EDCA Differentiation
HCCF Scheduling

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Thanks & Disclaimer

- These slides and results are based on the following recent reseach activities
  - "Performance Evaluation of Differentiated Access Mechanisms Effectiveness in 802.11 Networks", IleniaTinnirello , Giuseppe Bianchi , Luca Scalia, IEEE Globecomm 2004.
  - "Scheduling in 802.11e: Open-Loop or Closed-Loop?", P. Larcheri, R. Lo Cigno, IEEE WONS 2006
- As such they must be considered examples of the possible performances and tradeoffs
- Thanks to Bianchi and all the other authors for providing copy of the papers graphics and slides

EDCA or HCCA?

- How does EDCA support differentiation?
- Is this enough for standard purposes?
- Are parameters easy to tune and universal?

- How can HCCA polling-based sceduling be implemented?
- Do we need to use the feedback from the STA?
- How can the traffic be described?

Performance Evaluation of Differentiated Access Mechanisms Effectiveness in 802.11 Networks

G. Bianchi, I. Tinnirello, L. Scalia

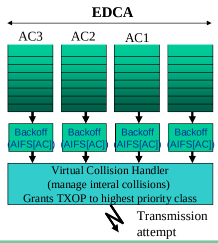
presented @ Globecom 2004

QoS Support issues in legacy 802.11

- DCF is long term fair
  - Equal channel access probability among the stations
  - Averagely, the same channel holding time (for homogeneous packet sizes)
    - Solution: differentiate packet sizes?
    - Solution: differentiate channel holding times?
- NO WAY! QoS is not a matter of how long I hold the channel
  - It means more…
    - Need to manage access delay problems for real-time apps!!!
    - Need to modify 802.11 channel access fairness!!!

QoS @ IEEE 802.11 MAC

- 802.11e defines different traffic classes onto map data flows
- Each traffic class behaves as an independent MAC entity
- Differentiated access priority is provided by:
  - Giving probabilistically lower backoff counters (**CWmin, CWmax**, **PF**)
  - Giving deterministically lower inter-frame spaces and backoff de-freezing times. (**AIFSN**)



Different MAC Access Parameters @ each class to differentiate channel access probability

Backoff based parameters: **CWmin, CWmax, PF**
Channel monitoring based parameters: **AIFS**

EDCA Performance Evaluation

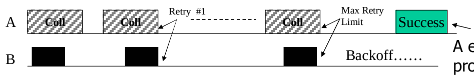
- Performance Evaluation: answers we try to give…
  - Homogeneous sources
    - Performance effectiveness of each differentiation MAC parameter, individually taken
    - How each differentiation parameter reacts to different load conditions?
  - Hetrogenous sources
    - What are the most effective settings to manage high-priority delay requirements?

EDCA Performance Evaluation

- Simulations
  - Same number of HP and LP stations
  - Same packet size (1024 bytes)
- Homogeneous sources scenario
  - Saturation conditions for HP and LP stations
    - Queues never empty
    - Data rate = Phy rate = 1 Mbps
- Heterogeneous sources scenario
  - 3 pkts/sec. for HP traffic
  - Saturation conditions for LP traffic
    - Data rate = Phy rate = 1 Mbps

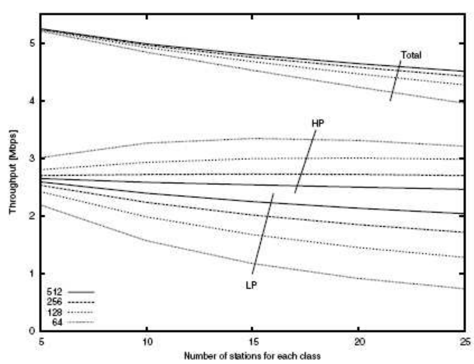
CWmax Differentiation (1)

- CWmax(A)<CWmax(B)
  - Once reached CWmax (repetead collisions), A gets access priority over B

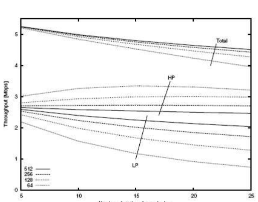


A extracts probablistically a lower backoff value due to its lower CWmax

CWmax Differentiation (2)



