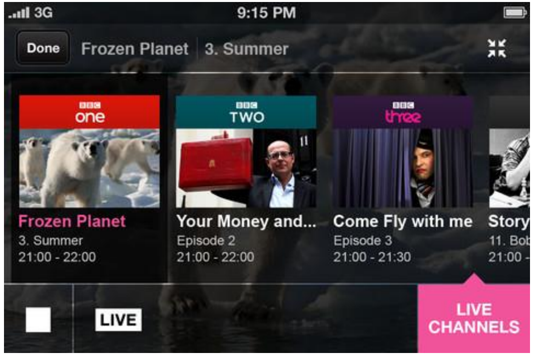
  90M for TV programs (13% of the requests were for live streams)

  40M for radio programs (77% of the requests were for live streams)

  Devices

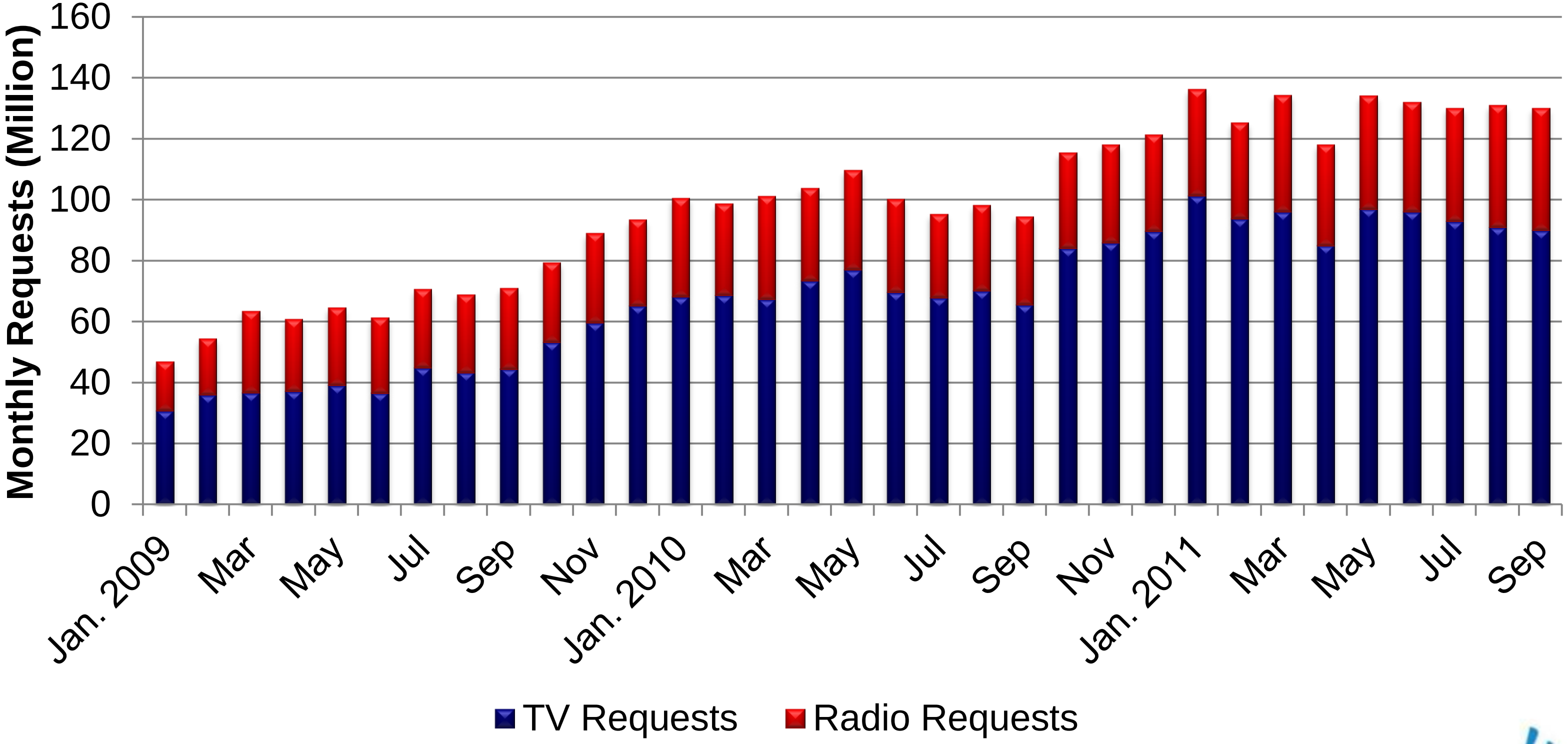
  65% computers, 15% Virgin Media, 5% game consoles, %6 mobile devices, %3 tablets

- 3G streaming is still unavailable on some platforms/operators



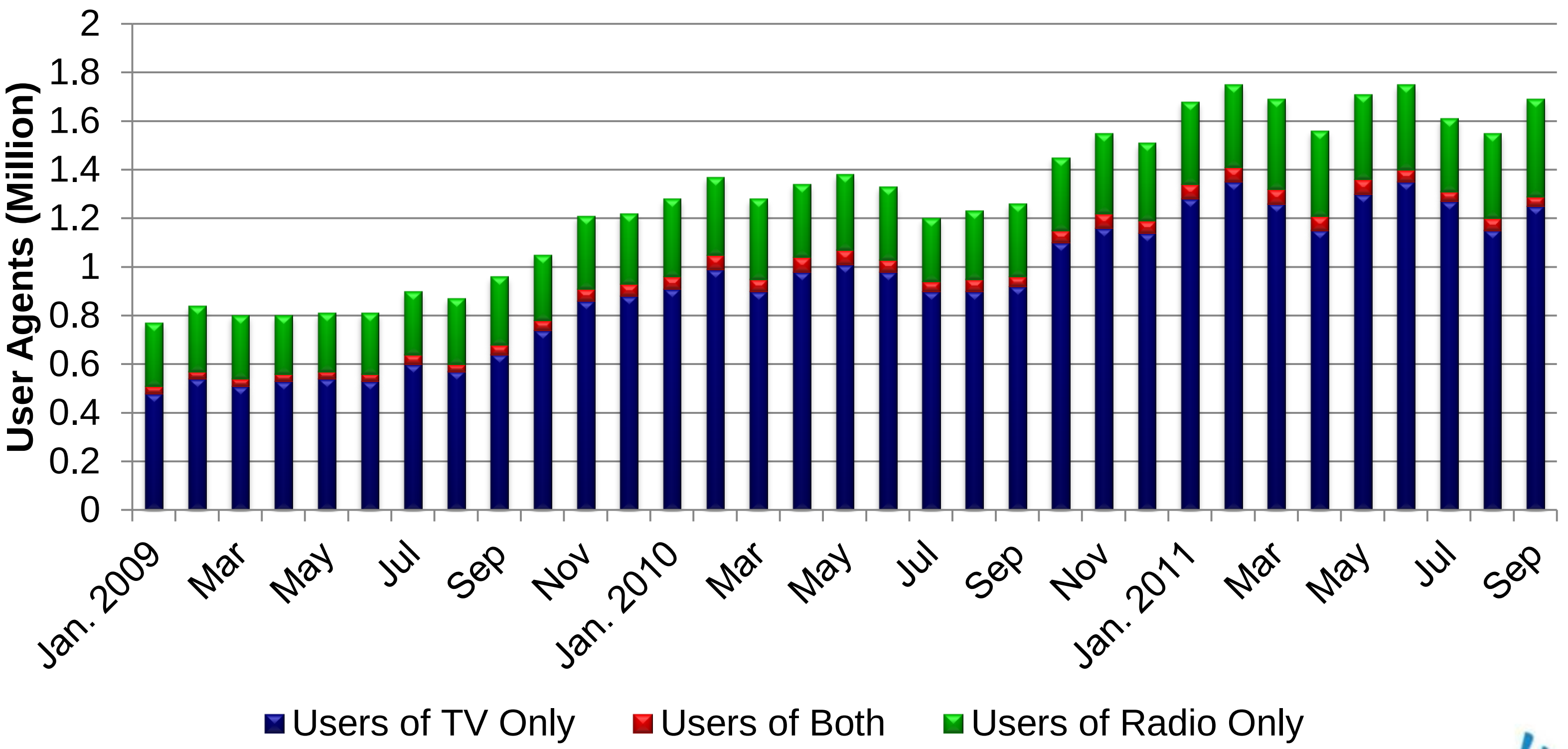
Source: BBC iStats

iPlayer – Monthly Online Requests



Source: BBC iStats

iPlayer – Average Daily Users



Source: BBC iStats

Internet Video in the US
October 2012

	Unique Viewers (x1000)	Videos (x1000)	Minutes per Viewer
Google Sites	153,212	13,028,148	399.5
Yahoo! Sites	55,253	496,318	53.1
NDN	53,215	550,884	74.3
VEVO	53,105	628,958	40.5
AOL, Inc.	53,089	711,008	45.6
Facebook.com	47,870	252,934	13.3
Viacom Digital	40,914	391,700	43.8
Microsoft Sites	37,214	432,457	43.8
CBS Interactive	31,805	297,749	59.9
Grab Media, Inc.	31,647	157,946	27.5
Total	**182,574**	**37,242,927**	**1,254.4**

