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

Ying Jian, Shigang Chen, Liang Zhang, Yuguang Fang

University of Florida

Presented by Shigang Chen

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)

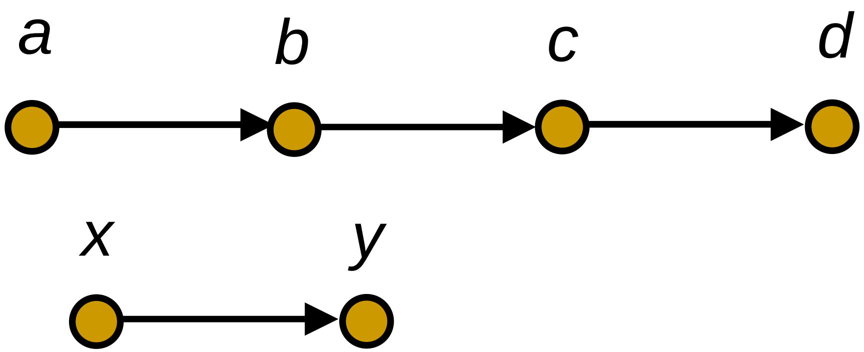
Classical Approach in Wired Networks

- 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.

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

Resource Reservation is Complicated



- Node *a* reserves 3 *r* 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

Prior Art

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

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

Dynamic Weight Adaptation (DWA) - Service Model

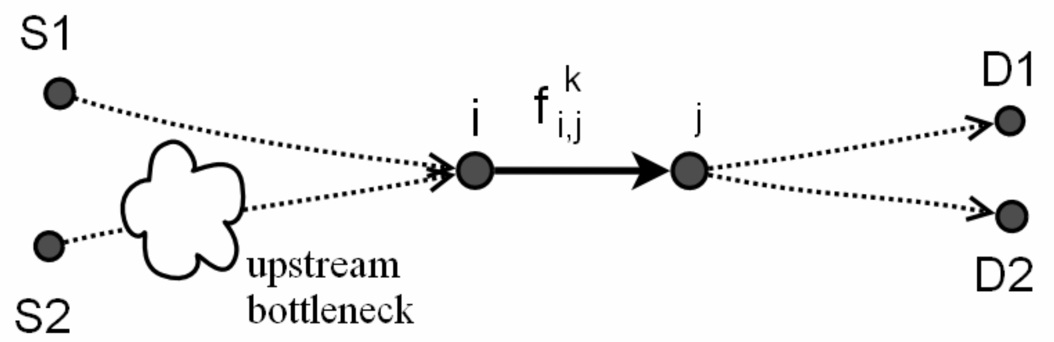
- ABR service for end-to-end flows
  - Multiple classes of QoS flows.
  - Each class is assigned a different priority.
  - Each QoS flow has a minimum rate requirement.
- Best-effort flows
  - Lowest priority
  - No minimum rate requirement
- physical link → multiple MAC flows
  - Each MAC flow carries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

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

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 $f_{i,j}^{k}$



end-to-end flows:
F1: S1 → D1
F2: S2 → D2

Dynamic Weight Adaptation (DWA) - Protocol

- Weight Adaptation:

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

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

  - $r_{i,j}^k$: actual rate of $f_{i,j}^k$
  - $q_{i,j}^k$: Rate requirement of $f_{i,j}^k$
  - $w_{i,j}^k$: weight of $f_{i,j}^k$.

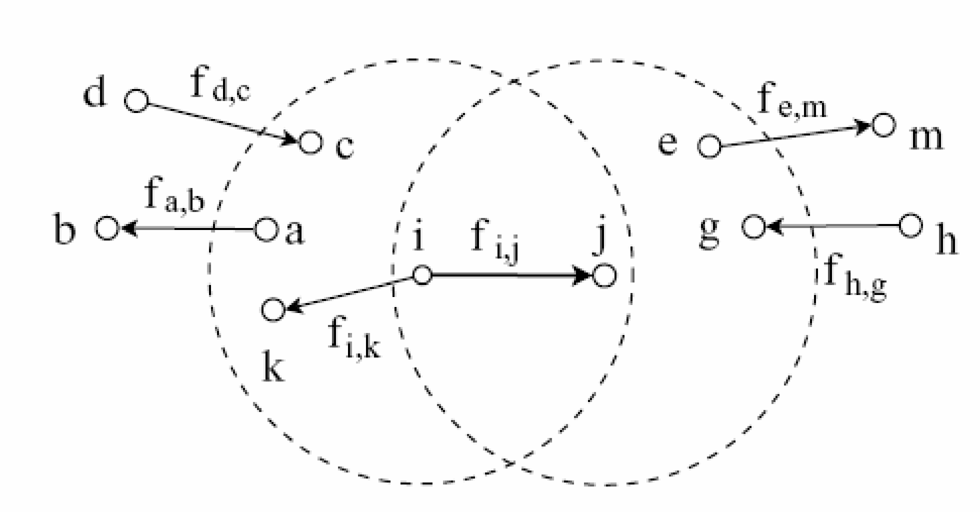
Dynamic Weight Adaptation (DWA) - Achieved Objectives

