Quality of Service Control: The case of IEEE 802.11e WLANs

Saverio Mascolo
Politecnico di Bari, italy
c3lab.poliba.it

KEYNOTE @

3rd International Workshop on
Networked Control Systems: Tolerant to Fault
June 20, 2007, University of Nancy, France

QoS?

Van Jacobson [interview March 7, 2005]:

"QoS has been an area of immense frustration for me. We're suffering death by 10,000 theses. It seems to be a requirement of thesis committees that a proposal must be sufficiently complicated for a paper to be accepted. Look at Infocom, look at IEEE papers; it seems as though there are 100,000 complex solutions to simple priority-based QoS problems.

The result is vastly increased noise in the signal-to-noise ratio. The working assumption is that QoS must be hard, or there wouldn't be 50,000 papers on the subject. The telephony journals assume this as a starting point, while the IP folks feel that progress in QoS comes from going out and doing something … [continue]"

More…

…..[continue]

“ I hope that the circuit obsession is transitional. Anytime you try to apply scheduling to a problem to give latency strict bounds, the advantages are not worth the cost of implementation

Because of the circuit-oriented background of ATM developers, they had bought into the telco religion that QoS equals scheduling. If you go down that path, it's a highway to disaster.”

A feedback control approach to QoS in IEEE 802.11e WLANs

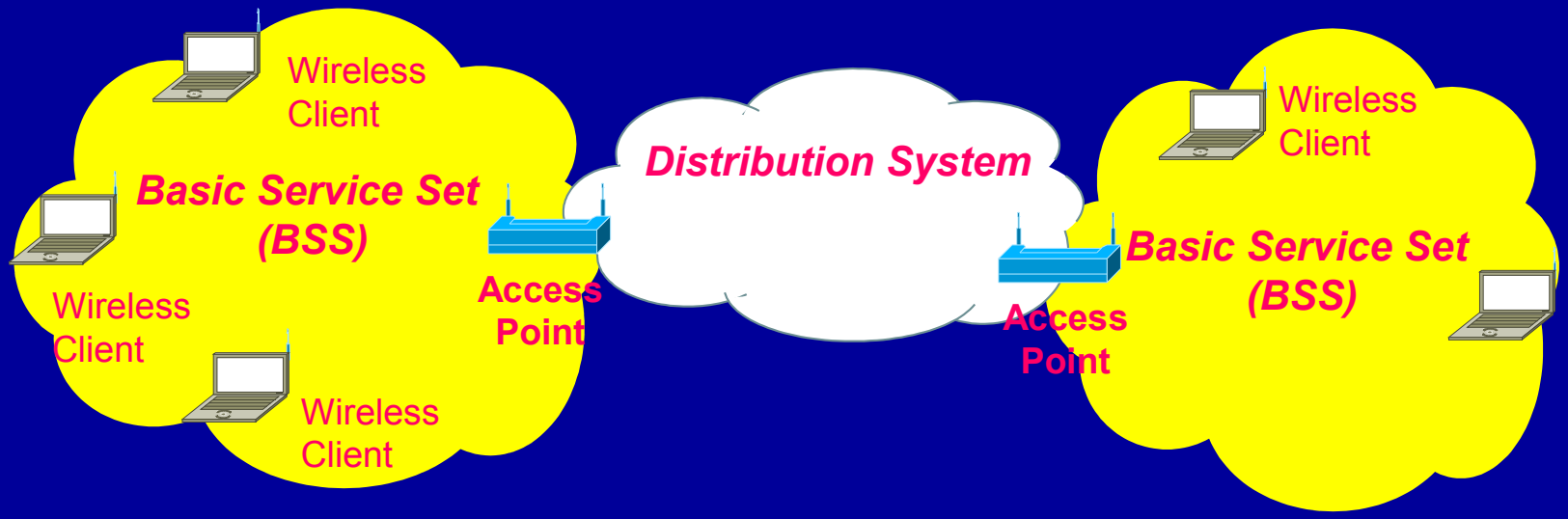
- Overview of IEEE 802.11
- 802.11e enhancements for QoS support
- Feedback based QoS
- Call Admission Control (CAC)
- Ns-2 results
- Future work

Motivations

The interest for multimedia transmission using WLan is increasing (home entertainment, IP TV, networking electronic media)

- The random Medium Access Control (MAC) of the IEEE 802.11 standard is not well suited for multimedia traffic, which is ***very sensitive*** to time ***delays***.

IEEE 802.11

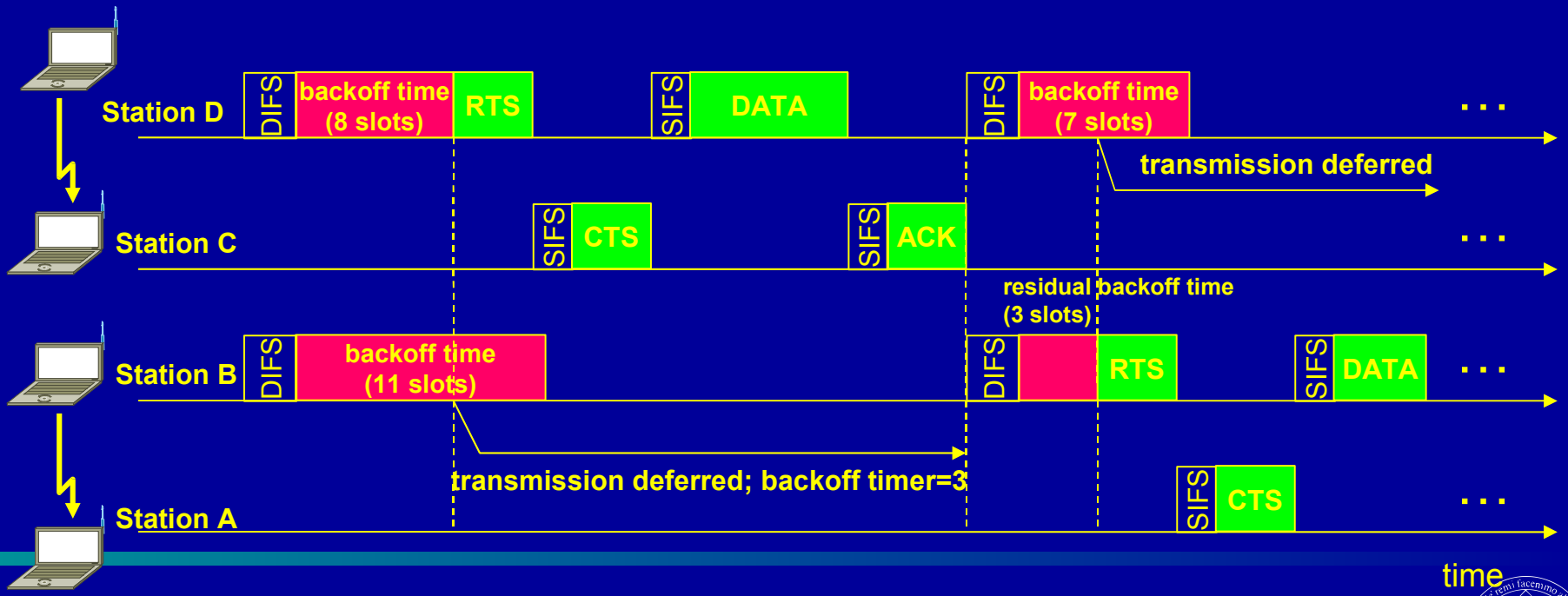


- Infrastructure WLAN
  - All the traffic of the **BSS** (Basic Service Set) is channelled through the Access Point (**AP**)
  - The Distribution System connects two or more BSSs.
  - This architecture is known as **ESS** (Extended Service Set)

Basic DCF access scheme

Basic MAC is the Distributed Coordination Function (DCF)

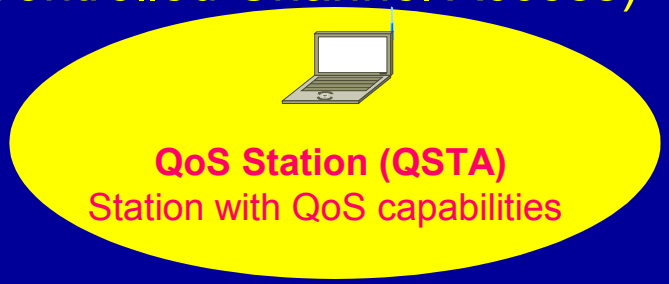
- it implements a Carrier Sense Multiple Access/Collision Avoidance (**CSMA/CA**) algorithm;
- it is mandatory;
- it uses a backoff scheme for retransmissions.



IEEE 802.11e enhancements

- Improved access method: HCF (Hybrid Coordination Function)
  - contention-based access, **EDCA** (Enhanced Distributed Coordination Access)
  - contention-free access, **HCCA** (HCF Controlled Channel Access)





- Call Admission Control (CAC)
- QoS Service level negotiation: TSPEC for traffic stream specification
  - e.g., Delay Bound; MSDU and Burst size; Data Rate; etc.

EDCA method

- EDCA is similar to DCF, but with different Contention parameters (AIFS) per **Access Category** (AC)
- 4 ACs to map the 8 Traffic Categories (TCs) of 802.1D

AC_BK (Background) → TC: 1, 2

AC_BE (Best Effort) → TC: 0, 3

AC_VI (Video) → TC: 4, 5

AC_VO (Voice) → TC: 6, 7

TXOP

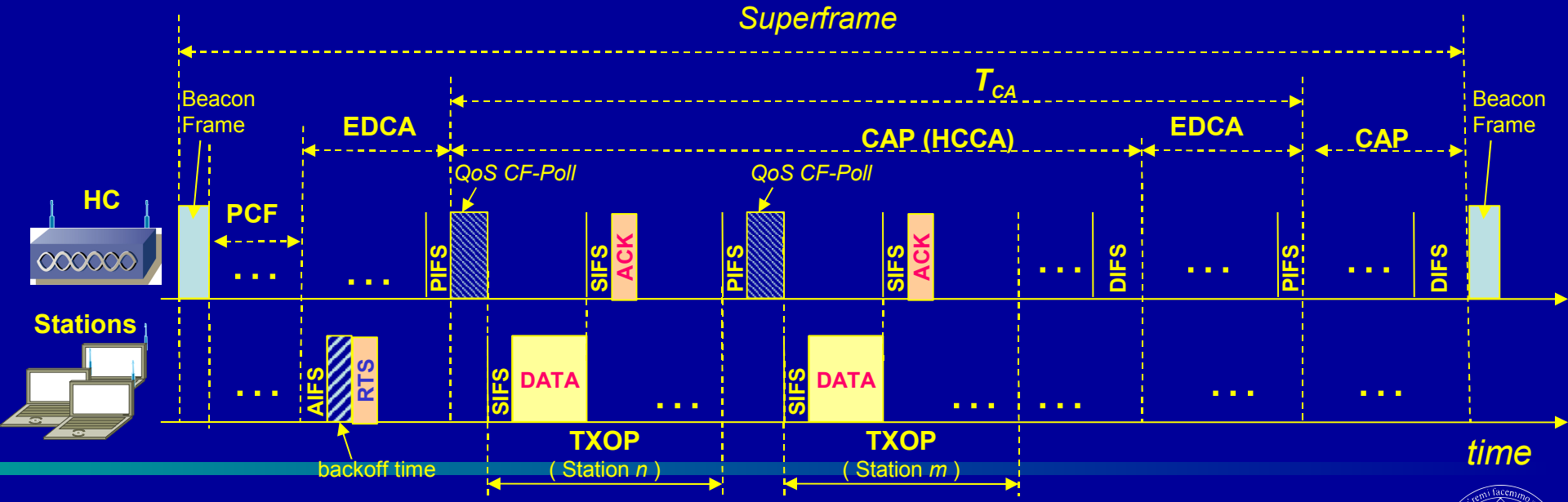
- **TXOPs** (Transmission Opportunities): time interval during which a station has the right to transmit



