Networks with Deterministic Quality-of-Service Guarantees

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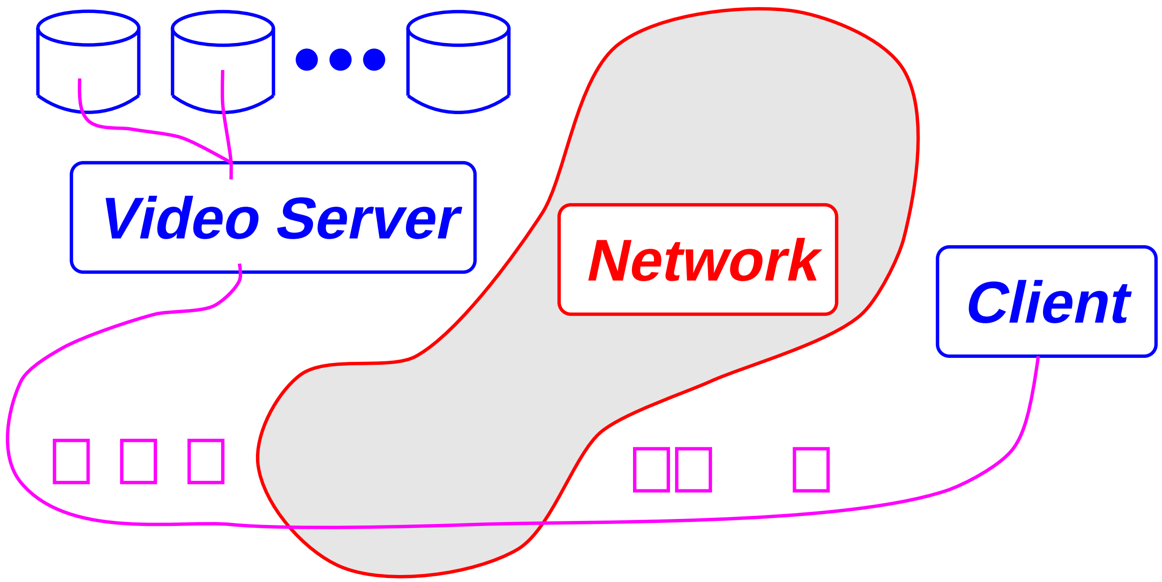
Motivation

- Transmission of video and audio over packet-switched networks.



- Requires *new networks and protocols*.

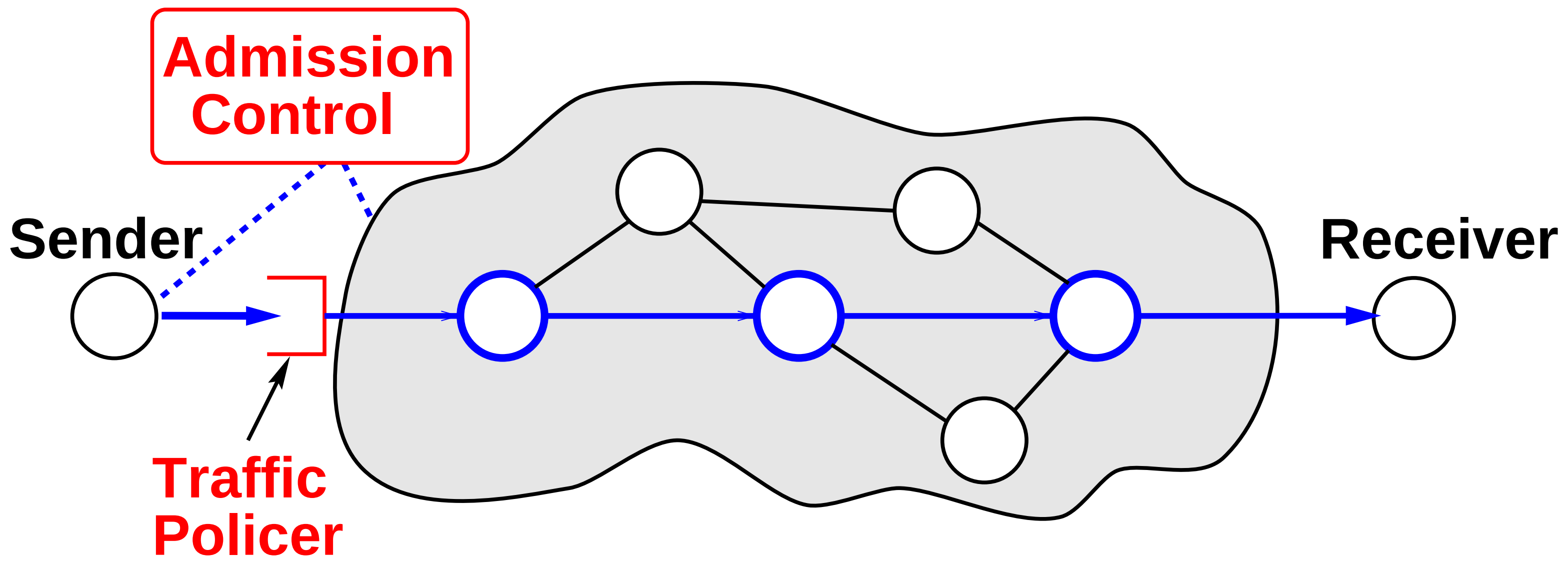
Overview

- Background
- *Traffic Characterization*
- *Packet Scheduling*
- Conclusions

Quality-of-Service

- Video and audio need *Quality-of-Service (QoS)* guarantees:
  - *delay*
  - jitter
  - throughput
  - loss rate
- A *deterministic service* gives worst-case guarantees.