Source: comScore Video Metrix

Internet Video in the EU
In 2011

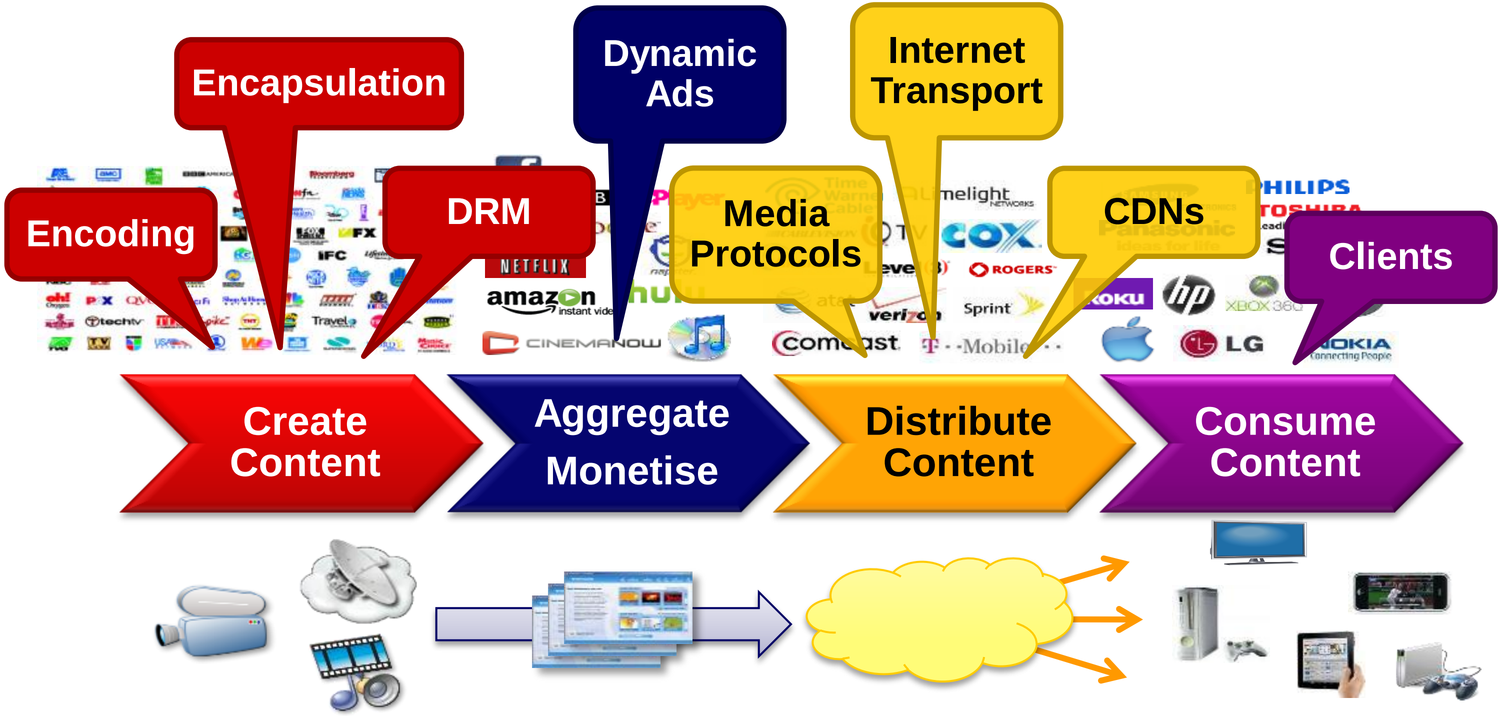
	Videos (March)	Videos (September)	Minutes per Video	Minutes per Viewer
Spain	3.0B	3.2B	6.9	1,096
Italy	2.3B	2.7B	6.7	914
Russia	3.1B	4.7B	7.2	792
Turkey	3.4B	5.0B	7.1	1,660

Source: comScore Video Metrix

Internet Video Delivery – CDN Market

- **Internet video CDN revenues are expected to grow to $2B in 2015**
  - Revenue was $600M in 2010
  - Price per GB has been decreasing to $0.15 - $2.0
- **Most Internet video providers outsource delivery**
  - 50% of the market is dominated by Akamai, Limelight Networks and Level 3
    - A few very large content providers build their own CDN infrastructure
    - E.g., Google, Microsoft, Amazon
  - Only a few network service providers will compete in the global CDN market
- **Traffic growth is driven by**
  - More users
  - More content
  - Longer viewing at higher qualities
- **CDN providers are diversifying into value-added services**
  - Advertising business
  - Application acceleration

Open Digital Media Value Chain



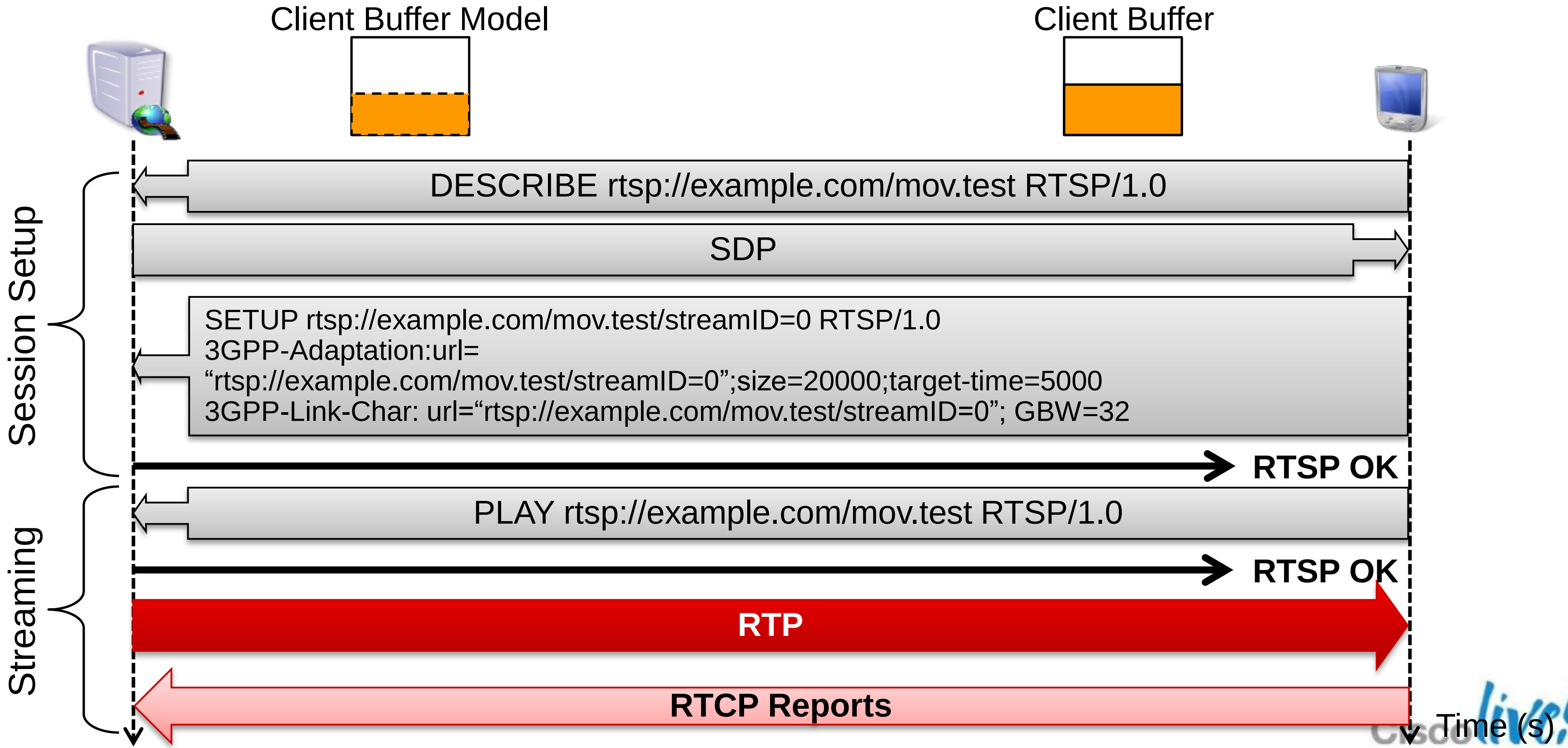
Any Content Any Storefront Any Network Any Device

Media Delivery over the Internet

Push and Pull-Based Video Delivery

	Push-Based Delivery	Pull-Based Delivery
Source	Broadcasters/servers like Windows Media Apple QuickTime, RealNetworks Helix Cisco CDS/DCM	Web/FTP servers such as LAMP Microsoft IIS Adobe Flash RealNetworks Helix Cisco CDS
Protocols	RTSP, RTP, UDP	HTTP, RTMPx, FTP
Video Monitoring and User Tracking	RTCP for RTP transport	(Currently) Proprietary
Multicast Support	Yes	No
Cacheability	No	Yes for HTTP

Push-Based Video Delivery over RTSP
3GPP Packet-Switched Streaming Service (PSS)



Pull-Based Video Delivery over HTTP

Progressive Download vs. Pseudo and Full Streaming

Progressive Download

- Server sends a file as fast as possible
- Client starts playout after a certain initial buffering

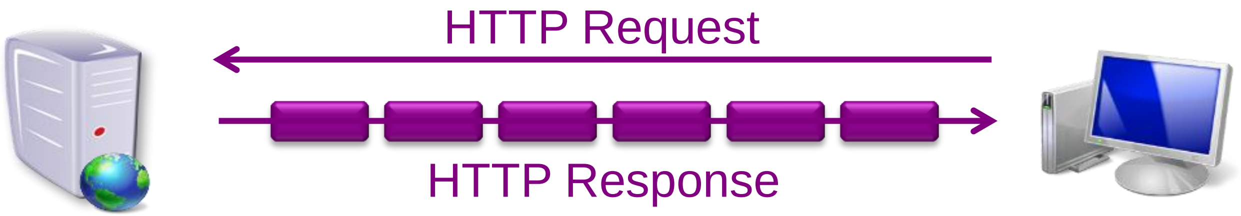
Pseudo Streaming

- Server paces file transmission
- Client can seek
- Some metadata is required

Full Streaming

- Client requests small chunks enabling adaptation
- Live streaming and dynamic ads are supported

Progressive Download
One Request, One Response



What is Streaming?