HCCA method

- It combines some EDCA characteristics
- The time is divided into repeated periods (*Superframes*)
- HC starts a **CAP** (Contention Access Phase) during which only polled and granted QSTAs are allowed to transmit for TXOPs (CAP ≤ *dot11CAPlimit*)

$$SuperFrameUtilization = \frac{\sum TXOP_i}{dot11CAPlimit}$$



Simple Scheduler

- The simple scheduler is described in the 802.11e Draft
- It does not exploit any feedback from stations
- It assigns fixed TXOPs based on static values declared in the TSPEC

$$TXOP_i = \max\left(\frac{N_i L_i}{C_i} + O, \frac{M}{C_i} + O\right)$$

L_i: nominal MSDU

C_i: physical data rate

M: maximum MSDU size

O: time overhead due to ACK frames, SIFS, and PIFS intervals

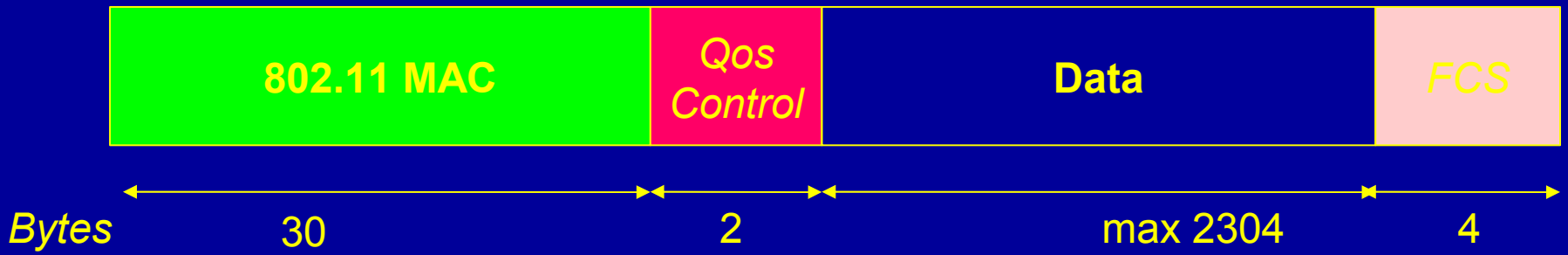
$$N_i = \left\lceil \frac{T_{SI}\rho_i}{L_i} \right\rceil$$

T_{SI}: Service Interval (minimum interval between two successive allocation to the same station)

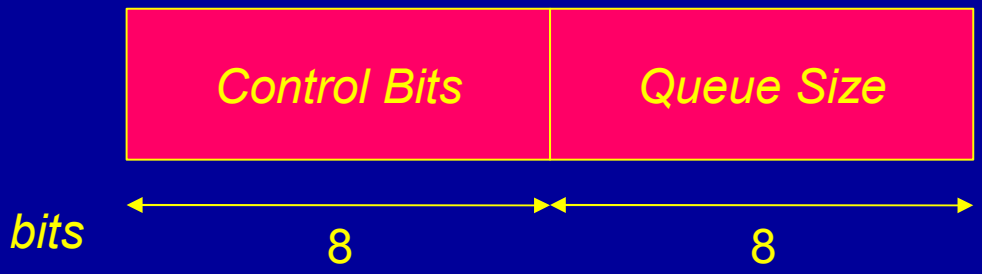
ρ_i: Mean Source Data rate

New MAC frame format

- New QoS Control field in the header of the MAC frame

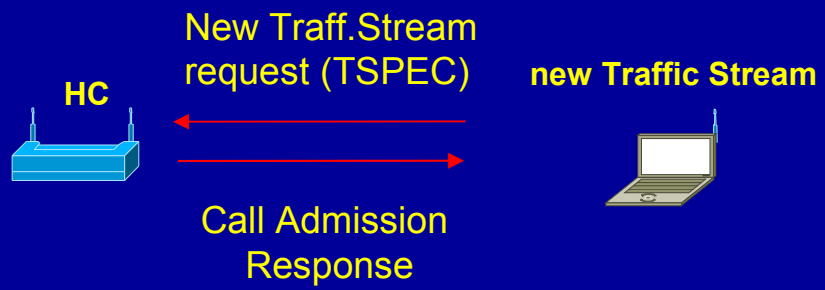


- Queue size (units of 256 octets) in the QoS Control Field



- This field is useful to design novel HCCA-based dynamic scheduler using feedback control

Call Admission Control



- Decision taken by the Admission Control Unit in the HC
- With k admitted flows, the flow k+1 is accepted if

$$\frac{TXOP_{k+1}}{T_{SI}} + \sum_{i=1}^{k} \frac{TXOP_i}{T_{SI}} \leq \frac{T - T_{CP}}{T}$$

T: Superframe duration
T_{CP}: time used for EDCA traffic during the superframe

Feedback Based Dynamic Scheduler

- Basic assumptions
  - HCCA method: T_{CA} (time between two successive CAPs) constant
  - Within each CAP, the HC is aware of all M traffic queue levels q_i in the network (feedback in frame header)

- Dynamic of the i^{th} queue:

$$q_i(k+1)=q_i(k)+d_i(k)T_{CA}+u_i(k)\ T_{CA}$$

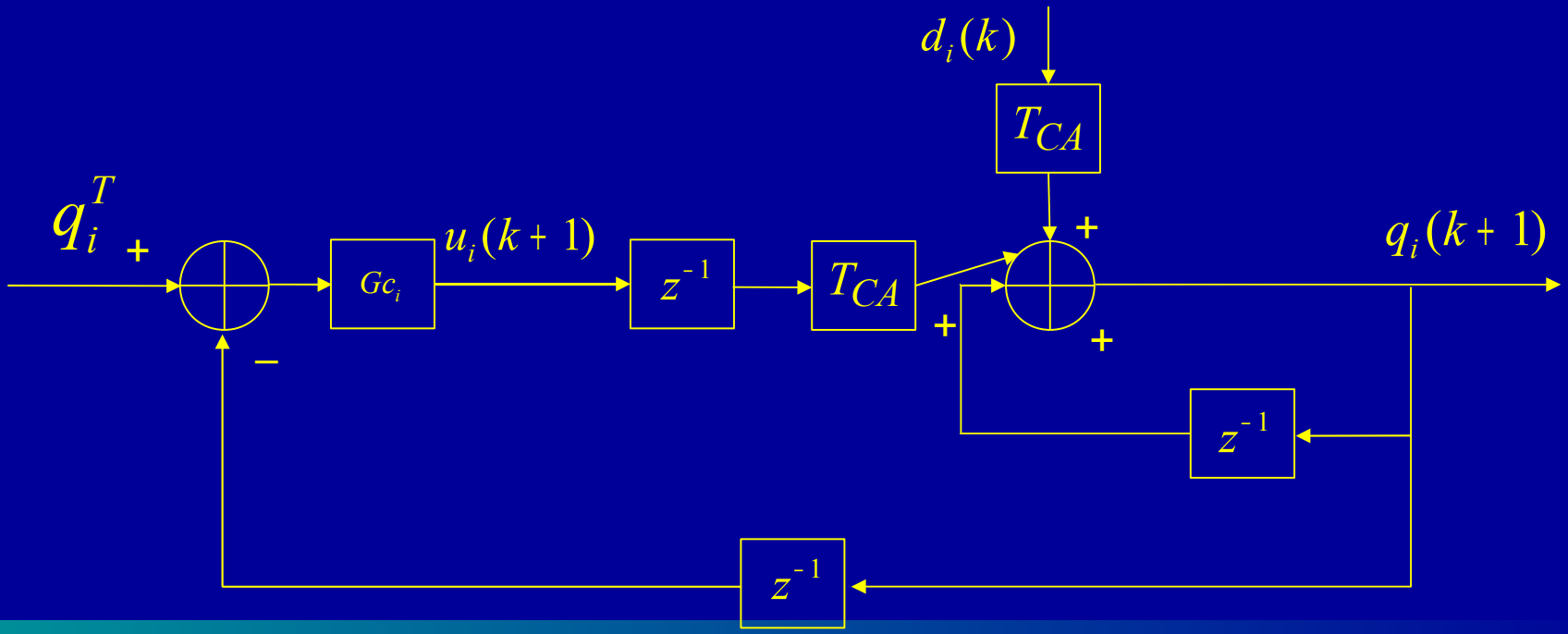
$q_i(k)$: i^{th} queue level at the beginning of the k^{th} CAP

$u_i(k)$: average depletion rate of the i^{th} queue level

$d_i(k)=d_i^S(k)-d_i^{CP}(k)$ difference between the average input rate at the i^{th} queue during the k^{th} T_{CA} interval and the amount of data transmitted during the k^{th} CP (i.e., EDCA) divided by T_{CA}

FBDS Control Law

- **Objective:** drive the queuing delay τ^i experienced by each frame of the *i*th queue to a desired target value τ^i_T.
- For each queue the target queue level q^T is 0



The Control Law

- After a little of reasoning and manipulation we can get a control law as simple as

$$u(t) = -k \cdot q(t)$$

- (…and as some others we think that a good equation has to be beauty to be good!)

Stability Analysis: Proportional Controller ($Gc_i=k_i$)

- Z-transforms of queue level q_i and depletion rate u_i

$$Q_i(z) = \frac{zT_{CA}}{z^2 - z + k_i T_{CA}} D_i(z)$$

$$U_i(z) = -\frac{k_i T_{CA}}{z^2 - z + k_i T_{CA}} D_i(z)$$

- System Poles $z_p = \dfrac{1 \pm \sqrt{1 - 4k_i T_{CA}}}{2}$

- Stability condition $0 < k_i < \dfrac{1}{T_{CA}}$

Queueing Delays

- After a little algebra, the steady state delay is

$$\tau_i(\infty) = \left| \frac{q_i(\infty)}{u_i(\infty)} \right| = \frac{1}{k_i}$$

- To satisfy the target delay τ_i^T the following inequality must be satisfied:

$$k_i \geq \frac{1}{\tau_i^T}$$

- Thus, we need :

$$T_{CA} < \min_{i=1,\ldots,M} \tau_i^T$$

Stability Analysis: PI Controller

- Controller Transfer Function $$Gc = kp\left(1 + \frac{z}{z-1}\frac{1}{T_I}\right)$$

- Stability conditions $$0 < k_i < \frac{1}{T_{CA}} \qquad T_I > \frac{1}{1 - T_{CA}kp}$$

- Due to the integral action the steady state queuing delay is zero

TXOP assignments

- From the computed u_i(k), the HC assigns the following TXOP

$$TXOP_i(k) = \frac{|u_i(k)T_{CA}|}{C_i} + O$$

- The extra quota of the assigned TXOP depends on the overhead due to ACK frames, SIFS and PIFS time intervals.
- The overhead could be estimated assuming that all MSDUs have the same nominal size, specified in the TSPEC

Channel Saturation (1)

