15-744: Computer Networking

L-16 QoS and Video Streaming

QoS and Video Streaming

- Assigned reading:
  - Video control plane
  - Bird's Nest: Sections 1-2
- Optional reading:
  - Coolstream
  - Live Video Streaming with Dynamic Application End-points

Overview

- QoS
  - Motivation
  - Integrated services
  - Adaptive applications
  - Differentiated services
- Video streaming
  - Background
  - Olympics study
  - Video control plane

Motivation

- Internet currently provides one single class of **"best-effort" service**
  - No assurances about delivery
- Existing applications are ***elastic***
  - Tolerate delays and losses
  - Can adapt to congestion
- Future "real-time" applications may be ***inelastic***

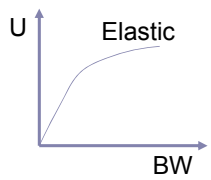
Inelastic Applications

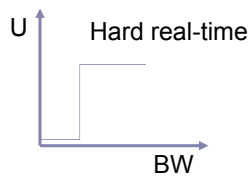
- Continuous media applications
  - **Lower and upper limit** on acceptable performance.
  - BW below which video and audio are not intelligible
  - Internet telephones, teleconferencing with high delay (200 - 300ms) impair human interaction
- Hard real-time applications
  - Require **hard limits on performance**
  - E.g. control applications

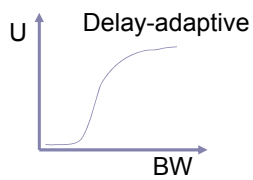
Why a New Service Model?

- What is the **basic objective** of network design?
  - Maximize total bandwidth? Minimize latency?
  - **Maximize user satisfaction** – the total **utility** given to users
- What does utility vs. bandwidth look like?
  - Must be non-decreasing function
  - Shape depends on application

Utility Curve Shapes





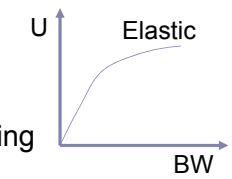


Stay to the right and you are fine for all curves

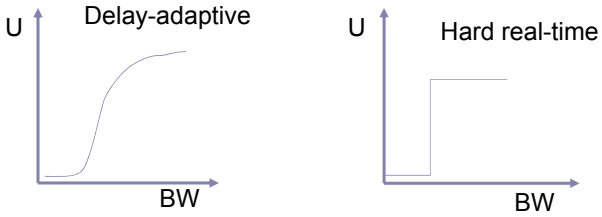
Admission Control

- If U(bandwidth) is concave → elastic applications
  - Incremental utility is decreasing with increasing bandwidth
  - Is always advantageous to have more flows with lower bandwidth
    - No need of admission control;

This is why the Internet works!



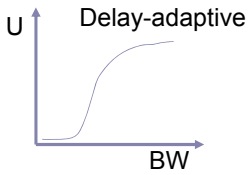
Utility Curves – Inelastic traffic



Does equal allocation of bandwidth maximize total utility?

Admission Control

- If U is convex → inelastic applications
  - U(number of flows) is no longer monotonically increasing
  - Need admission control to maximize total utility
- **Admission control** → deciding when the addition of new people would result in reduction of utility
  - Basically avoids overload



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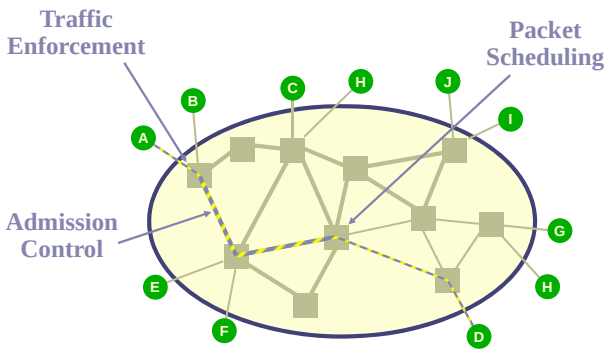
Components of Integrated Services

1. **Type of commitment**
   What does the network promise?
2. Packet scheduling
   How does the network meet promises?
3. Service interface
   How does the application describe what it wants?
4. Establishing the guarantee
   How is the promise communicated to/from the network
   How is admission of new applications controlled?