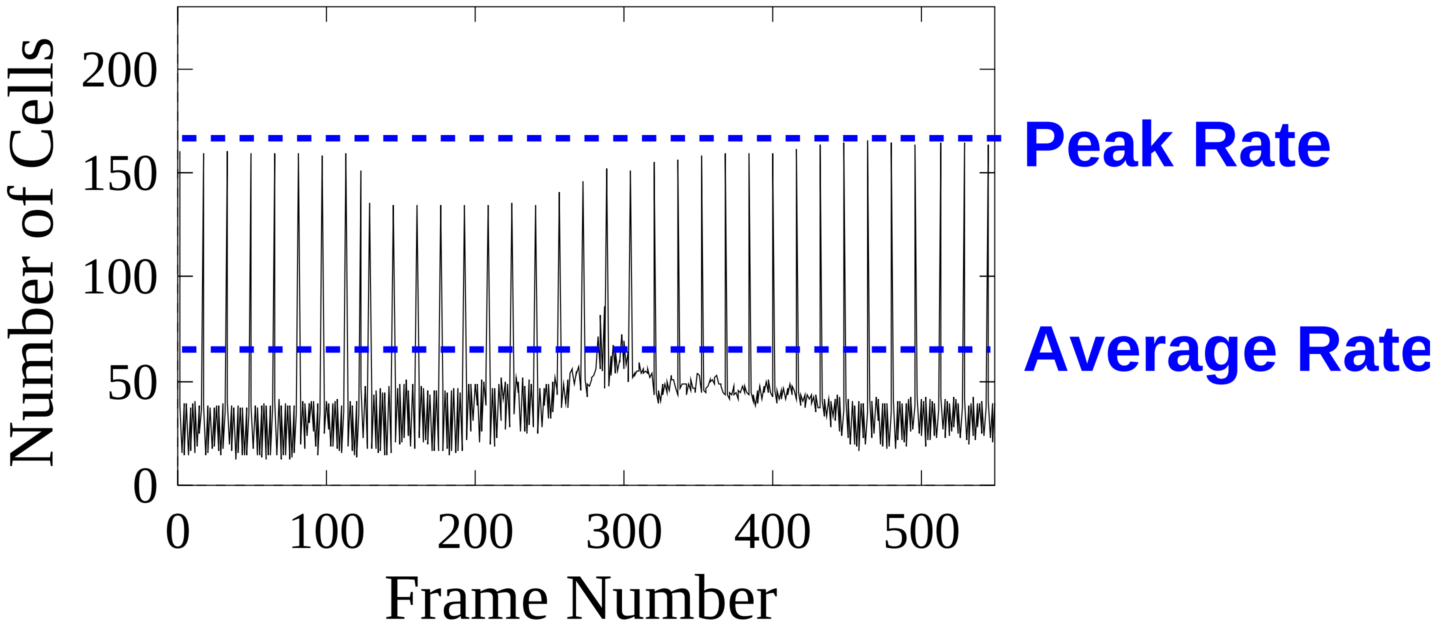
Multimedia Networks



- Multimedia connections have *QoS* and *traffic* parameters.
- Multimedia networks need *resource reservation*.

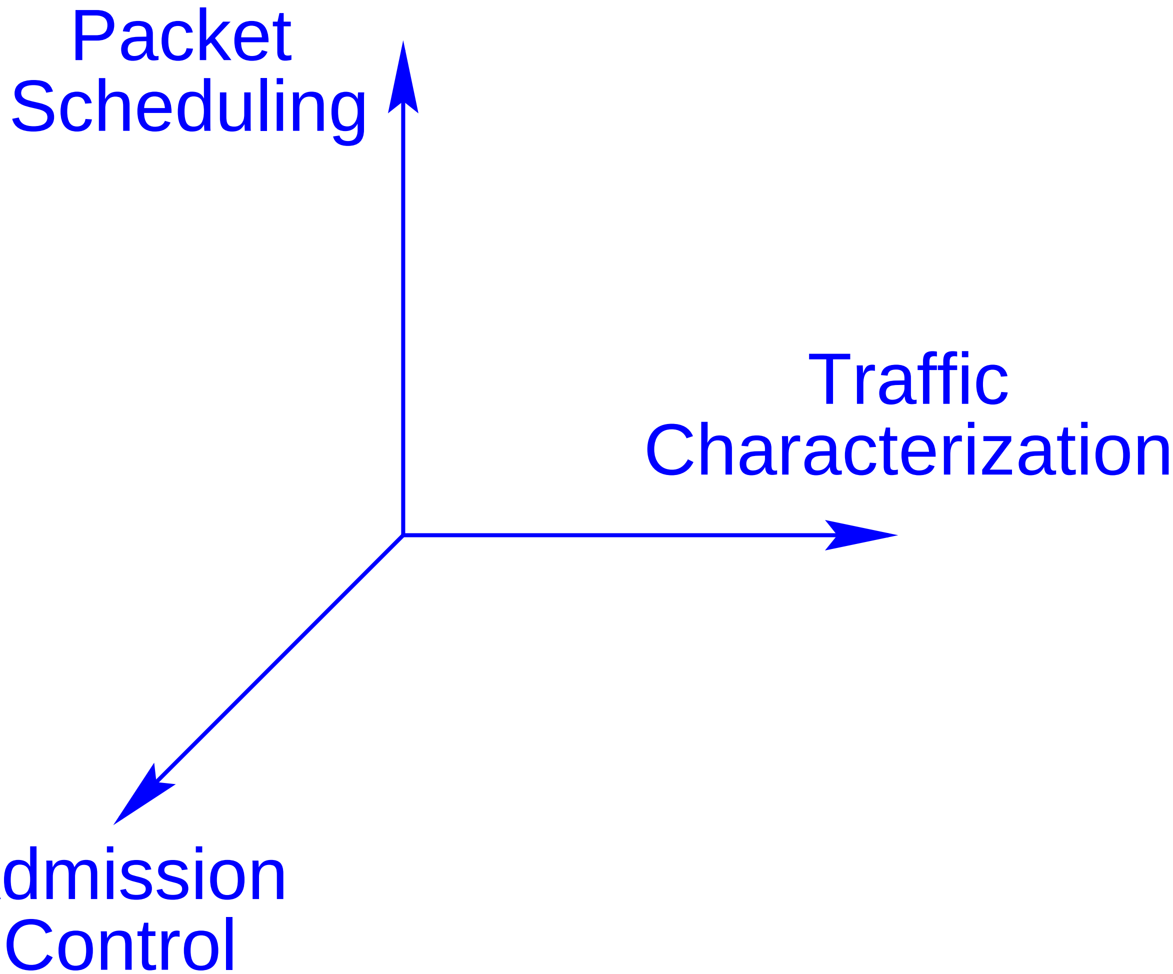
Why is Resource Reservation Difficult?

- Compressed digital video has a *variable bit rate*.

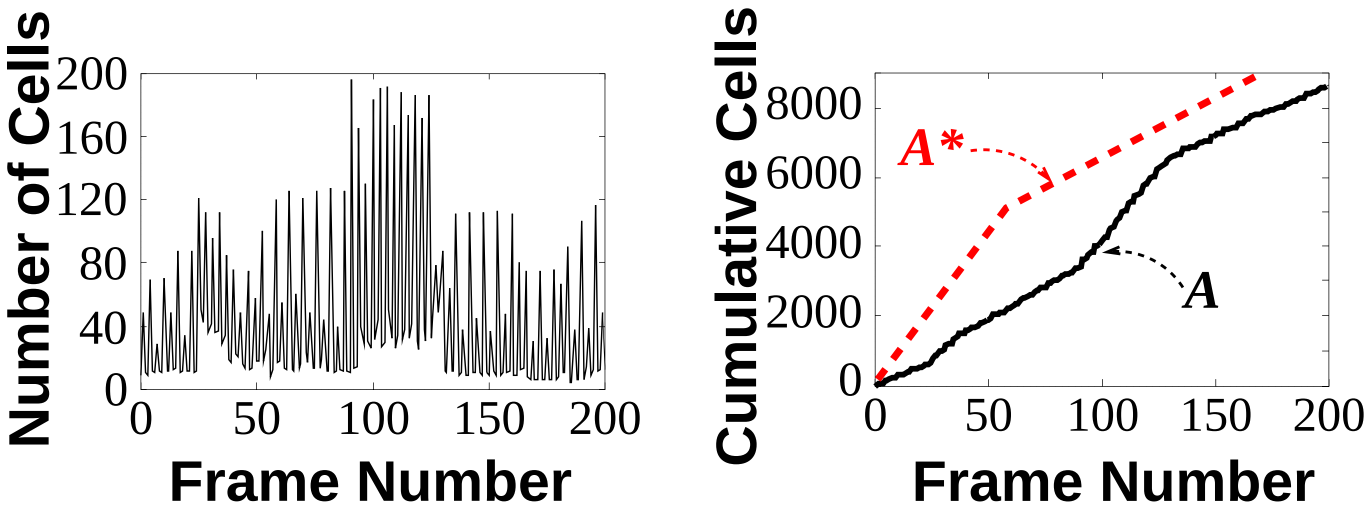


- *Problem:* How do we provide deterministic QoS without peak-rate reservation?

