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# New Adaptive Protocols for Fine-Level End-to-End Rate Control in Wireless Networks

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# Fine-Level E2E Wireless Rate Control

- Problem

- Rate Assurance
- Differentiated Bandwidth Allocation

- Solution

- Cross Layer: Dynamic Weight Adaptation with floor and ceiling (DWA)
  - Link Layer: Proportional Packet Scheduling (PPS)
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# Classical Approach in Wired Networks

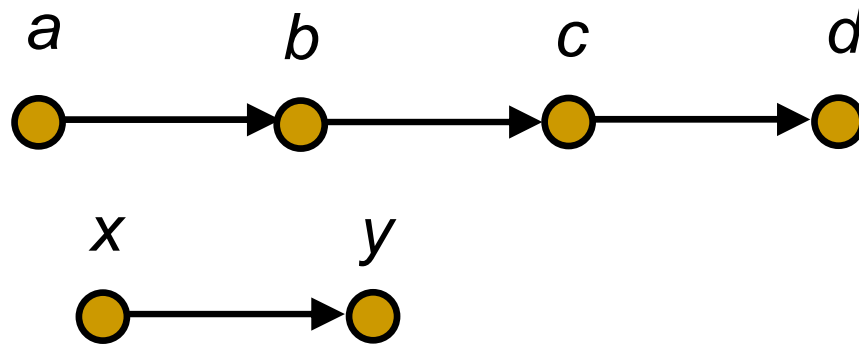
- Wired Networks
    - Resource Reservation
    - Admission Control
  - Assumptions
    - Capacity of each link is fixed and known.
    - Sender of a link has information about all flows that compete in the link.
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# Fixed Capacity in CSMA/CA Networks?

- Link Capacity
    - Load of contending links
    - Relative positions of contending links
  - Channel Capacity
    - Dynamic channel conditions
    - Multi-rate links
    - Two overlapping wireless networks
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# Resource Reservation is Complicated



- Node  $a$  reserves  $3r$  in the channel perceived by link  $(a, b)$ .
- The same thing for  $(b, c)$  and  $(c, d)$ .
- How much reservation on  $(x, y)$ ?
  - Contention with  $(a, b)$ ,  $(b, c)$ , and  $(c, d)$
  - Spatial reuse in its channel

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## Prior Art

- Restrict study on Wireless LAN
  - Coarse-level service differentiation
    - IEEE 802.11e
  - Heuristics for resource reservation and admission control
    - Estimating residual bandwidth
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# Our Approach

- Resource Reservation and Admission Control?
    - Fundamental difference requires fundamentally different solution
    - Handling network/traffic dynamics
    - Simple yet effective
  - Adaptive Rate Control
    - Support rate requirements in the order of priorities
    - Global objective, localized operations
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# Dynamic Weight Adaptation (DWA)

## - Service Model

- ABR service for end-to-end flows
    - Multiple classes of QoS flows.
    - Each class is assigned a different priority.
    - Each QoS flow has a minimum rate requirement.
  - Best-effort flows
    - Lowest priority
    - No minimum rate requirement
  - physical link → multiple MAC flows
    - Each MAC flow carries all end-to-end flows of one class.
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# Dynamic Weight Adaptation (DWA)