QoS Framework



Type of Commitments

- **Guaranteed** service
  - For **intolerant and rigid** applications
  - Fixed guarantee, network meets commitment as long as clients send at match traffic agreement
- **Predicted** service
  - For **tolerant and adaptive** applications
  - Two components
    - If conditions do not change, commit to current service
    - If conditions change attempt to deliver consistent performance
- **Datagram/best effort service**

Components of Integrated Services

1. Type of commitment
   What does the network promise?
2. **Packet scheduling**
   How does the network meet promises?
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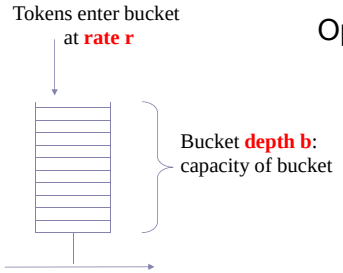
Scheduling for Guaranteed Traffic

- Use **token bucket filter** to characterize traffic
  - Described by rate *r* and bucket depth *b*
  - Can also be used to do traffic enforcement by reshaping the traffic at the network ingress
- Use **WFQ** at the routers
- Parekh's bound for

  Worst case queuing delay = b/r

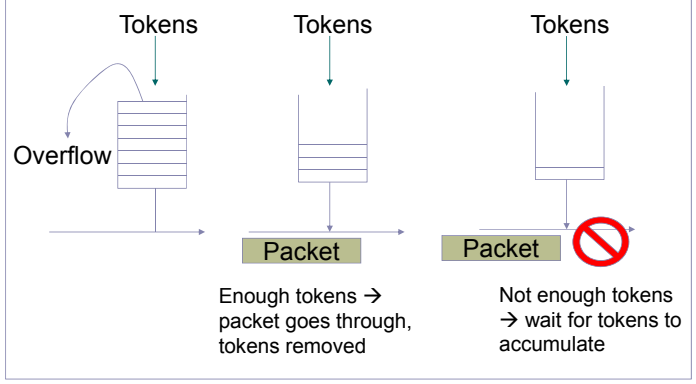
Token Bucket Filter



Operation:

- If bucket fills, tokens are discarded
- Sending a packet of size P uses P tokens
- If bucket has P tokens, packet sent at max rate, else must wait for tokens to accumulate

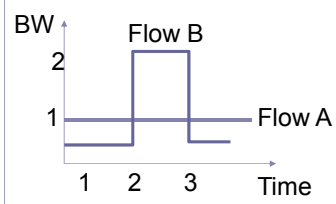
Token Bucket Operation



Token Bucket Characteristics

- On the long run, rate is limited to r
- On the short run, a burst of size b can be sent
- Amount of traffic entering at interval T is bounded by:
  - Traffic = b + r*T
- Information useful to admission algorithm

Token Bucket Specs



Flow A: r = 1 MBps, B=1 byte

Flow B: r = 1 MBps, B=1MB

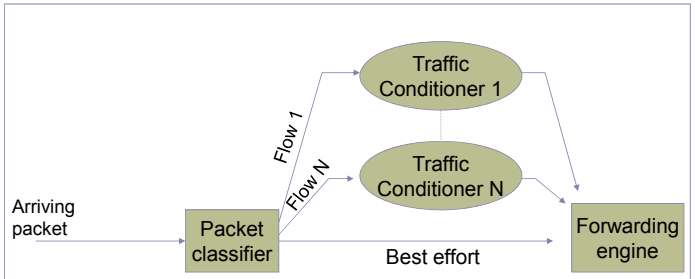
DiffServ

- Analogy:
  - Airline service, first class, coach, various restrictions on coach as a function of payment
- Best-effort expected to make up bulk of traffic, but revenue from first class important to economic base (will pay for more plentiful bandwidth overall)
- Not motivated by real-time! Motivated by economics and assurances