Design Space of a Multimedia Network

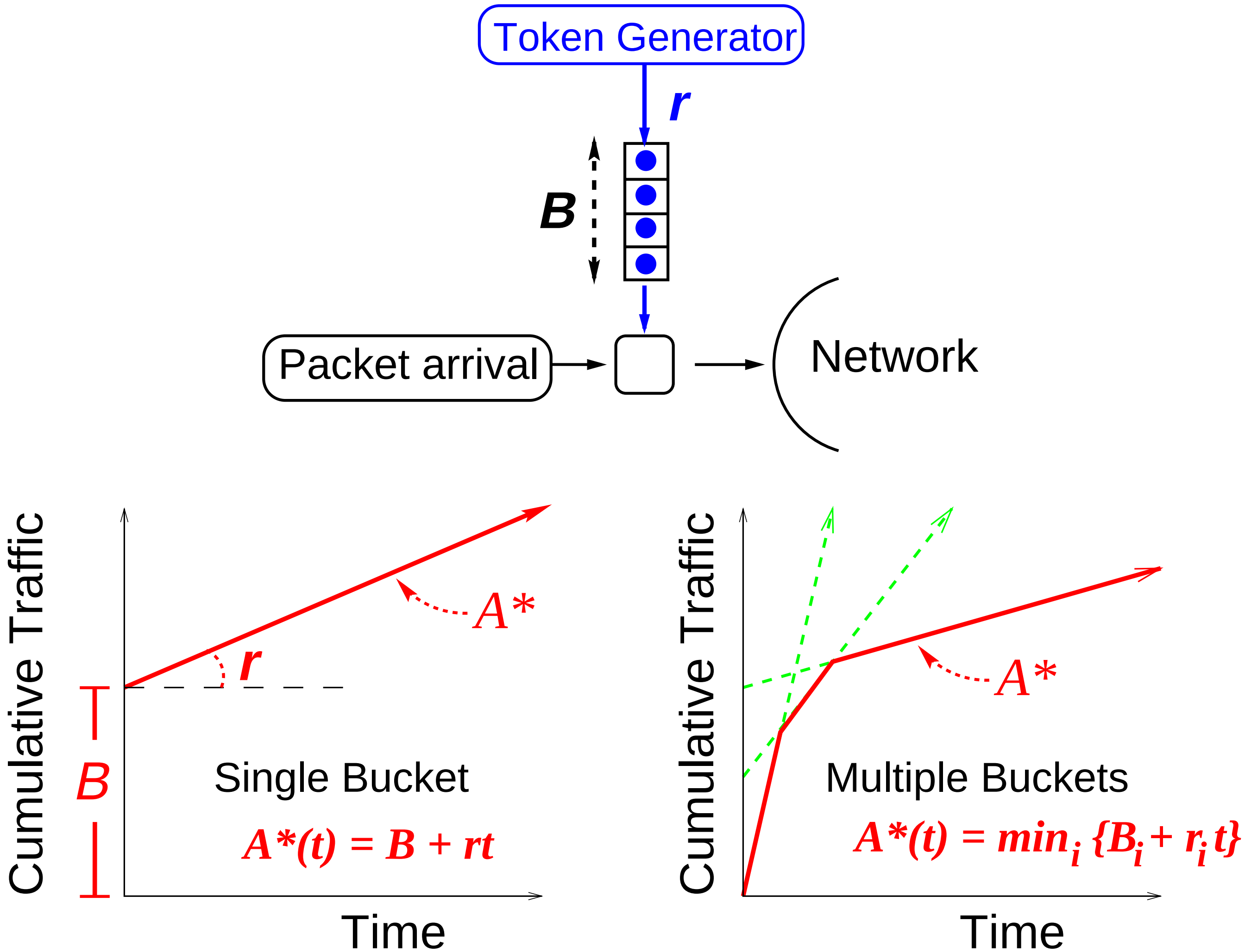


What is Traffic Characterization?



- A *traffic characterization* is a bound for the traffic over any interval.
  - *Time-invariant*: $A^*(t) \geq A[\tau, \tau + t], \quad \forall t, \tau$
  - *Subadditive*: $A^*(t_1 + t_2) \leq A^*(t_1) + A^*(t_2), \quad \forall t_1, t_2$
- Traffic characterization must map to traffic policer.

The "Leaky Bucket" Traffic Characterization

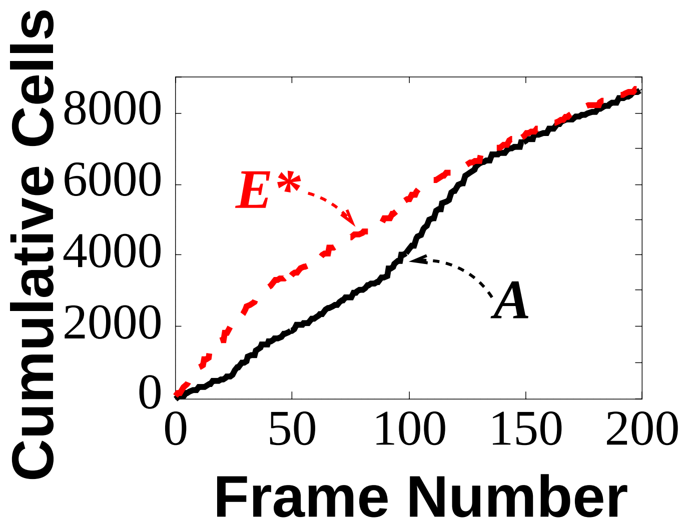


- Used in: ATM, Integrated-services Internet

Traffic Characterization Problem

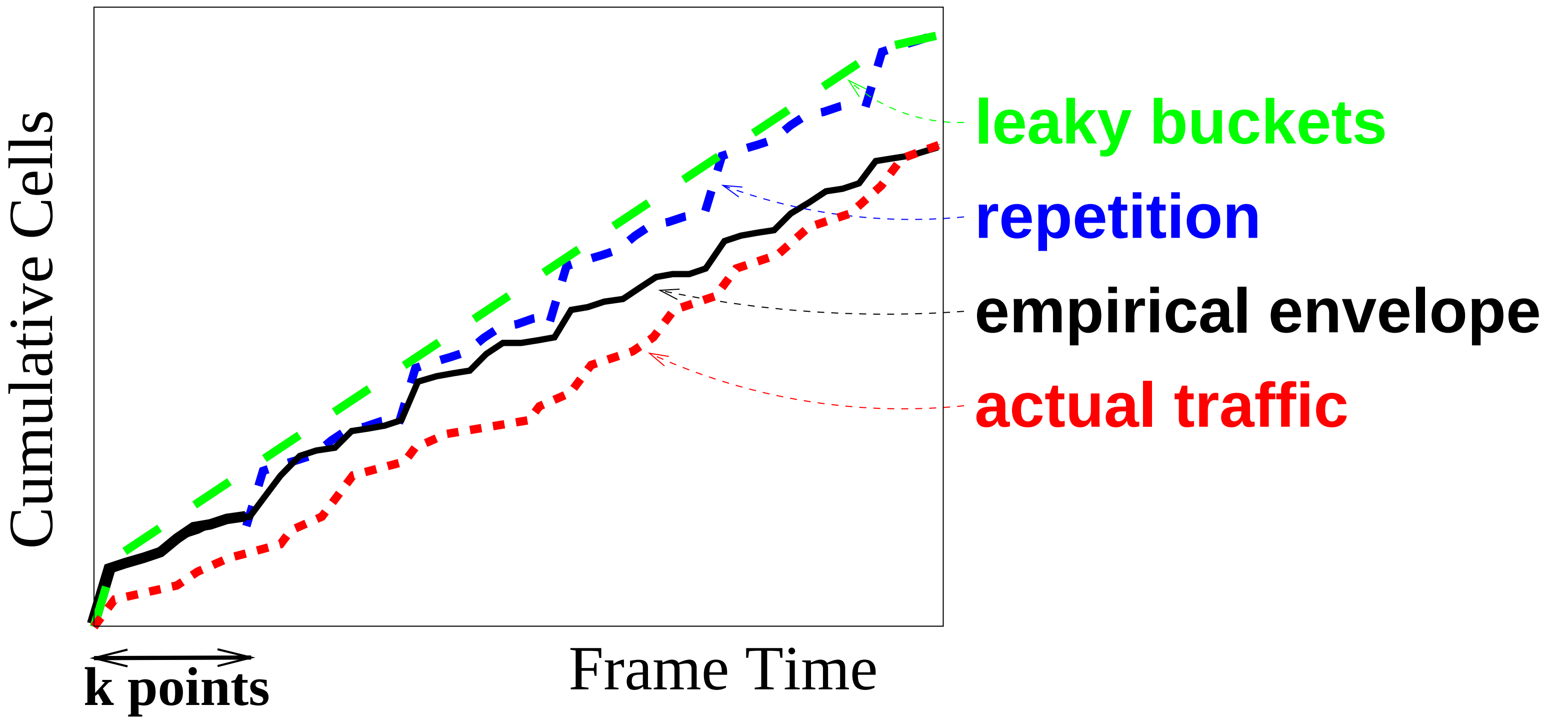
- Given a video sequence, how do I select leaky bucket parameters?
- Previous approaches:
  - *Candidate Sets* (Low and Varaiya 1991).
  - Choose B according to buffer space availability (Pancha and El Zarki 1995).
  - Relative importance of buffer space and bandwidth (Guillemin et. al. 1995).
  - *Empirical envelope* (Wrege, Knightly, Zhang, and Liebeherr 1996).

