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Hybrid Video on Demand Architecture with Supply-Demand based Optimization

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Brief Introduction to DOCOMO USA Labs

- Part of NTT DOCOMO
- Located in Palo Alto, CA.
- Consists of three labs
  - Network and Media Lab
  - Wireless Lab
  - Mobile Device Lab
- Research topics in the Network Architecture Group
  - Next mobile network architecture
    - Cloud computing, utility-based communication/computation/storage, infrastructure virtualization, measurement, middleware research.
  - Transport
    - Media delivery, P2P, coding, congestion control, cross-layer optimization.
  - Scalable routing
    - Flat-id routing, geographical routing.
  - Network Economics and Security
    - Incentive modeling and engineering, risk management, admission control, resource management.

Talk Outline

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- Video on Demand (VoD) Scenario
  - Requirements
  - Alternative solutions
- Overview of Hybrid Video on Demand Streaming Architecture
  - Peer, Control Server, Media Server
  - Supply-Demand Optimization
- Performance comparisons w.r.t. heuristic methods
- Extensions with Scalable Video
- Synopsis and Ongoing Work

VoD Scenario of Interest

- **Short play-back delays**
  - Download and play-back operations are concurrent.
- **Popular content**
  - The same video title must be requested by many users during the lifetime of that video session.
- **Asynchronous user access**
  - The video can be requested by multiple users at arbitrary times.

Client-Server based Solutions

- Straw-man approach:
  - Client-Server model with unicast sessions
  - Each user connects on separate channels.
  - Server bandwidth scales as $\Theta(N)$
    - *N: number of users with simultaneous demand*

- More advanced schemes based on multicast or combination of multicast and unicast:
  - Periodic broadcasting
    - *E.g., Pyramid broadcasting, Skyscraper broadcasting, etc.*
    - *Server bandwidth scales as* $\Theta(1)$
  - Patching
    - Server bandwidth scales as $\Theta(N^{1/2})$
  - Bandwidth skimming
    - Server bandwidth scales as $\Theta(\log N)$

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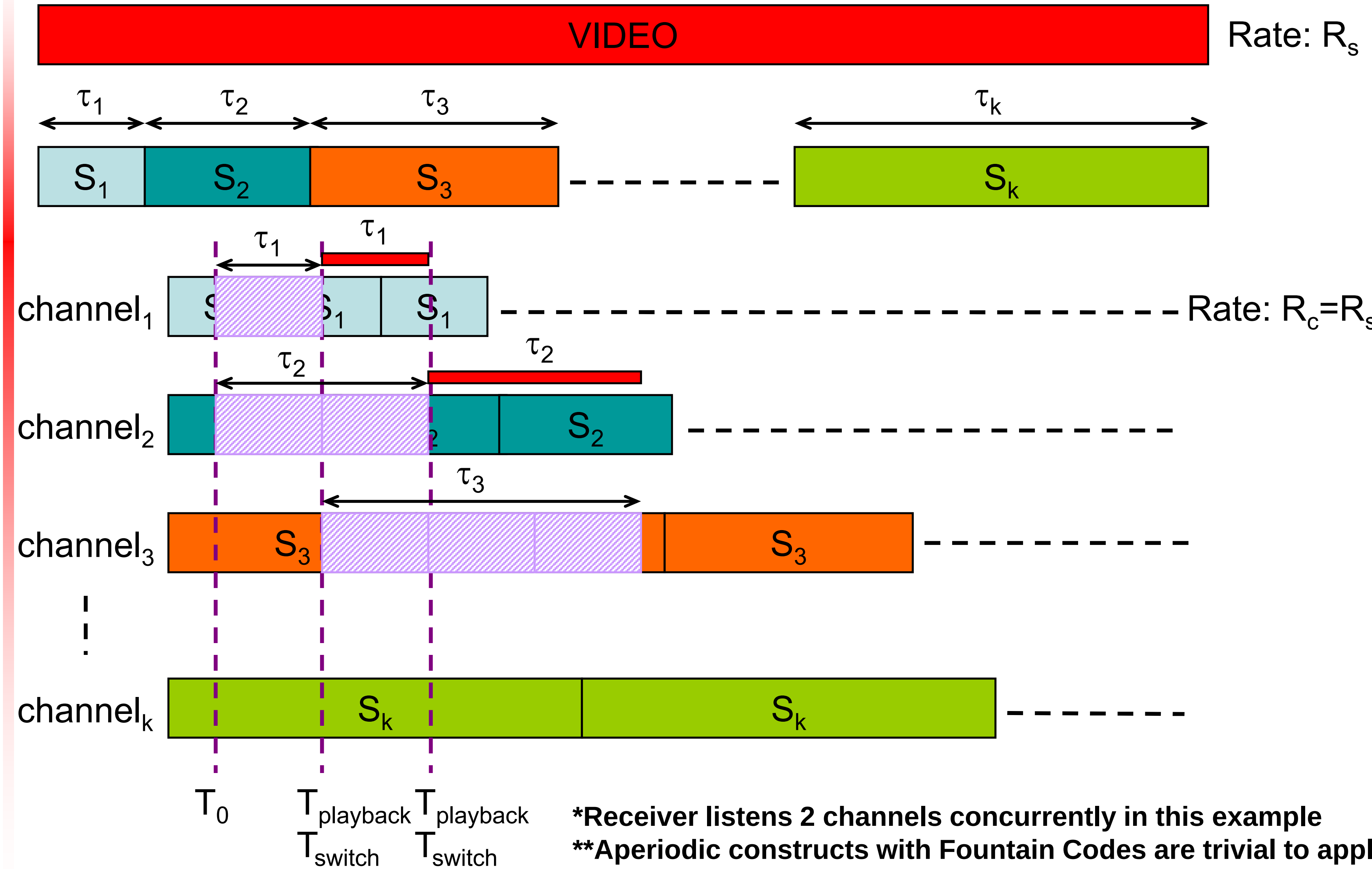
Periodic Broadcasting



***Receiver listens 2 channels concurrently in this example**
****Aperiodic constructs with Fountain Codes are trivial to apply**

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Patching

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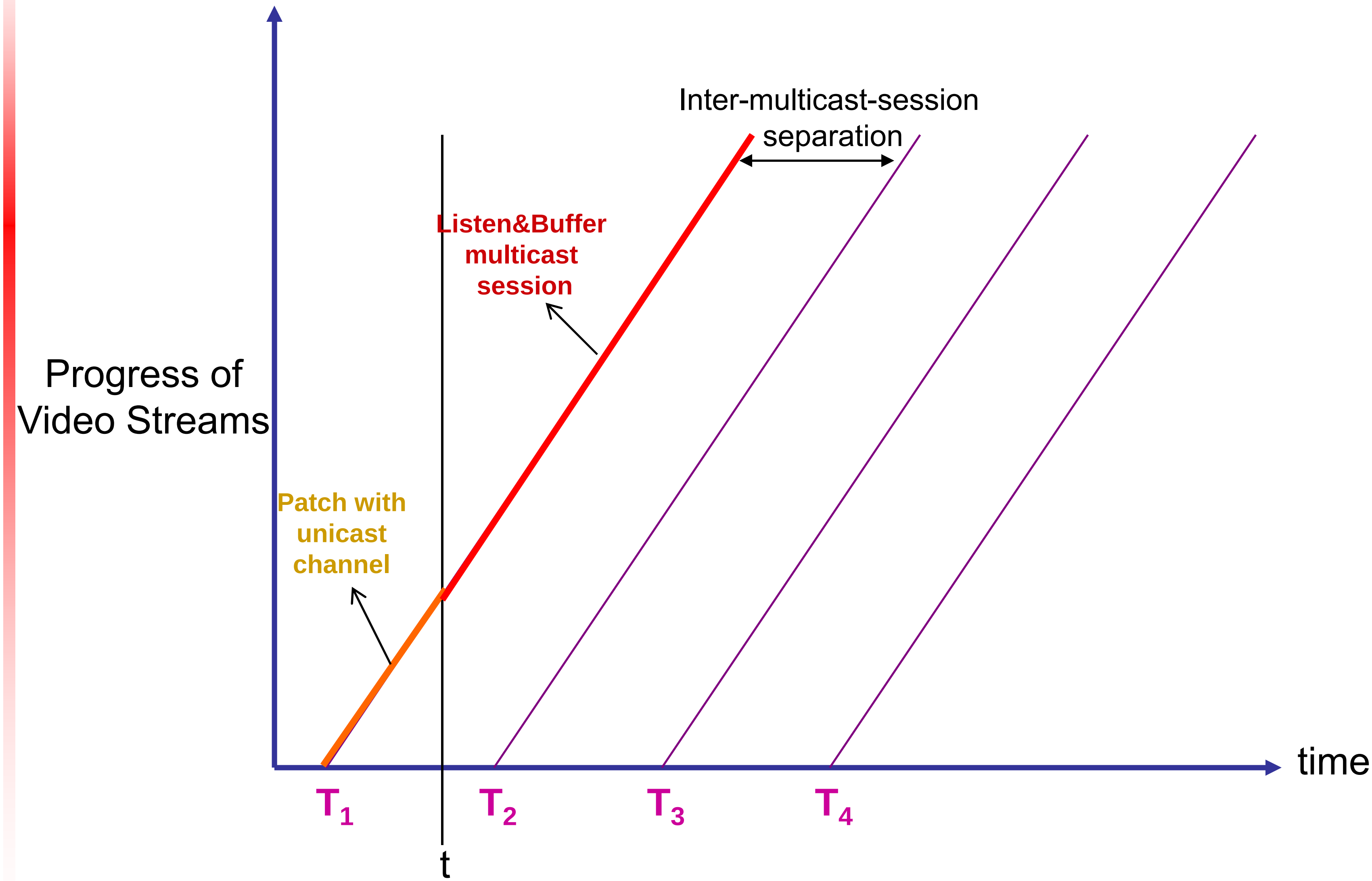