- If the the WLAN is not overloaded, than the sum of assigned TXOPs is smaller than the maximum CAP duration *dot11CAPLimit*.
- If the channel is saturated i.e.:

$$\sum_{i=1}^{M} TXOP_i(k) > dot11CAPLimit$$

each computed TXOP is decreased by an amount Δ TXOP so that

$$\sum_{i=1}^{M} \left[TXOP_i(k) - \Delta TXOP_i(k)\right] = dot11CAPLimit$$

Channel Saturation (2)

- The generic ΔTXOP is given by

$$\Delta TXOP_i(k) = \frac{TXOP_i(k)C_i}{\sum_{j=1}^{M} TXOP_j(k)C_j} \left(\sum_{j=1}^{M} TXOP_j(k) - dot11CAPLimit \right)$$

ΔTXOP is proportional to the physical data rate

CAC proposal

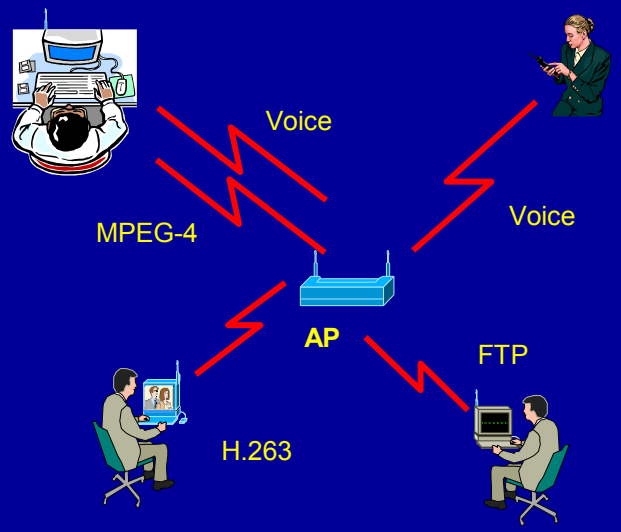
- Similar to the CAC proposed by the IEEE standard
- Use TXOPs dynamically assigned instead of fixed values
- The proposed CAC test takes into account the bandwidth actually used by traffic streams

$$\frac{TXOP_{k+1}}{T_{CA}} + \sum_{i=1}^{k} \frac{TXOP_i}{T_{CA}} \leq \frac{T - T_{CP}}{T}$$

T: Superframe duration
T_{CP}: time used for EDCA traffic during the superframe

ns results

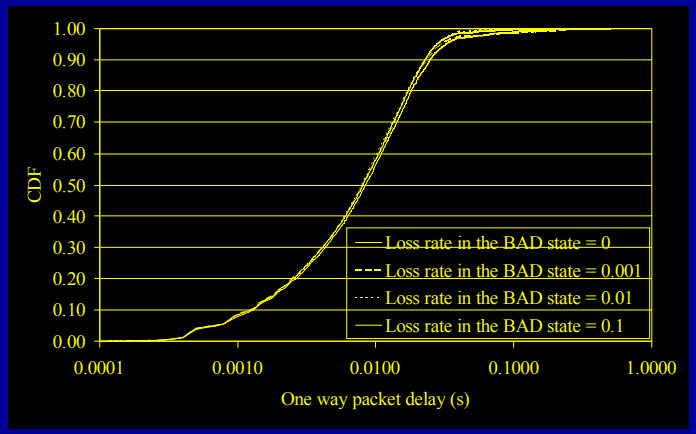
- Ns-2 simulations (54Mbps)
- 3α G.729 Voice Flows with VAD
  (Markov ON/OFF model)
- α H.263 flows
  (library traces)
- α MPEG-4 Flows
  (library traces)
- α FTP Flows



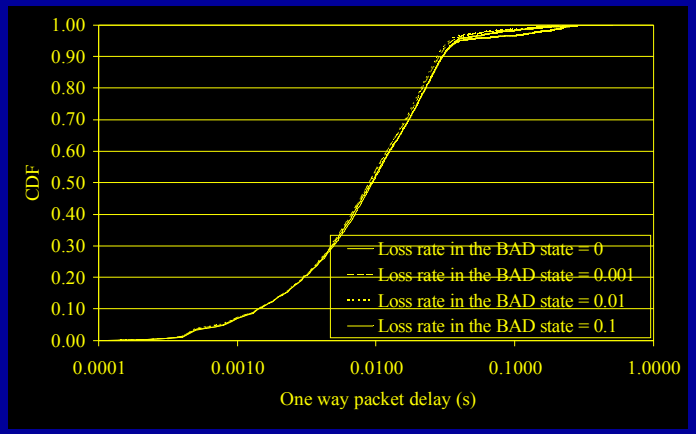
Type of flow	*Nominal (Maximum) MSDU Size*	*Mean (Maximum) Data Rate*	*Target Delay*
H.263 VBR	1536 (2304) byte	450 (3400) kbps	40 ms
MPEG-4 HQ	1536 (2304) byte	770 (3300) kbps	40 ms
G.729 VAD	60 (60) byte	8.4 kbps	30 ms

Ns Results

MPEG-4 flows (α = 5): CDFs of the one-way packet delay



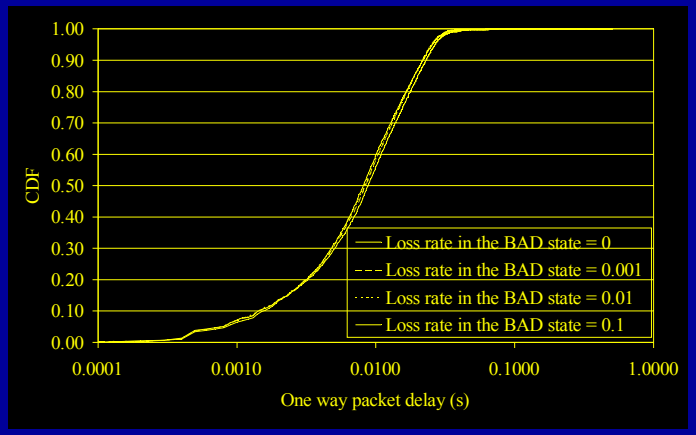
DCF



EDCA



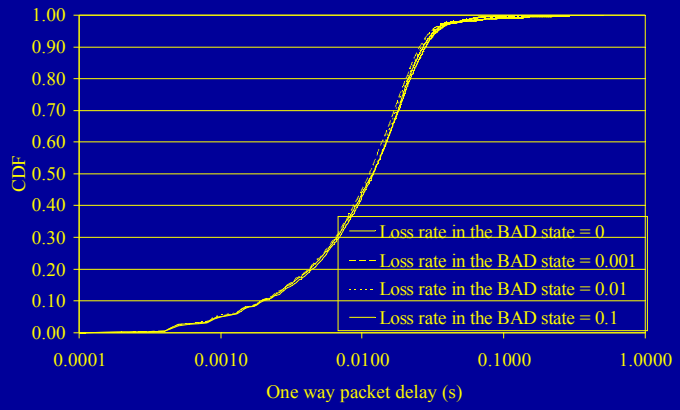
Simple Scheduler



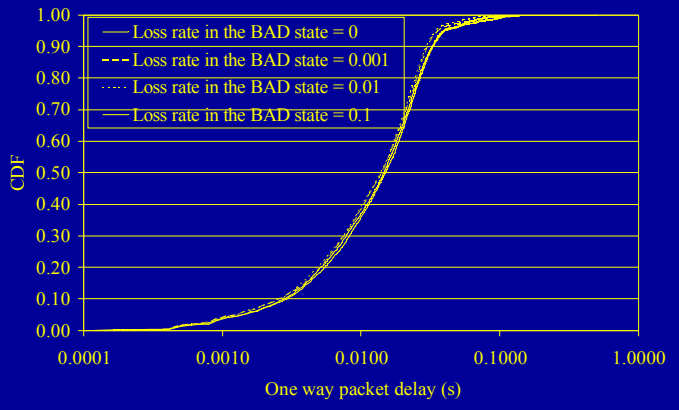
FBDS

Ns Results

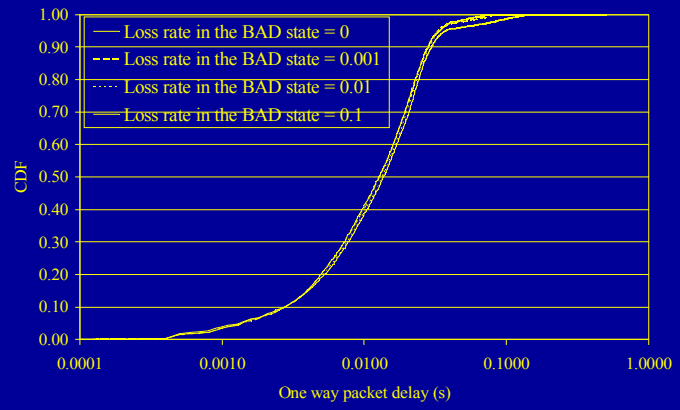
H.263 flows (α = 5): CDFs of the one-way packet delay



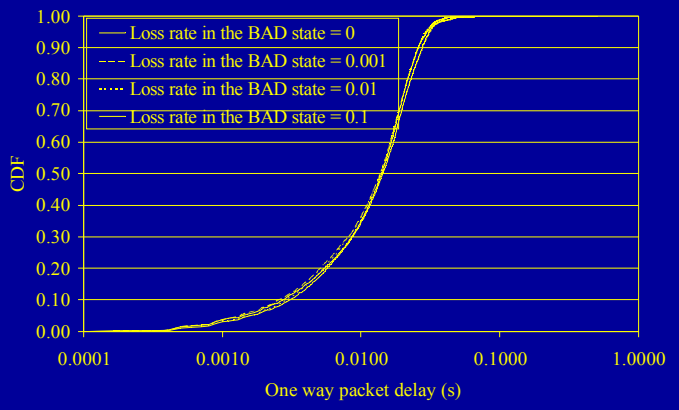
DCF



EDCA



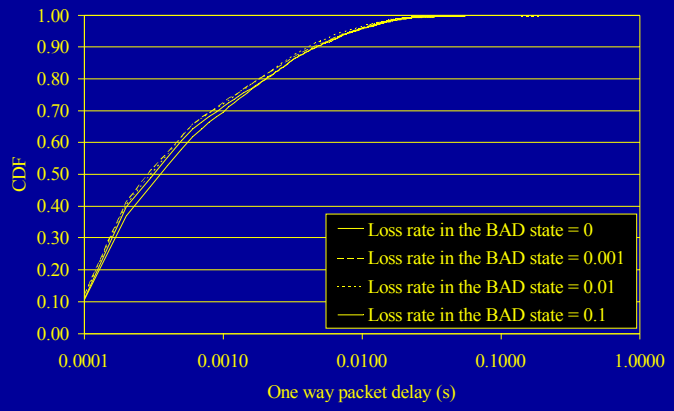
Simple Scheduler



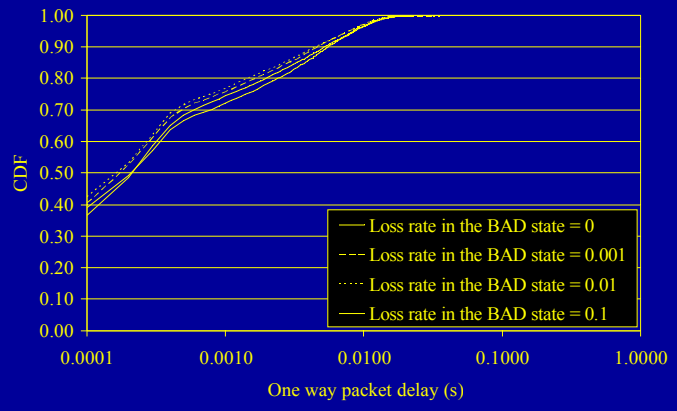
FBDS

Ns Results

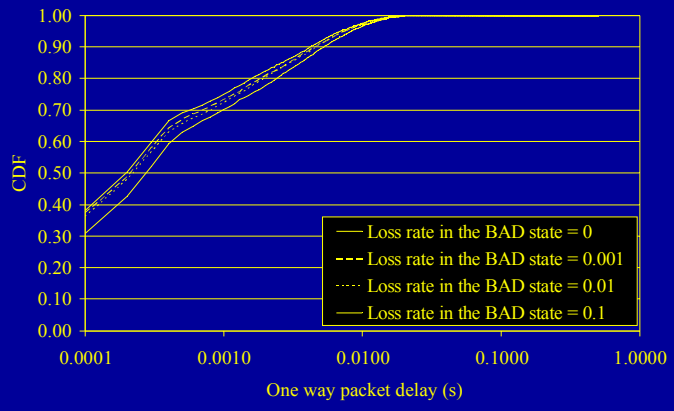
G.729 flows (α = 5): CDFs of the one-way packet delay