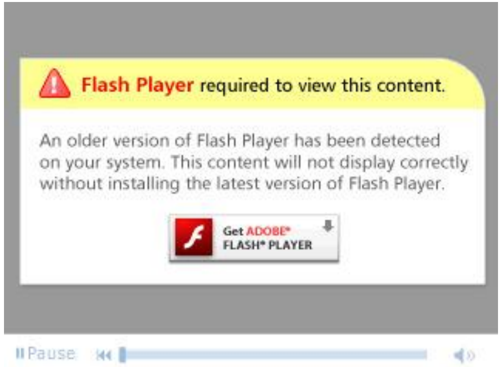
Streaming is transmission of a continuous content from a server to a client and its simultaneous consumption by the client

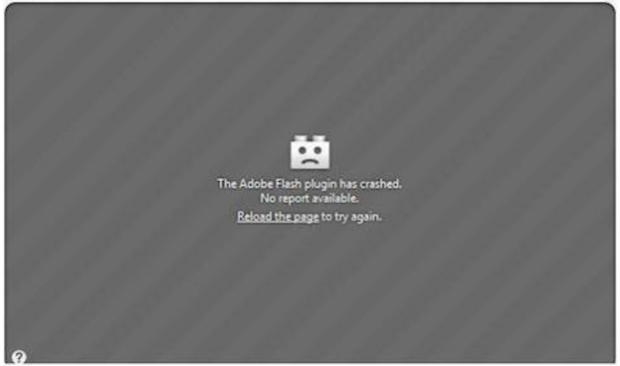
Two Main Characteristics

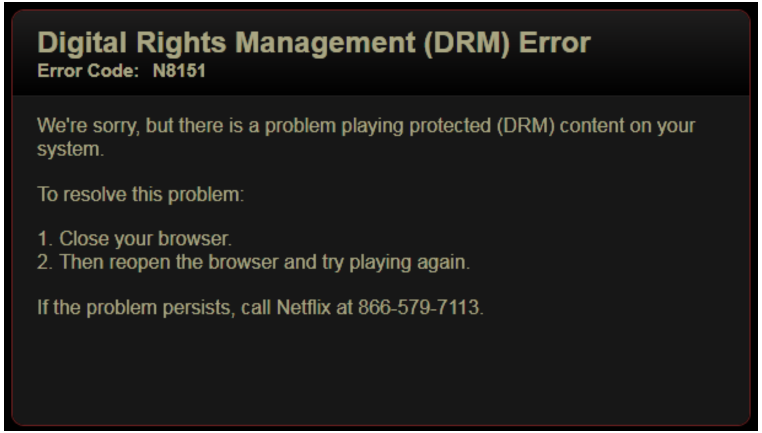
1. Client consumption rate may be limited by real-time constraints as opposed to just bandwidth availability
2. Server transmission rate (loosely or tightly) matches to client consumption rate

Common Annoyances in Streaming

Stalls, Slow Start-Up, Plug-In and DRM Issues





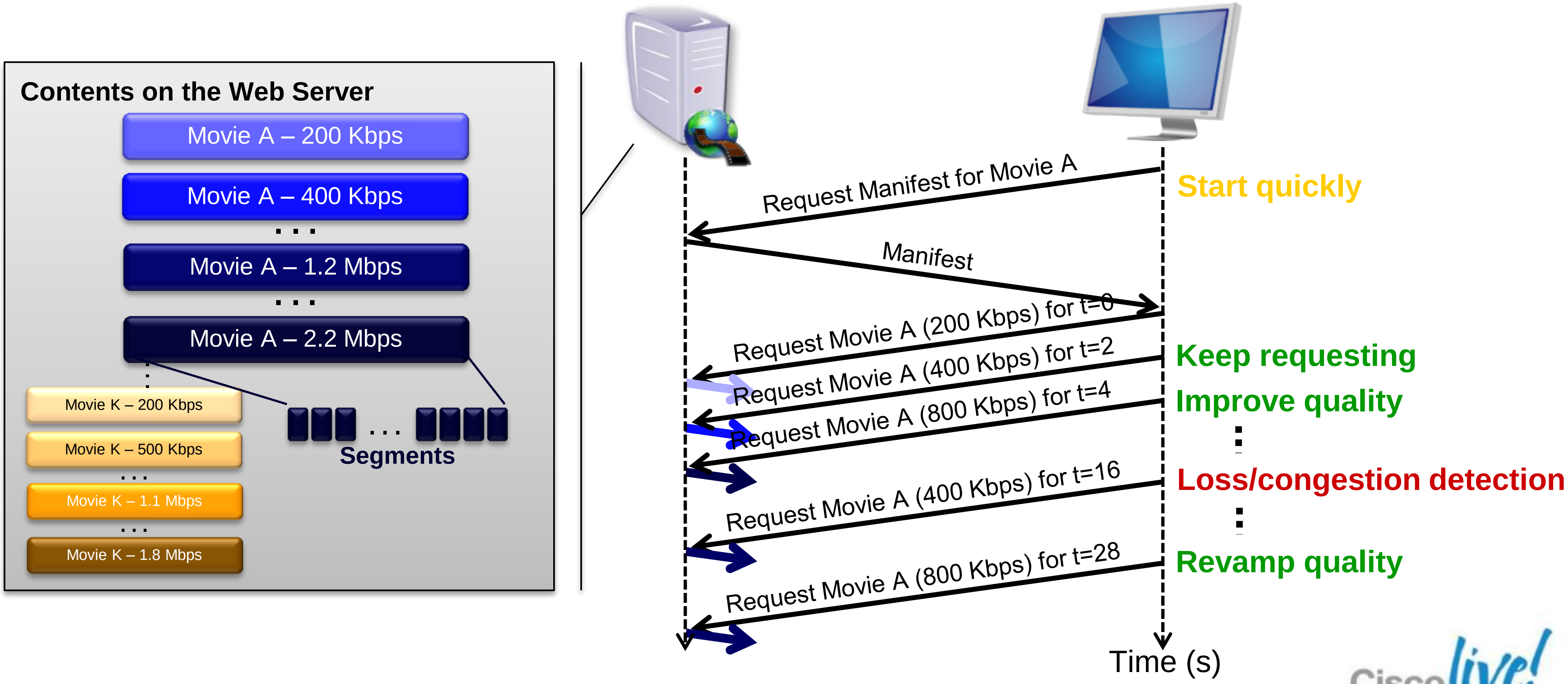


Adaptive Streaming over HTTP

Adaptive Streaming over HTTP
Adapt Video to Web Rather than Changing the Web

- **Imitation of Streaming via Short Downloads**
  - Downloads desired portion in small chunks to minimise bandwidth waste
  - Enables monitoring consumption and tracking clients
- **Adaptation to Dynamic Conditions and Device Capabilities**
  - Adapts to dynamic conditions anywhere on the path through the Internet and/or home network
  - Adapts to display resolution, CPU and memory resources of the client
  - Facilitates "any device, anywhere, anytime" paradigm
- **Improved Quality of Experience**
  - Enables faster start-up and seeking (compared to progressive download), and quicker buffer fills
  - Reduces skips, freezes and stutters
- **Use of HTTP**
  - Well-understood naming/addressing approach, and authentication/authorisation infrastructure
  - Provides easy traversal for all kinds of middleboxes (e.g., NATs, firewalls)
  - Enables cloud access, leverages existing HTTP caching infrastructure (Cheaper CDN costs)