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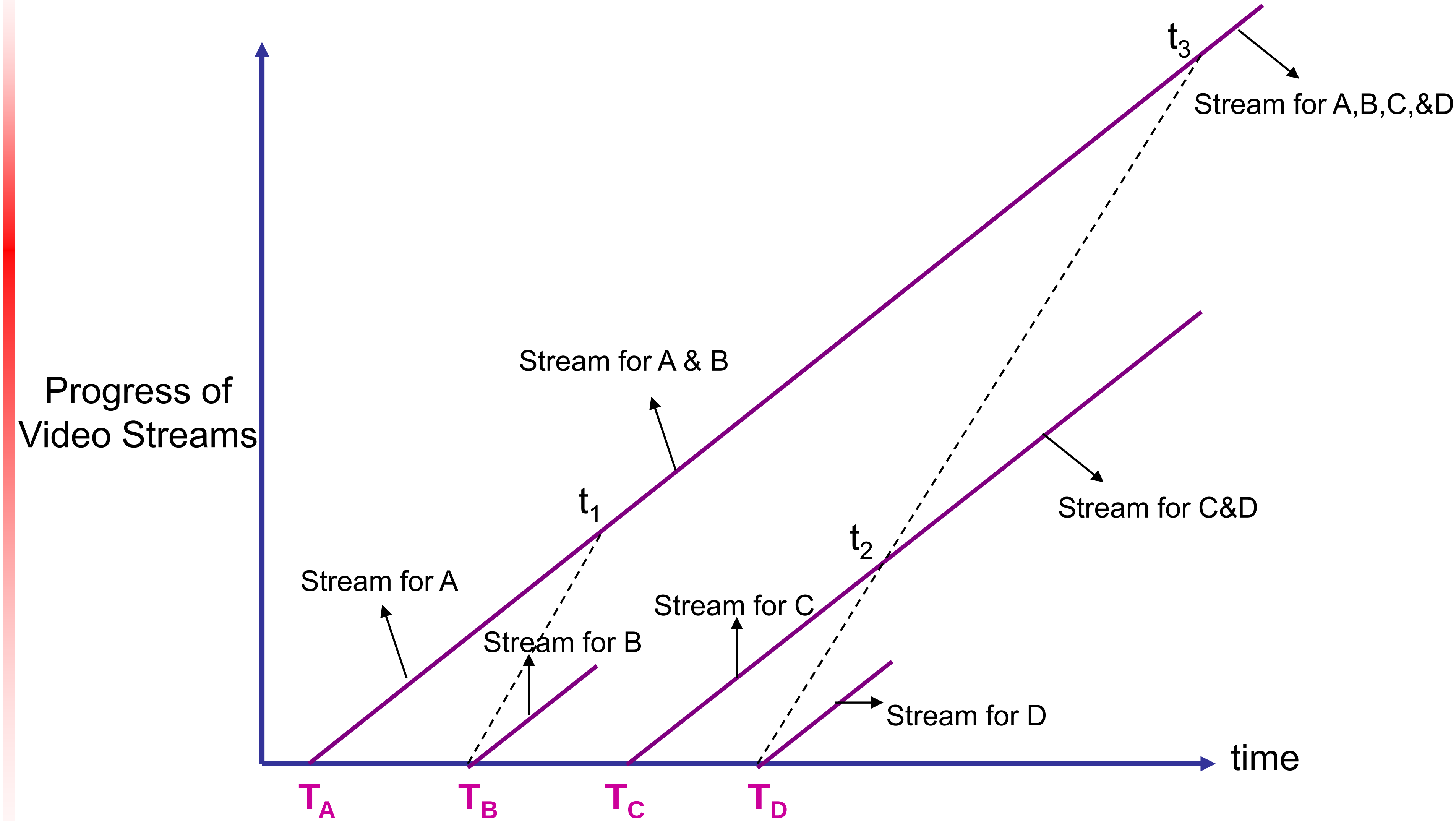
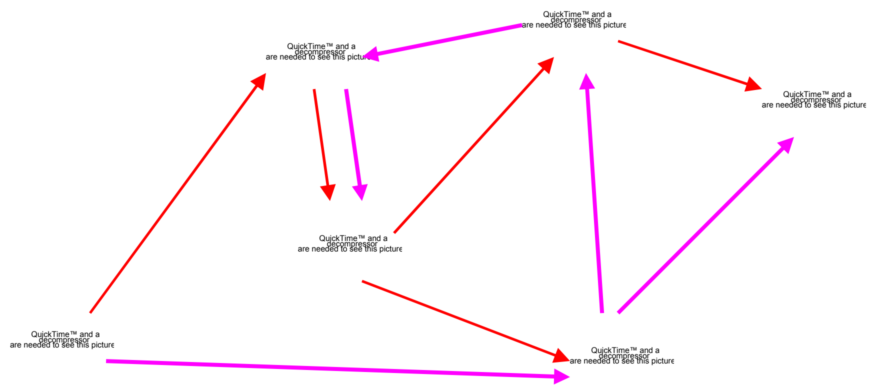
Bandwidth Skimming



*Source: Mahanti et. al, "Scalable on-demand media streaming with packet loss recovery" in Sigcomm'01

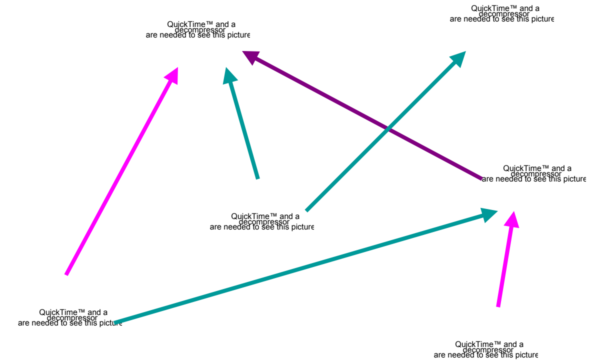
P2P Video on Demand

- Many real systems and implementations
  - PPLive, SopCast, Joost, ppStream, Coolstreaming/DONet, PPMate, UUSee, P2VoD, GloVE, …
- Promise of $\Theta(1)$ server bandwidth scalability
  - **without multicast support** from the network…