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

Discussions

- Avoiding Packet Drops
- Flow Dynamics and Channel Dynamics
- Intra-flow Contention and Inter-flow Contention

Proportional Packet Scheduling (PPS) -Objective



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

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

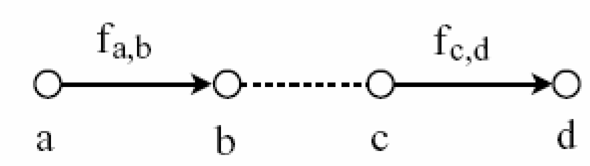
Proportional Packet Scheduling (PPS) -Protocol

- 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 couner;
  - reply CTS, if otherwise.

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.

Proportional Packet Scheduling (PPS)

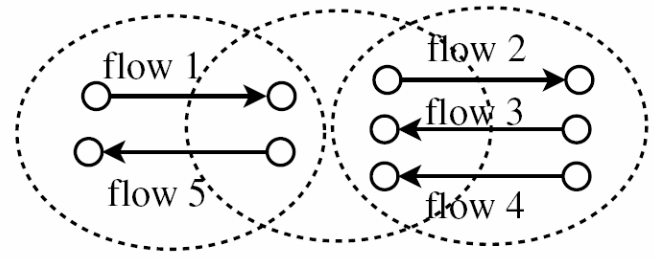


	$f_{a,b}$	$f_{c,d}$
802.11 DCF	64.6	381.0
802.11e EDCA	347.8	193.1
AdjConWin*	232.0	229.5
PPS	227.9	228.8

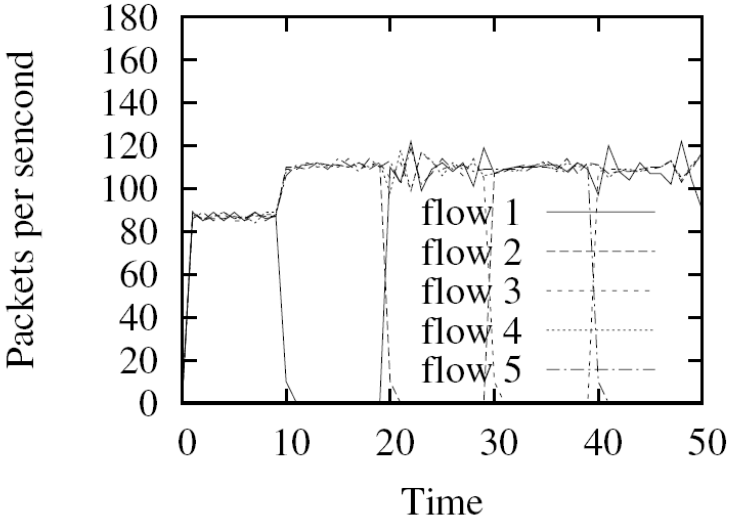
Flow rates (in packets per second)