DCF



EDCA



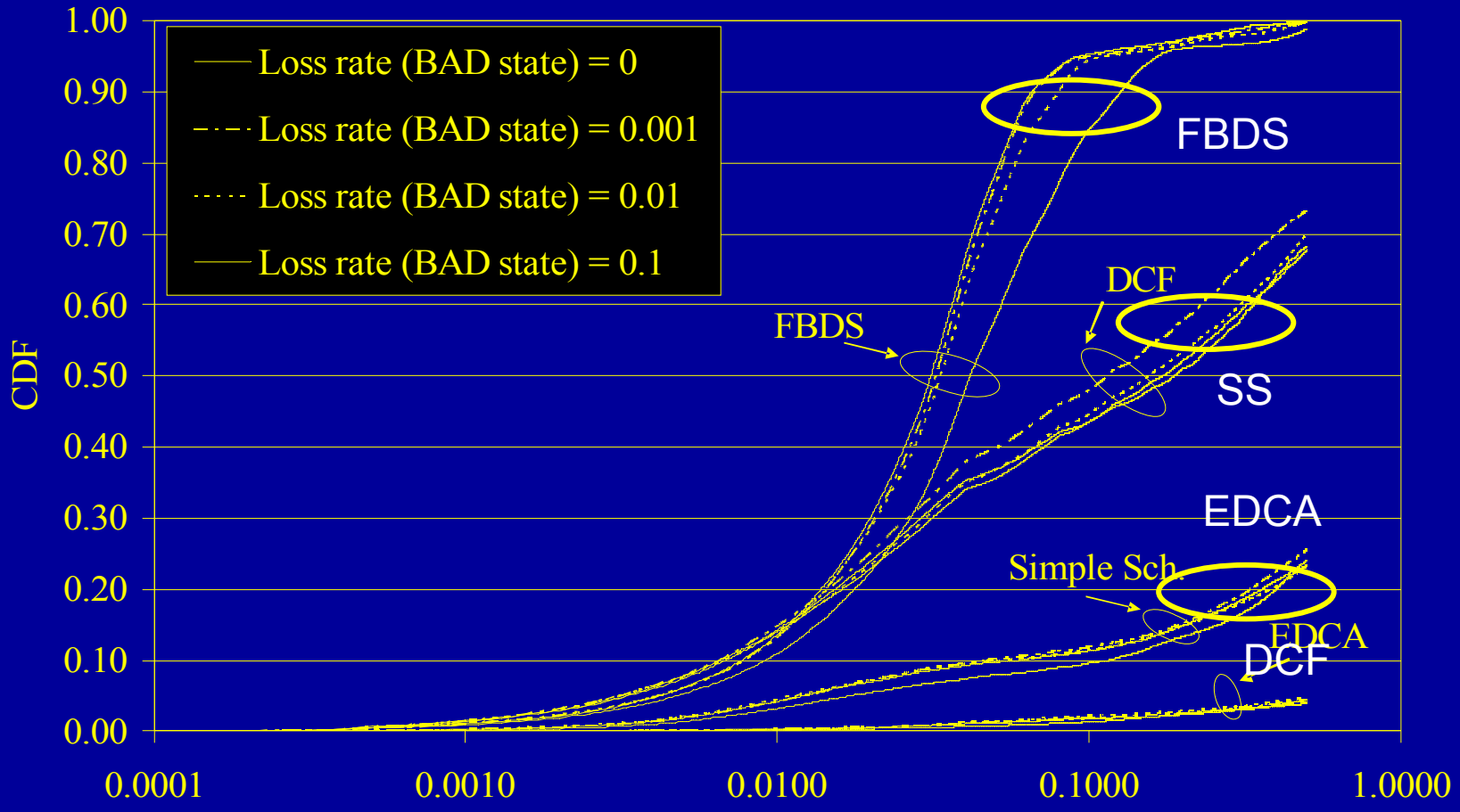
Simple Scheduler



FBDS

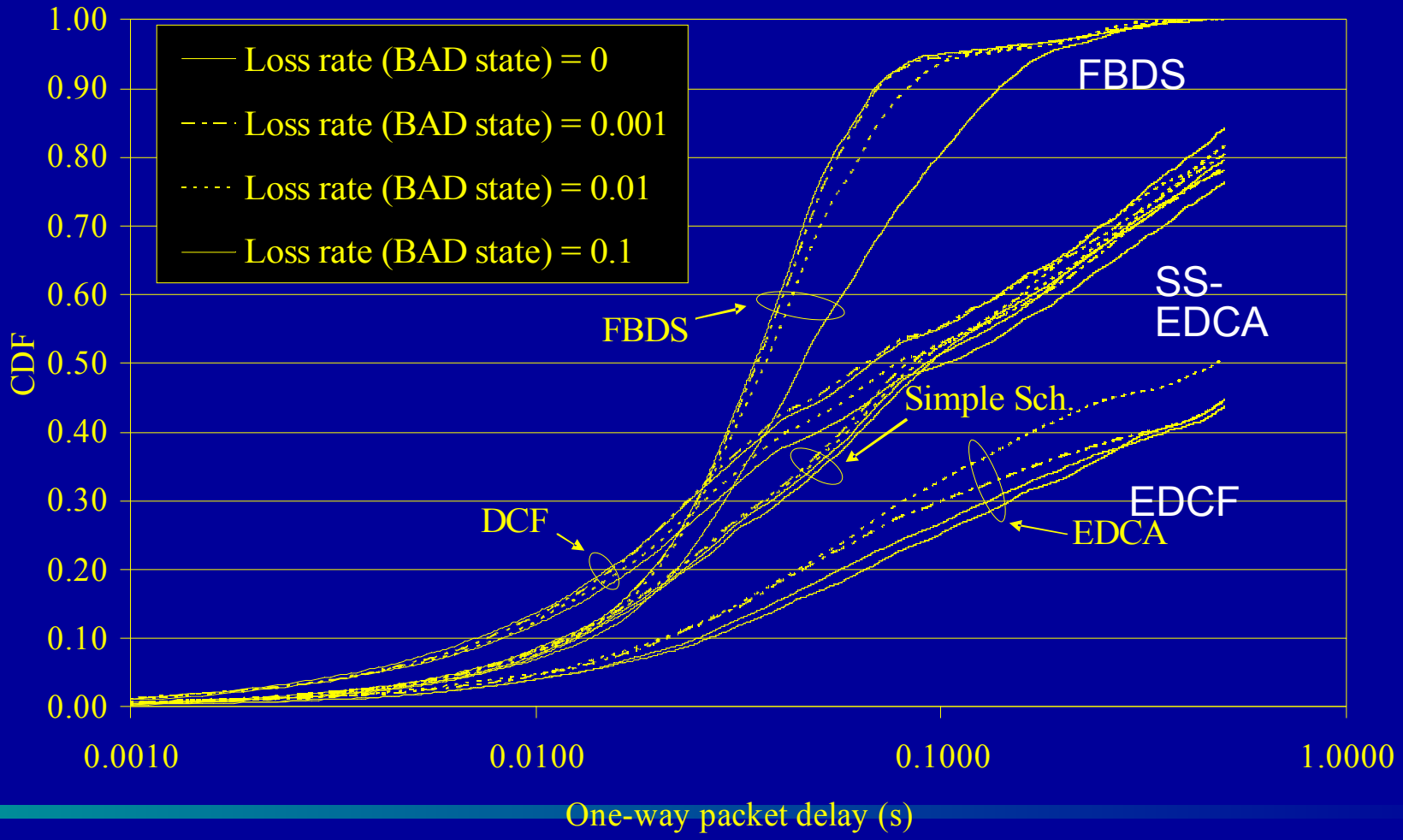
Ns Results

MPEG-4 flows (α = 10): CDFs of the one-way packet delay



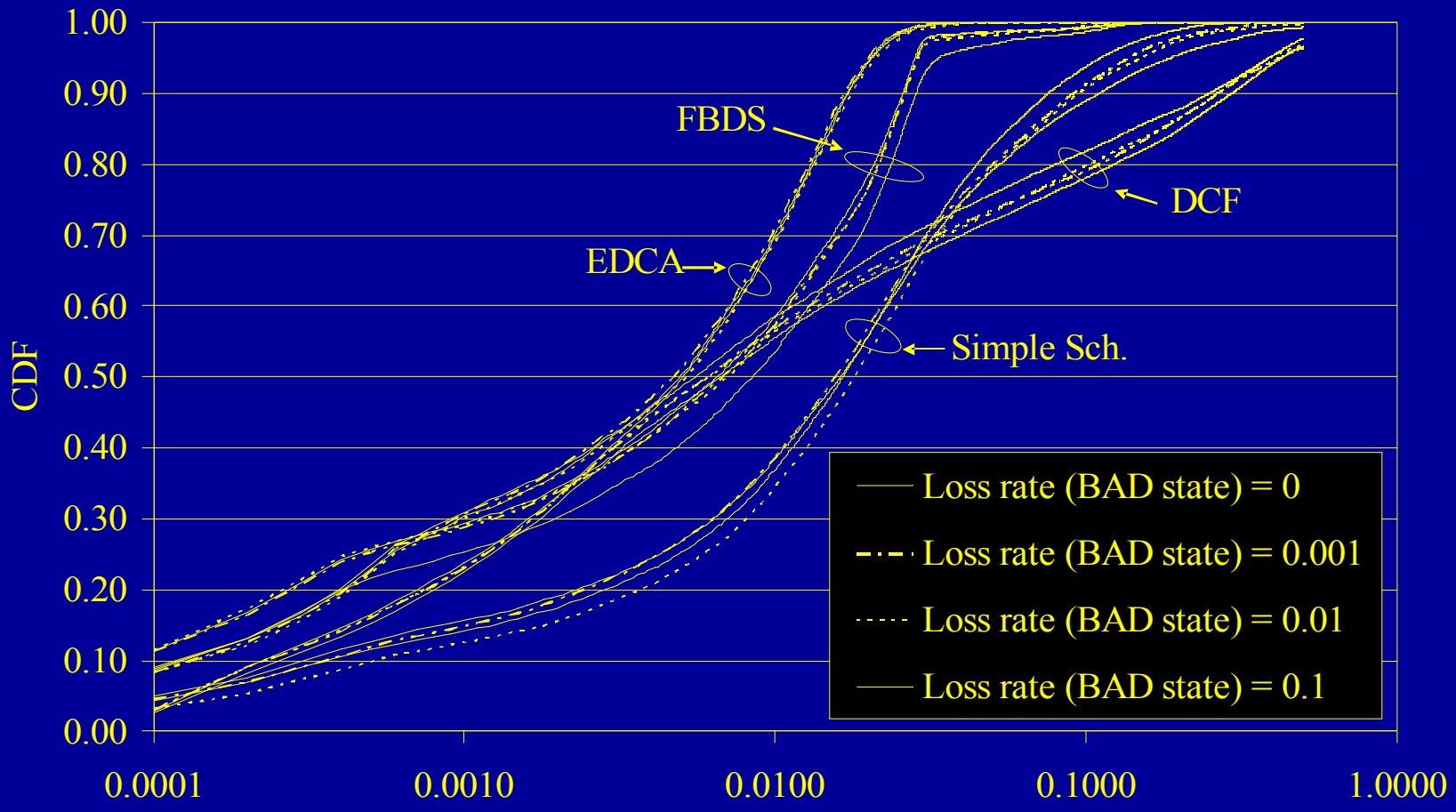
ns Results

H.263 flows (α = 10): CDFs of the one-way packet delay