Source

Chaining, distribution trees/meshes



Swarming

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Hybrid P2P + CDN Systems

- Pure P2P lacks
  - Reliability
  - Availability
- Hybrid P2P+CDN combines reliability, availability, and scalability.
  - See
    - Johari&Shakkottai “Revenue management for content delivery”
    - Setton&Appostolopoulos “Towards quality of service for peer to peer video multicast”
- Increasing industry interest
  - Nano Data Centers as a collective of residential gateways
  - IETF ALTO WG, P4P, network caches
  - Further opportunities based on elastic computing on computing clouds (e.g., Amazon’s EC2)

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System Overview

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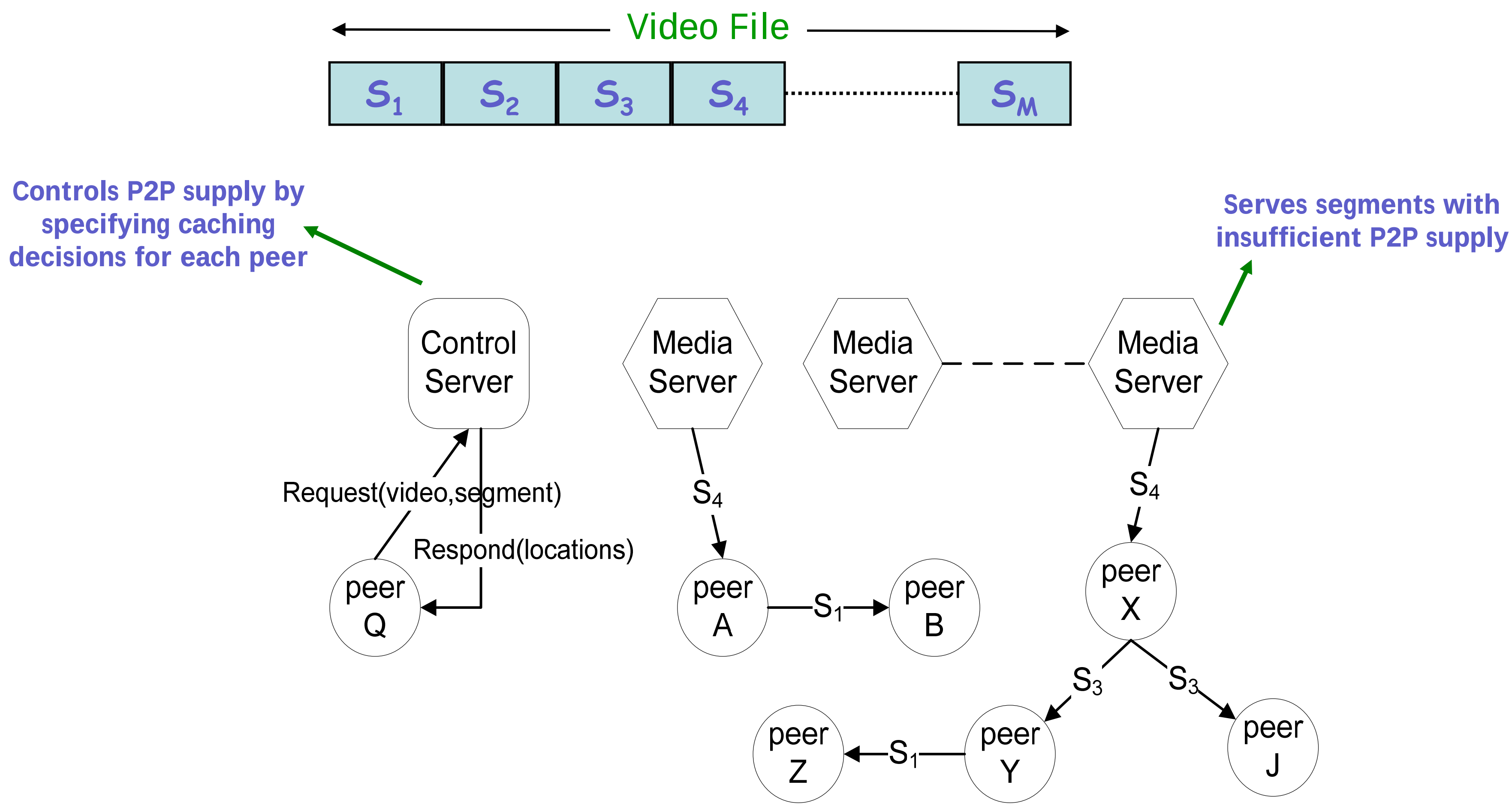
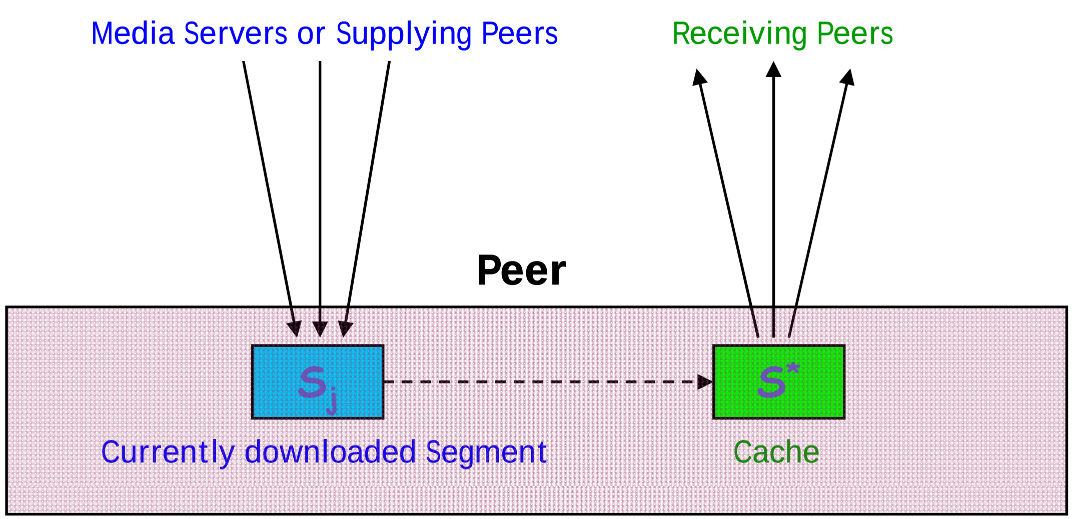


Peers dedicate limited memory and upload bandwidth to the system.

Peers contribute to the system only when they are actively streaming a video.

Peer

- Receives video content from Media Servers or other peers
- Dedicates upload BW to serve other peers
- Stores one segment as cache to serve other peers
  - Motivation: Limited dynamic memory, DRM concerns
  - Generalization to multiple segment cache can be done easily
- End of segment download
  - Cache may be replaced by the segment just downloaded