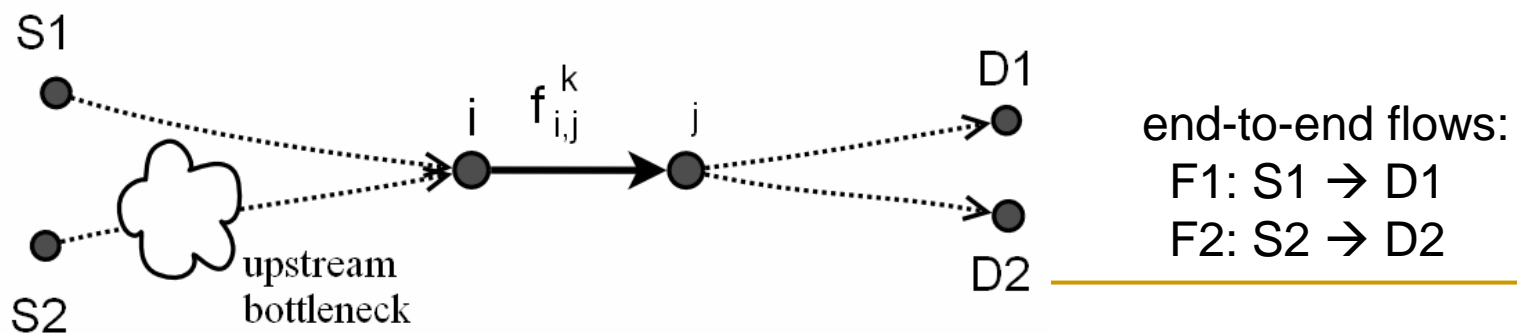
## - Basic Idea

- Assumption: Weighted Bandwidth Allocation among Contending MAC Flows
  - Adapting Weights of the MAC flows
    - Ceiling and Floor
  - Two Levels of Bandwidth Allocation
    - First, allocate bandwidth to MAC flows
    - Second, within each MAC flow, allocate bandwidth to end-to-end flows
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# Dynamic Weight Adaptation (DWA)

## - Ceiling and Floor

- For a MAC flow  $f_{i,j}^k$  ,
  - Ceiling:  $H_{i,j}^k = a \times d_k \times q_{i,j}^k$
  - Floor:  $L_{i,j}^k = a \times q_{i,j}^k$
- $d_k$  : differentiation factor
- $q_{i,j}^k$  : effective rate requirement on  $f_{i,j}^k$



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# Dynamic Weight Adaptation (DWA) - Protocol

## ■ Weight Adaptation:

$$\text{if } r_{i,j}^k < q_{i,j}^k, \quad w_{i,j}^k \leftarrow \min\{w_{i,j}^k \cdot (1 + \beta), H_{i,j}^k\}$$

$$\text{if } r_{i,j}^k > q_{i,j}^k, \quad w_{i,j}^k \leftarrow \max\{w_{i,j}^k \cdot (1 - \beta), L_{i,j}^k\}$$

- $r_{i,j}^k$ : actual rate of  $f_{i,j}^k$
  - $q_{i,j}^k$ : Rate requirement of  $f_{i,j}^k$
  - $w_{i,j}^k$ : weight of  $f_{i,j}^k$ .
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# Dynamic Weight Adaptation (DWA)

## - Achieved Objectives

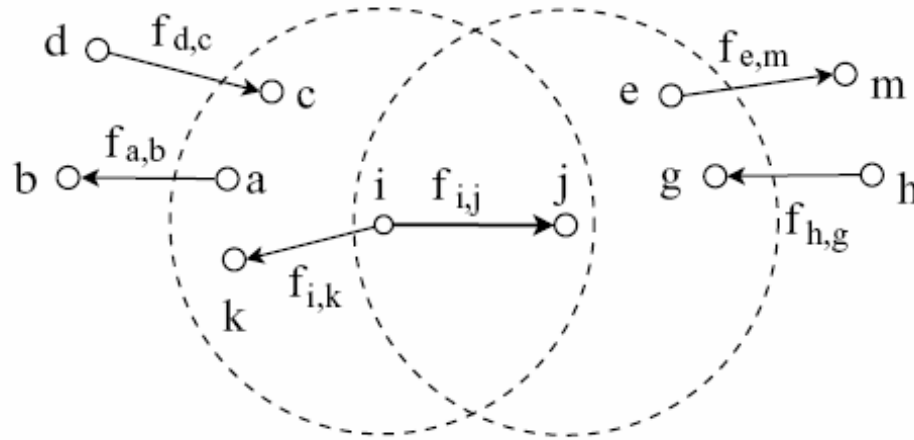
- Prioritized Rate Assurance
  - Differentiated Bandwidth Allocation
  - No Starvation and Maximum Utilization
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# Discussions

- Avoiding Packet Drops
  - Flow Dynamics and Channel Dynamics
  - Intra-flow Contention and Inter-flow Contention
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# Proportional Packet Scheduling (PPS) -Objective



- Weighted Bandwidth Allocation among MAC Flows
  - Fully localized
  - Provable weighted maxmin
  - Dynamic channel and flows

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# Proportional Packet Scheduling (PPS)

## - Basic Idea

- Prior Solutions: Changing Backoff Window
  - Our Solution:
    - Each MAC flow maintains a counter.
    - Counter advances at a rate proportional to flow weight.
    - Flow with the smallest counter transmits.
    - Equalizing counters → weighted bandwidth allocation
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# Proportional Packet Scheduling (PPS) -Protocol

## Packet

carry the flow counter.