Empirical Envelope



- The best possible characterization for a video source is its *empirical envelope* E^*.
- $E^*(t) := \sup_{\tau \geq 0} A[\tau, \tau + t]$, for all $t \geq 0$.
- *Difficult to police, expensive to compute*.

Our Approach



- Approach: approximate the empirical envelope E^*.
- Use only a subset of E^*.
- Select leaky bucket parameters.

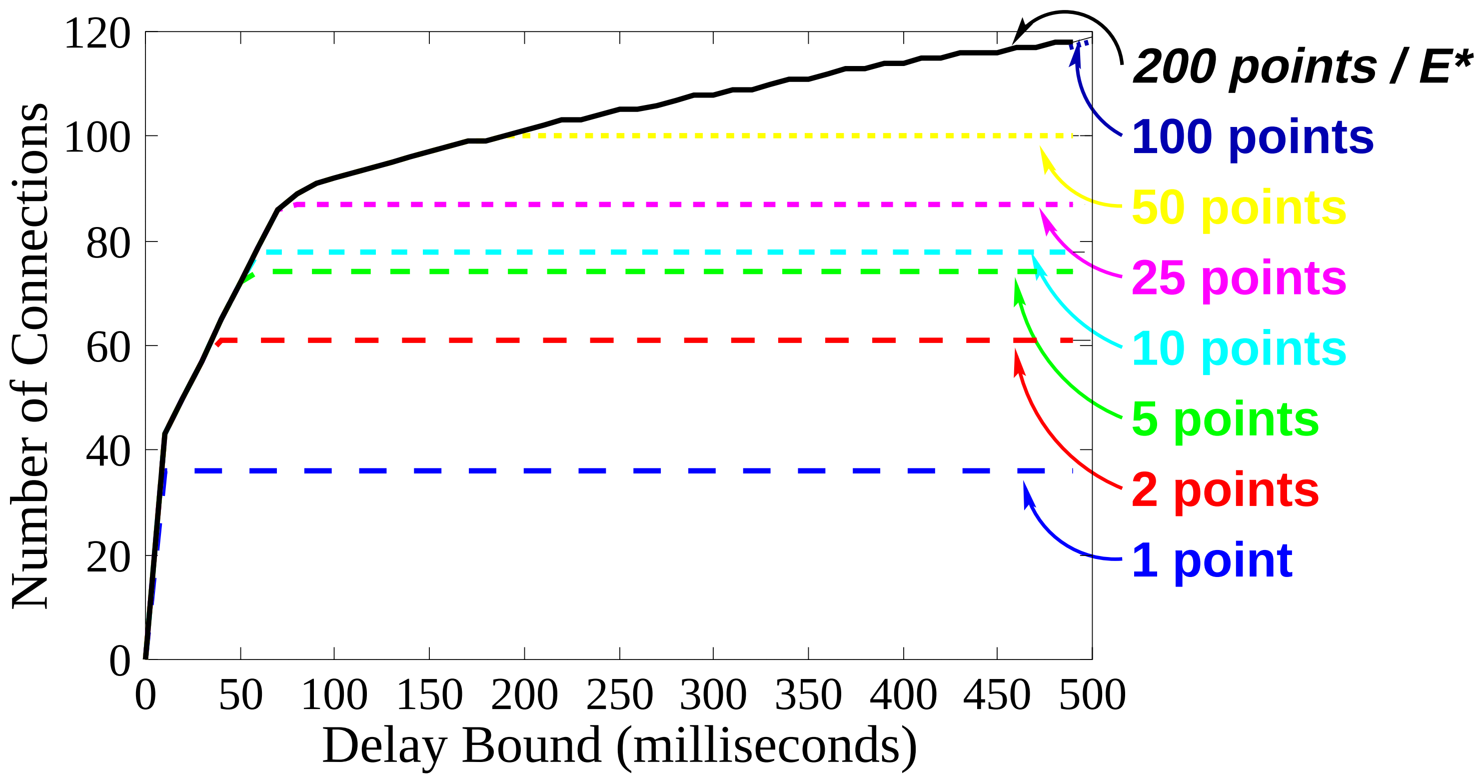
Evaluation

- How much information do we need from the envelope?
- How good is our approximation?