Cache Evolution Paths

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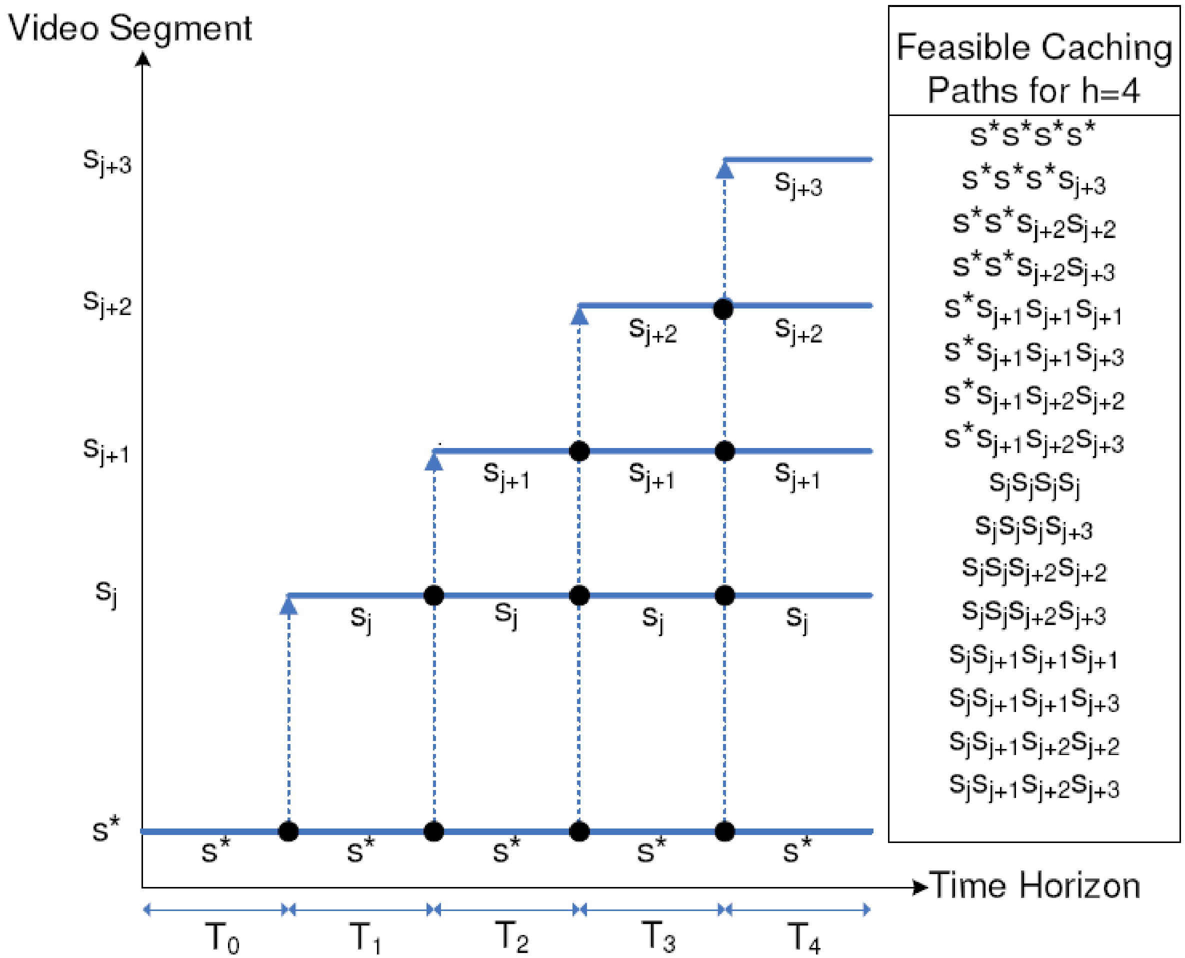
Cache updates occur at segment boundaries.



Caching opportunities for various segments naturally arise during course of normal streaming operation!

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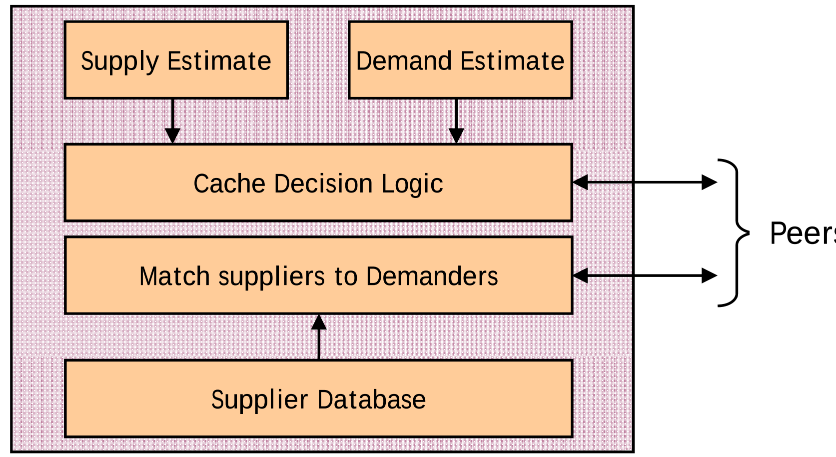
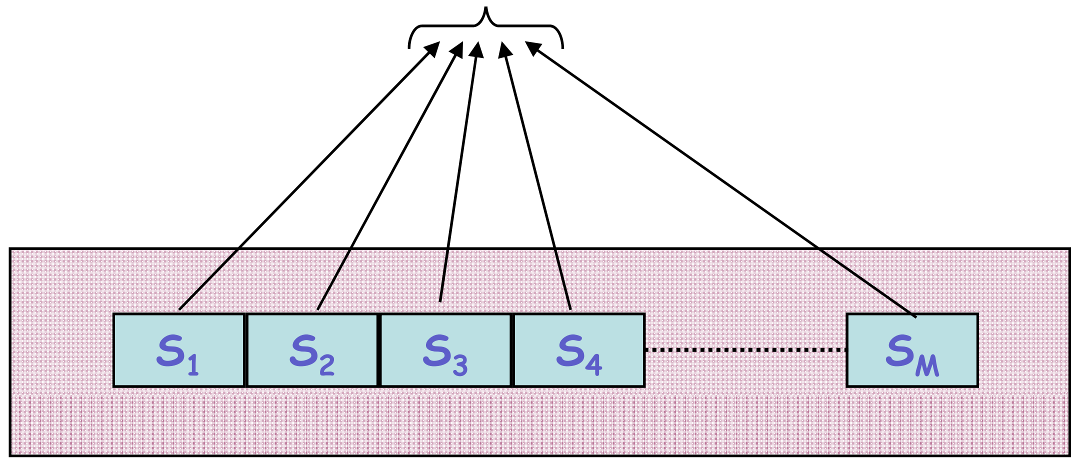
Control Server and Media Server

- Control Server
  - Matches supplying peers to demanding peers
  - Computes the caching decision for each peer
  - Maintains estimates of supply and demand for each segment over time

Control Server



- Media Server
  - Supplies segments with insufficient P2P supply



Media Server

Cache Decision Logic

- Utility-based optimization over a horizon of ‘h’ time steps
  - Utility based on the demand-supply gap

$$U(t_i, s_k) = \begin{cases} 0 & \tilde{D} \le \tilde{S} \\ \tilde{D}(t_i, s_k) - \tilde{S}(t_i, s_k) & \tilde{S} < \tilde{D} \le \tilde{S} + r_u \\ r_u & \tilde{D} > \tilde{S} + r_u \end{cases}$$

  - Choose the path with the best utility

$$U(P) = \sum_{i=1}^{h} U(t_i, p_i), \qquad P = [p_1, p_2, ..., p_h]$$

- Two methods introduced
  - Dynamic Programming (DP)
    - Choose the best path over the horizon
    - Exponential number of paths as a function of ‘h’
    - The best path can be computed with quadratic complexity
  - Static Optimal (SO)
    - Choose between the two static paths ([s*,s*,s*,…,s*] or [s_j,s_j,s_j,…,s_j])
    - Very simple

Supply and Demand Estimate

- Supply Estimate
  - Based on caching path ‘P(i)’ selected for each peer ‘i’

$$\tilde{S}(t,s) = \sum_{i:p_t(i)=s,\ \ i\in peer} r_u(i)$$

- Demand Estimate
  - Assumes normal streaming operation

$$\tilde{D}(t,s) = \tilde{D}(t-1,s-1)$$

  - Uses estimated rate of arrivals ‘λ’ for future demand

$$\tilde{D}(t,0) = \lambda$$

Randomness due to segment skips, peer departures, rate fluctuations, new arrivals, etc.

