End-to-end Window-Constrained Scheduling for Real-Time Communication

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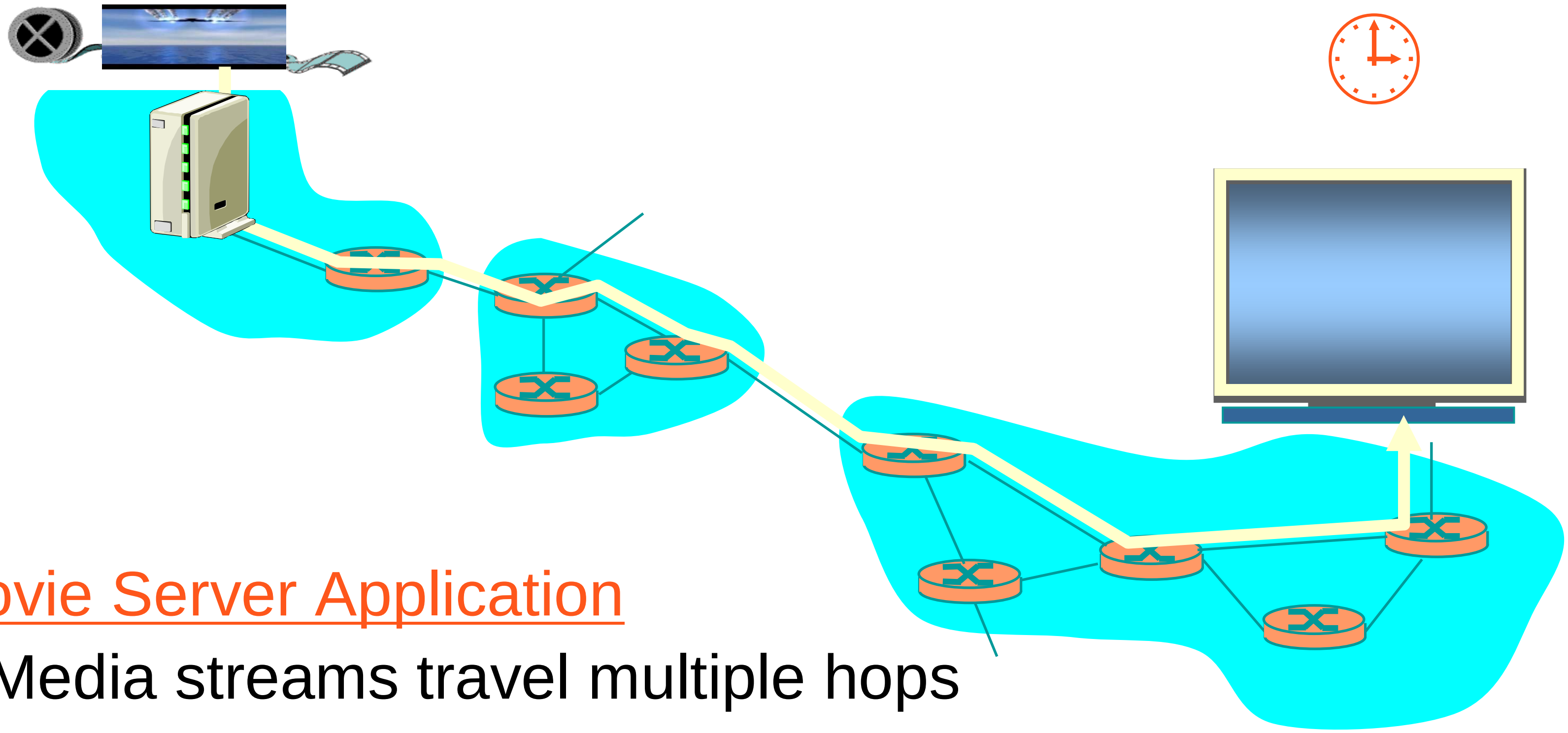
RTCSA 2004