## Sender

refrain, if overhearing smaller or equal counter;  
transmit RTS, if otherwise.

## Receiver (after receiving RTS)

not reply or REJ, if overhearing smaller or equal counter;  
reply CTS, if otherwise.

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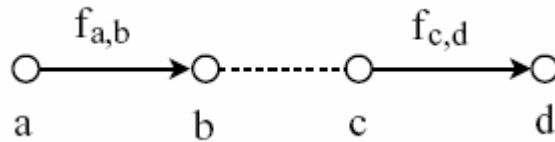
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# Proportional Packet Scheduling (PPS)

## - Maxmin fairness

- Theorem 1: When the flow rates attained by PPS achieve weighted maxmin fairness with an error that can be made arbitrarily small as the PPS period increases.
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# Proportional Packet Scheduling (PPS)

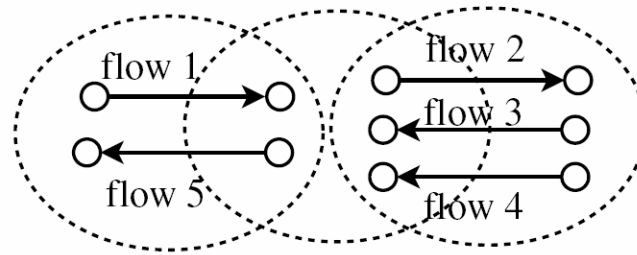


	$f_{a,b}$	$f_{c,d}$
802.11 DCF	64.6	381.0
802.11e EDCA	347.8	193.1
AdjConWin*	232.0	229.5
PPS	227.9	228.8

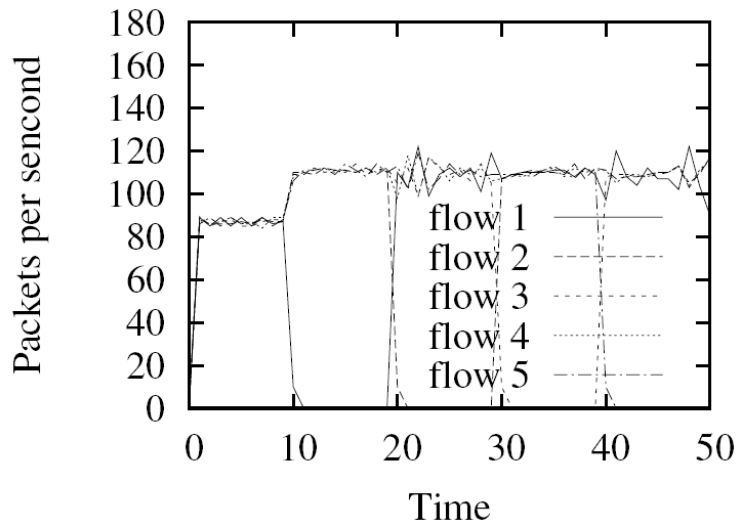
Flow rates (in packets per second)

\*X. Huang and B. Bensaou. On Max-Min Fairness and Scheduling in Wireless Ad Hoc Networks: Analytical Framework and Implementation. Proc. ACM MOBIHOC, 2001.