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

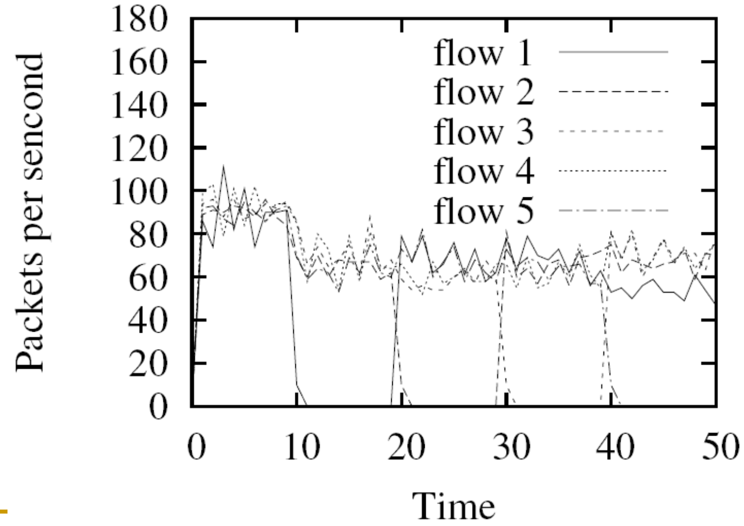
Flow Dynamics



Five-flow topology

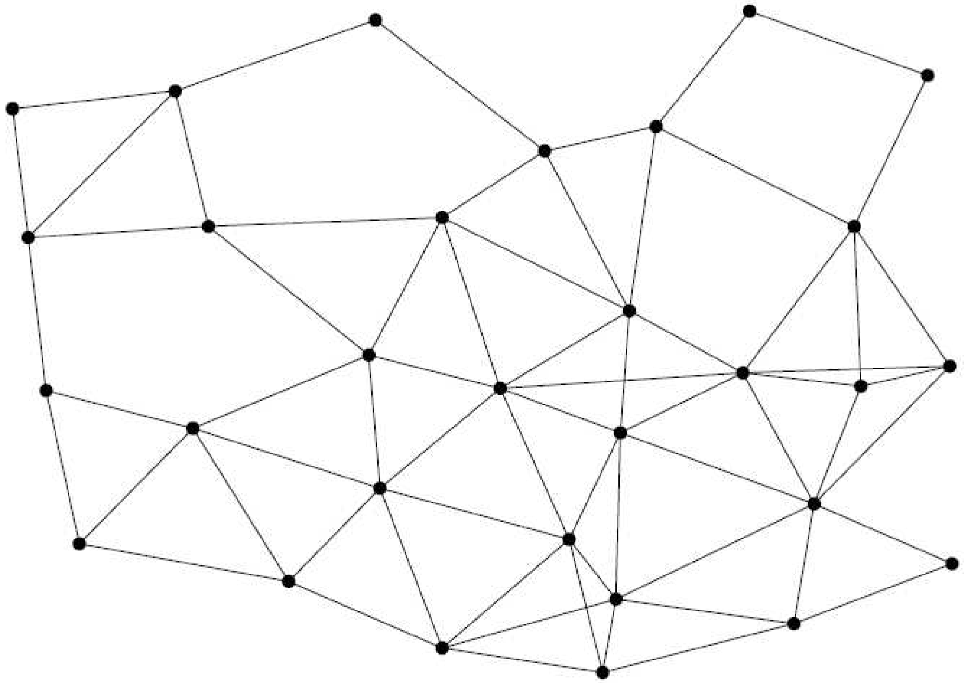


Flows leave and come, PPS



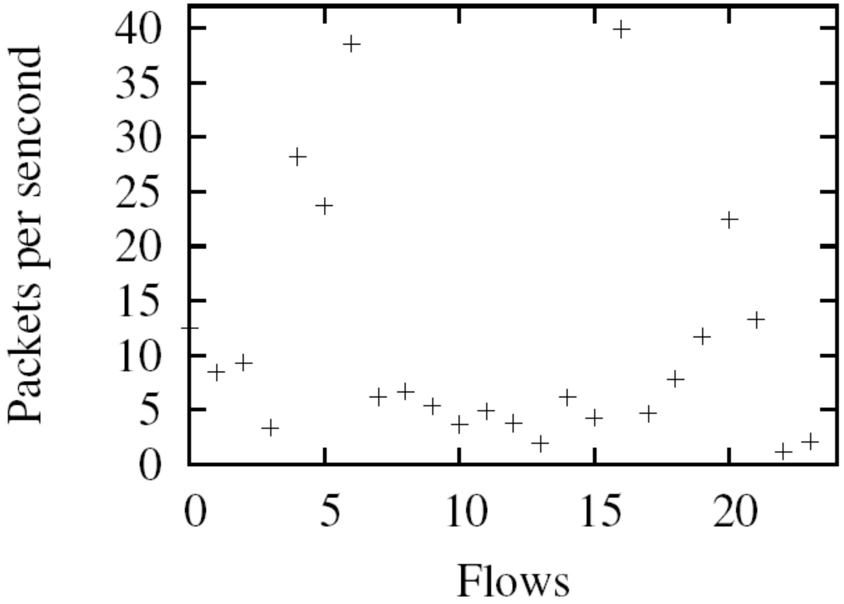
Flows leave and come, AdjConWin

Performance Evaluation