Computer Science

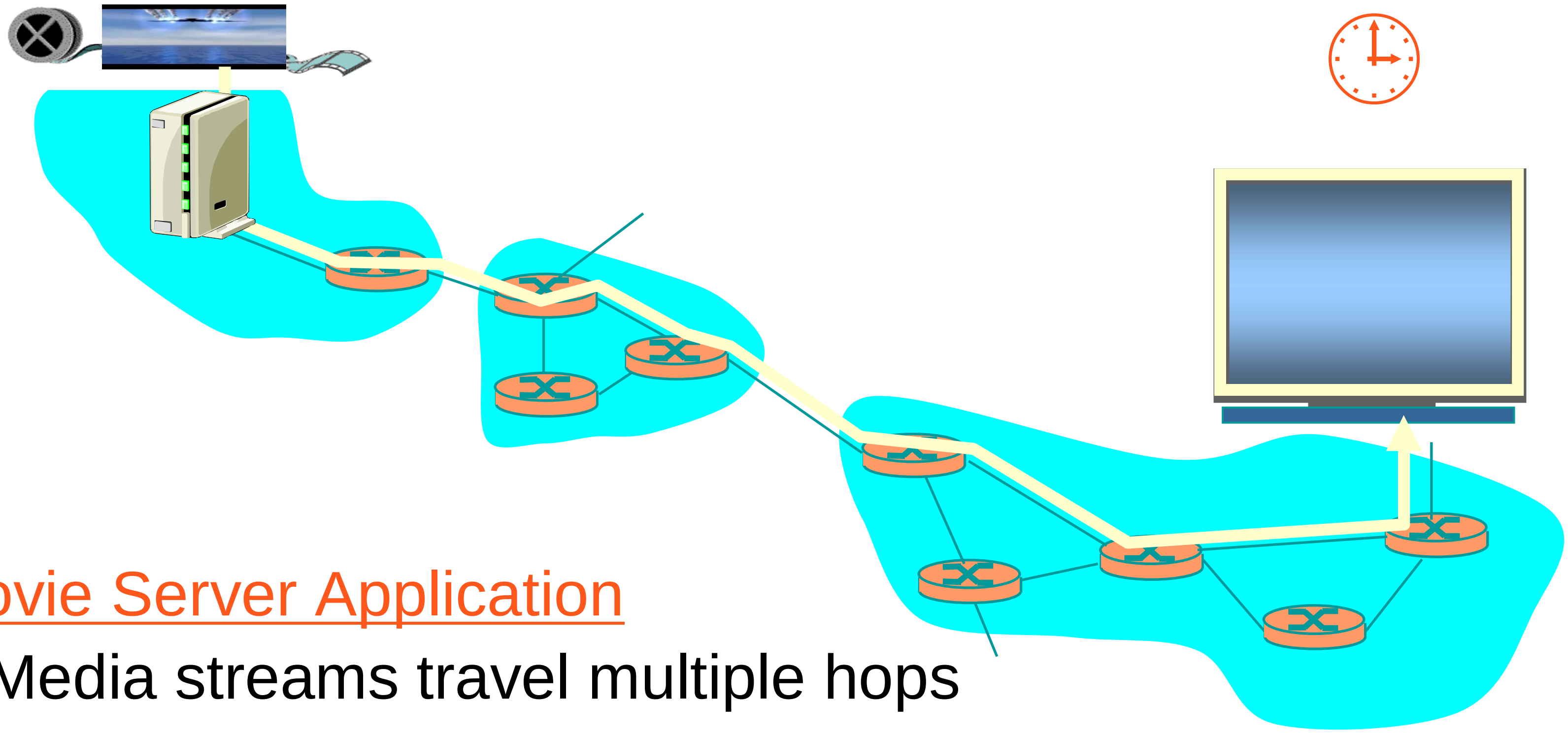
Motivation



Movie Server Application

- Media streams travel multiple hops
- Have end-to-end QoS
  - Deadline requirement
  - Jitter requirement
  - Can tolerate some lost or late packets

Motivation

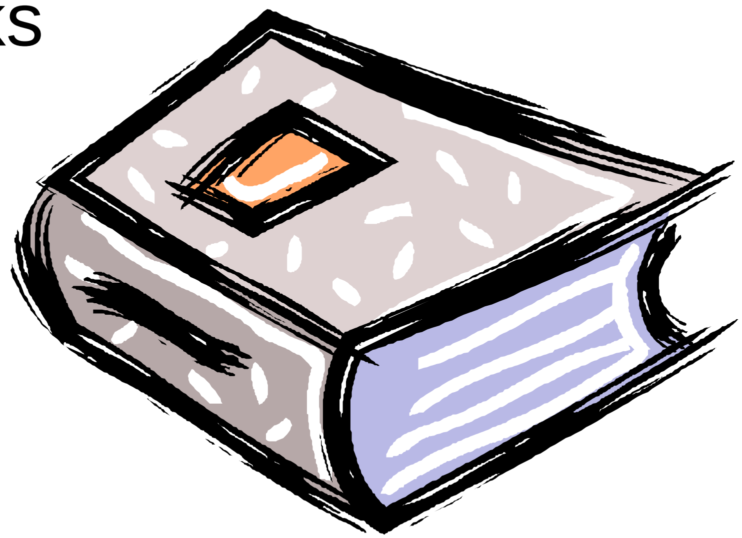


<u>Movie Server Application</u>

- Media streams travel multiple hops
- Have end-to-end QoS
  - Deadline requirement
  - Jitter requirement
  - Can tolerate some lost or late packets
- End-to-end Window-constrained Scheduling Problem

Talk Outline

- Introduction
- Problem statement
- MVDS algorithm
- Evaluation
- Concluding remarks



Window-constrained Model (1/3)

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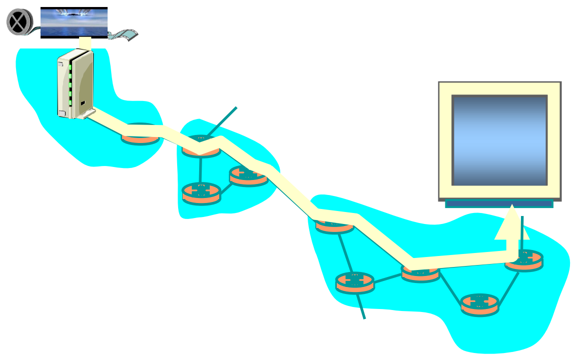
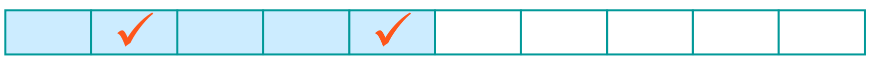
- Suitable for e.g., multimedia & weakly-hard real-time systems:
  - Not every deadline needs to be met
    - Impossible to meet every deadline in overload case
    - Can tolerate some lost or late packets without degrading service too much
    - Constraints on loss patterns



Window-constrained Model (2/3)

- Guarantee a fraction of service over a fixed window of packets in real-time streams
  - (m, k) window-constraint:
    m out of every k packets meet their deadlines
  - Example:

(m,k) = (2,5)



(m,k) = (2,5)

Window-constrained Model (3/3)

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- Characteristics:
  - Independent service guarantees
    - Each stream gets at least a fixed share of service without being affected by others
  - Suitable for overload cases
    - Strategically skip some packets
    - **Min utilization** may still be 100% for feasible schedule
  - Bounded delay and jitter
    - Within a given window

Prior Research

- DWCS [West, Zhang et al: IEEE TOC'04]
  - Window-constrained service guarantees with unit processing time and same packet inter-arrival time
- VDS [Zhang, West, Qi: RTSS'04]
  - Outperforms DWCS especially when packet inter-arrival times **are different**

☹ Previously assumed single server

⯑ Problem : How to extend original window-constrained scheduling problem across multiple hops (or servers)?

E2E Window-constrained Problem

- Each stream S_i is characterized by:
  - Packet size (transmission time = pkt size/bandwidth)
  - Inter-arrival time at 1st hop (request period)
  - Path length: (# of hops to travel)
  - End-to-end delay bound D_i
    - Mainly determined by queue delay due to scheduling
  - End-to-end window-constraint (m_i,k_i)

- Goal:
  - Minimize end-to-end window-constraint violations
  - Maximize link utilization

Challenges

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- Assumption:
  - No global control mechanism or feedback signal from downstream to upstream servers
  - All actions are taken locally

Challenge: Given end-to-end QoS requirement, what is:
  - Local (per hop) scheduling policy?
  - Local QoS requirement?
  - Local drop scheme?