Basic Architecture

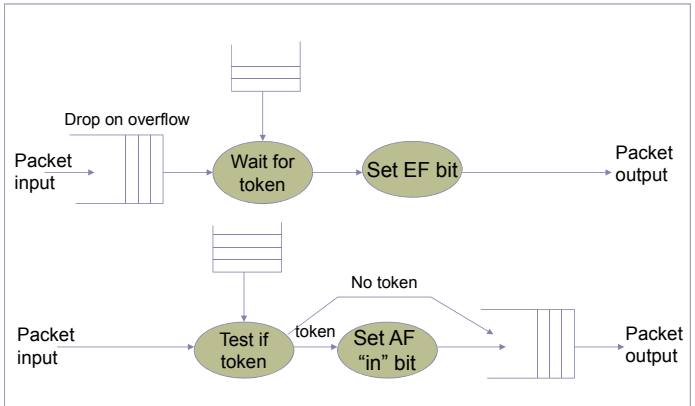
- Agreements/service provided within a domain
  - Service Level Agreement (SLA) with ISP
- Edge routers do traffic conditioning
  - Perform per aggregate shaping and policing
  - Mark packets with a small number of bits; each bit encoding represents a class or subclass
- Core routers
  - Process packets based on packet marking and defined per hop behavior: default, expedited forwarding, and assured forwarding
- More scalable than IntServ
  - No per flow state or signaling

Edge Router Input Functionality



classify packets based on packet header

Traffic Conditioning



Comparison

	Best-Effort	Diffserv	Intserv
Service	• Connectivity • No isolation • No guarantees	• Per aggregation isolation • Per aggregation guarantee	• Per flow isolation • Per flow guarantee
Service Scope	• End-to-end	• Domain	• End-to-end
Complexity	• No set-up	• Long term setup	• Per flow setup
Scalability	• Highly scalable • (nodes maintain only routing state)	• Scalable (edge routers maintains per aggregate state; core routers per class state)	• Not scalable (each router maintains per flow state)

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Internet Video Today

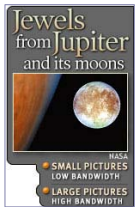
- DVD transfer
  - BitTorrent → P2P lecture
- Client-server streaming ("on demand")
  - Hulu, Netflix, ..
- Synchronized video ("live")
  - Sports events, IPTV, …
- Interactive video conferencing
  - Skype, …
  - Latency really matters

Client-Server Streaming: Adaptation Quality to Link

Long Time Scale

Short Time Scale

Content Negotiation



Server Selection

Adaptive Media

Problems Adapting to Network State

- TCP hides network state
- New applications may not use TCP
  - Often do not adapt to congestion

Need system that helps applications learn and adapt to congestion

Feedback about Network State

- Monitoring successes and losses
  - Application hints
  - Probing system
- Notification API (application hints)
  - Application calls cm_update(nsent, nrecd, congestion indicator, rtt)

Long History of Research in Video

- Early application Video Conferencing Tool
  - VIC – used the SIP protocol
- Motivated new TCP friendly congestion ctl
- Motivated multicast research
- Adaptive (multi-layer) video streaming
- Motivated lots of QoS research
- Video delivery leveraging peer-to-peer
- How much of this is currently in use?

Some Example Systems

- IPTV: delivery of TV using IP technology
  - Multicast and R-UDP over private network
  - QoS limited to small number of flow class
- Video playback over the Internet
  - Uses playback buffers to avoid stalls
  - Tends to burst chunks of data using TCP
  - Rate adaptation is emerging technology
- Video conferencing
  - High quality over VPNs or dedicated lines
  - Best effort systems such as Skype

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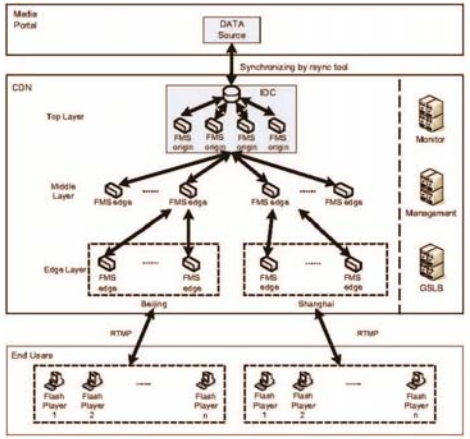
  - Video control plane (based on slides authors)