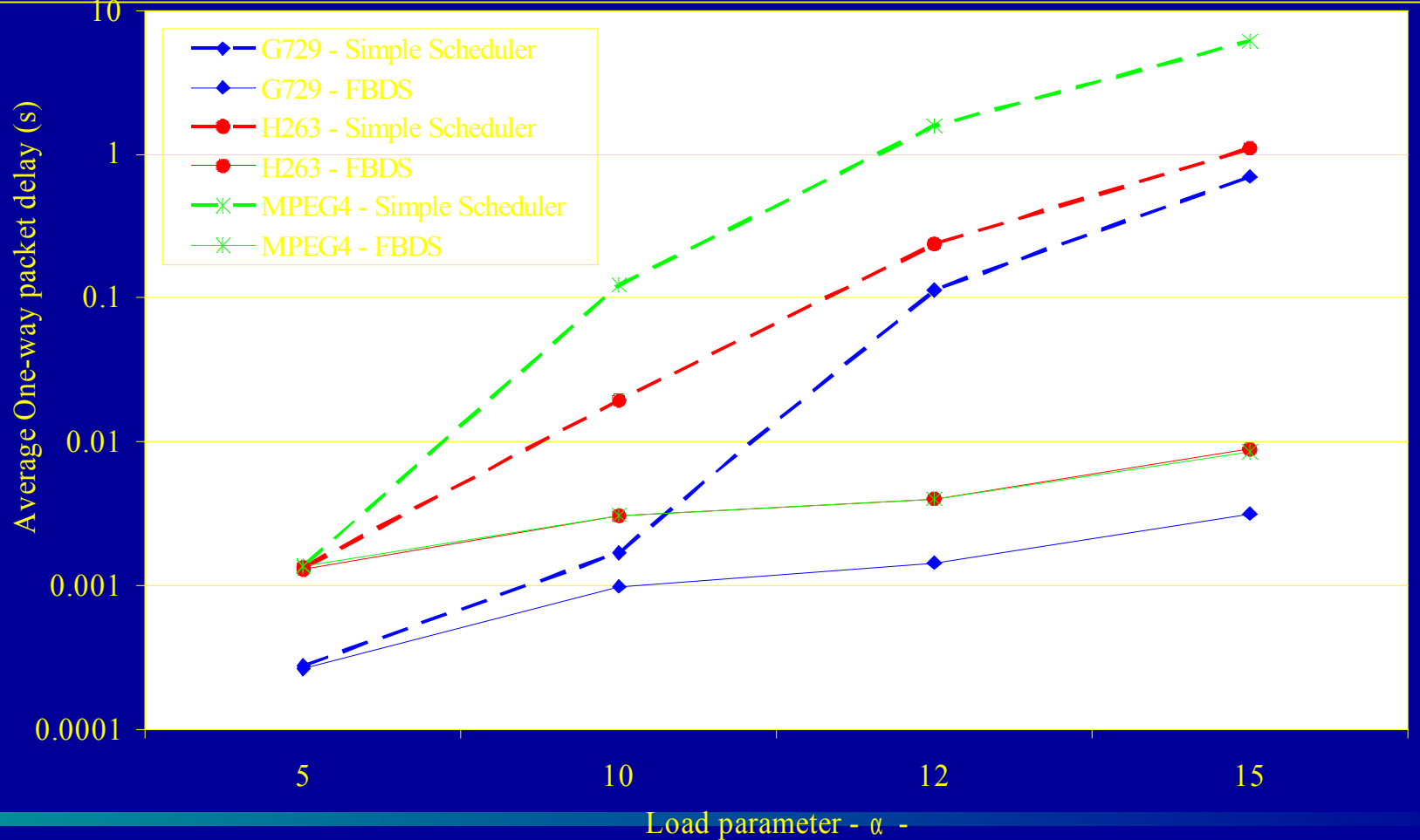
Ns Results

G.729 flows (α = 10): CDFs of the one-way packet delay



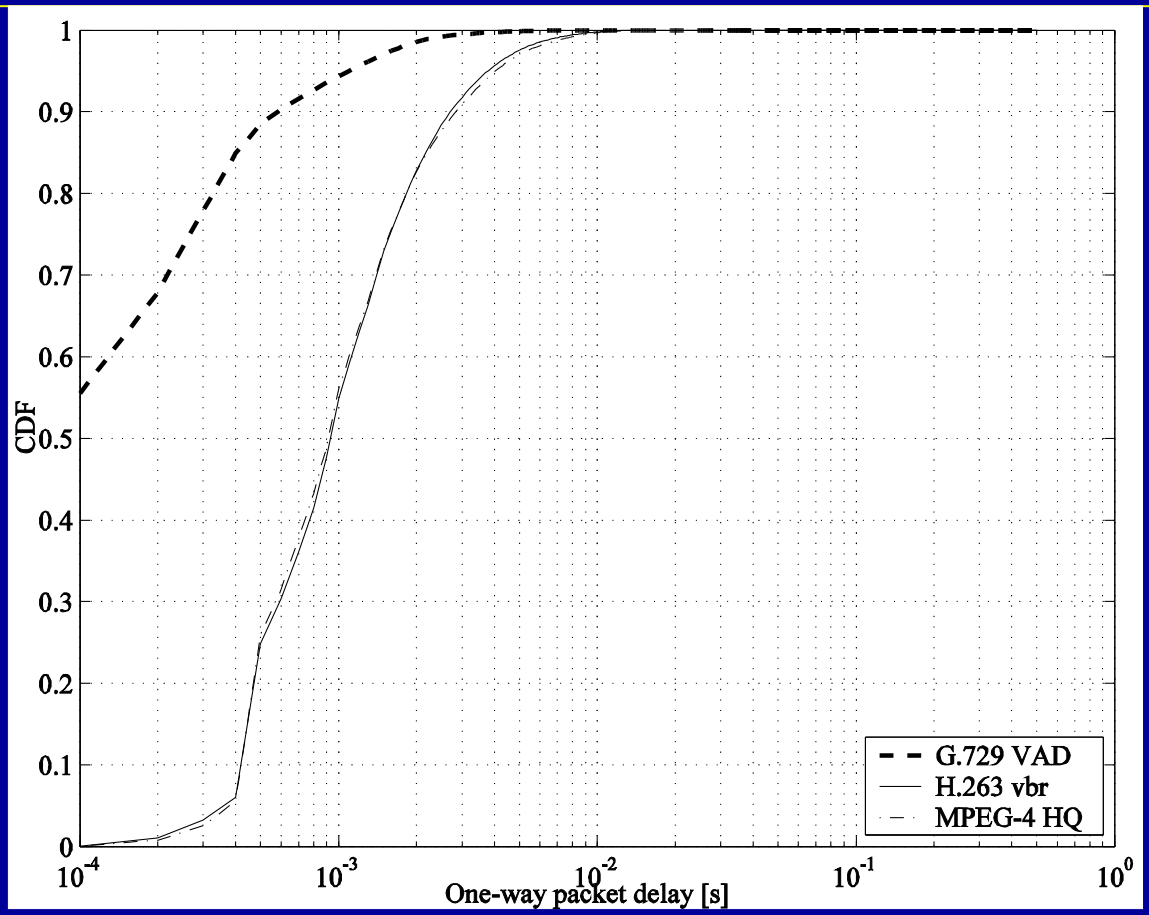
ns Results

- Average one-way packet delay



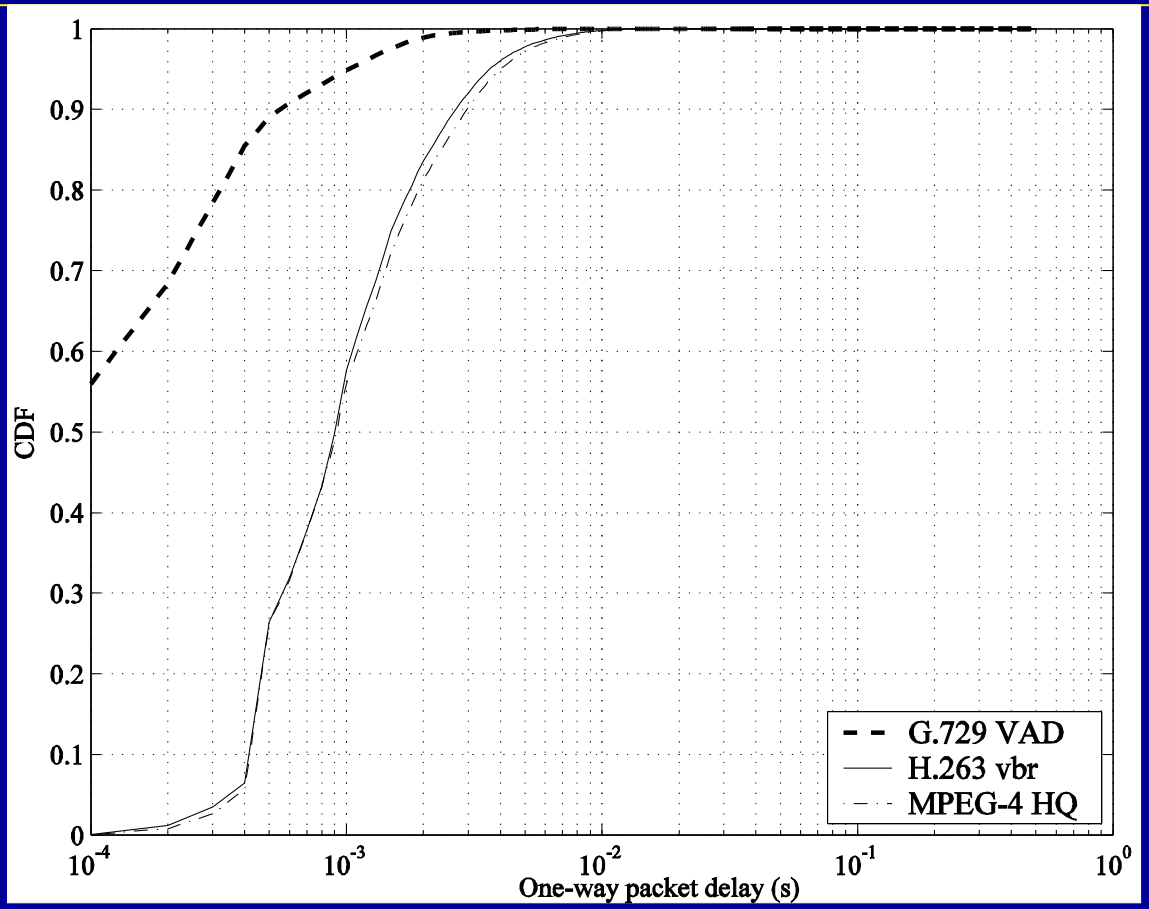
ns Results

- Simple Scheduler + CAC (α=5)