Performance Evaluations (1/2)

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- Unlimited server bandwidth
- Measure the average server bandwidth usage
- Evaluate against arrival rate, flash crowds, random departures, peer upload capacity, homogeneous vs. heterogeneous rates
- Competing methods
  - Pre-fetching (SO optimized, round robin, random)
  - Random
  - Last Played (segment just downloaded)

Arrival Rate/User Load

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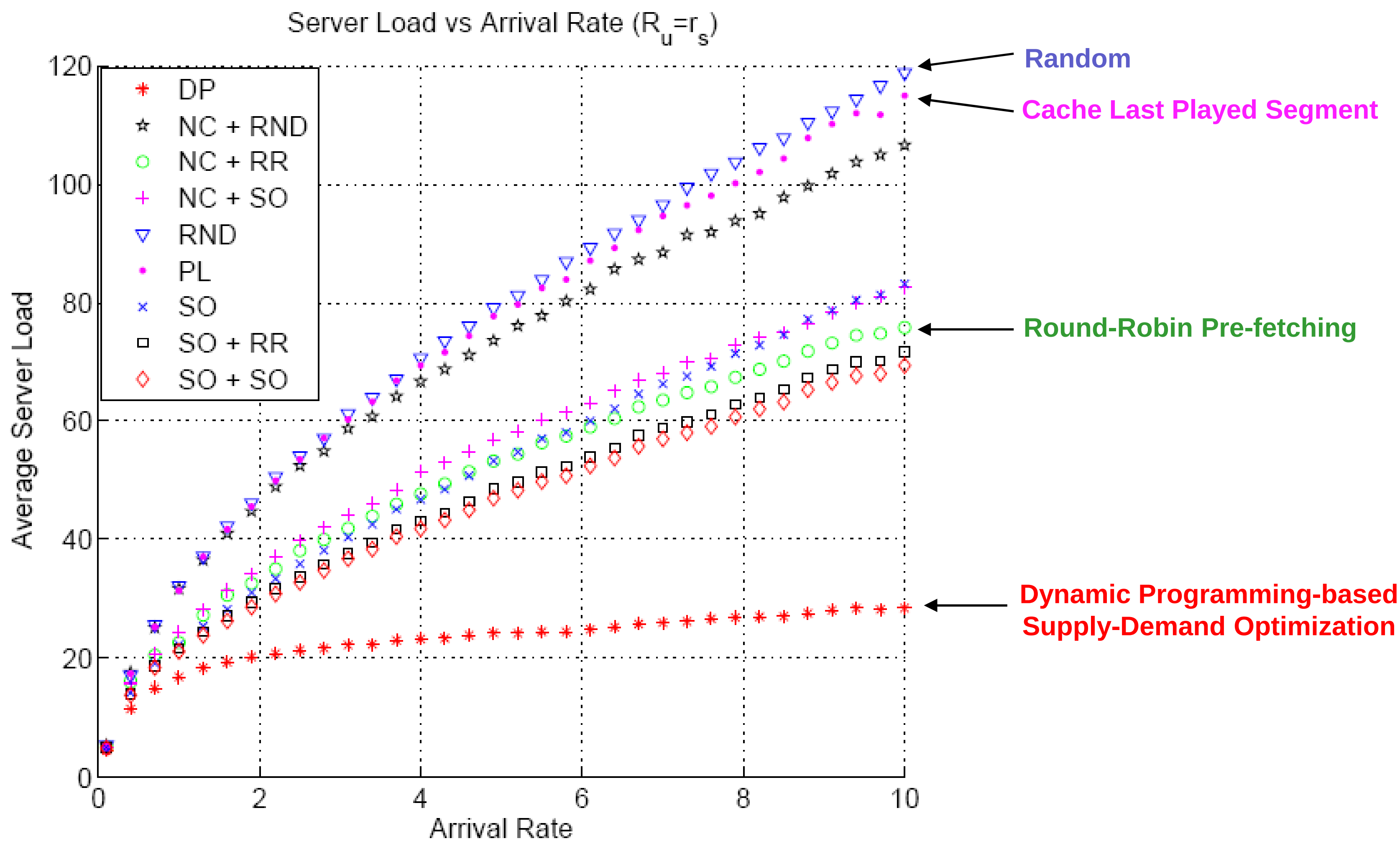

*Video length = 60 segments

**Arrival rate is measured per segment duration

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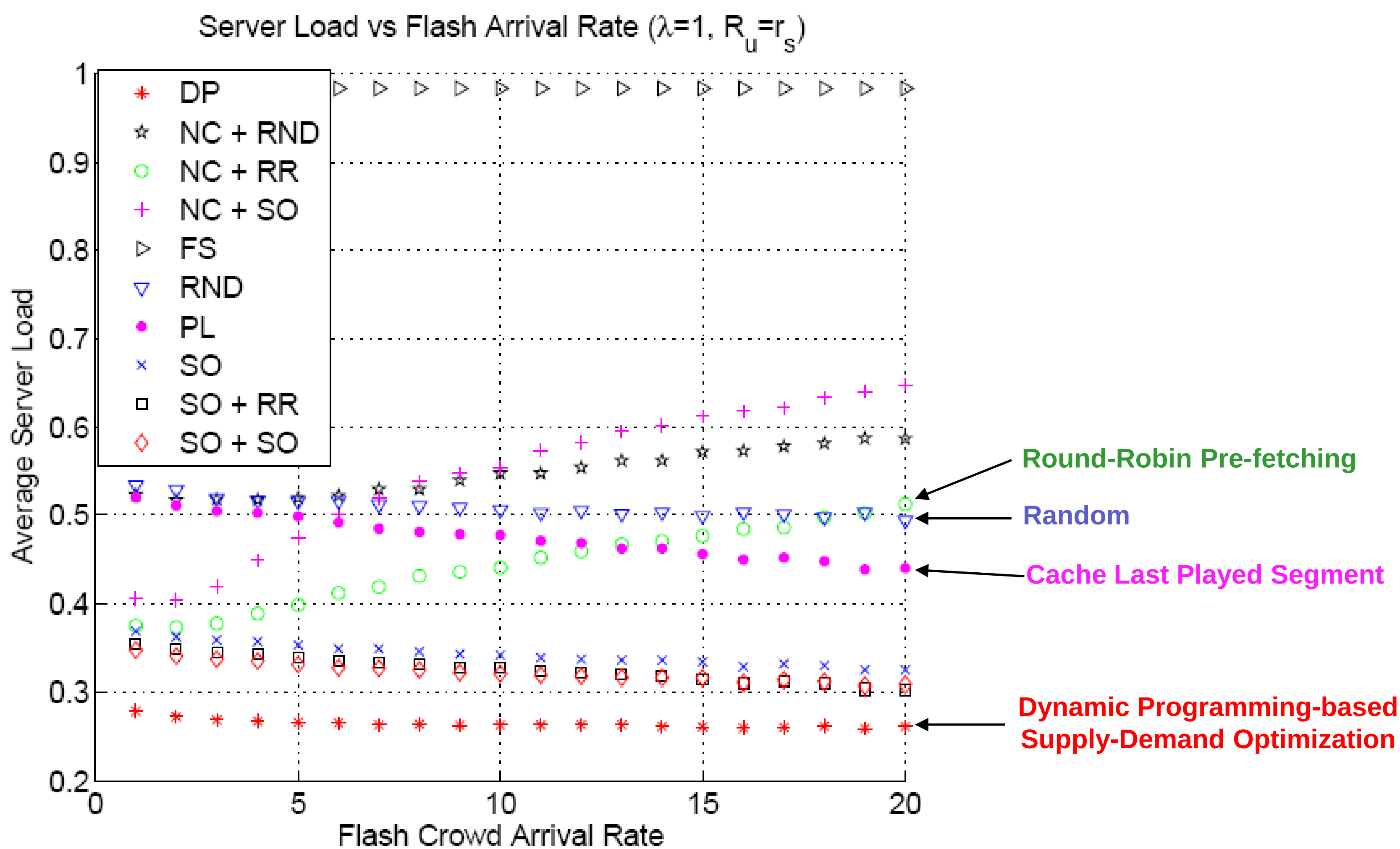
Flash Crowd Arrivals