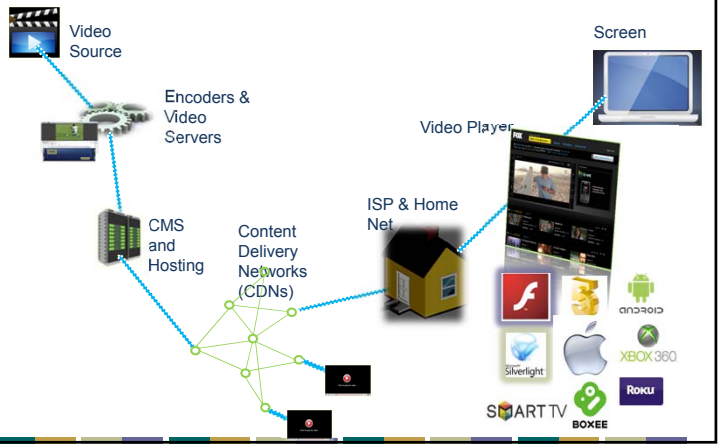
Video Distribution Architecture



Architecture Overview

- Multiple layers of CDN nodes for scalability
  - Run the Adobe Flash Media Software (FMS)
  - Can run in original (top) or edge mode (other)
- FMS provide streaming capability
  - Pause, seek, etc. - similar to DVD players
  - Alternative is HTTP download (next)
- Operations Support Systems control load balancing, billing, …

Video Ecosystem: Data-Plane



Video Quality Matters [Sigcomm'11]

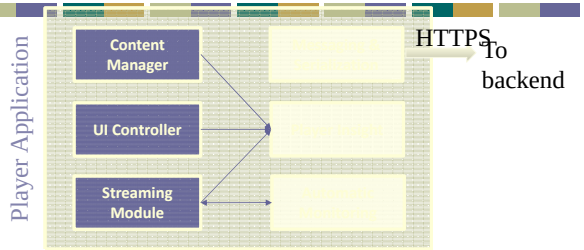
- Quality has substantial impact on viewer engagement
  - Need to ensure uninterrupted streaming at high bitrates
- Buffering ratio is most critical across video traffic types
  - Highest impact for live: 1% of buffering reduced play time by 3min
  - **1% increase in buffering can lead to more than 60% loss in audience over one month**

Our Argument

- CDN performance varies widely in time, geography, and ISPs
- Opportunity for significantly improving video Quality by selecting best CDN (and bitrate) for each viewer
- Hence, we argue for a logically **centralized** control plane to **dynamically** select CDN and bitrate

Assumptions:
- Content is encoded at multiple bitrates
- Content is delivered by multiple CDNs

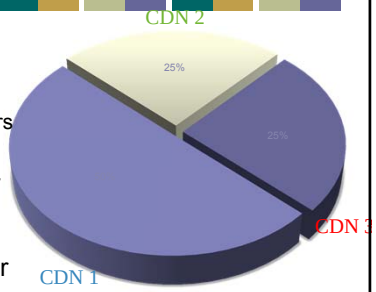
How do We Collect Data?



- Automatic and continuous monitoring of video player
  - Flash: NetStream, VideoElement
  - Silverlight: MediaElement, SmoothStreamMediaElement
  - iOS: MPMoviePlayerElement

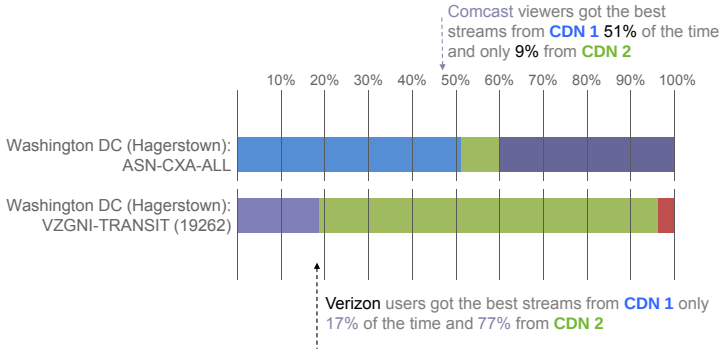
CDNs Vary in Performance over Geographies and Time