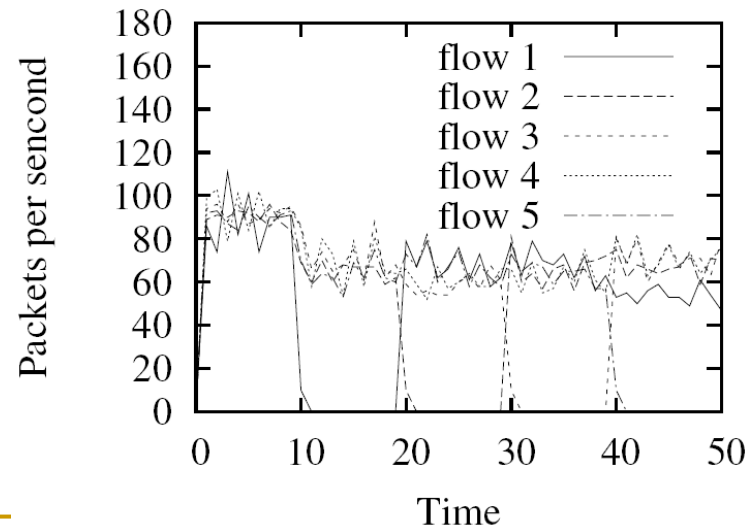
# Flow Dynamics



Five-flow topology



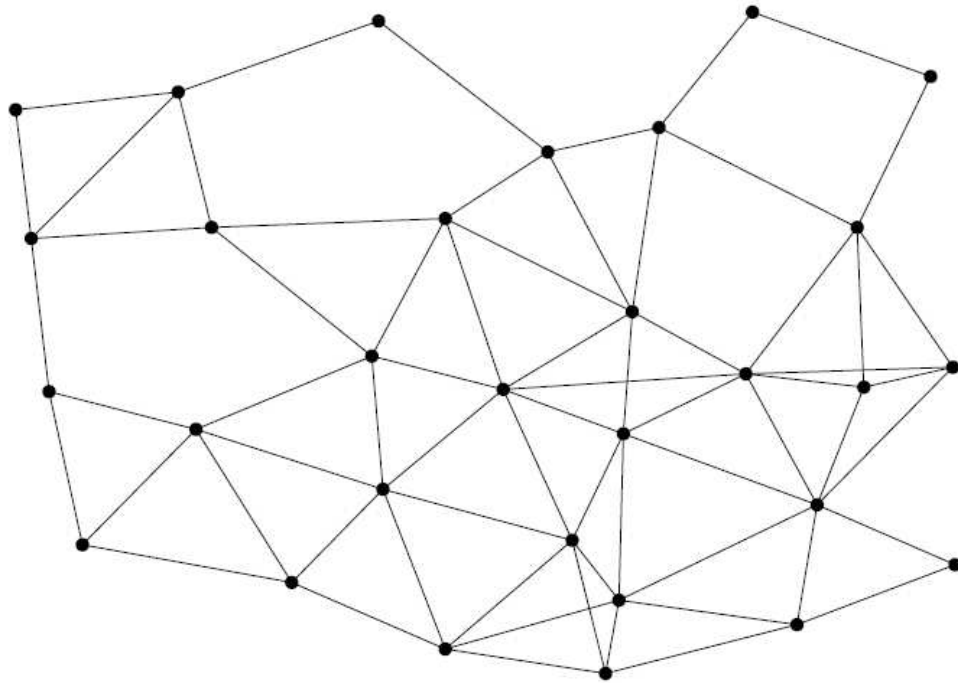
Flows leave and come, PPS



Flows leave and come, AdjConWin

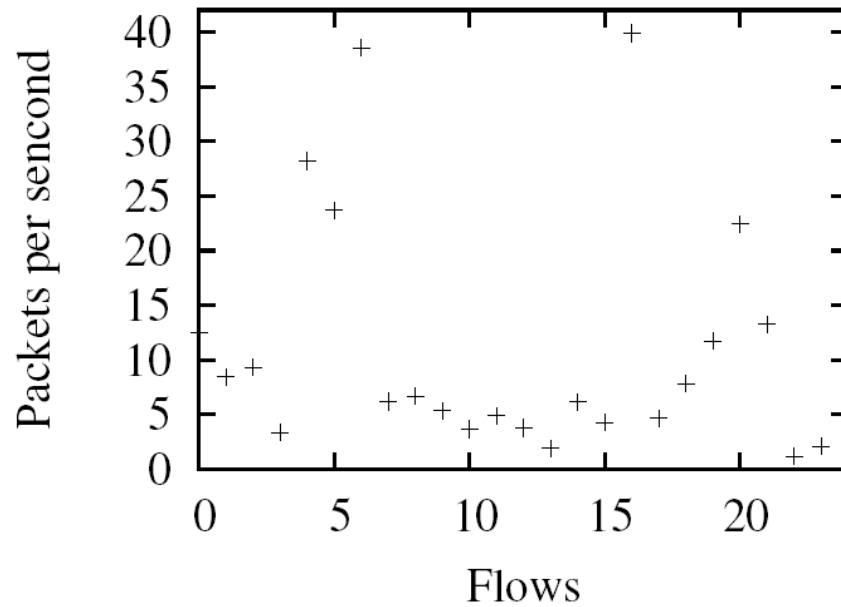
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# Performance Evaluation