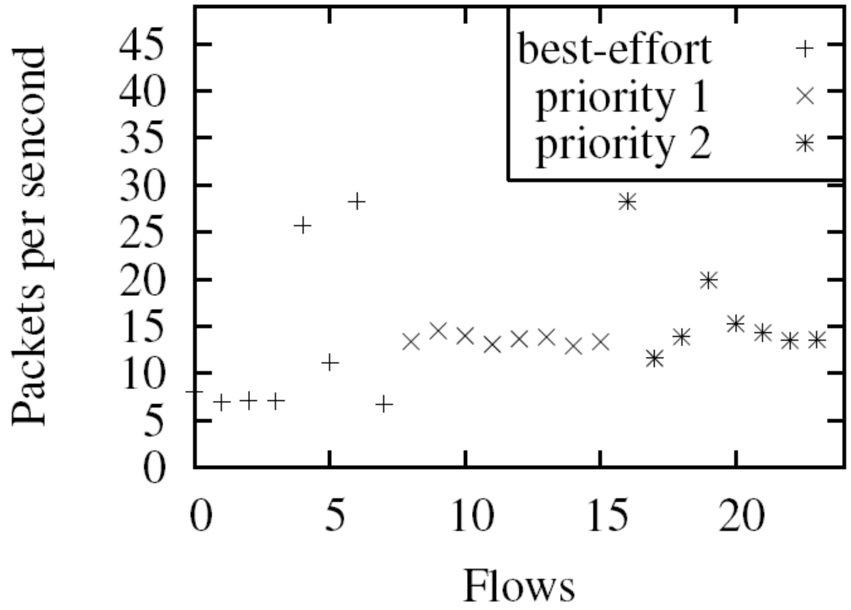


- 30 nodes
- 24 end-to-end flows are random selected

DWA/PPS

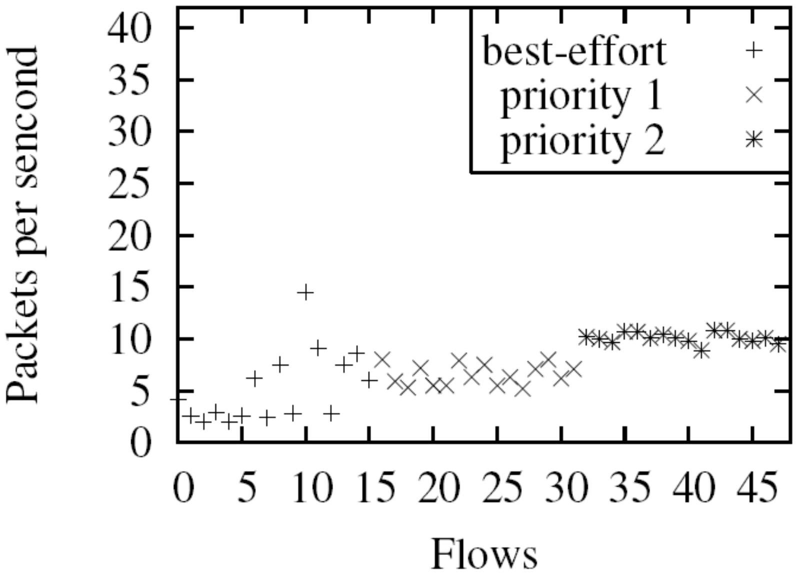


IEEE 802.11 DCF

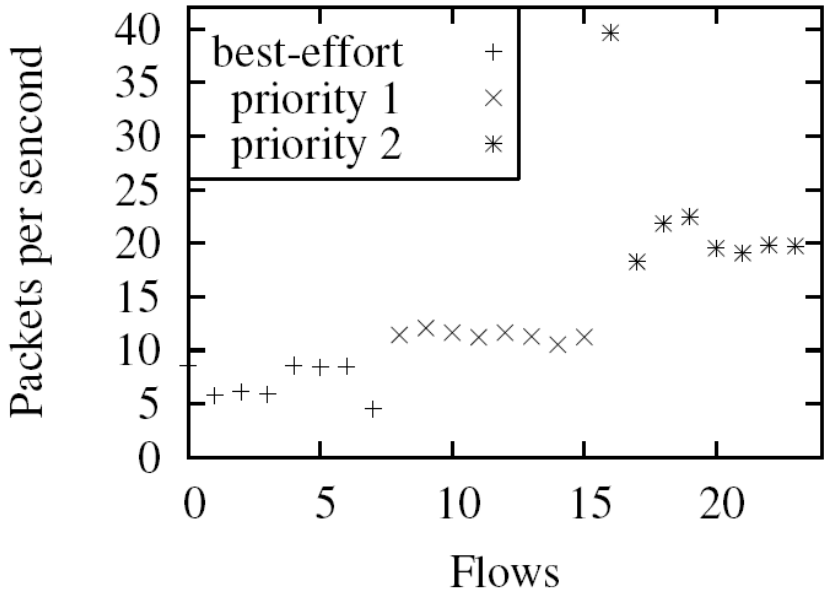


DWA/PPS
(rate requirement: 10)

DWA/PPS

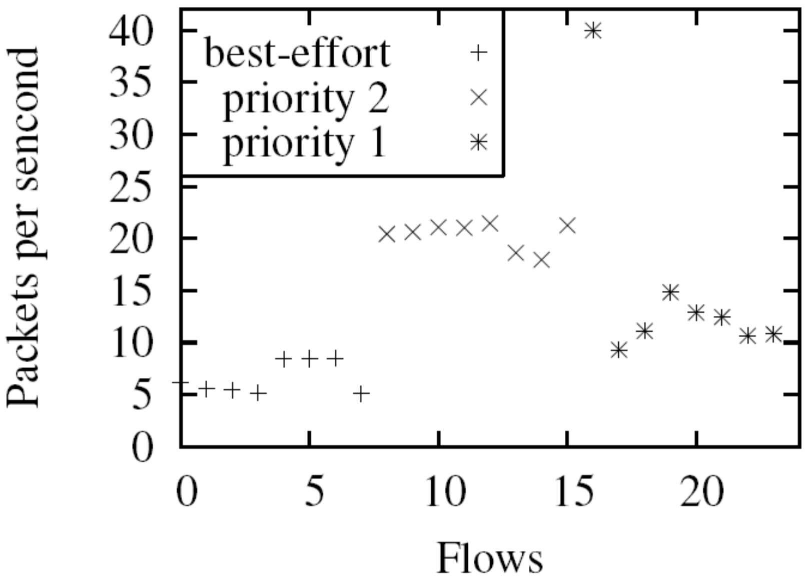