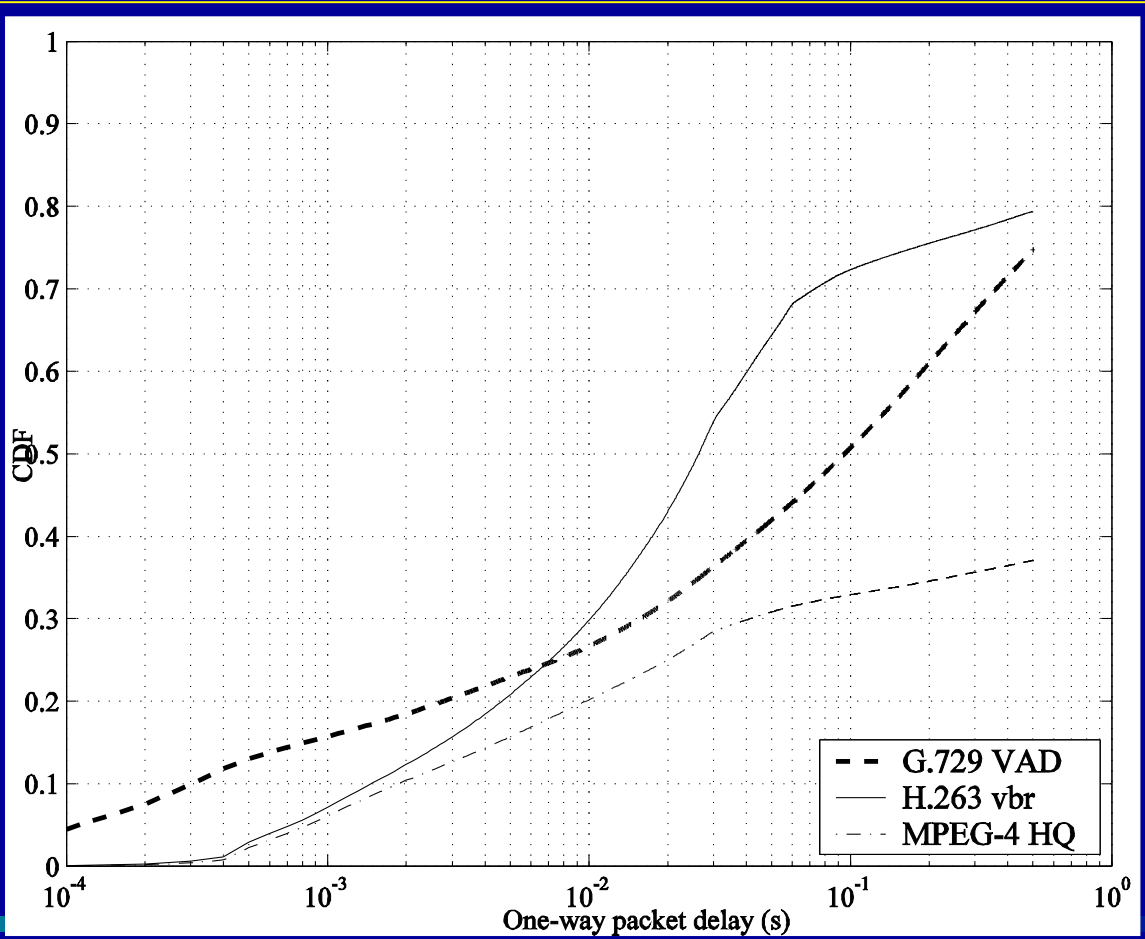
Ns Results

- FDBS + modified CAC (α=5)



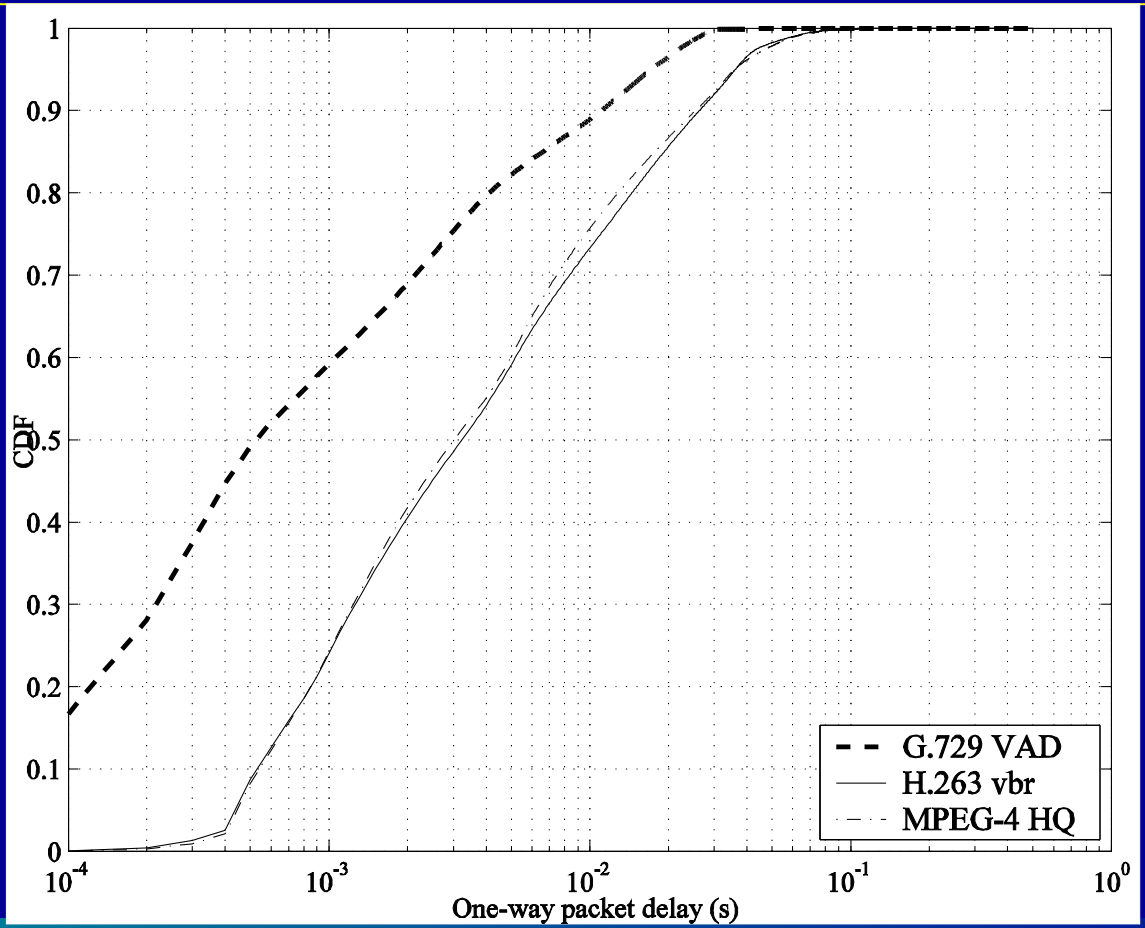
Ns Results

- Simple Scheduler + CAC (α=15)



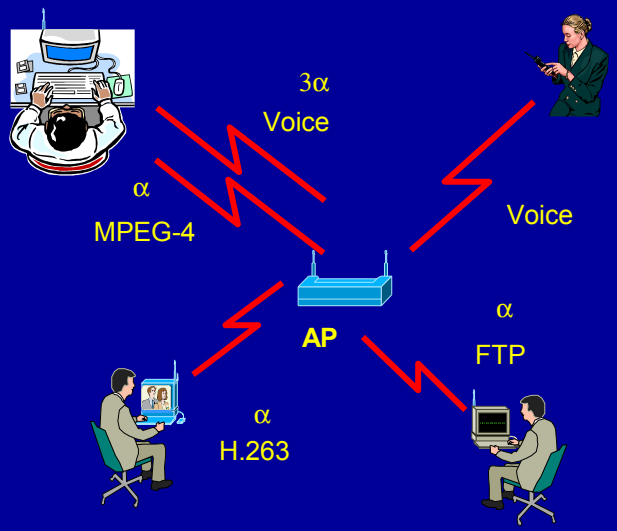
Ns results

- FDBS + modified CAC (α=15)