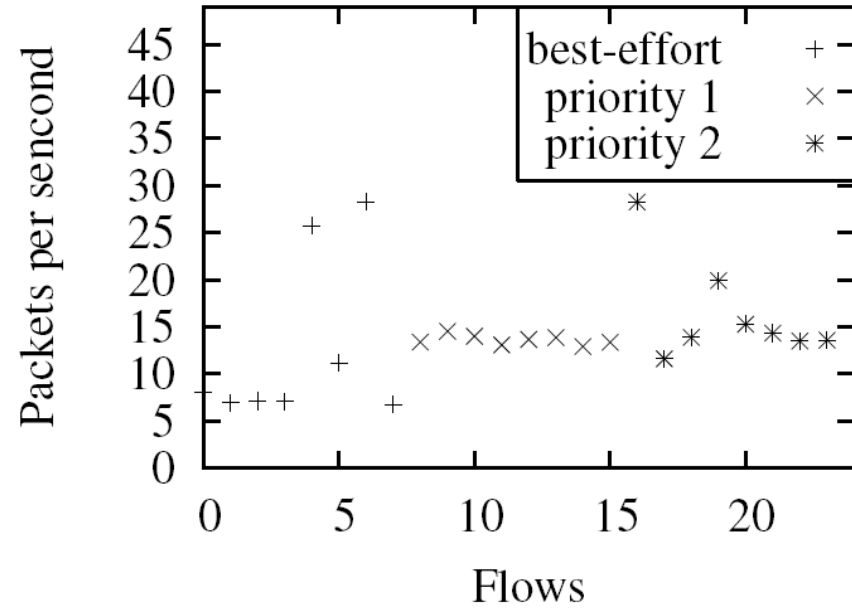


- 30 nodes
- 24 end-to-end flows are random selected

# DWA/PPS

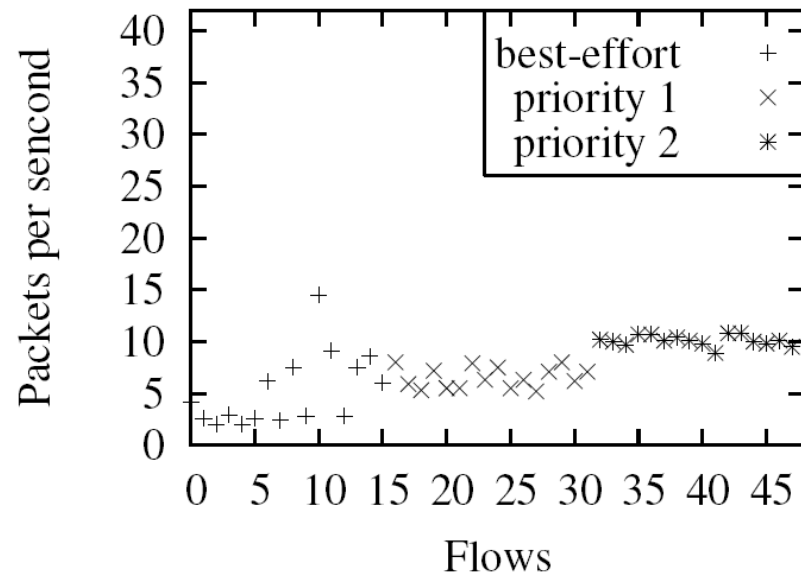


IEEE 802.11 DCF

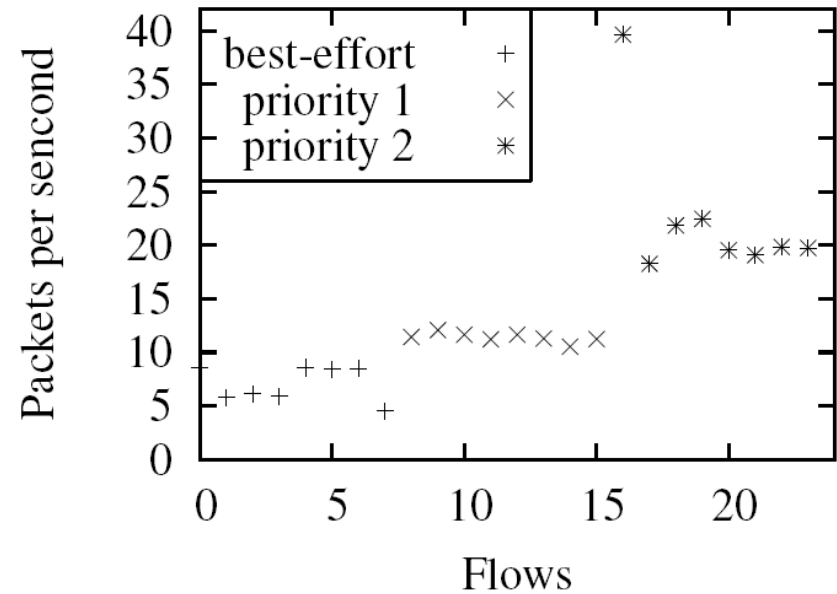


DWA/PPS  
(rate requirement: 10)