*Server Load is normalized with respect to average user load

**Video length = 60 segments

***Arrival rate is measured per segment duration

Random Departures

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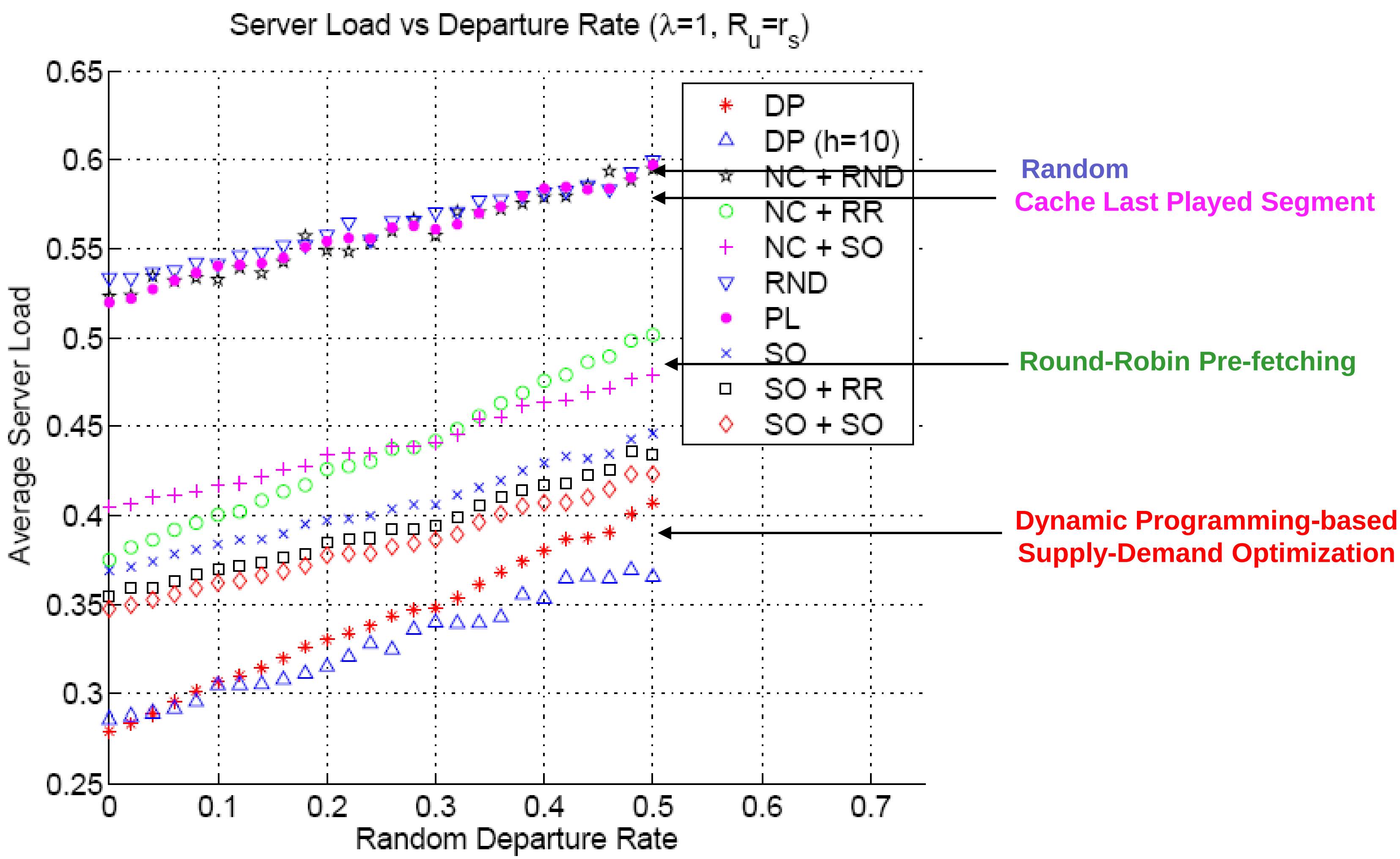

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Upload Rate

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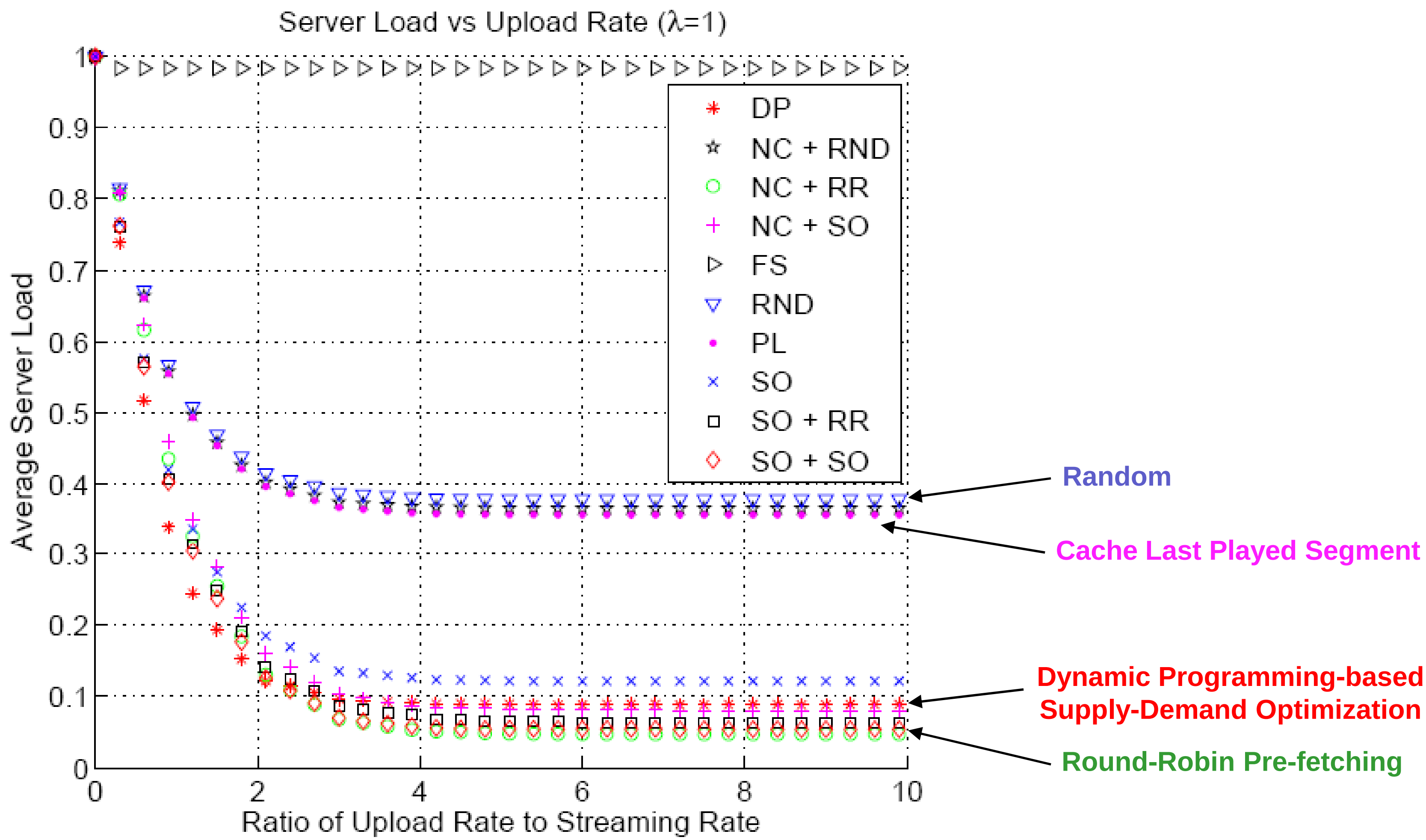
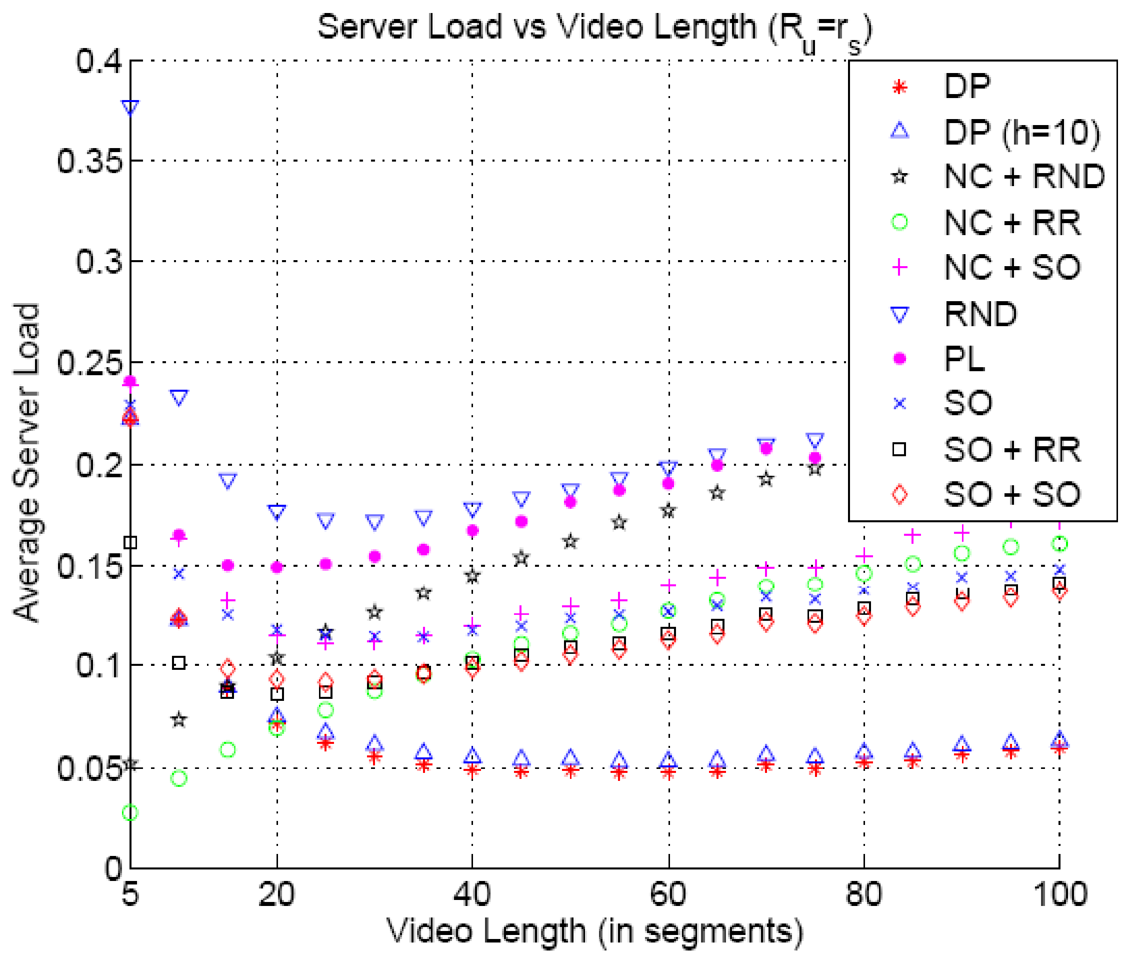