Experimental Setup

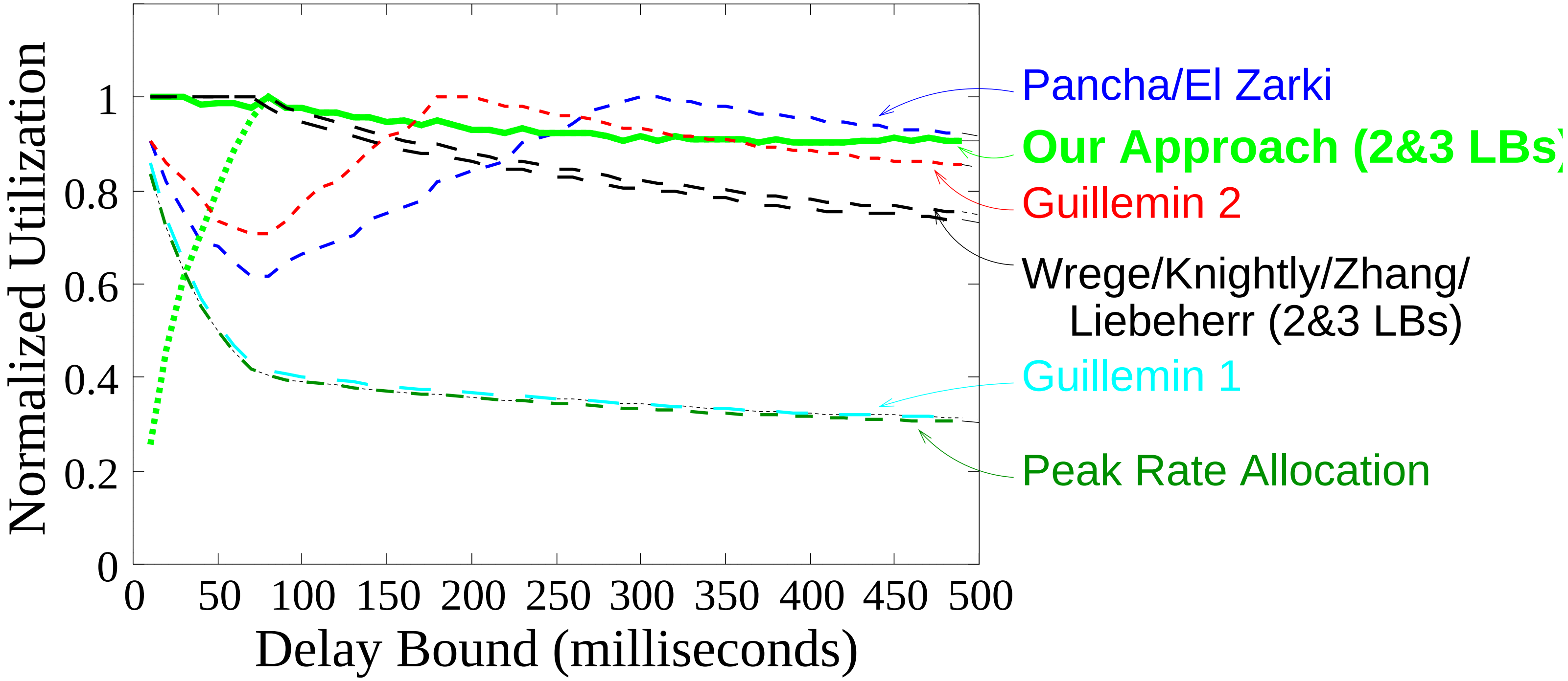
- Single 155 Mbps switch.
- Characterize a “typical” MPEG-compressed traffic source.
- Frame pattern: IBBPBBPBBPBB
- Video frames partitioned into 53-byte cells.

How much of E^* do we need?



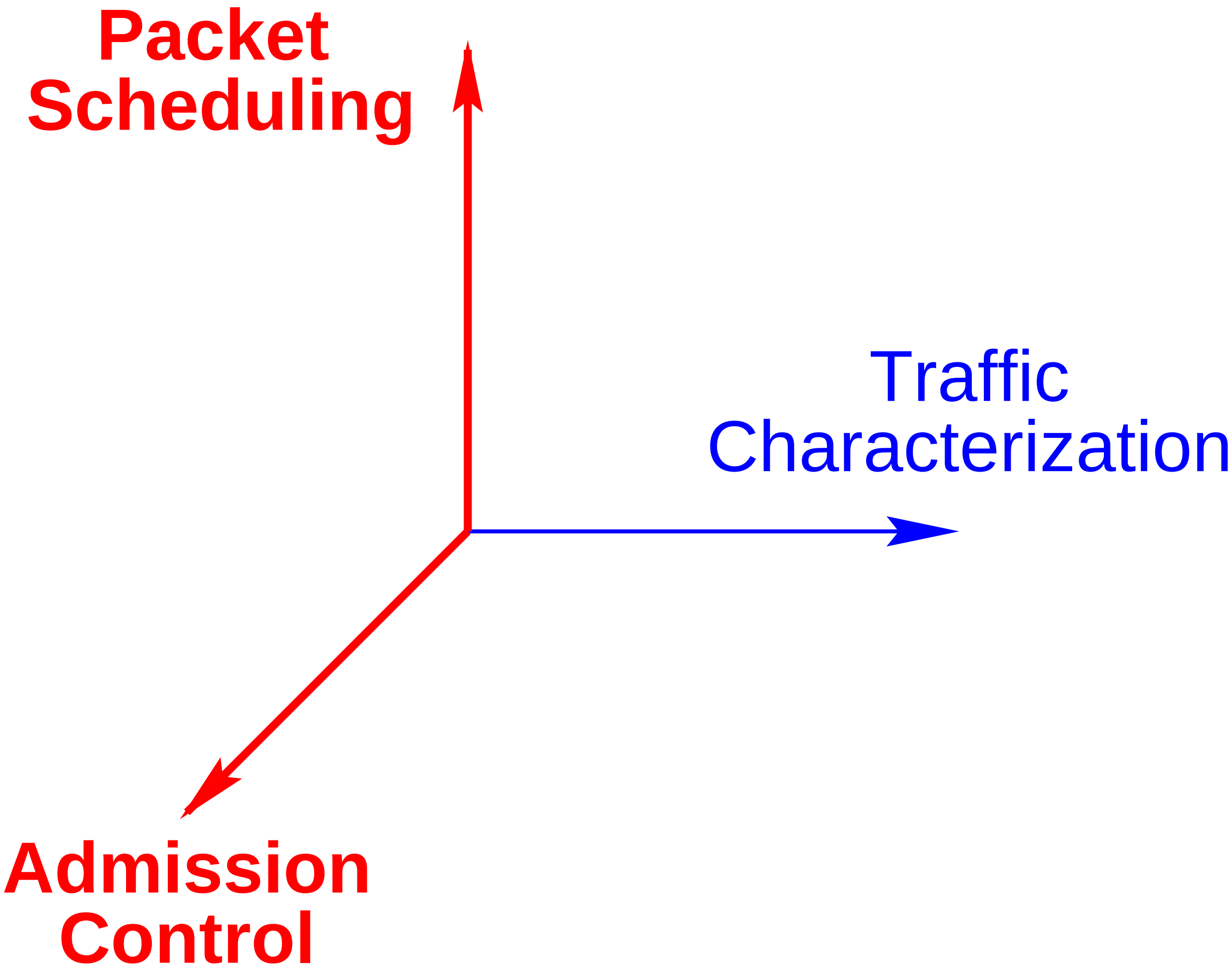
- *200 points* of the envelope are sufficient.
- Empirical envelope has 40,000 points.

How Good is Our Method?