Multi-Bitrate Encoding and Representation Shifting

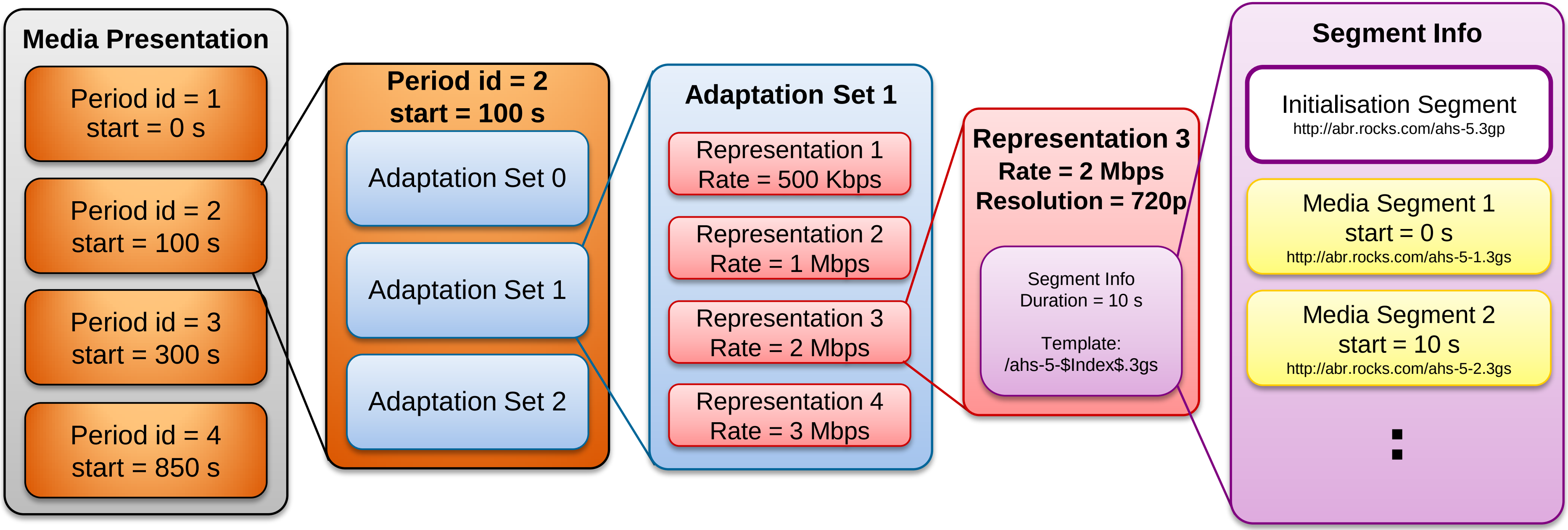


Example Representations
From Vancouver 2010 Winter Olympics

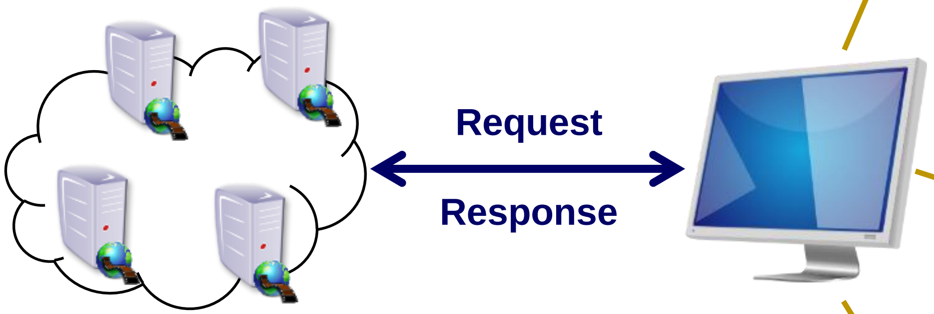
	Target Encoding Bitrate	Resolution	Frame Rate
Representation #1	3.45 Mbps	1280 x 720	30 fps
Representation #2	1.95 Mbps	848 x 480	30 fps
Representation #3	1.25 Mbps	640 x 360	30 fps
Representation #4	900 Kbps	512 x 288	30 fps
Representation #5	600 Kbps	400 x 224	30 fps
Representation #6	400 Kbps	312 x 176	30 fps

Source: Vertigo MIX10

DASH Media Presentation Description
List of Accessible Segments and Their Timings



Smart Clients



Client manages
- Manifest(s)
- HTTP transport
- TCP connection(s)

Client monitors/measures
- Playout buffer
- Download times and throughput
- Local resources (CPU, memory, screen, etc.)
- Dropped frames

Client performs adaptation

Major Players in the Market

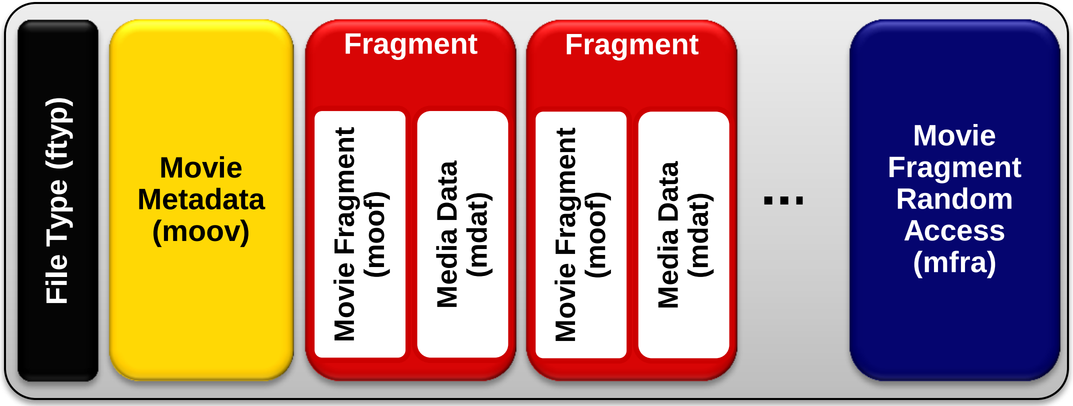
- **Microsoft Smooth Streaming**
  - http://www.iis.net/expand/SmoothStreaming
- **Apple HTTP Live Streaming**
  - http://tools.ietf.org/html/draft-pantos-http-live-streaming
  - http://developer.apple.com/library/ios/#documentation/networkinginternet/conceptual/streamingmediaguide/
- **Netflix**
  - http://www.netflix.com/NetflixReadyDevices
- **Adobe HTTP Dynamic Streaming**
  - http://www.adobe.com/products/httpdynamicstreaming/
- **Move Adaptive Stream (Acquired by Echostar)**
  - http://www.movenetworks.com
- **Others**
  - Widevine Adaptive Streaming (Acquired by Google)
  - Vidiator Dynamic Bitrate Adaptation

Example Request and Response
Microsoft Smooth Streaming

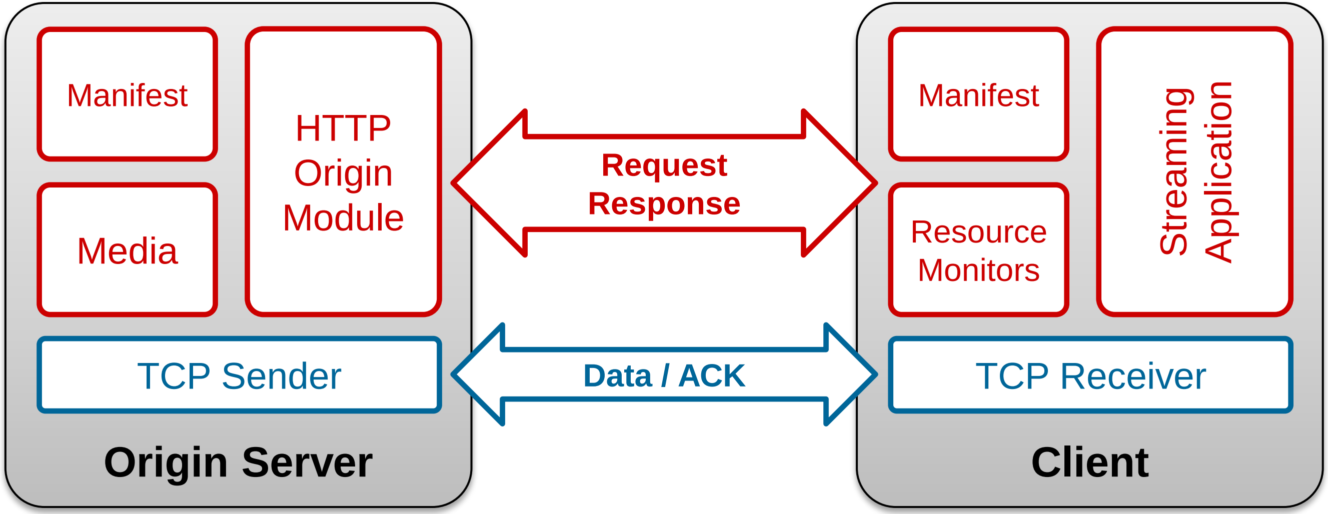
- **Client sends an HTTP request**

  GET 720p.ism/QualityLevels(572000)/Fragments(video=160577243) HTTP/1.1

- **Server**
  1. Finds the MP4 file corresponding to the requested bitrate
  2. Locates the fragment corresponding to the requested timestamp
  3. Extracts the fragment and sends it in an HTTP response