*Server Load is normalized with respect to average user load

**Video length = 60 segments

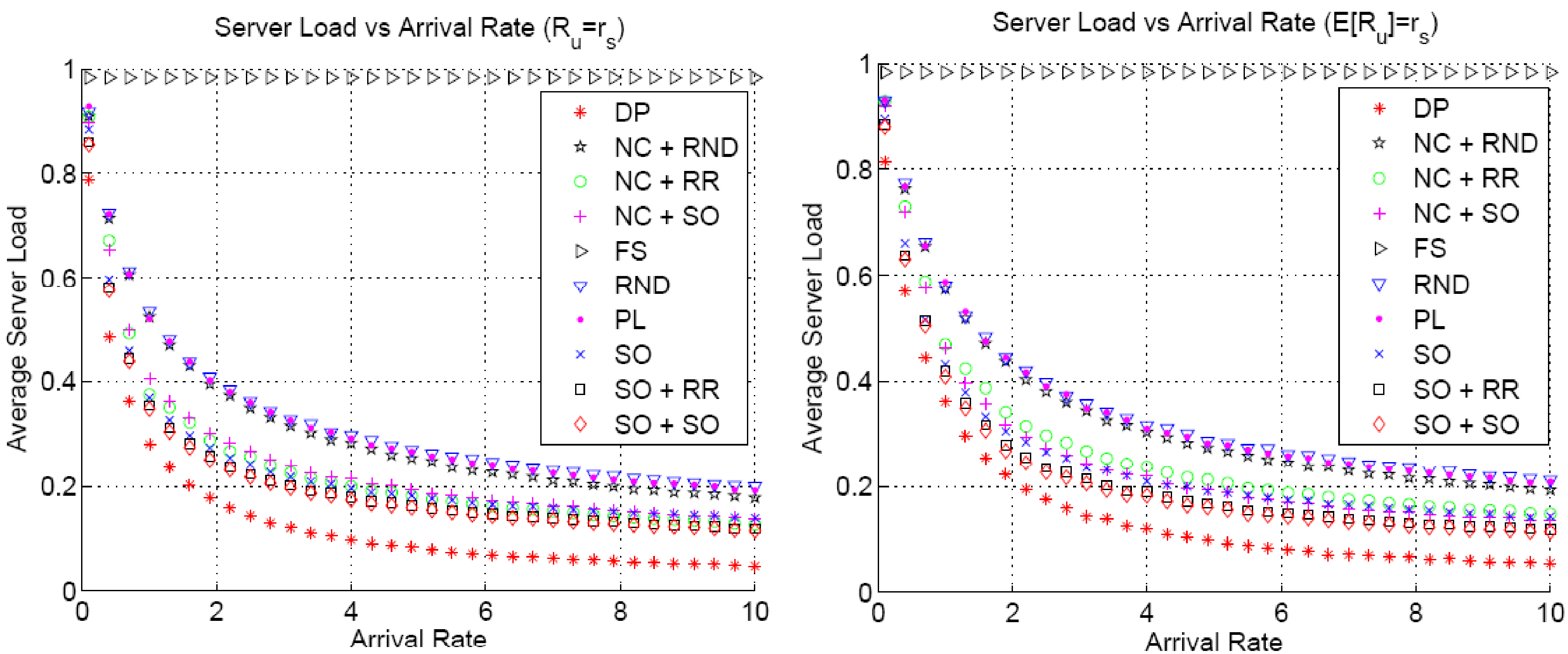
***Arrival rate is measured per segment duration

Video Length



*Arrival rate is 600 users per video duration
**Video duration is fixed in time

Homogeneous vs Heterogeneous Peers



Homogeneous peers

Heterogeneous peers

*Server Load is normalized with respect to average user load

**Video length = 60 segments

***Arrival rate is measured per segment duration

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Extensions with Scalable Video

- Video is composed of core and enhancement layers
  - Core layer
    - Content served by media servers
  - Enhancement layer
    - Served using peer-assisted streaming system
    - Content served by media servers and peers
- Evaluation Scenario
  - Limited Media Server BW for Enhancement layer
    - Enhancement layer may not be completely received
    - Measure the enhancement layer reception rate
  - Unlimited Media Server BW for Core layer
    - All peers receive the core layer completely