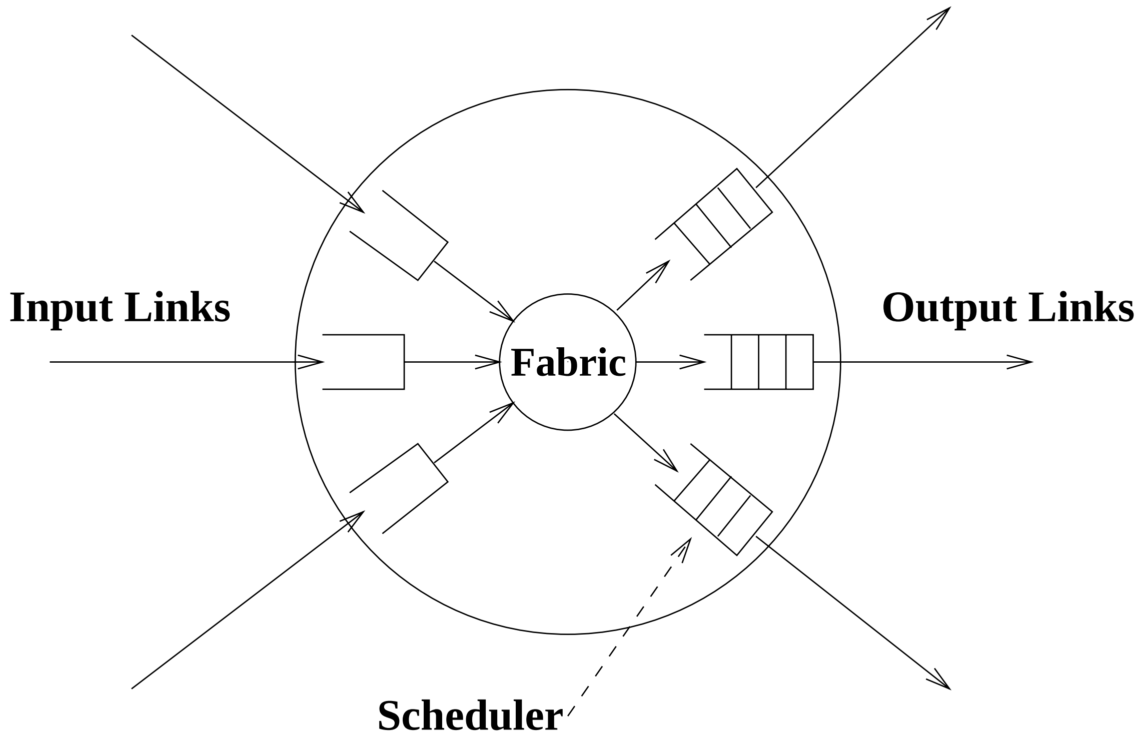


- We plot a normalized utilization $U(d) = \#A^*/\#E^*$.

Design Space of a Multimedia Network

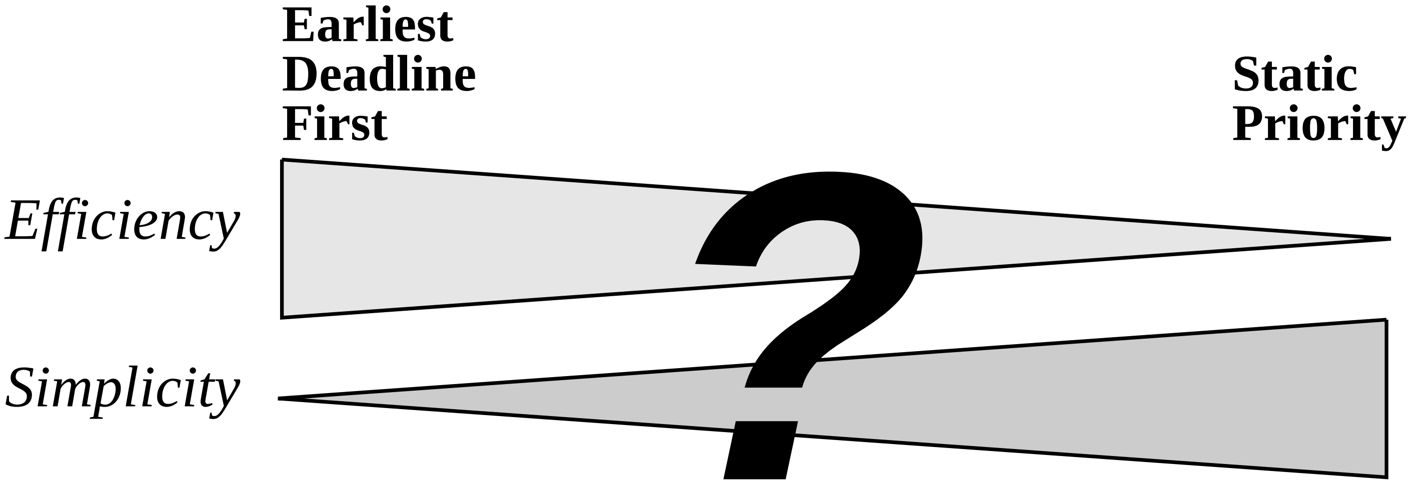


Packet Scheduling



- A connection j has a *delay bound* d_j.
- *Packet scheduling discipline* determines *delay*.

What is a good scheduler?



Approximate EDF with FIFO queues

Approximations that require *no sorting*:

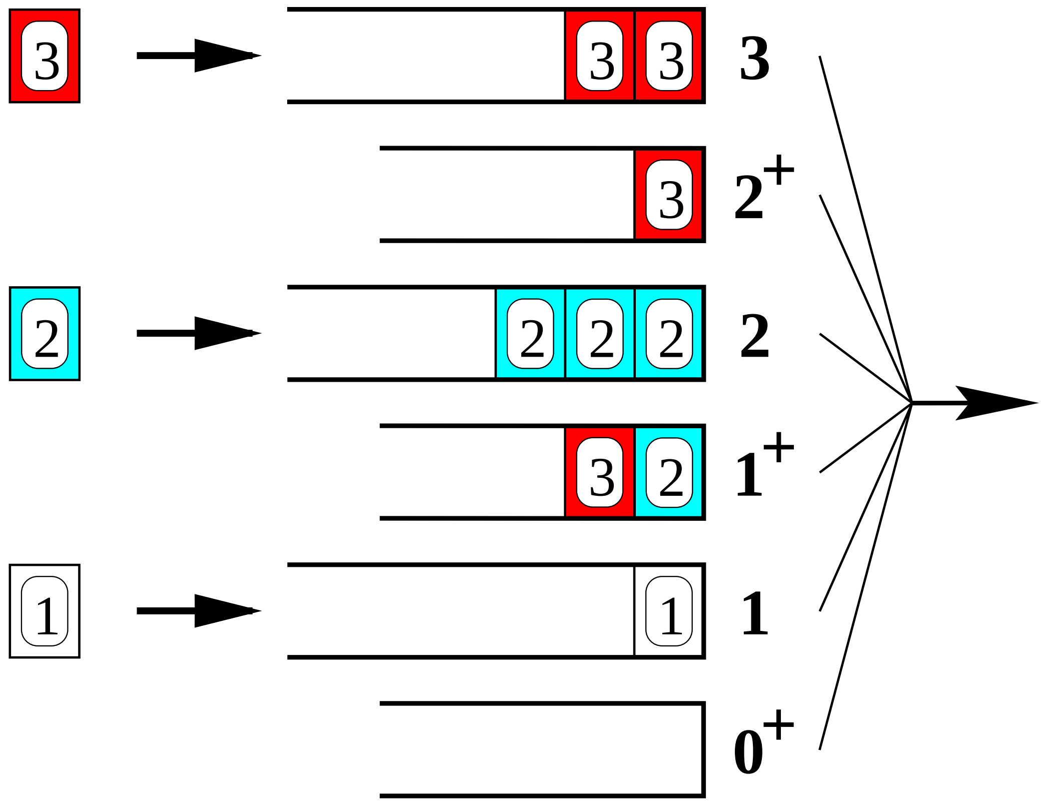
- *HOL-PJ* (Lim/Kobza 1990)
- *Relabeling Architecture* (Peha/Tobagi 1991)
- *Rotating-Priority-Queues* (RPQ) (Liebeherr/Wrege 1994)

Rotating-Priority-Queues$^+$ (RPQ$^+$)