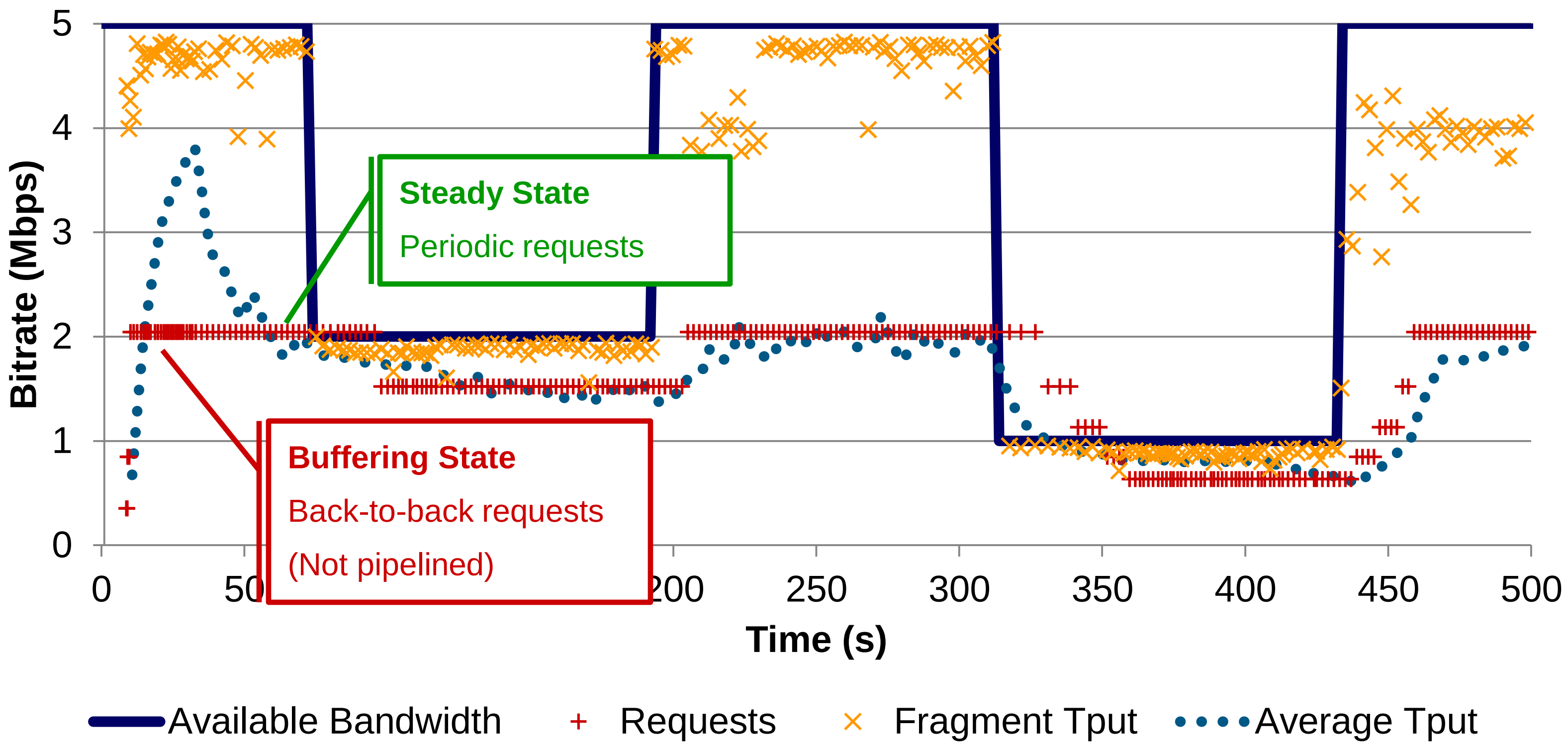
Inner and Outer Control Loops



There could be multiple TCPs destined to potentially different servers

Interaction of Inner and Outer Control Loops

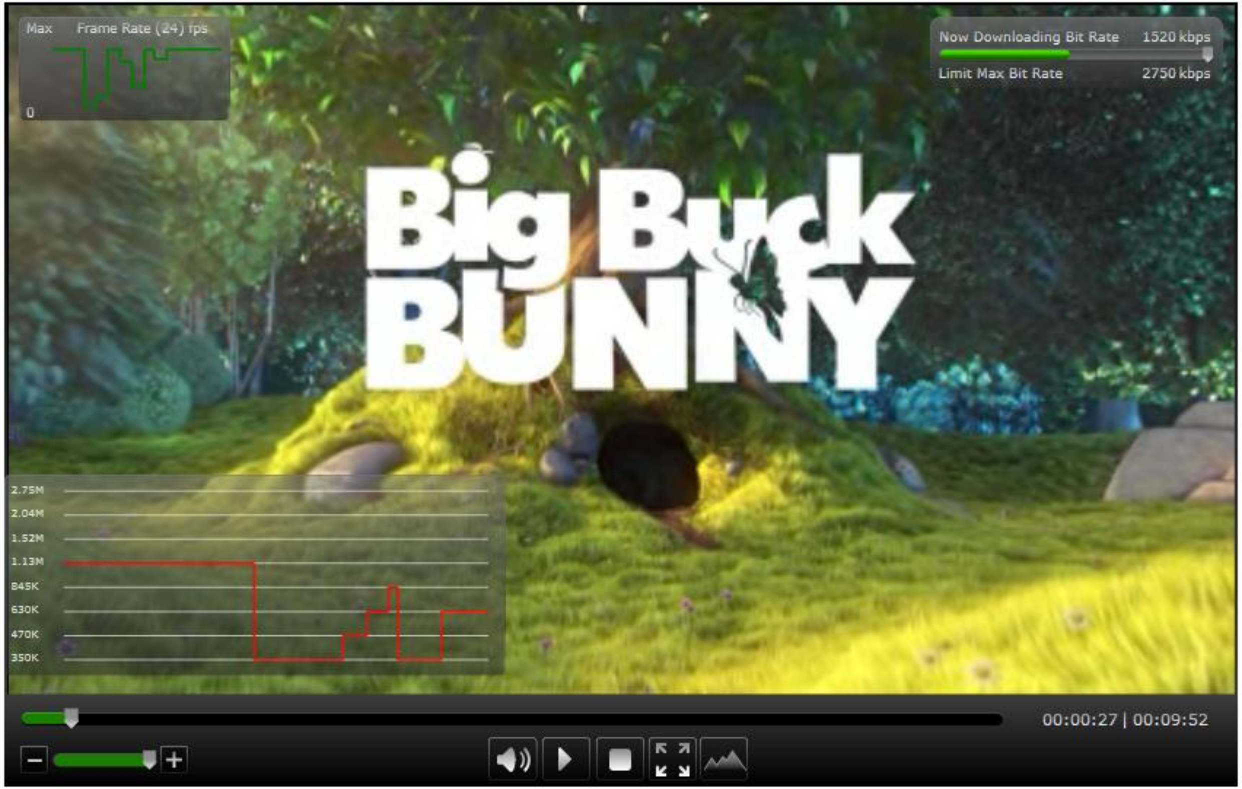
Microsoft Smooth Streaming Experiments



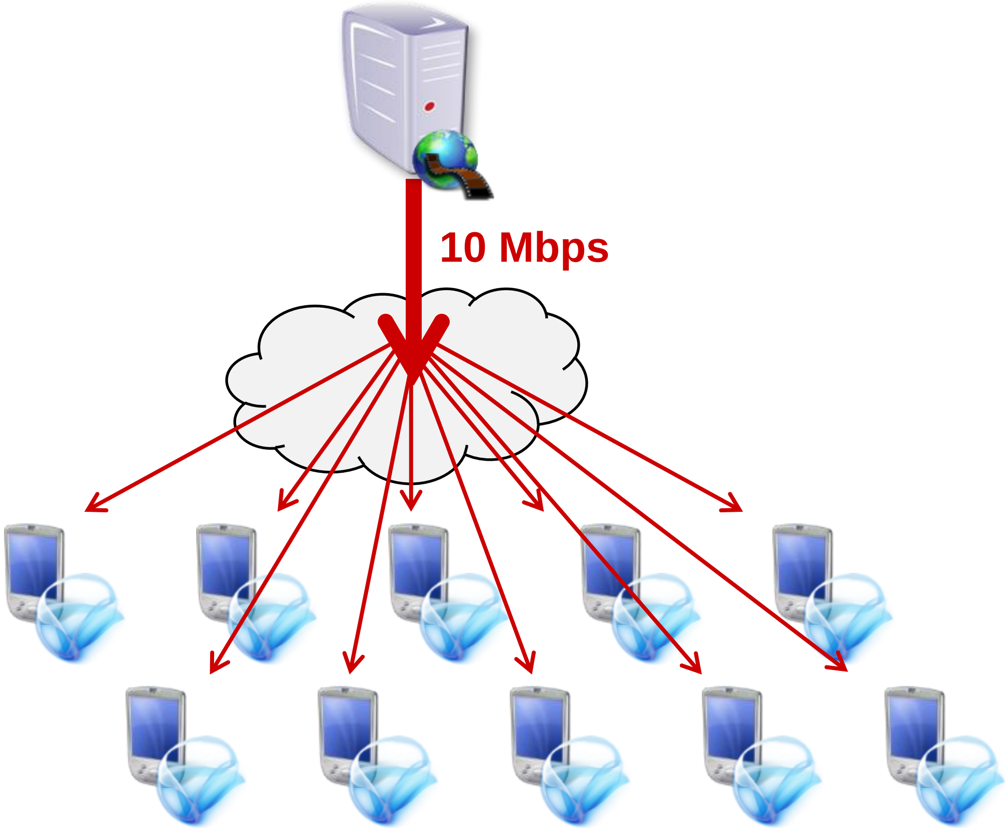
Reading: "An experimental evaluation of rate-adaptation algorithms in adaptive streaming over HTTP," ACM MMSys 2011