- Approach:
  - Use MVDS – an extension of VDS for a single server

Virtual Deadline Scheduling (VDS)

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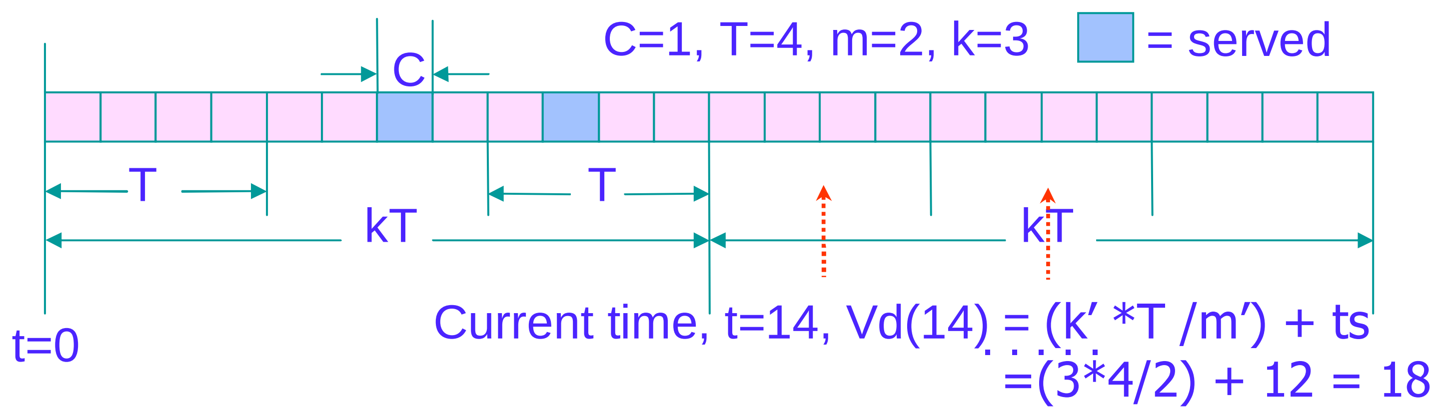
- Serve the head packet of eligible stream with the lowest virtual deadline
- Virtual Deadline
  - Combines *request deadline* and *window-constraint* together
  - if current constraint is (m’, k’), next packet should be served within (k’*T)/m’ time units

$$Vd_i(t) = k_i'T_i/m_i' + ts_i(t) \quad (m_i' > 0)$$

($ts_i(t)$ is start of current request period at time unit)



VDS Algorithm

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- Service constraint updates for S_i:

  if (packet from S_i serviced before deadline)

      $m_i' = m_i' - 1$;

  if (new packet arrives from S_i)

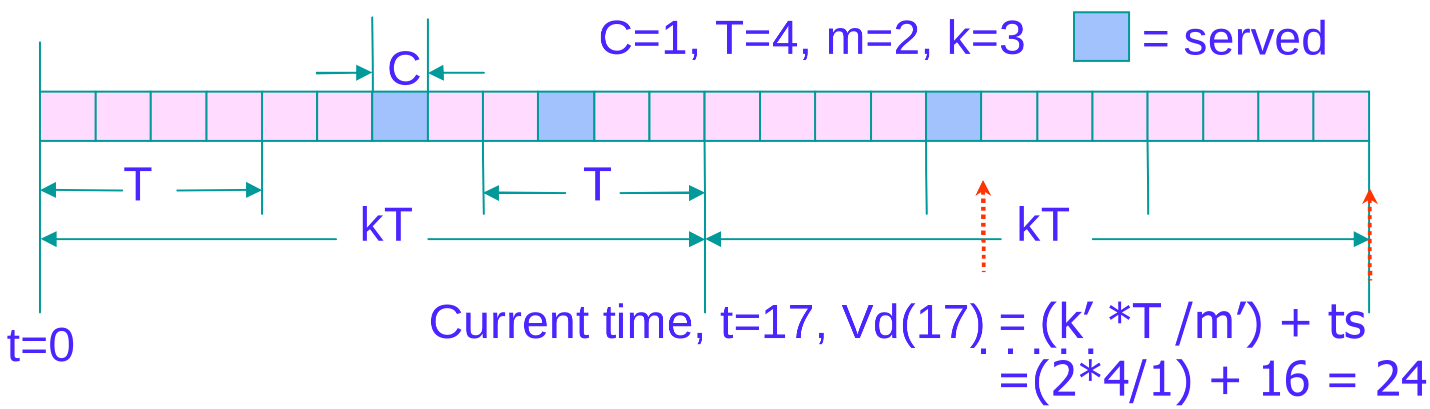
      $k_i' = k_i' - 1$;

      if ($k_i' == 0$) {

          if ($m_i' > 0$) tag stream with a violation;

          $k_i' = k_i$; $m_i' = m_i$;

      }



MVDS Algorithm

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- At each hop:

  Local Virtual deadline ← *Local* Real-time deadline
  + *Local* window-constraint

- Challenge:
  - How to derive the local values from the global service requirements

Problem to solve:

1. Mapping end-to-end deadlines to per-hop local deadlines
2. Updating local current window-constraints and local scheduling states
3. When to drop late packets

Local Deadline Assignment

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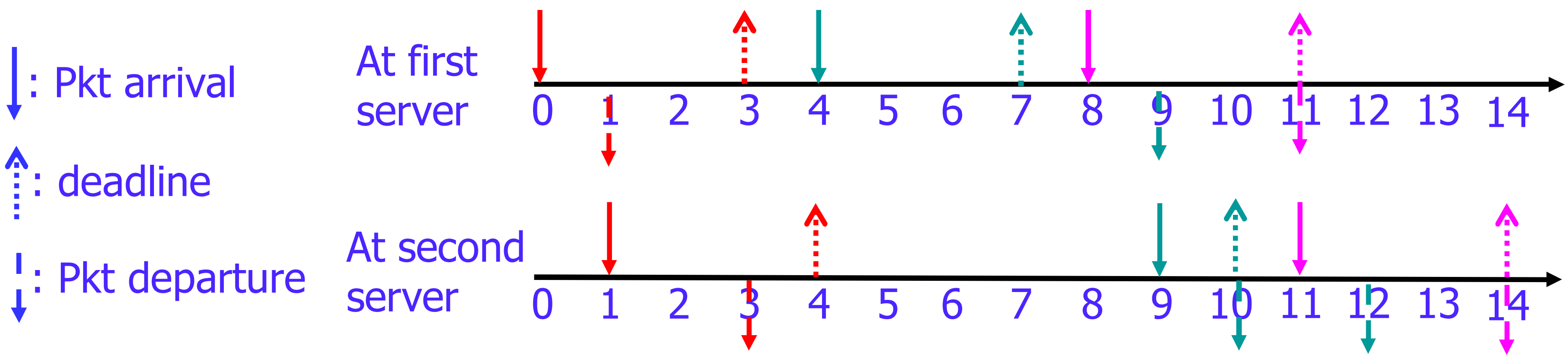
- Downstream server can compensate for upstream service
- Local deadline = previous deadline + local delay bound
  - Local delay bound end-to-end delay bound