DWA/PPS, 24 new flows added
(rate requirement: 10)

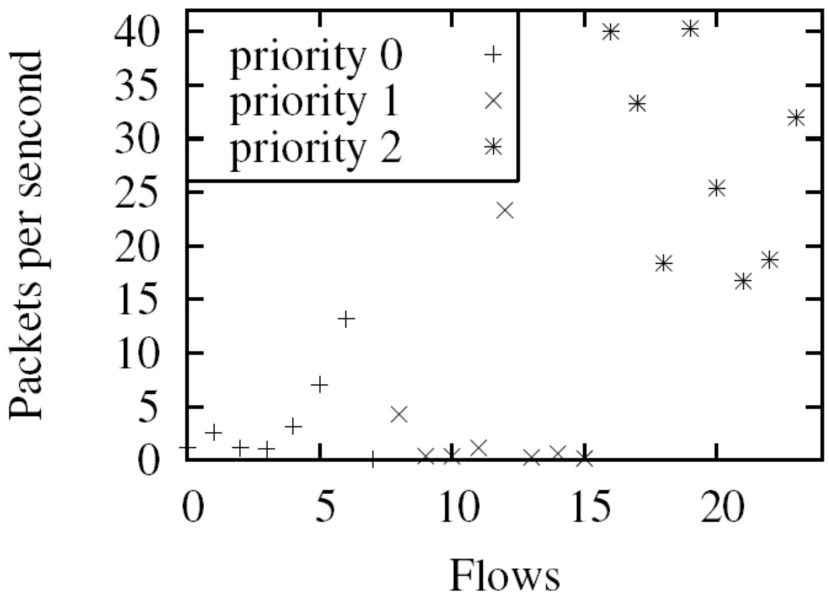


DWA/PPS
(rate requirement: 20)

DWA/PPS



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



IEEE 802.11e EDCA

Conclusion

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

Thank you!