Microsoft Smooth Player Showing Adaptation

http://www.iis.net/media/experiencesmoothstreaming



Simple Competition Experiment
10 Microsoft Smooth Clients Sharing 10 Mbps Link

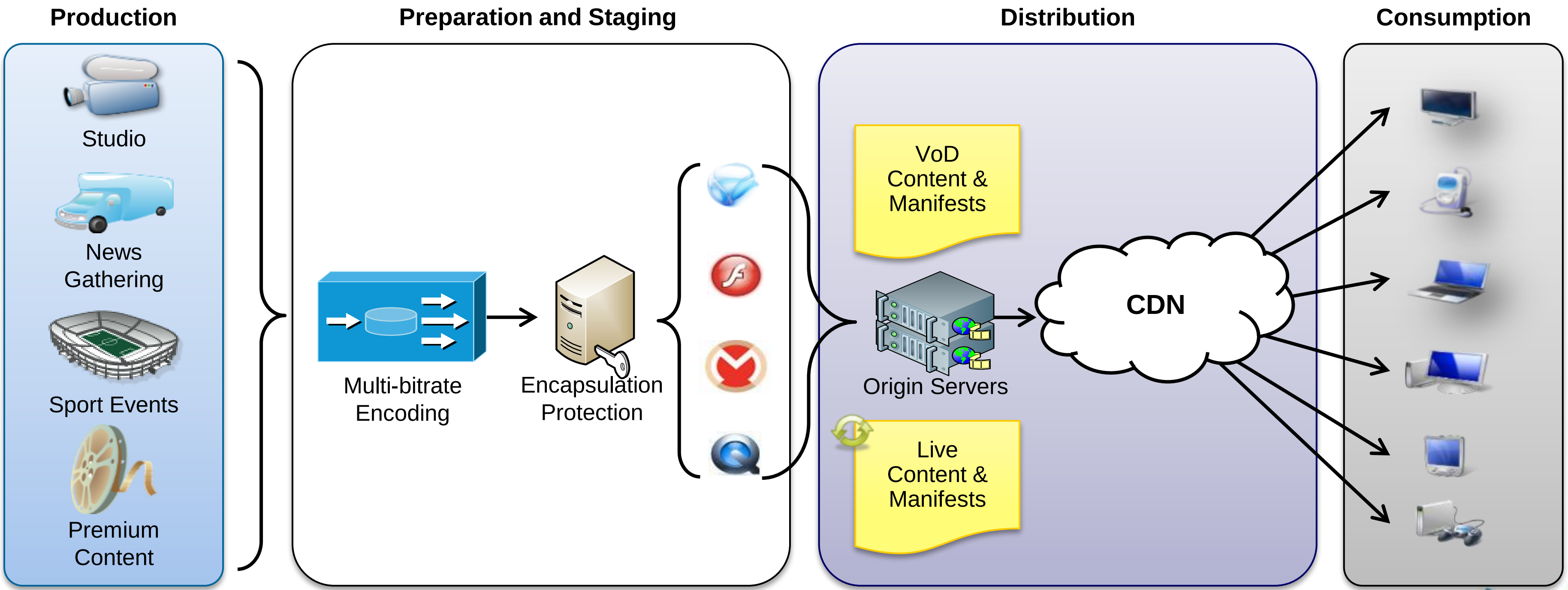


10 Microsoft Smooth Clients Sharing 10 Mbps Link

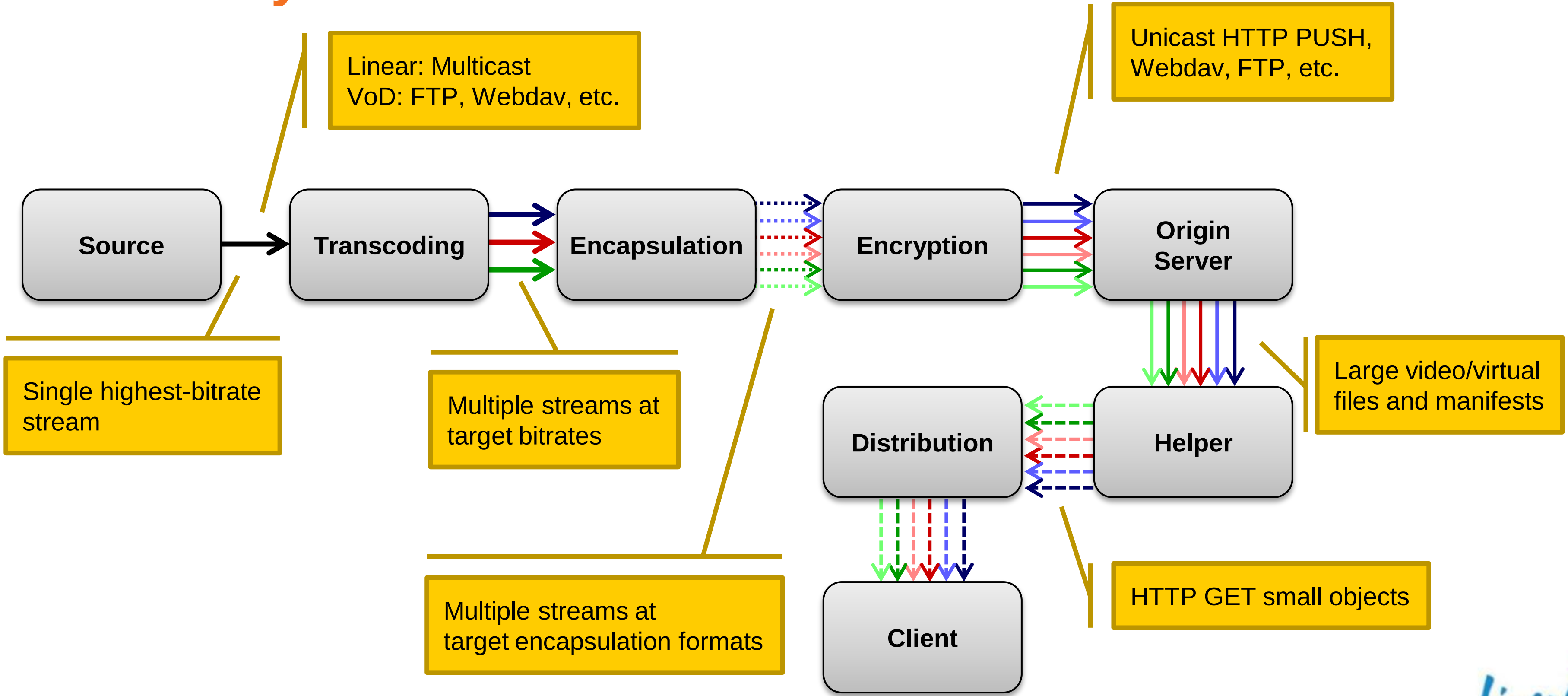
Streaming "Big Buck Bunny" (Three Clients are Shown)

Available Representations: 300, 427, 608, 866, 1233, 1636, and 2436 Kbps

End-to-End Over-the-Top Adaptive Streaming Delivery



Adaptive Streaming Content Workflow
Today



Source Representation

	Container	Manifest	Packaging Tools
Move	2-s chunks (.qss)	Binary (.qmx)	Proprietary
Apple HLS	Fixed-duration MPEG2-TS segments (.ts)	Text (.m3u8)	Popular encoders
Adobe Zeri	Aggregated MP4 fragments (.f4f – a/v interleaved)	Client: XML + Binary (.fmf) Server: Binary (.f4x)	Adobe Packager
Microsoft Smooth	Aggregated MP4 fragments (.isma, .ismv – a/v non-interleaved)	Client: XML (.ismc) Server: SMIL (.ism)	Popular encoders MS Expression
MPEG DASH	MPEG2-TS and MP4 segments	Client/Server: XML	Under development

- **Source containers and manifest files are output as part of the packaging process**
  - These files are staged on to origin servers
  - Some origin server implementations could have integrated packagers
- **Adobe/Microsoft allow to convert aggregated containers into individual fragments on the fly**
  - In Adobe Zeri , this function is called a Helper
  - In Microsoft Smooth, this function is tightly integrated as part of the IIS
- **Server manifest is used by Helper modules to convert the large file into individual fragments**

Staging and Distribution

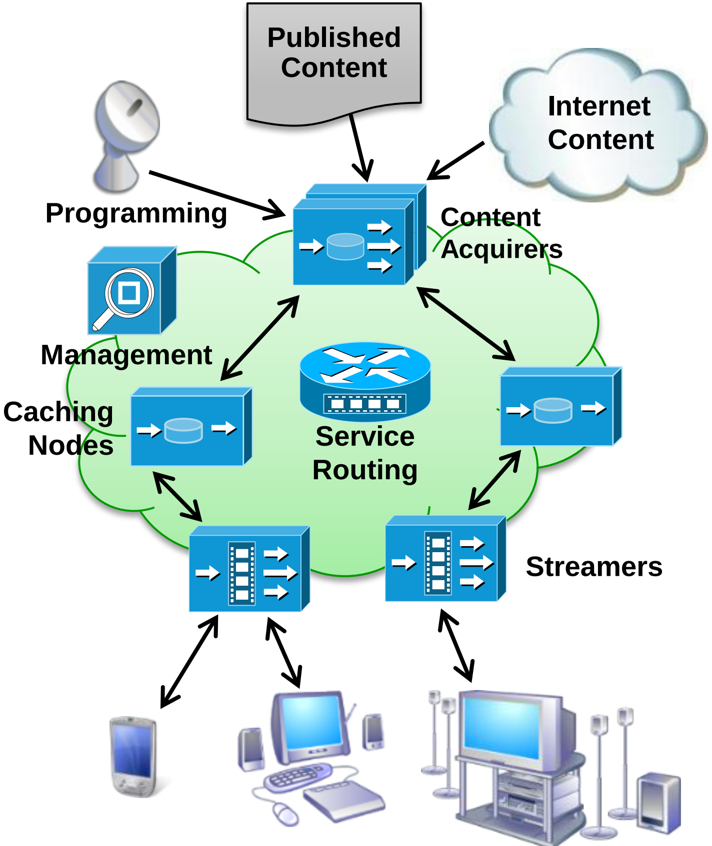
	Origin Server	Packager → OS Interface	Distribution
Move	Any HTTP server	DFTP, HTTP, FTP	Plain Web caches
Apple HLS	Any HTTP server	HTTP, FTP, CIFS	Plain Web caches
Adobe Zeri	HTTP server with Helper	Integrated packager for live and JIT VoD Offline packager for VoD (HTTP, FTP, CIFS, etc.)	Plain Web caches → Helper running in OS Intelligent caches → Helper running in the delivery edge
Microsoft Smooth	IIS	WebDAV	Plain Web caches Intelligent IIS servers configured in cache mode
MPEG DASH	Any HTTP server	HTTP, FTP, CIFS	Plain Web caches