e.g. Local delay bound = $\frac{\text{end-to-end delay bound}}{\text{\# of hops}}$



Local Current Window-constraints

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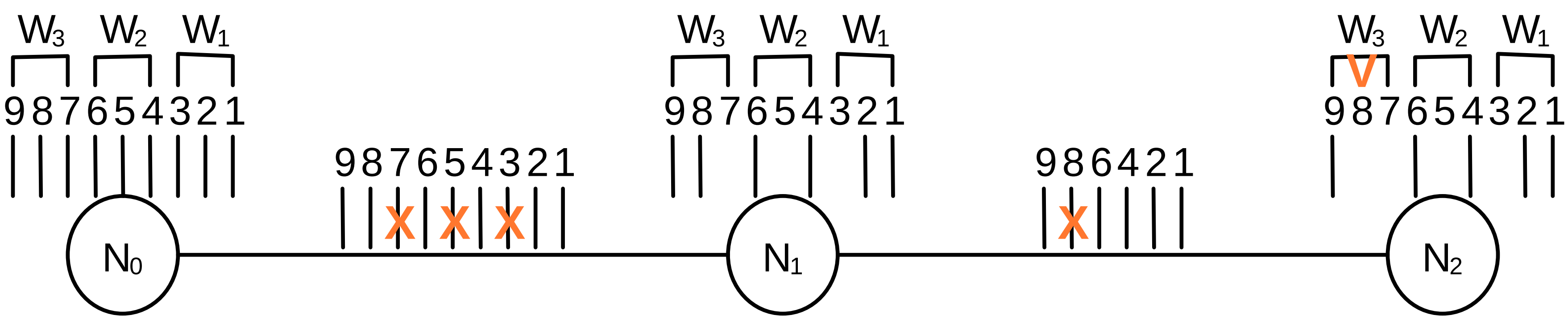
- Key: keep the original window at each hop

  e.g using packet sequence number



Local Drop Scheme

- Meet the local deadline at *every* hop ➔ meet e2e deadline
- Miss the local deadline at *some* hop ➔ miss e2e deadline?
  - Delay can be made up at the following hop
  - May be possible to still meet e2e deadline

Problem: Whether packet should be serviced or dropped if it missed its local deadline, given e2e deadline can still be met

Different Drop Schemes

- “Drop-local”: drop if the local deadline is missed
  - May be too early ☹
- “Drop-end”: drop if the end-to-end deadline is missed
  - May be too late ☹
- “Drop-prob”: drop according to some probability
  - Adaptive and fair ☺

Probabilistic Drop Scheme

- How to decide drop probability?
  - Minimum Utilization (at hop h): minimum required service

$$U^h_{min} = \sum_{\forall i \in S(h)} \frac{m_i C_i}{k_i T_i}, \mid S(h) = \{i \mid S_i \ passes \ through \ hop \ h\}$$

    - 1-U_{min}: Surplus capacity to compensate for wasted service (due to missed deadlines)
    - As tolerable wasted service ↑ drop probability ↓
      No tolerable wasted service, always drop
    - Drop probability ∝ 1/(1-U_{min}), U_{min} < 1.0
      Prob = 1, U_{min} = 1.0

Probabilistic Drop Scheme

- Latency
  - How late is packet relative to local and e2e deadlines?
  - Intuition: As latency ↑ chance to meet e2e deadline ↓ & drop probability ↑
  - Distinguish the packets based on delay
- Drop probability
  - F(1/(1-U_{min}), Latency)

MVDS Algorithm

- MVDS
  - Local virtual deadline:

$$Vd_{i,j}^{h}(t) = \frac{k_i^{h'} \delta_{i,j}^{h}}{m_i^{h'}} + ts_{i,j}^{h} \quad (m_i^{h'} > 0)$$

(jth packet is the head packet of stream S_i)