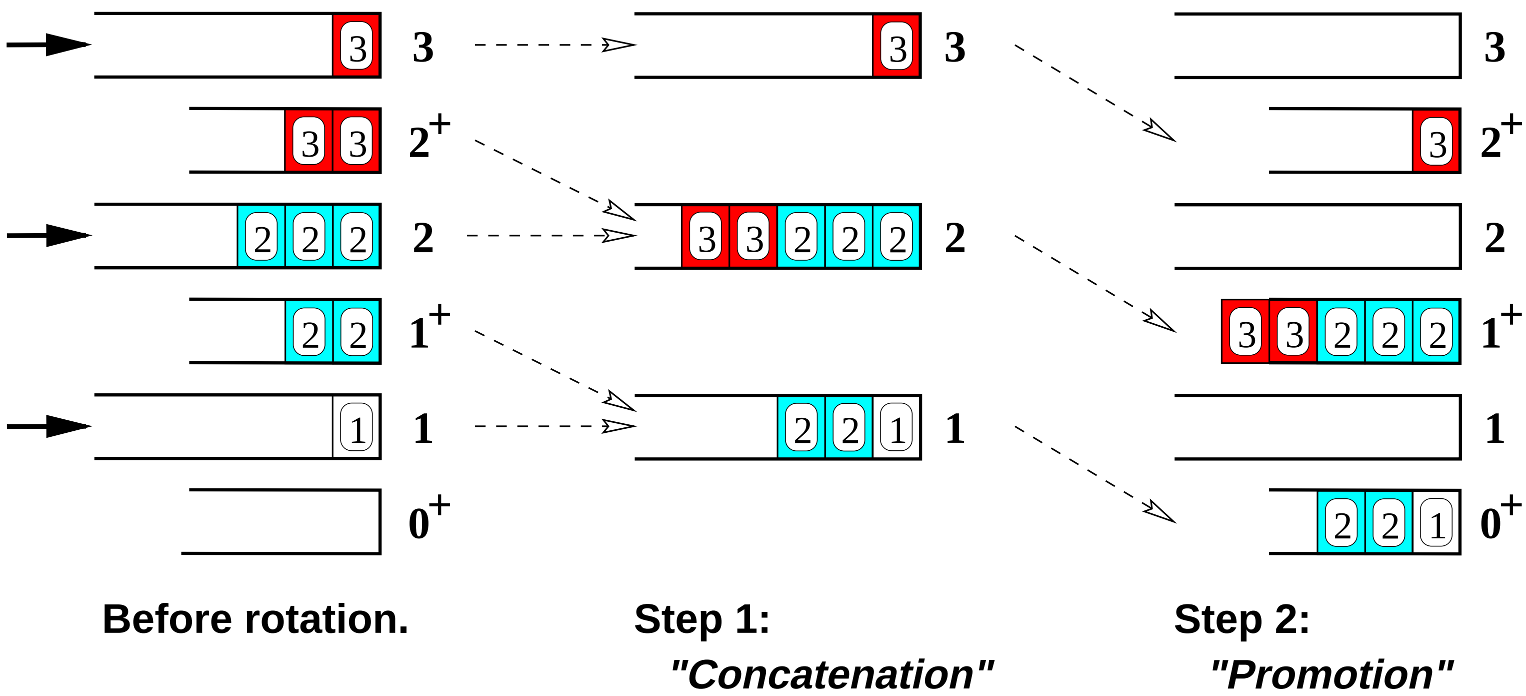
Design Principles:

- P priority sets.
- $2P$ FIFO queues with labels.
- Relabel queues every Δ time units.
- One delay bound for each priority set: $d_p = p \cdot \Delta$.

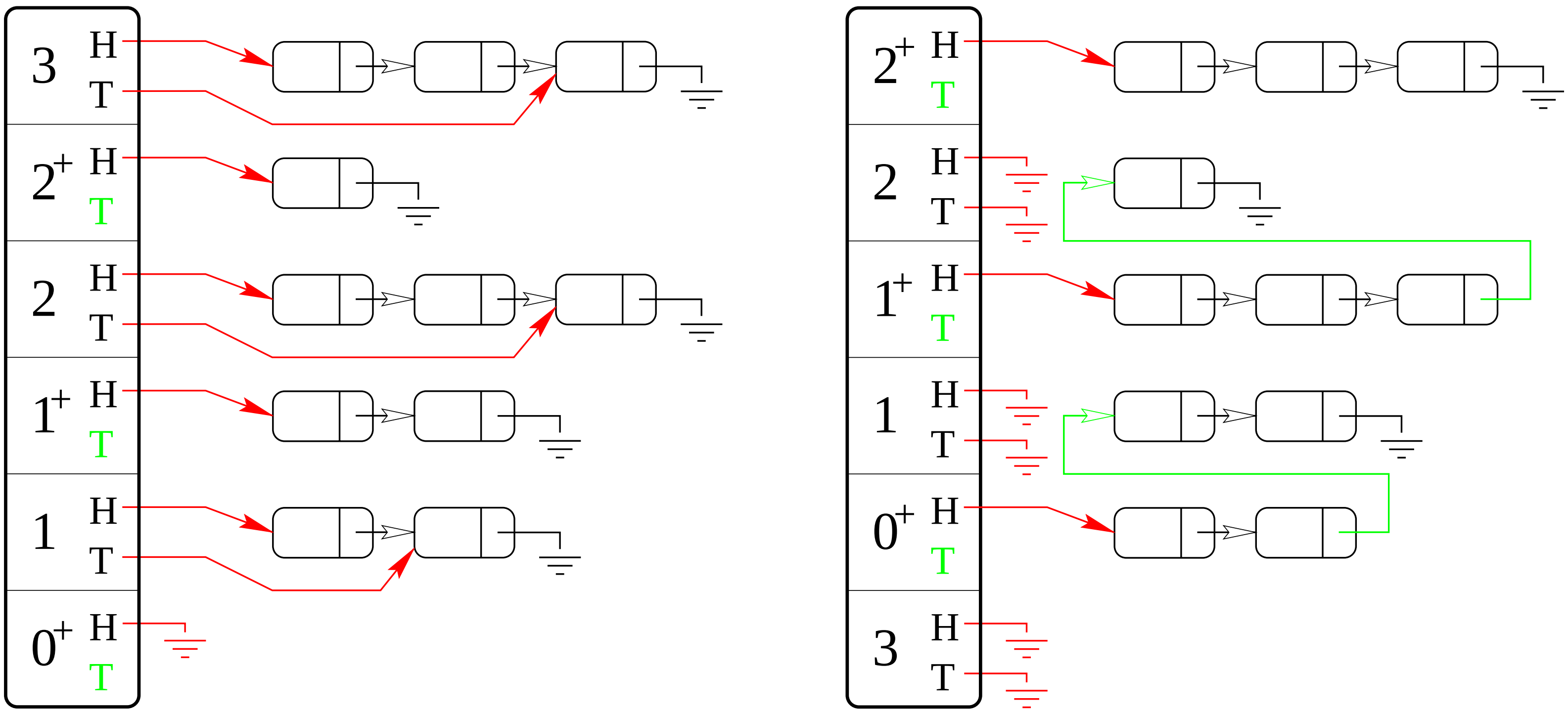
RPQ^{+} Scheduler



RPQ+ Queue Rotation



Implementating RPQ$^+$ in Shared Memory



- No movement of packets.
- Operations independent of queued packets.