- Metric: buffering ratio
- One month aggregated data-set
  - Multiple Flash (RTMP) customers
  - Three major CDNs
- 31,744 DMA-ASN-hour with > 100 streams from each CDN
  - DMA: Designated Market Area
- Percentage of DMA-ASN-hour partitions a CDN has lowest buffering ratio



There is no single best CDN across geographies, network, and time

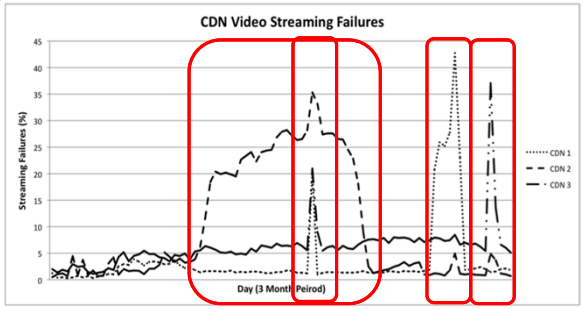
Washington, DC viewer experience differed greatly…



There is no single best CDN in the same geographic region or over time

CDN Streaming Failures Are Common Events

- % of stream failures: % of streams that failed to start
- Three months dataset (May-July, 2011) for a premium customer using Flash



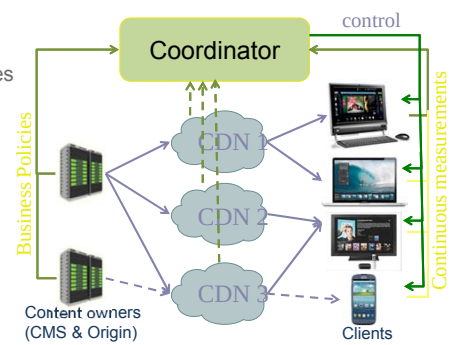
CDN (relative) performance varies greatly over time

Possible Actions to Improve Quality

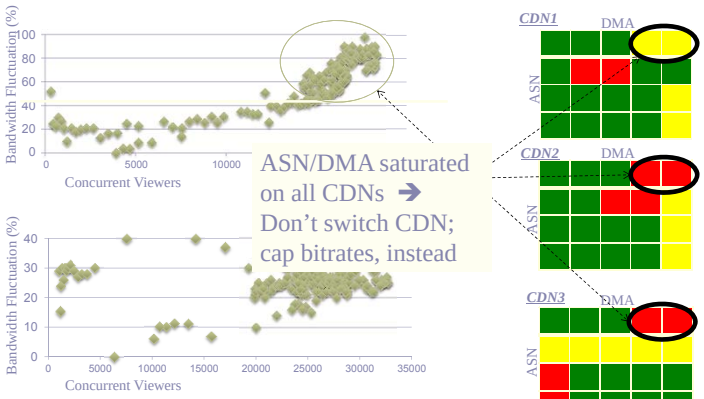
- Switch the bitrate
  - ↓ Buffering, high frame drops, high start time, …
  - ↑ High available bandwidth, …
- Switch the CDN
  - ↔ Connection error, missing content, buffering on low bitrate, ...
- When to perform switching/selection?
  - Start time selection only
  - Start time selection & midstream switching

Video Control Plane Architecture

- Coordinator implementing a global optimization algorithm that dynamically select CDN & bitrate for each client based on
  - Individual client
  - Aggregate statistics
  - Content owner policies
  - (CDN/ISP info)



Example: Local vs. Global Optimization



What is Next?

- Three lectures on wireless next week
- Three "Choice" lectures:
  - Datacenter networks
  - Sensor Networks
  - Energy efficient wireless

46

Next Lecture: Data Center Networks

- Lecture starts at 3:30
- Readings
  - Portland
  - Sections 1, 2, and 4 of Incast
  - Sections 1-2 of VL2
- Optional
  - DCTCP

51