The packet with earliest local virtual deadline has highest service priority

Evaluation

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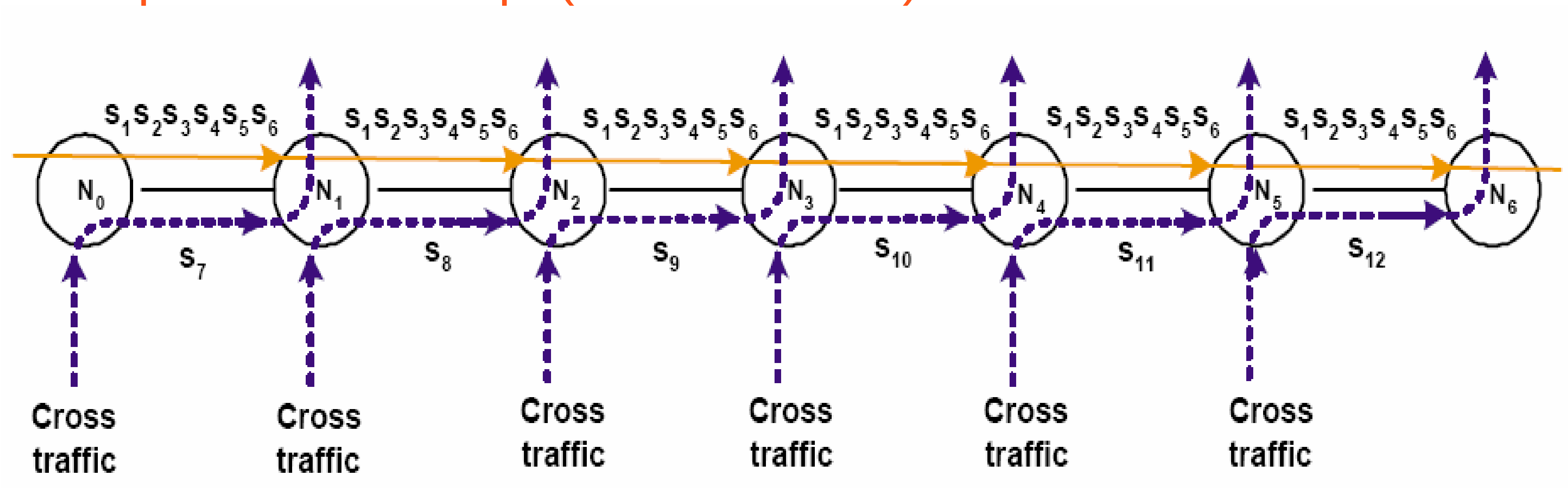
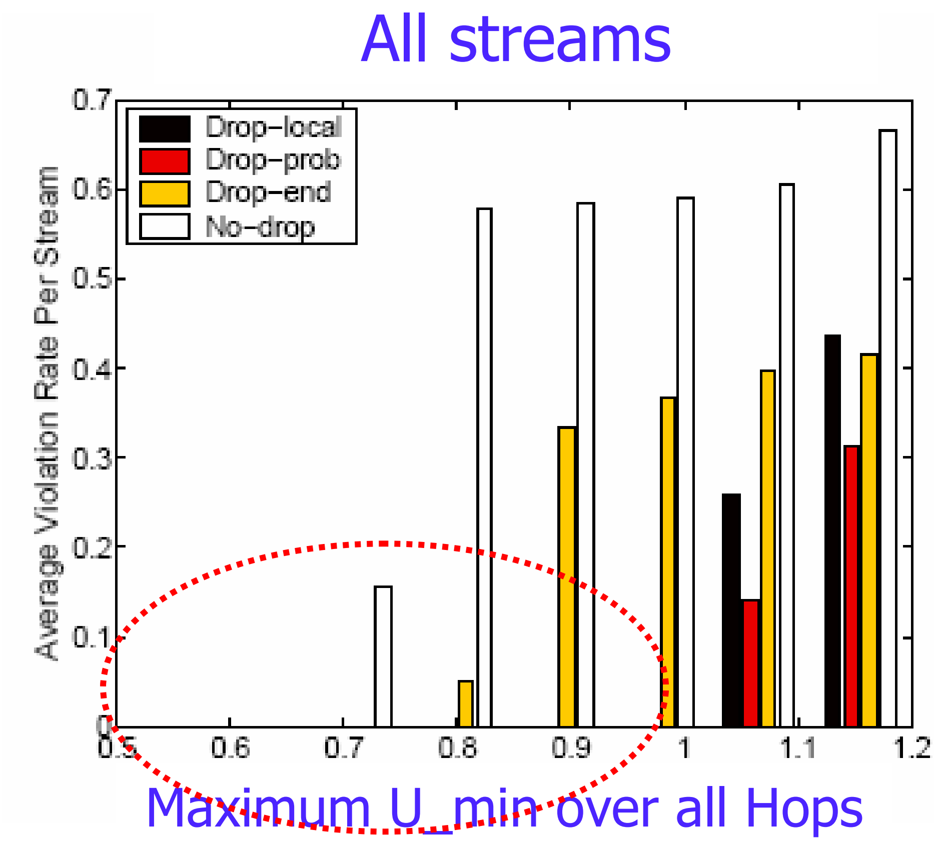
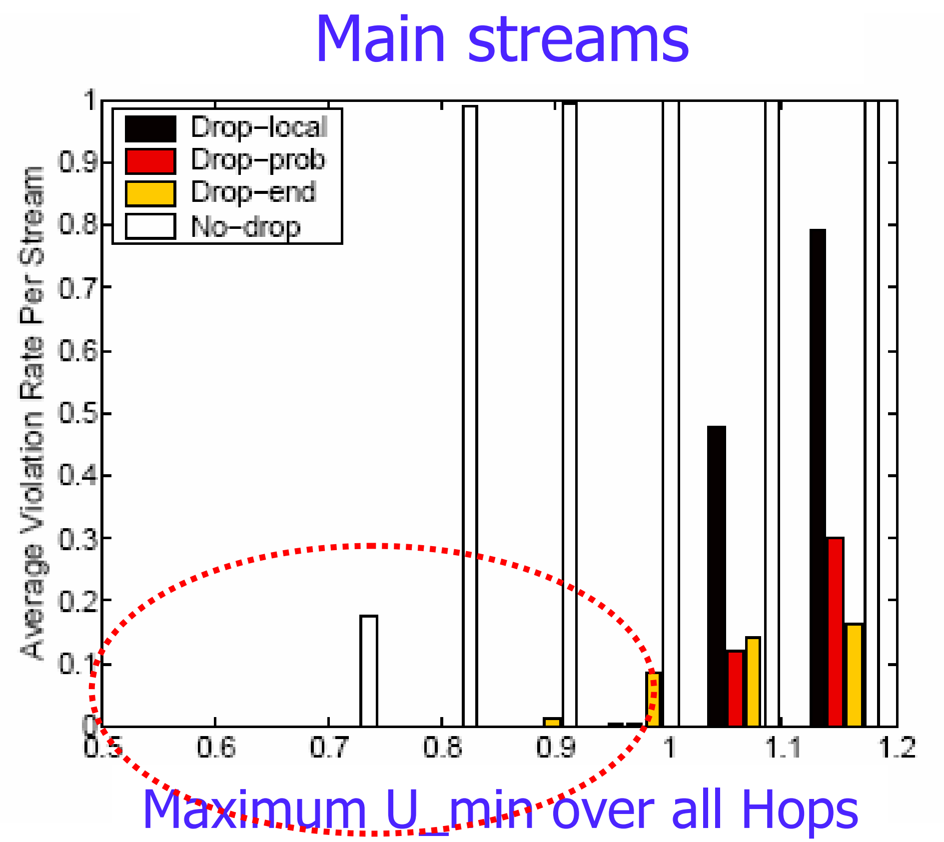
- Experimental setup: (NS-simulation)