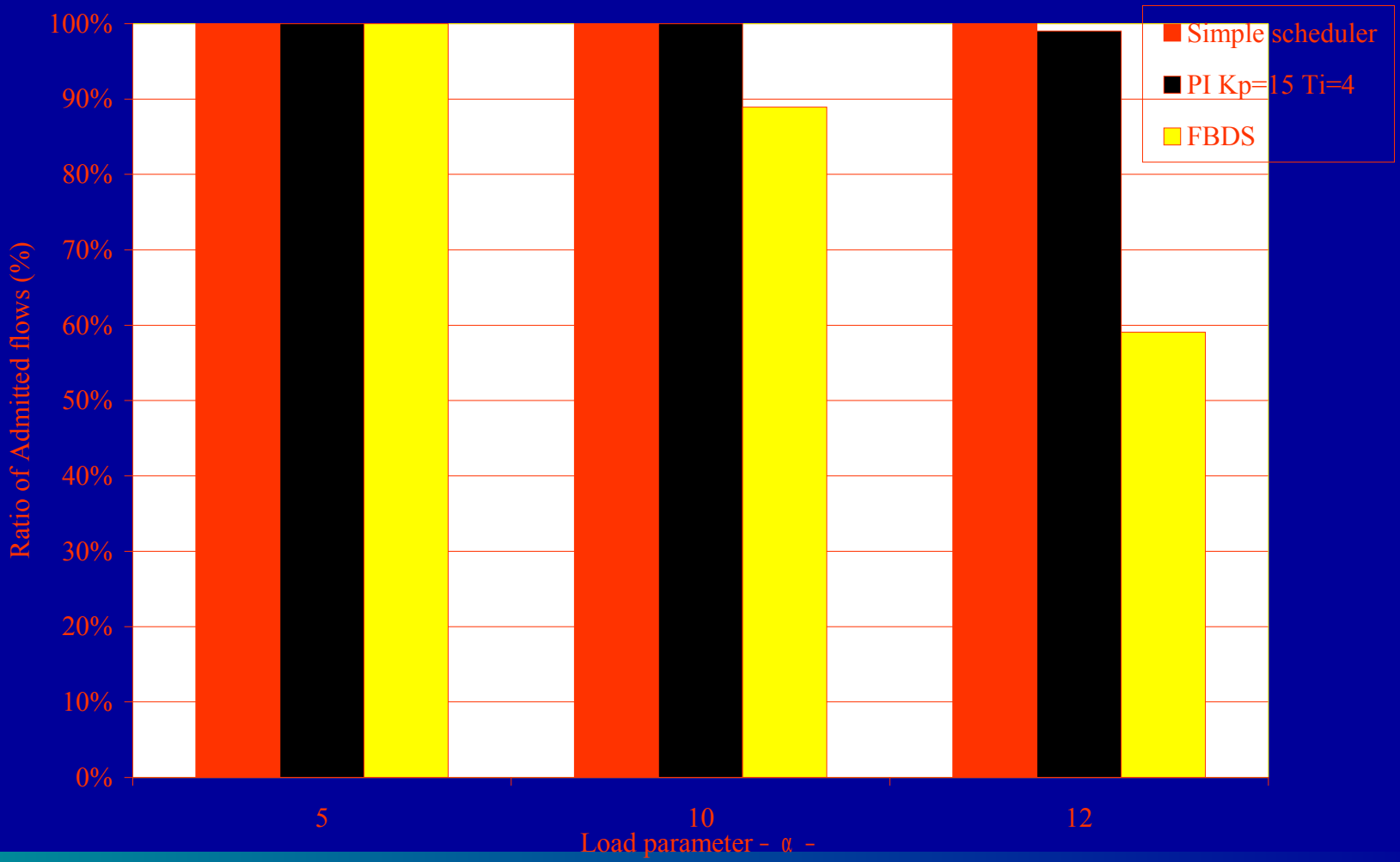


Ns Results

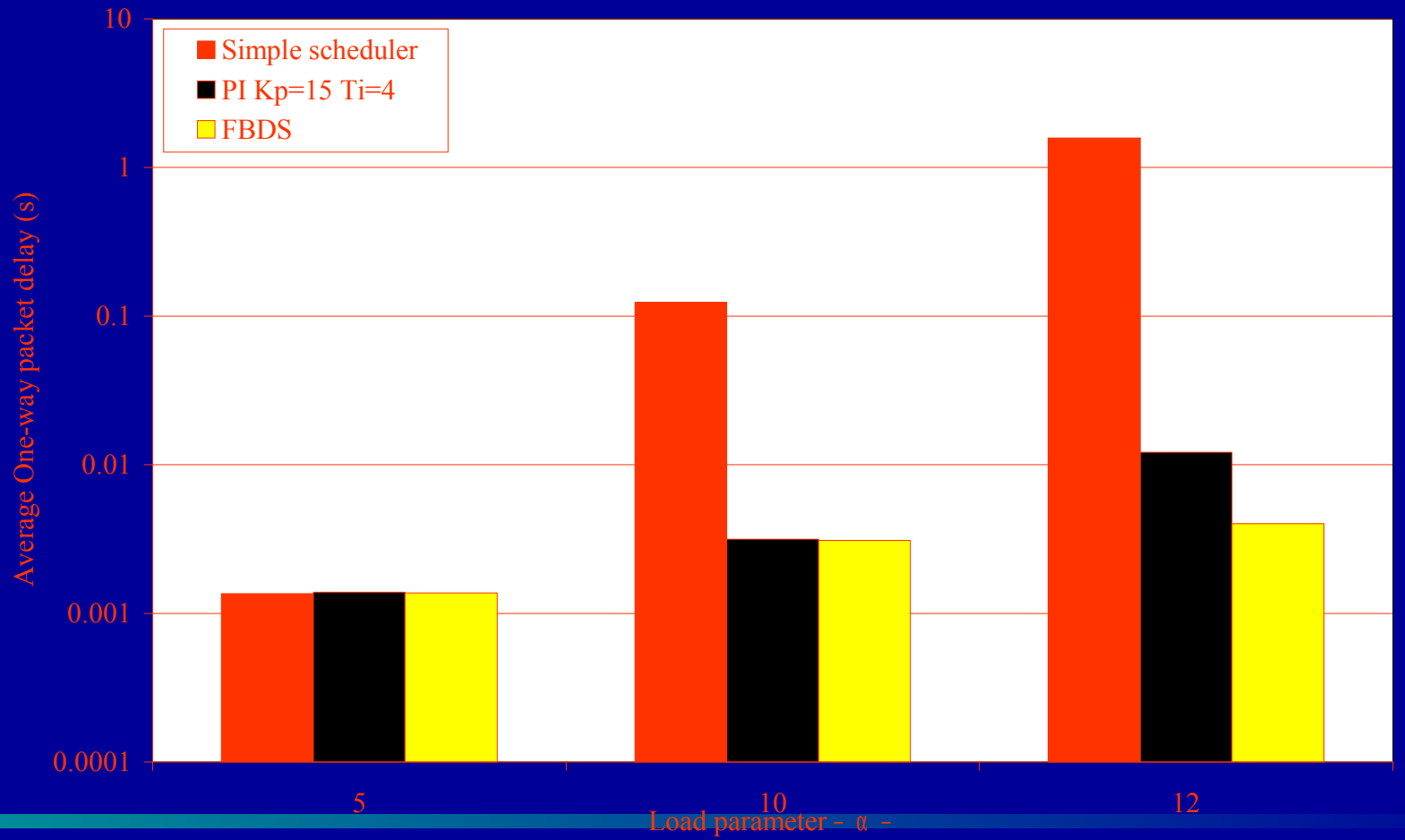
- CAC Scheme
  - If a station does not receive a response to an admission request, it repeats the same request after Δ_{TO}=1.5 s
  - An admission request is repeated up to N_{adm}=10 times
  - A new request is initiated after an exponential distributed random time with average value equal to 1 min.



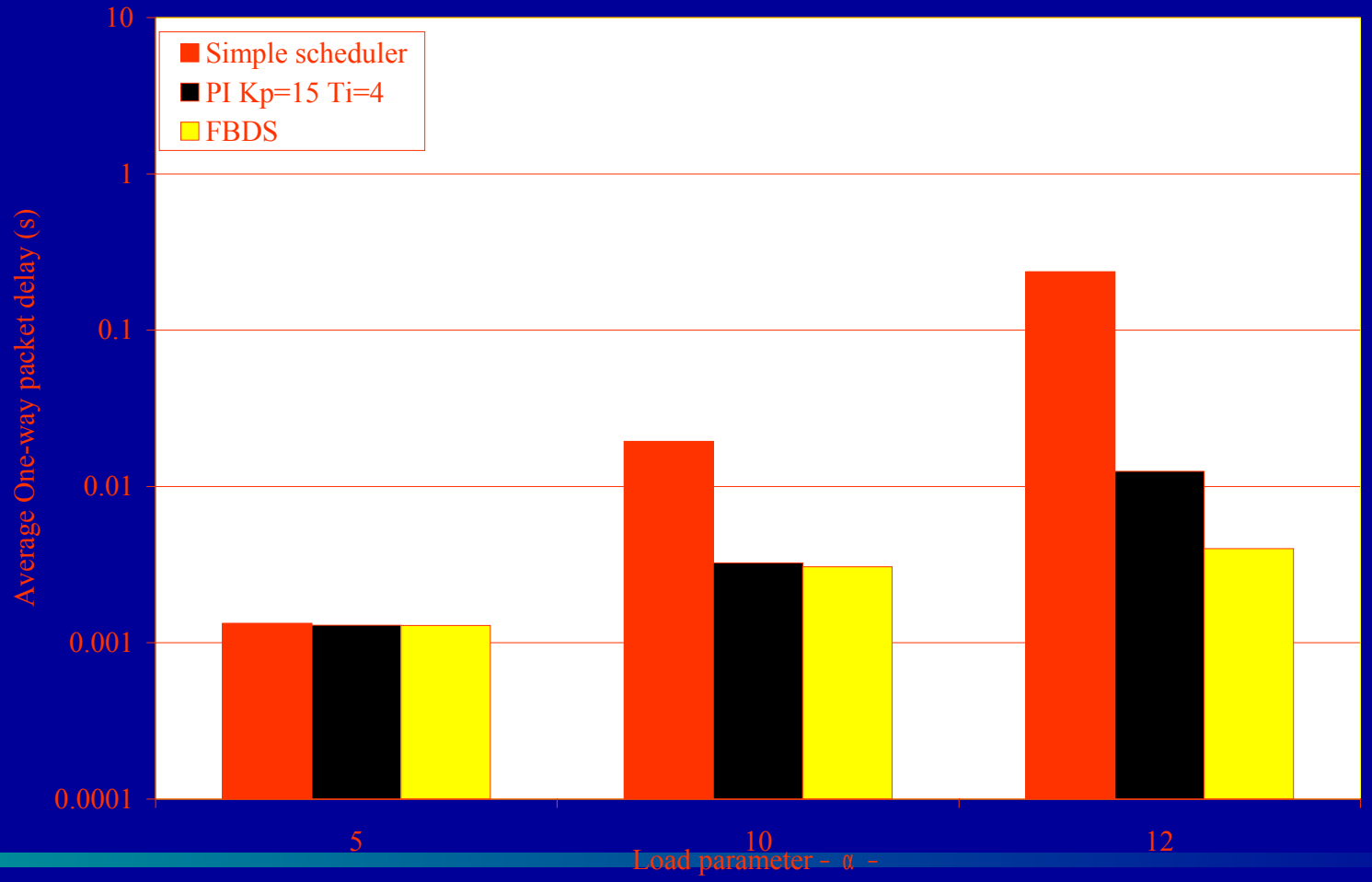
Ns Results


Simple scheduler
PI Kp=15 Ti=4
FBDS
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Ratio of Admitted flows (%)
5
10
12
Load parameter - α -