Admission Control Test for RPQ^{+}

For all priorities p and all $t \geq d_p$,

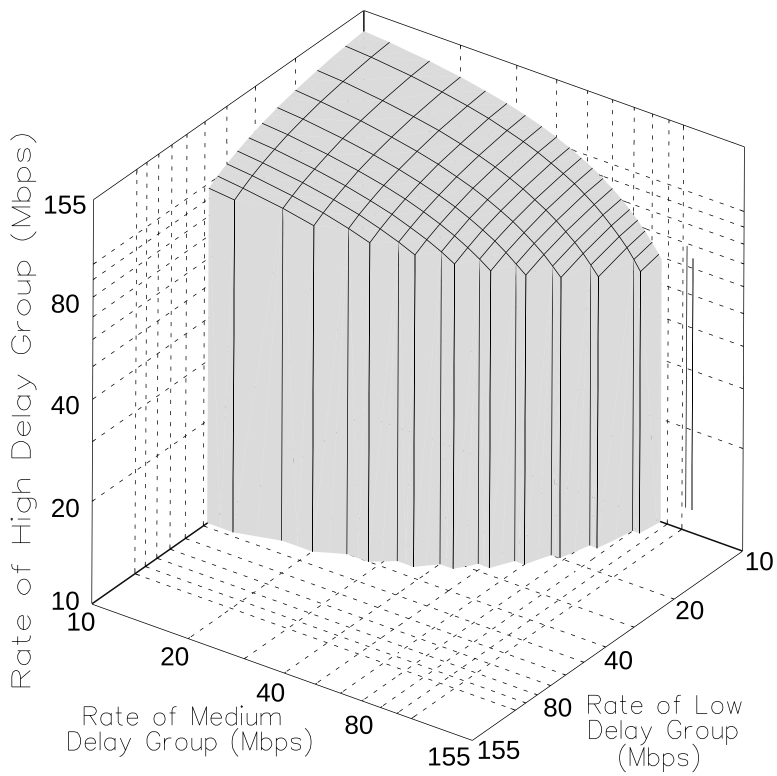
$$t \geq \sum_{q=1}^{p-1} \sum_{j \in \mathcal{C}_q} A_j^*(t - d_q + \Delta) + \sum_{q=p}^{P} \sum_{j \in \mathcal{C}_q} A_j^*(t - d_q) + \max_{r, d_r > t} s_r^{max}$$

Experimental Setup

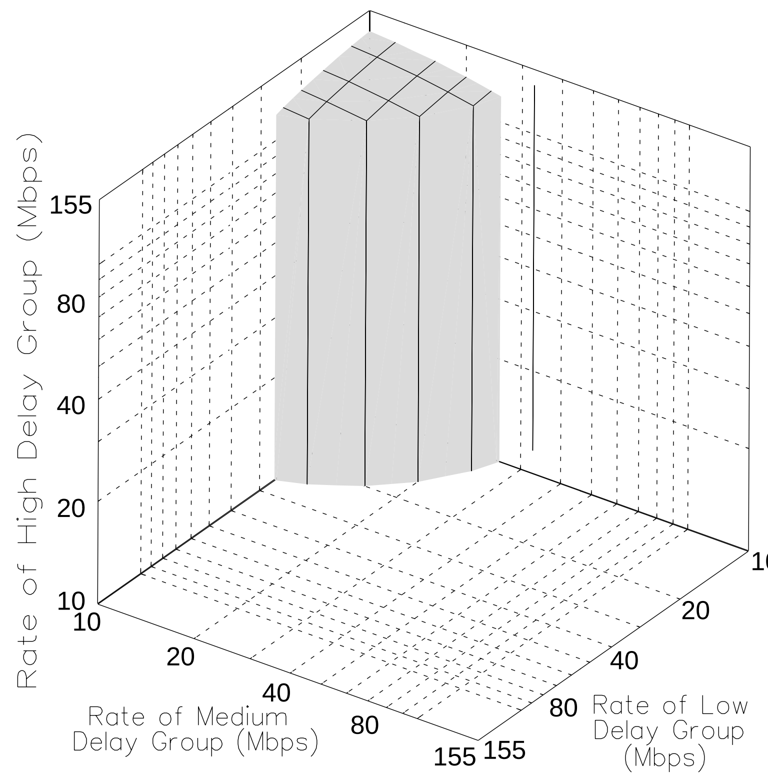
- Single 155 Mbps switch.
- Three connection groups *Low, Medium, High Delay*.

	Index j	Delay Bound d_j	Burst Size B_j	Rate r_j
Low	1	12 ms	4,000 cells	10-155 Mbps
Medium	2	24 ms	2,000 cells	10-155 Mbps
High	3	36 ms	4,000 cells	10-155 Mbps

Evaluation

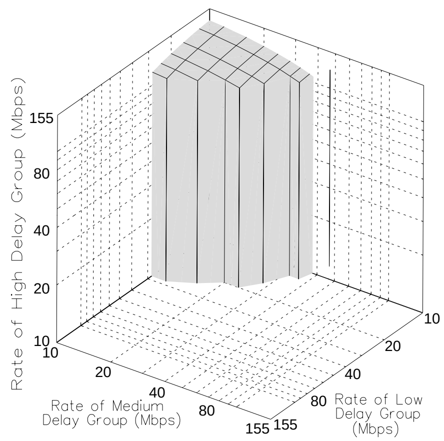


EDF

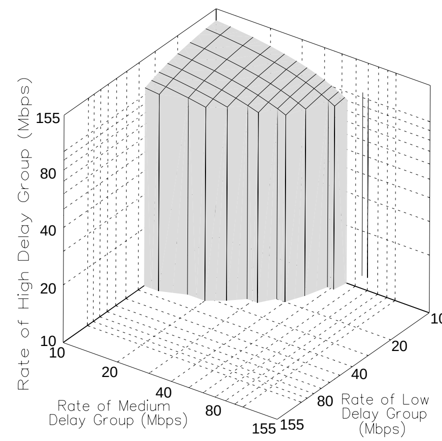


SP

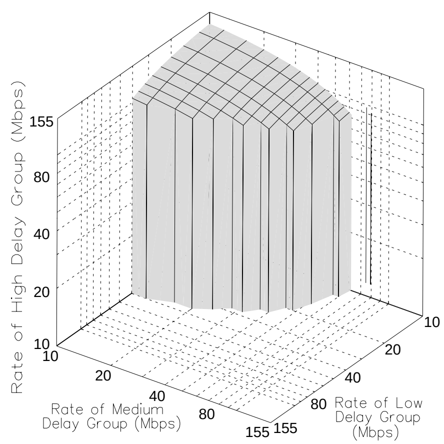
Evaluation



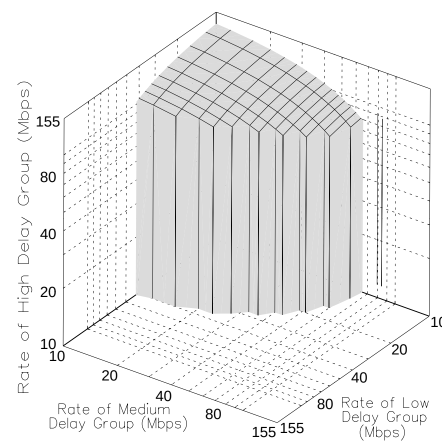
RPQ$^+$ ($\Delta = 12ms$; 6 FIFOs)



RPQ$^+$ ($\Delta = 6ms$; 12 FIFOs)



RPQ$^+$ ($\Delta = 4ms$; 18 FIFOs)



RPQ$^+$ ($\Delta = 3ms$; 24 FIFOs)

Conclusions

- Relax deterministic service.
- Implement RPQ$^+$ for IP forwarding.
- Combine advantages of delay schedulers (EDF,RPQ) and rate schedulers (WFQ).
- Reading:

  `IEEE/ACM Transactions on Neworking`, December 1996.

  `Proc. IEEE Infocom '96`, San Francisco, March 1996.

  `Proc. IEEE Infocom '97`, Kove, April 1997.