- Performance metrics:
  - Violation rate
  - Miss/drop rate

Different Drop Schemes - Violation Rate





- Drop-prob performs well in both under-load and over-load case
- Drop-local (favors cross traffic), drop-end (main-stream), drop-prob (fairer)

Different Drop Schemes – Violation Rate

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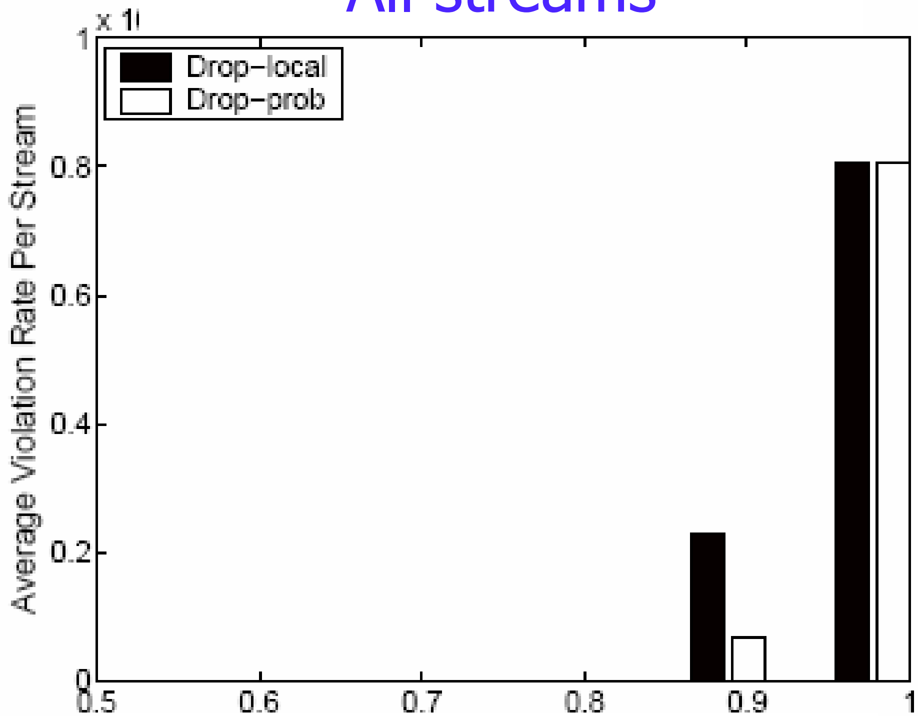
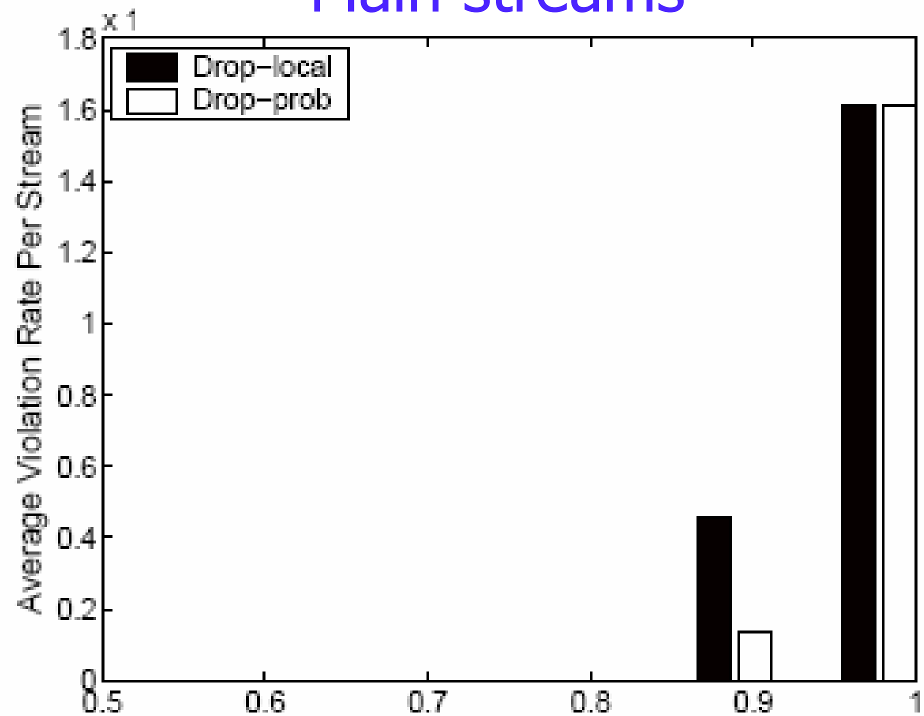
All streams



Maximum U_min over all Hops

Main streams



Maximum U_min over all Hops

Under-load case

Different Drop schemes – Miss/Drop Rate

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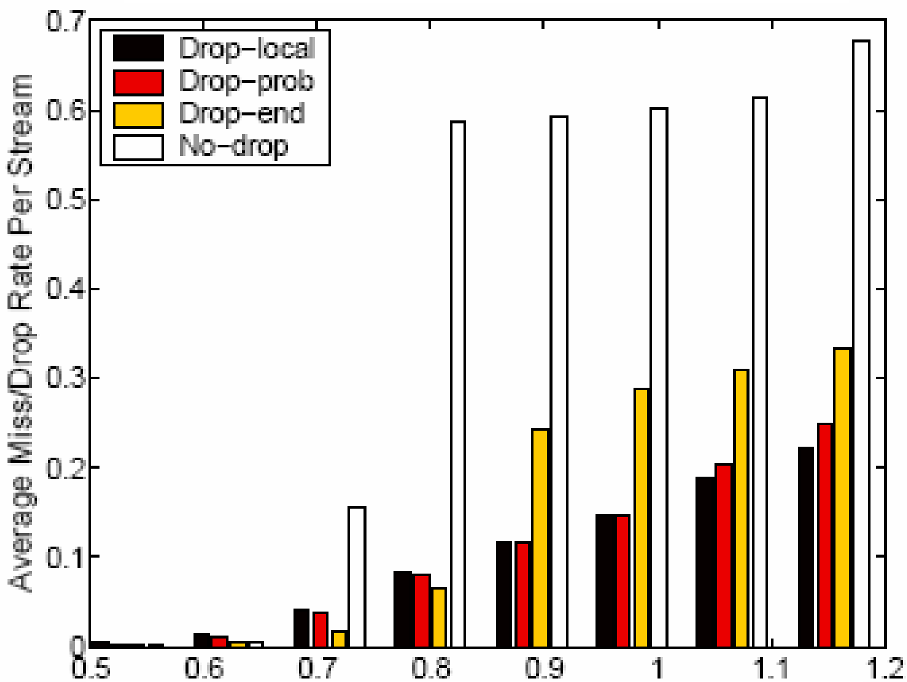
All streams