Delivery

	Client	# of TCP Connections	Transaction Type
Move	Proprietary Move player	3-5	Byte-range requests
Apple HLS	QuickTime X	1 (interleaved)	Whole-segment requests Byte-range requests (iOS5)
Adobe Zeri	OSMF client on top Flash player	Implementation dependent	Whole-fragment access Byte-range access
Microsoft Smooth	Built on top of Silverlight	2 (One for audio and video)	Whole-fragment requests
MPEG DASH	DASH client	Configurable	Whole-segment requests Byte-range requests

- **In Smooth, fragments are augmented to contain timestamps of future fragments in linear delivery**
  - Thus, clients fetch the manifest only once
- **In HLS, manifest is continuously updated**
  - Thus, clients constantly request the manifest

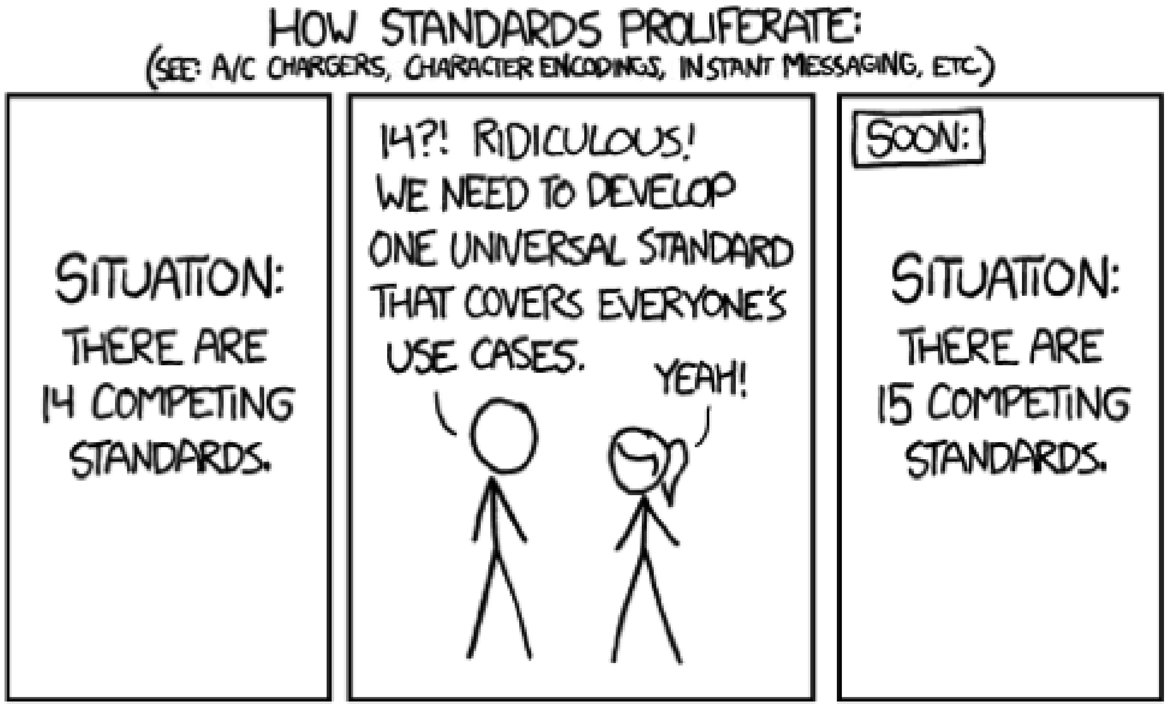
Cisco Videoscape Distribution Suite (VDS)
The Network is the Platform



- **Extensible Architecture**
  - Independent scalability of storage, caching and streaming
  - Non-stop service availability
  - Convergence of live and on-demand content
- **Distributed Network**
  - Multi-protocol centralised ingest
  - Popularity-based multi-tier caching
  - Multi-protocol decentralised streaming
- **Service Routing Functionality**
  - Service routing at the edge or headend
  - Global and local load balancing

Emerging Standards

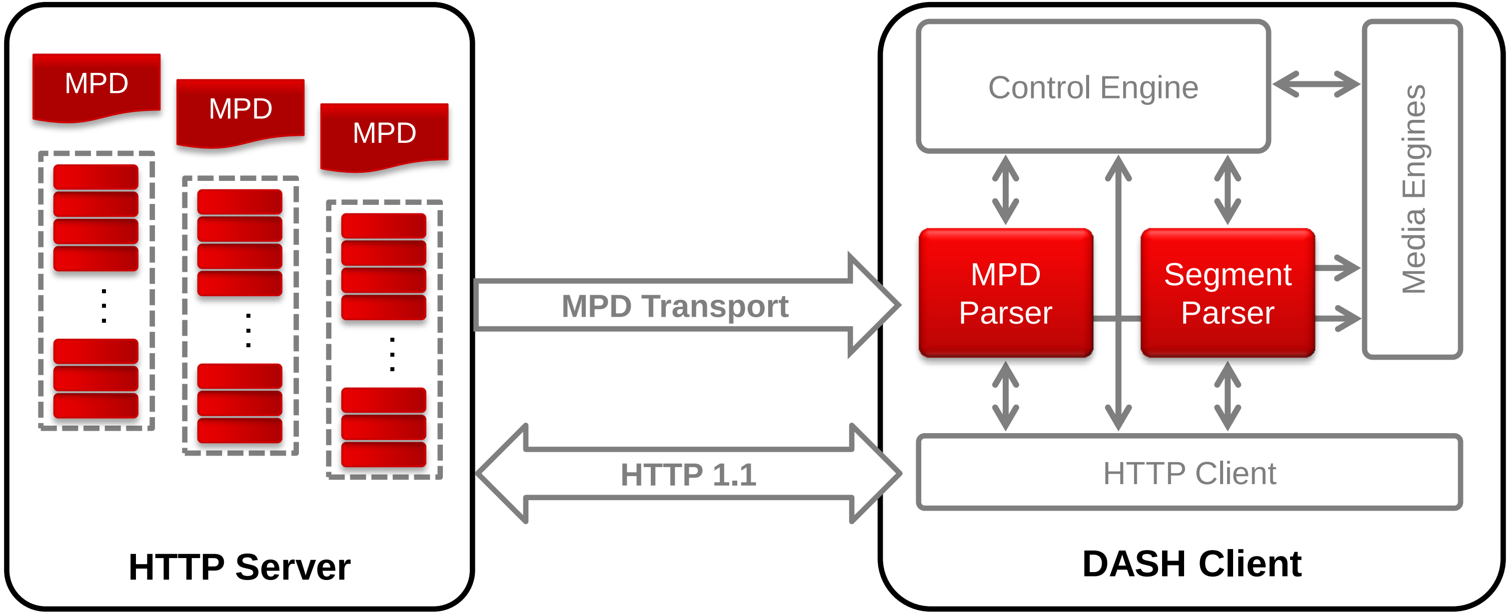
Where We were



MPEG – Dynamic Adaptive Streaming over HTTP
A New Standard: ISO/IEC 23009-1

- **Goal**
  - Develop an international, standardised, efficient solution for HTTP-based streaming of MPEG media
- **The Dynamic Adaptive Streaming over HTTP (DASH) Standard**
  - Defines the MPD (manifest) format and delivery formats using ISO BMFF and MPEG2-TS
    - Support for ISO BMFF content is richer than MPEG2-TS
  - Is not a system, protocol or codec specification and does not specify
    - Size and duration of segments, number and bitrates of representations, frequency of RAPs
    - Download times of segments, switching between different representations
    - Transport of MPD
  - Supports
    - Live, on-demand and time-shifted content delivery and trick modes
    - Splicing and ad insertion, byte-range requests
    - Content descriptors for protection, accessibility and rating

Scope of MPEG DASH
Shown in Red



Timeline in MPEG

Working Draft (WD)
July 2010

→

Committee Draft (CD)
Oct. 2010

→

Draft International Standard (DIS)
Jan. 2011

→

Final Draft International Standard
July 2011

→

International Standard
2012

Ongoing Work in MPEG DASH

- **ISO/IEC 23009 Parts**
  - Part 1 Corrigenda and Amendments: Media Presentation Description and Segment Formats
  - Part 2: Conformance and Reference Software
  - Part 3: Implementation Guidelines
  - Part 4: Format Independent Segment Encryption and Authentication
- **Core Experiments**
  - Generic transports and storage of DASH formats
  - Signalling of quality-related information in DASH
  - Low-latency live streaming
  - Parameters insertion in URL
  - DASH push events

Timeline in 3GPP SA4

- **SA4 started its activity mid 2009 and completed specification work early March 2010 for Release 9**
  - Integrated in Transparent End-to-end Packet-switched Streaming Service (PSS)
  - TS 26.234 (Codecs and Protocols)
  - TS 26.244 (3GPP File Format – 3GP)
- **SA4 has done bug fixing and maintenance for Release 10**
  - Editorial corrections and clarifications
  - Alignment sought with other SDOs (MPEG and OIPF)
  - New separate spec for 3GP-DASH
    - TS 26.247 (PD and Dynamic Adaptive Streaming over HTTP – 3GP-DASH)
  - Release 10 was published in June 2011
- **Release 11 was published in September 2012**