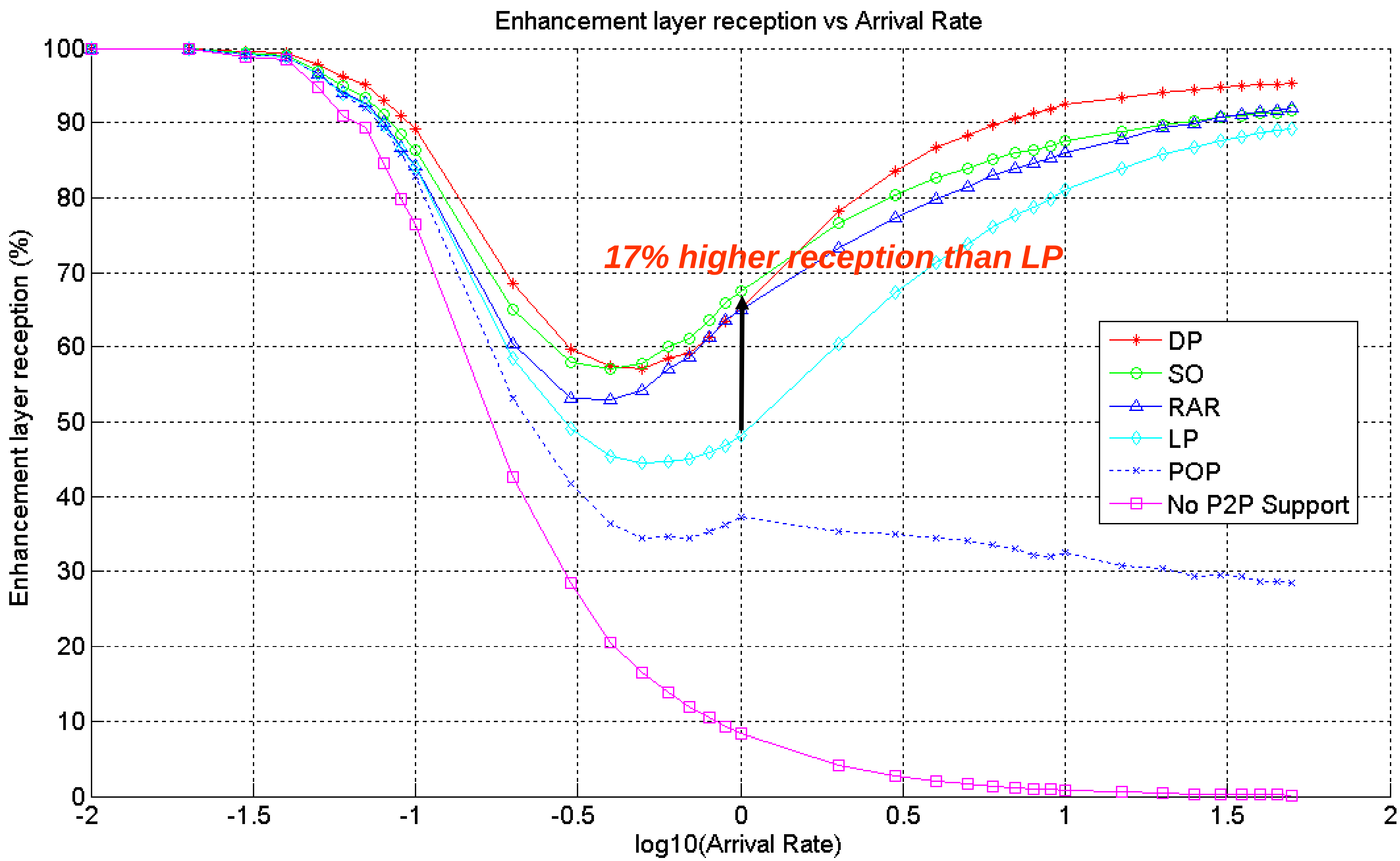
Performance Evaluations (2/2)

- Experiment Settings
  - Simulation time ~ 27 hours
  - Video Length = 10 minutes
    - 10 second segments
  - JSVM Video Codec
    - Base Layer: 500Kbps (media servers)
    - Enhancement Layer: 750Kbps (media servers and other peers)

- Competing Methods
  - Last Played (segment just downloaded)
  - Rarest (smallest supply)
  - Popular (largest demand)
  - Random (coin toss)
  - Round-Robin (prefetching-based)

Arrival rate/User Load

Server BW @ 3.75Mbps; Peer Upload BW @ 750Kbps; Enhancement BW @ 750Kbps



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Server Capacity

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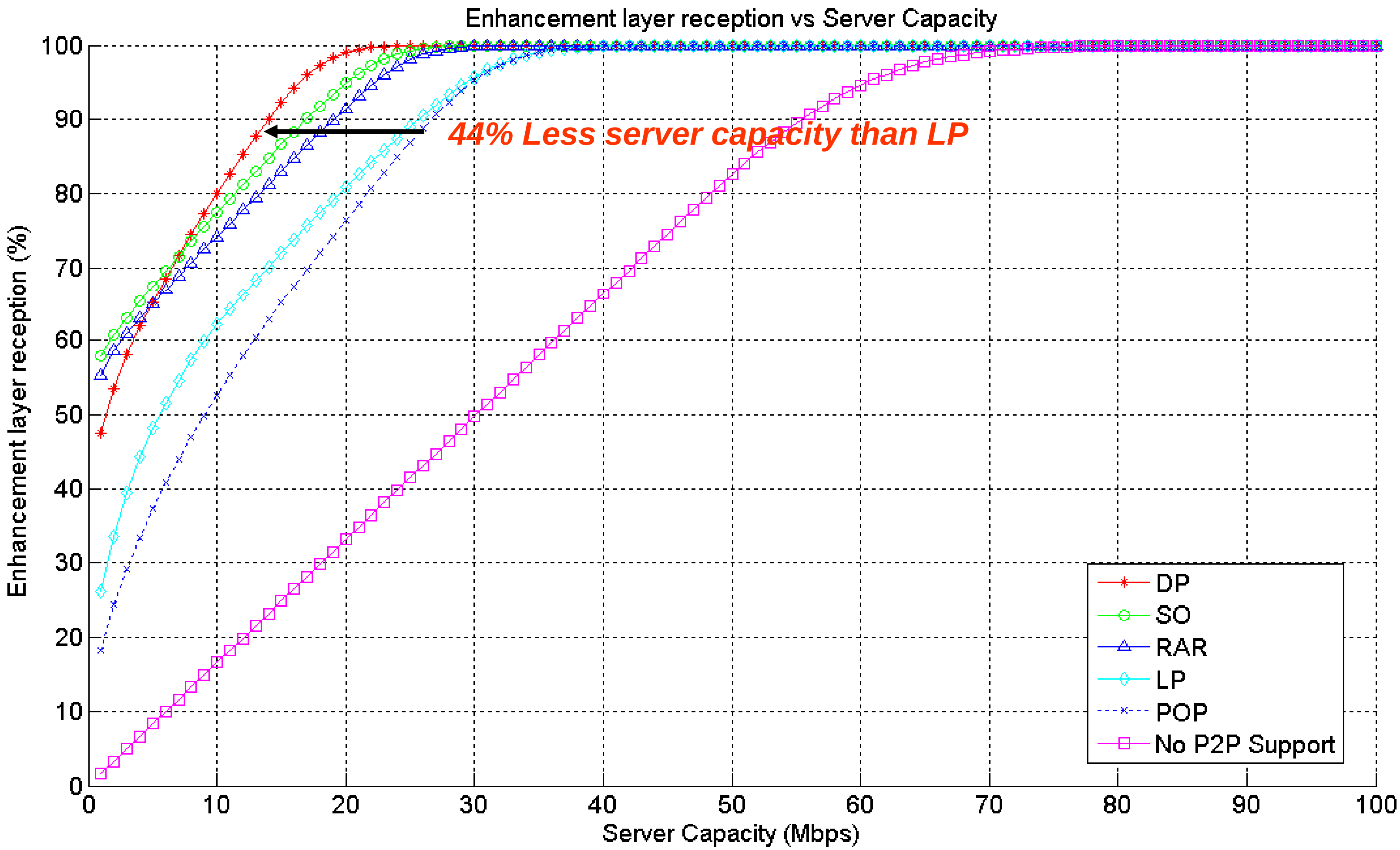
Arrival rate @ 1user/segment; Peer Upload BW @ 750Kbps; Enhancement BW @ 750Kbps



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Synopsis

- Hybrid P2P VoD architecture with limited cache
  - The assumption on fixed cache size of 1 segment can be relaxed
- A new framework of cache optimization
  - Using supply and demand estimates
- Two methods proposed
  - Static Optimal (SO)
  - Dynamic Programming (DP)
- Significant reduction in Server BW
  - Proposed method outperforms existing methods
- Robust to system variations
  - Flash crowds, random departures, etc.

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Ongoing Efforts

- Large scale wide-area deployment
  - Most of the control and signaling frameworks are implemented
  - Optimization modules and PlanetLab deployments are the next steps
- Integration with elastic public computing clouds
  - Amazon's EC2 is the strongest candidate
    - Acquire more servers as you need, pay per server usage and in/out traffic
    - Release the servers you do not need as demand decreases
    - Vast server resources through statistical multiplexing and economy of scale
  - Nicely fits to our model
    - Use P2P supply-demand optimization to reduce the server load
    - Patch the gap in supply-demand by dynamically acquiring servers from the cloud

Questions?

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