Maximum U_min over all Hops

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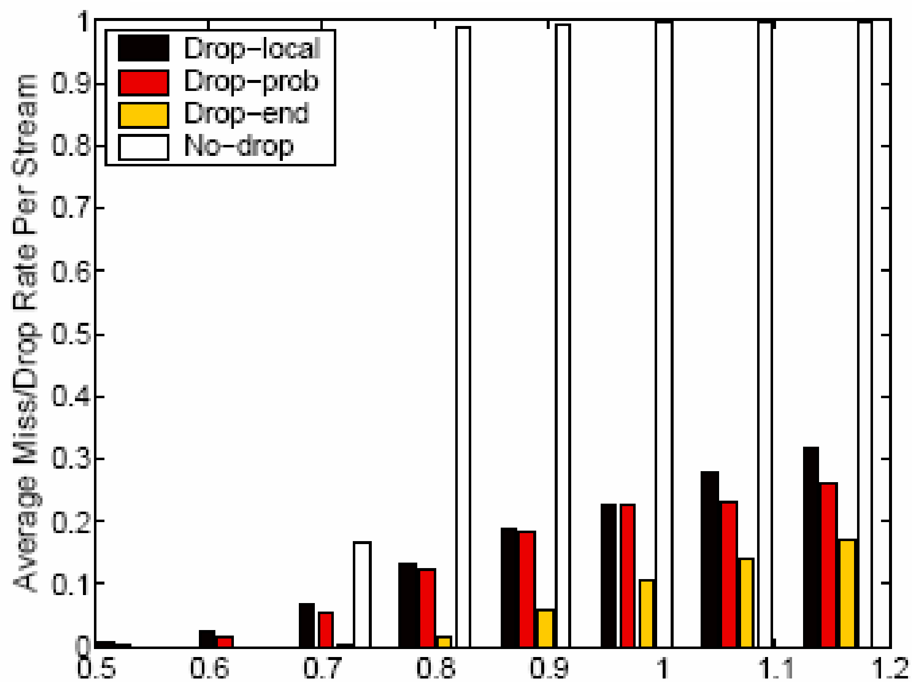

Maximum U_min over all Hops

- Drop-prob drops less than drop-local in under-load
- Drop-local (favors cross traffic), drop-end (main-stream), drop-prob (fairer)

Different Priority Schemes – Violation Rate

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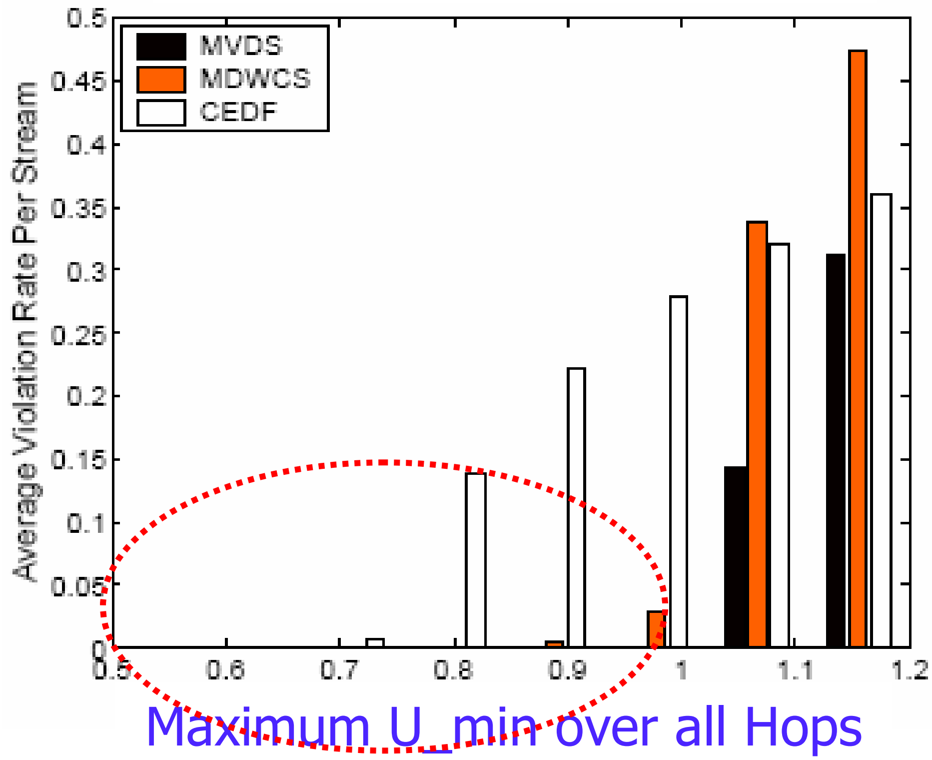
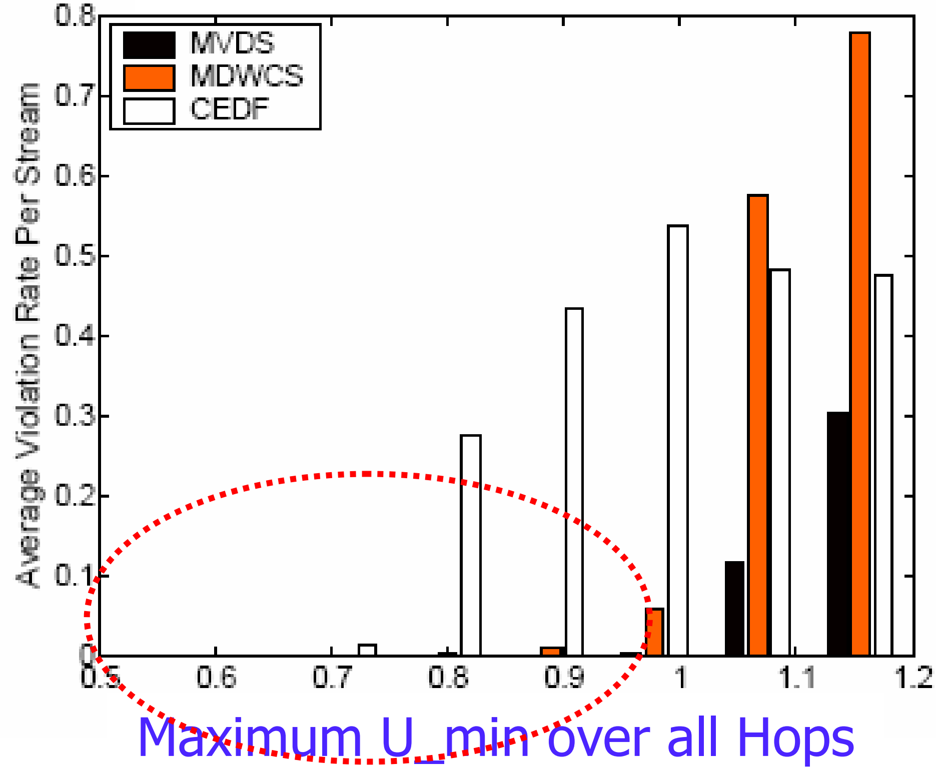
All streams