TS 26.247: 3GP-DASH

- **TS 26.247**
  - Describes (XML-based) media presentation description (MPD) file
  - Defines segment types and formats
  - Defines profiles for Releases 10 and 11
  - Provides metrics for QoE reporting
  - Provides informative description for an adaptive streaming client
- **TS 26.247 does not talk about 3G/4G specific issues**
  - 3GP-DASH clients perform adaptation solely based on HTTP-layer (and TCP-layer, if any at all) observations
- **TS 26.247 is not concerned about content generation/distribution**
  - No specific guidelines on content generation appropriate for wireless networks
  - No discussion on distribution scalability issues over the last-mile wireless link

DASH Industry Forum
http://dashif.org

- **Objectives**
  - Promote and catalyse market adoption of MPEG DASH
  - Publish interoperability and deployment guidelines (DASH264 Base)
  - Facilitate interoperability tests
  - Collaborate with SDOs and industry consortia in aligning ongoing DASH standards development and the use of common profiles
- **DASH IF defines several interoperability points (IOP) regarding**
  - MPEG DASH specific features
  - Codecs including levels and profiles
  - Subtitles and closed captioning
  - DRM specific aspects
  - Transport-layer specific aspects
  - Metadata

DASH264 Base IOPs Overview

- **Profiles**
  - Restricted version of ISO BMFF Live and On-demand profiles
  - No playlist-based addressing
- **Encoding**
  - Video: H.264/AVC MP@3.0
  - Audio: HE-AAC v2
  - No muxed audio/video
  - No open-GoP switching
- **Subtitles**
  - SMPTE Timed Text
- **DRM Baseline**
  - ISO/IEC 23001-7 Common Encryption

QUALCOMM

SAMSUNG

ALPEN-ADRIA UNIVERSITÄT
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Microsoft

BUYDRM
Market Monetize Monitor

PATH 1

AuthenTec

ERICSSON

Akamai

intel

MEDIAEXCEL

DIGITAL TV LABS
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Adobe

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MEDIA SYSTEMS

dialog
Smart Stream Video Platform

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HUAWEI

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espial

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Unified Streaming
Platform

VisualOn

imagine
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OPERATING EUROVISION

sorenson media

verimatrix

ZiXi

Links for Organisations and Specs

- **3GPP PSS and DASH**
  http://ftp.3gpp.org/specs/html-info/26234.htm
  http://ftp.3gpp.org/specs/html-info/26247.htm
- **MPEG DASH**
  http://standards.iso.org/ittf/PubliclyAvailableStandards/index.html
  Mailing List: http://lists.uni-klu.ac.at/mailman/listinfo/dash
- **DECE – UltraViolet**
  http://www.uvvu.com/
- **HbbTV (Hybrid Broadcast Broadband TV)**
  http://www.hbbtv.org/pages/about_hbbtv/specification.php
- **Digital TV Group (DTG)**
  http://www.dtg.org.uk/publications/books.html
- **W3C Web and TV Interest Group**
  http://www.w3.org/2011/webtv

Summary

- Part I: IPTV
  - IPTV – Architecture, Protocols and SLAs
  - Video Transport in the Core Networks
  - Video Distribution in the Access Networks
  - Improving Viewer Quality of Experience
- Part II: Internet Video and Adaptive Streaming
  - Example Over-the-Top (OTT) Services
  - Media Delivery over the Internet
  - Adaptive Streaming over HTTP
  - Emerging Standards

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Further Reading and References

Further Reading and References

IPTV Basics – Architecture, Protocols and SLAs

- **Articles**

  "Not all packets are equal, part I: streaming video coding and SLA requirements," IEEE Internet Computing, Jan./Feb. 2009

  "Not all packets are equal, part II: the impact of network packet loss on video quality," IEEE Internet Computing, Mar./Apr. 2009

  "Deploying diffserv in backbone networks for tight SLA control," IEEE Internet Computing, Jan./Feb., 2005

- **Special Issues**

  EURASIP Signal Processing: Image Communication (August 2011)

  IEEE Network (March 2010)

  IEEE Transactions on Broadcasting (June 2009)

  IEEE Internet Computing (May/June 2009)

  IEEE Communications Magazine (Multiple issues in 2008)

Further Reading and References
Video Transport in the Core Networks

- **Articles**

  "Toward lossless video transport," IEEE Internet Computing, Nov./Dec. 2011

  "Designing a reliable IPTV network," IEEE Internet Computing, May/June 2009

- **Standards**

  http://tools.ietf.org/html/rfc2475

  http://tools.ietf.org/html/rfc2205

  http://tools.ietf.org/html/rfc3209

  http://tools.ietf.org/html/rfc4090

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- **Articles**

  “Error control for IPTV over xDSL networks,” IEEE CCNC 2008

  “IPTV service assurance,” IEEE Communications Magazine, Sept. 2006

  “DSL spectrum management standard,” IEEE Communications Magazine, Nov. 2002

- **Standards and Specifications**

  “Asymmetric digital subscriber line (ADSL) transceivers,” ITU-T Rec. G.992.1, 1999

  http://www.dvb.org/technology/standards/index.xml#internet

  http://tools.ietf.org/html/rfc5760

  http://tools.ietf.org/html/rfc5740

  http://tools.ietf.org/html/rfc4588

  http://tools.ietf.org/html/rfc4585

  http://tools.ietf.org/html/rfc3550

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- **Articles**
  - "Scaling server-based channel-change acceleration to millions of IPTV subscribers," Packet Video Wksp. 2012
  - "Reducing channel-change times with the real-time transport protocol," IEEE Internet Computing, May/June 2009
  - "On the scalability of RTCP-based network tomography for IPTV services," IEEE CCNC 2010
  - "On the use of RTP for monitoring and fault isolation in IPTV," IEEE Network, Mar./Apr. 2010
- **Standards and Specifications**
  - http://www.broadband-forum.org/technical/download/TR-126.pdf
  - https://www.atis.org/docstore/product.aspx?id=22659
- **Open Source Implementation for VQE Clients**
  - Documentation
    - http://www.cisco.com/en/US/docs/video/cds/cda/vqe/3_5/user/guide/ch1_over.html
  - FTP Access
    - ftp://ftpeng.cisco.com/ftp/vqec/

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Targeted Advertising

- **SCTE Standards**

  SCTE 30: Digital Program Insertion Splicing API

  SCTE 35: Digital Program Insertion Cueing Message for Cable

  SCTE 130: Digital Program Insertion – Advertising Systems Interfaces

  URL: http://www.scte.org/standards/Standards_Available.aspx

Further Reading and References
Industry Tests

- **Light Reading: Cisco Put to the Video Test**

  http://www.lightreading.com/document.asp?doc_id=177692&site=cdn

- **EANTC Experience Provider Mega Test**

  http://www.cisco.com/en/US/solutions/ns341/eantc_megatest_results.html

- **IPTV & Digital Video QoE: Test & Measurement Update**

  http://www.heavyreading.com/insider/details.asp?sku_id=2382&skuitem_itemid=1181

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Adaptive Streaming

- **Articles**

  "Watching video over the Web, part 2: applications, standardisation, and open issues," IEEE Internet Computing, May/June 2011

  "Watching video over the Web, part 1: streaming protocols," IEEE Internet Computing, Mar./Apr. 2011

  "Mobile video delivery with HTTP," IEEE Communications Mag., Apr. 2011

- **Special Sessions in ACM MMSys 2011**

  Technical Program and slides: at http://www.mmsys.org/?q=node/43

  VoDs of the sessions are available in ACM Digital Library

  http://tinyurl.com/mmsys11-proc

  (Requires ACM membership)

- **W3C Web and TV Workshops**

  http://www.w3.org/2011/09/webtv

  http://www.w3.org/2010/11/web-and-tv/

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Source Code

- **Microsoft Media Platform: Player Framework**

    http://smf.codeplex.com/

- **Adobe OSMF**

    http://sourceforge.net/adobe/osmf/home/Home/

- **OVP**

    http://openvideoplayer.sourceforge.net

- **LongTail Video JW Player**

    http://www.longtailvideo.com/jw-player/about/

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Demos

- **Akamai HD Network**
  - http://wwwns.akamai.com/hdnetwork/demo/flash/default.html
  - http://wwwns.akamai.com/hdnetwork/demo/flash/hds/index.html
  - http://wwwns.akamai.com/hdnetwork/demo/flash/hdclient/index.html
  - http://bit.ly/testzeri
  - Also watch http://2010.max.adobe.com/online/2010/MAX137_1288195885796UHEZ
- **Microsoft Smooth Streaming**
  - http://www.iis.net/media/experiencesmoothstreaming
  - http://www.smoothhd.com/
- **Adobe OSMF**
  - http://www.osmf.org/configurator/fmp/
  - http://osmf.org/dev/2.0gm/debug.html
- **Apple HTTP Live Streaming (Requires QuickTime X or iOS)**
  - http://devimages.apple.com/iphone/samples/bipbopall.html
- **OVP**
  - http://openvideoplayer.sourceforge.net/samples
- **Octoshape Infinite Edge**
  - http://www.octoshape.com/showcase/overview/