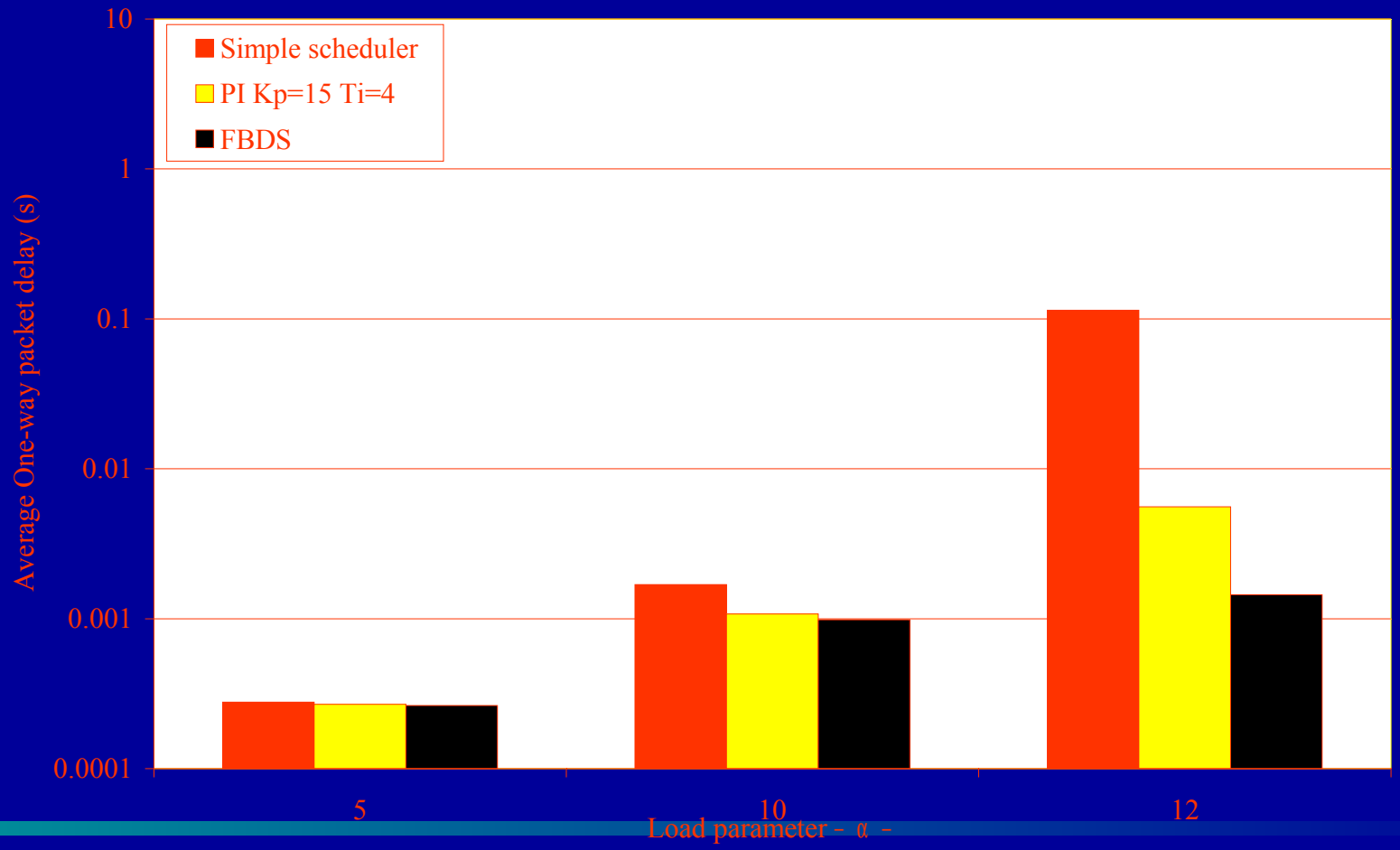
Ns Results (MPEG4 flows)



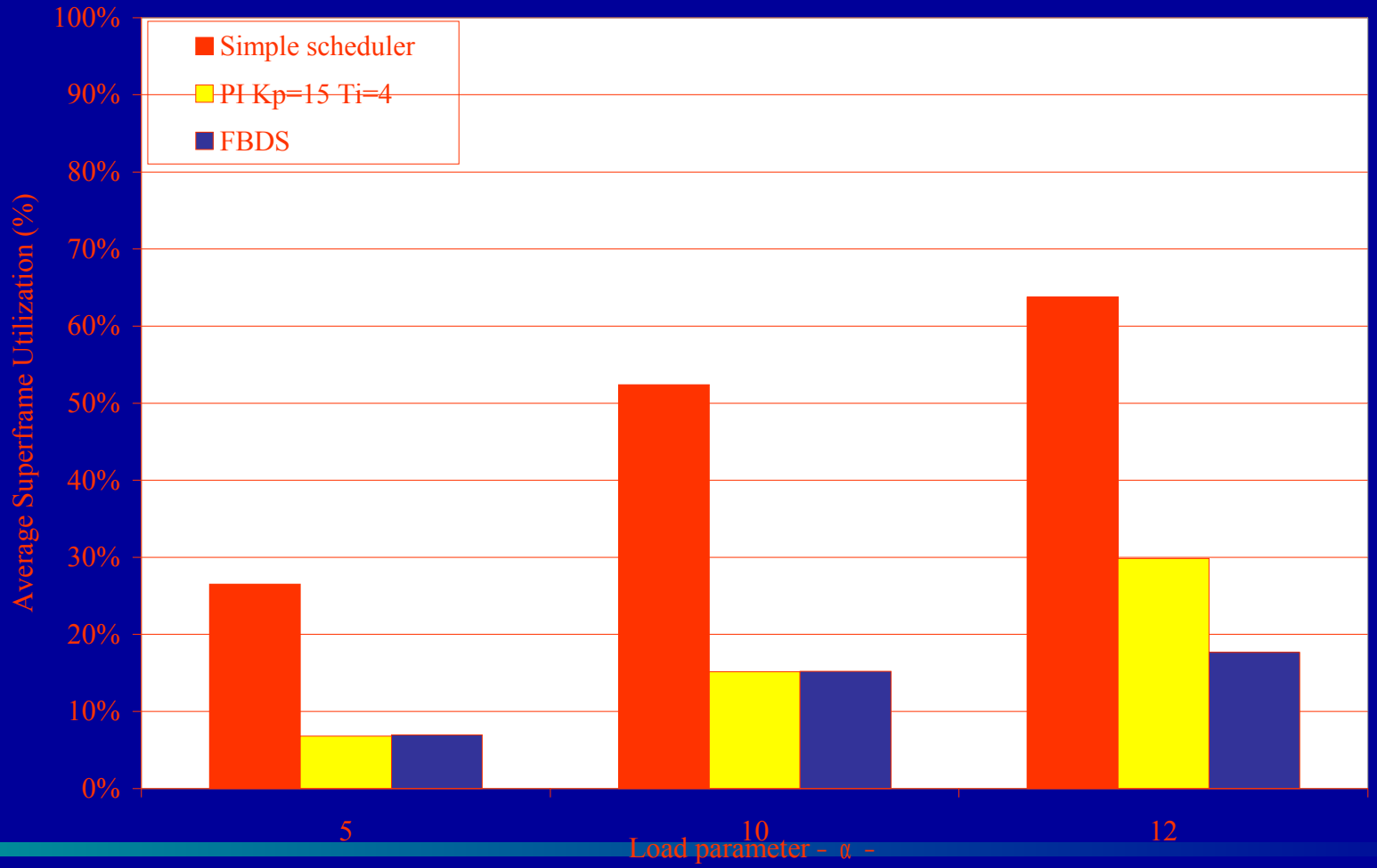
Ns Results (H.263 flows)



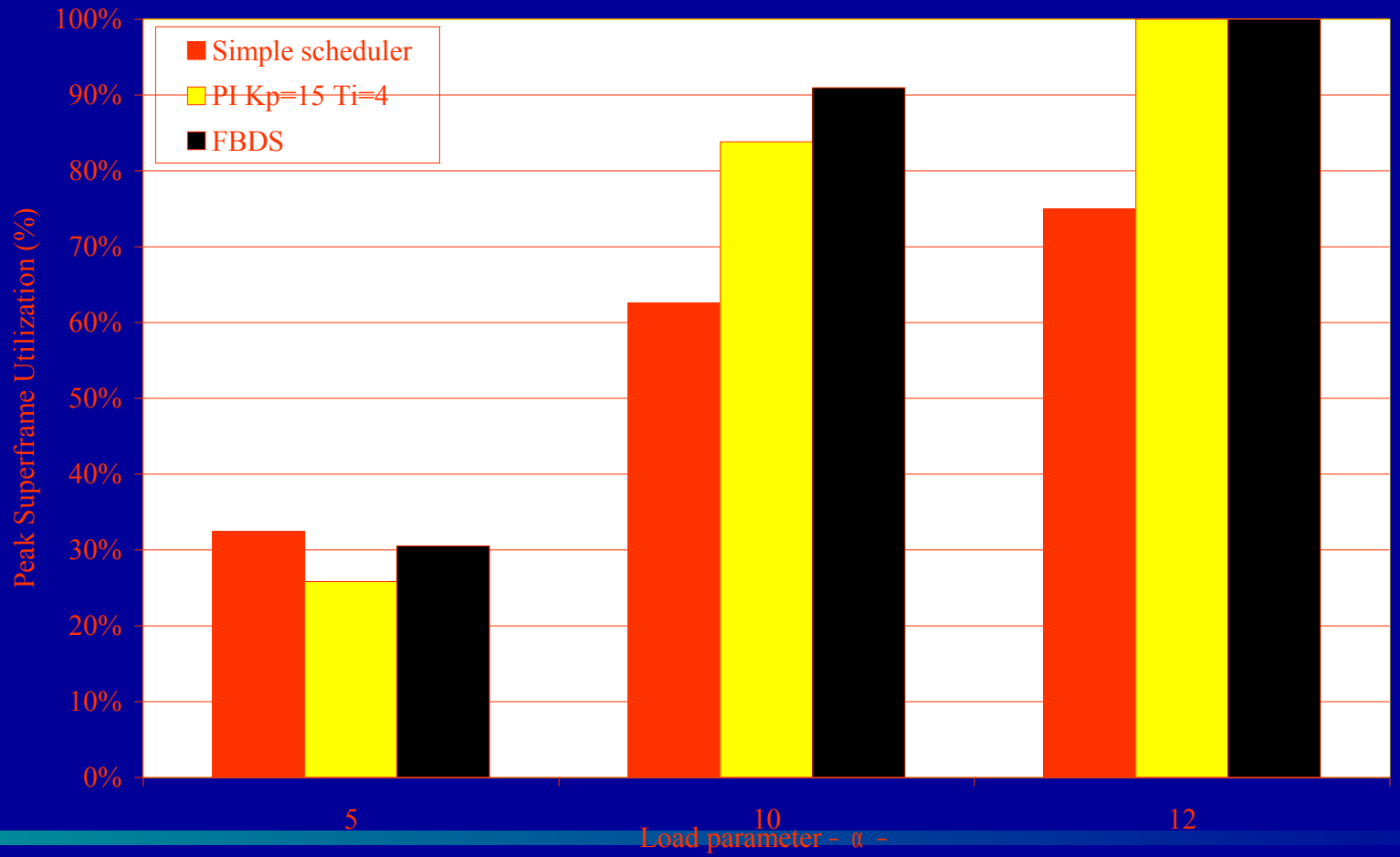
Ns Results (G.729 flows)



Ns Results


Simple scheduler
PI Kp=15 Ti=4
FBDS
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Average Superframe Utilization (%)
5
10
12
Load parameter - α -

Ns Results


Simple scheduler
PI Kp=15 Ti=4
FBDS
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Peak Superframe Utilization (%)
5
10
12
Load parameter - α -

Conclusions

- A simple feedback based scheduler provides bounded delays to real-time flows in a wide range of traffic conditions and frame loss probabilities
- Using a PI regulator, the CAC scheme admits the same flows than the proposed standard scheme, but still providing bounded delays (i.e., QoS guarantee) to each admitted flow
- We are extending this approach to power saving

Main References

- G. Boggia, P. Camarda, L. A. Grieco, S. Mascolo, Feedback-based Control for Providing Real-time Services using the 802.11e MAC, IEEE/ACM Trans. on Networking - April, 2007
- G. Boggia, P. Camarda, L.A. Grieco, S. Mascolo, Energy Efficient Feedback-based Scheduler for Delay Guarantees in IEEE 802.11e Networks, Computer Communications, Volume 29, Number 13-14, page 2680-2692, Aug. 2006
- Gennaro Boggia, Pietro Camarda, Luigi Alfredo Grieco, Saverio Mascolo, Feedback-based bandwidth allocation with call admission control for providing delay guarantees in IEEE 802.11e networks, Computer Communications, Elsevier,Volume 28, Number 3, page 325--337, Feb. 2005
- L. A. Grieco, G. Boggia, S. Mascolo, and P. Camarda, “A control theoretic approach for supporting quality of service in IEEE 802.11e WLANs with HCF," in *Proceedings of 42nd IEEE Conference on Decision and Control, CDC'03*, Hawaii, USA, Dec. 2003.

ns Results

- Ratio of admitted traffic flows