Main streams



- MVDS performs well in both under-load and over-load case
- MDWCS, CEDF (favors cross traffic), MVDS (fairer)

Different Priority Schemes – Violation Rate

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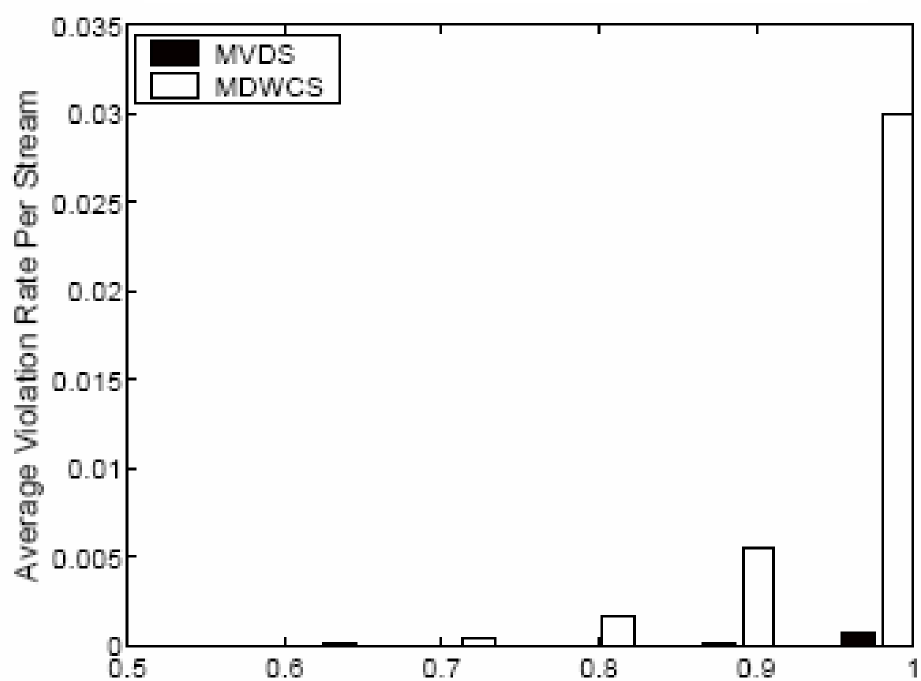
All streams



Maximum U_min over all Hops

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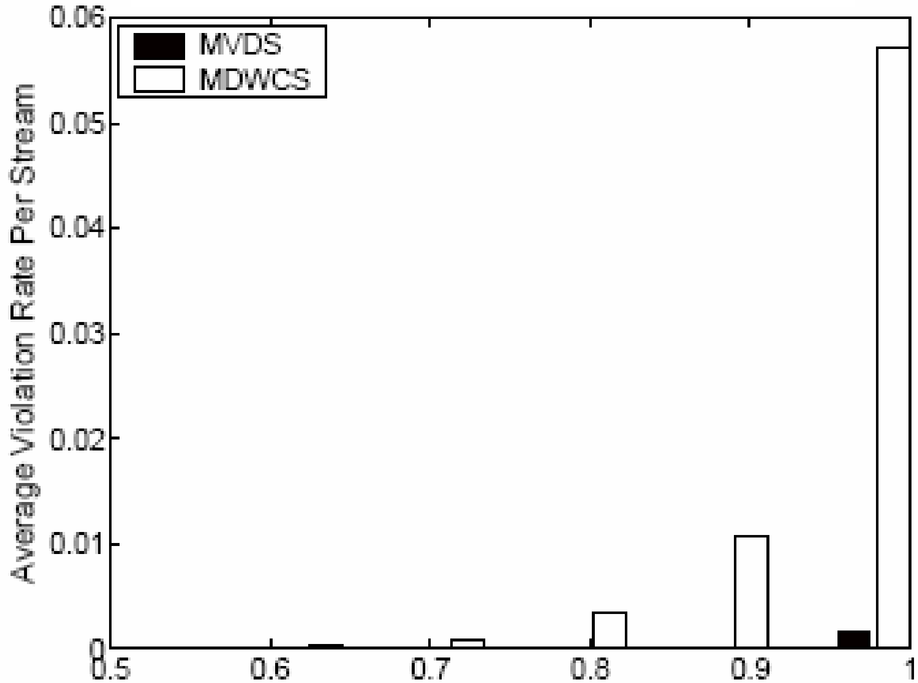

Maximum U_min over all Hops

Under-load case

Conclusions

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- We propose a multi-hop VDS algorithm (MVDS) for the end-to-end window-constrained scheduling problem
- Have shown:
  - how to transform global service constraints of real-time streams into localized values for use at each hop
    - to exploit cooperation between servers
  - how to combine window-constraints and deadlines to decide the scheduling priority – *virtual deadline*
  - how to drop packets to minimize service violation rates while maximizing link utilization – *probabilistic drop*

The End

Thank You!

Questions?