# DWA/PPS

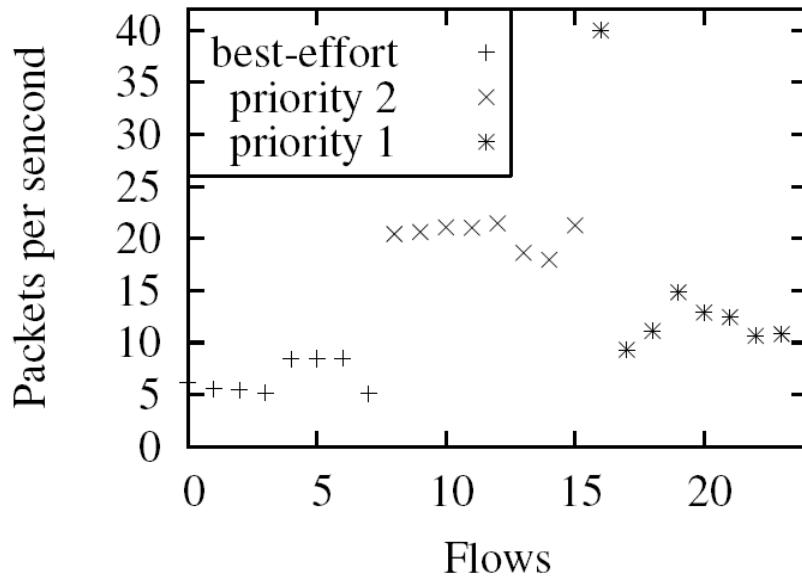


DWA/PPS, 24 new flows added  
(rate requirement: 10)

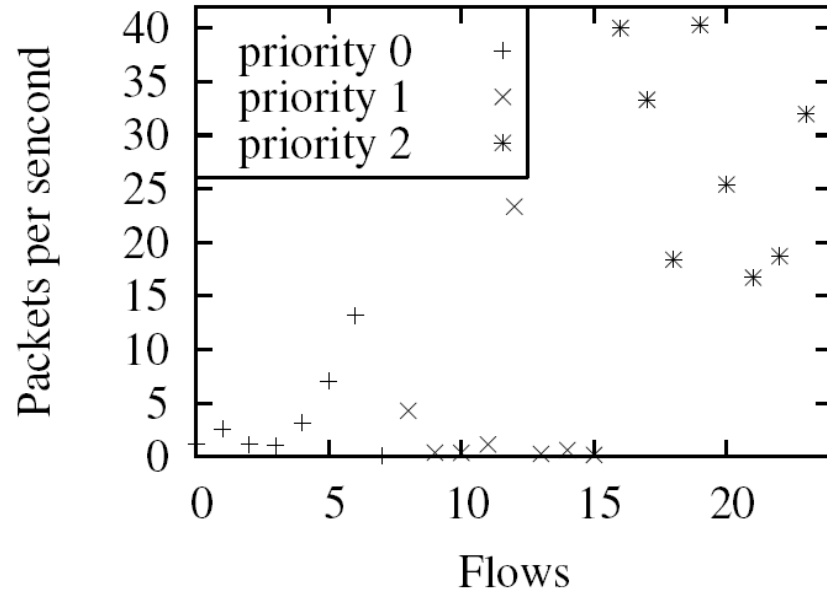


DWA/PPS  
(rate requirement: 20)

# DWA/PPS



DWA/PPS, re-assign priorities  
(rate requirement: 20.0)



IEEE 802.11e EDCA

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# Conclusion

- Dynamic Weight Adaptation with floor and ceiling (DWA)
  - Proportional Packets Scheduling (PPS)
  - Fine-level Rate Control
    - Prioritized rate assurance
    - Differentiated bandwidth distribution
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Thank you!

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