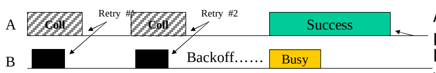
CWmax Differentiation (3)



- Low throughput differentiation
  - Only with CWmax=64 effective
  - @ low loads poor performance
    - Few collisions
- Inefficient channel usage
  - Consecutive Collisions are needed for the differentiation effect
  - Overall throughput suffers @ high loads

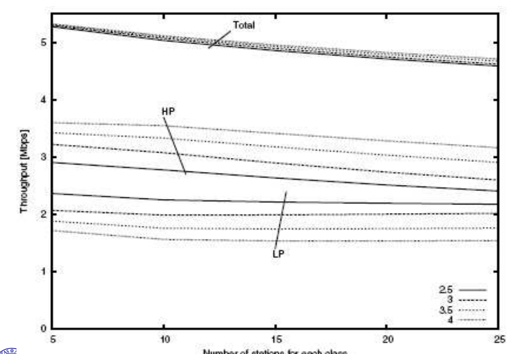
PF Differentiation (1)

- PF(A)<PF(B)
  - once a collision occurs, station A has probabilistically an higher chance to extract a lower backoff value, thus it may retransmits first.

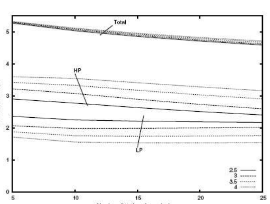


A extracts probablistically a lower backoff value due to its lower CW

PF Differentiation (2)



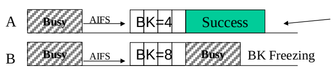
PF Differentiation (3)



- PF is greater than 2 for LP stations.
- CW_new = PF * CW_old
- It is sufficient a single collision to begin the differentiation process.
- Impossible to force LP traffic to zero!
  - After a packet successful transmission, the PF effect is no more present

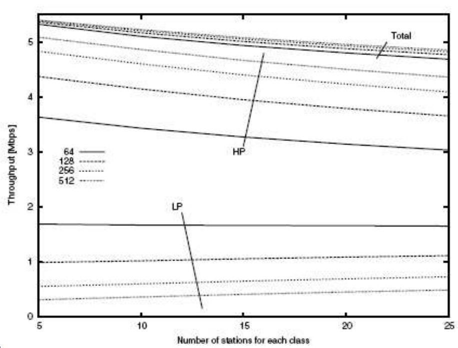
CWmin Differentiation (1)

- CWmin(A)<CWmin(B)
  - In average, station A has a lower backoff than B

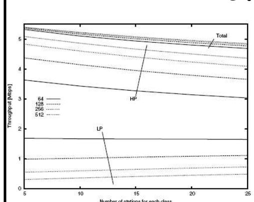


Thanks to its lower CWmin, A extracts probablistically a lower backoff value

CWmin Differentiation (2)



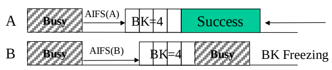
CWmin Differentiation (3)



- Very High differentiation performance
- @ low loads peformance is good
  - Collision effects among HPs not significant
- @ high loads collisions mainly involve HP stations (because of their small CW)
  - Degradations regard HP traffic -> bad!
  - LP traffic not affected
    - Collision effects un-altered

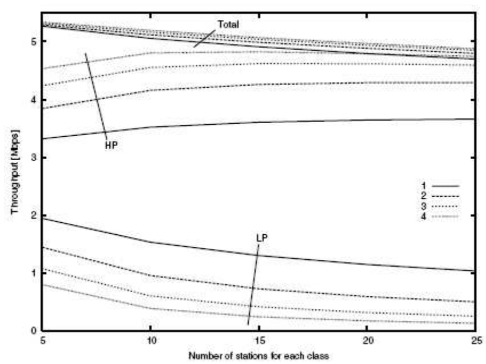
AIFS Differentiation (1)

- AIFS(A)<AIFS(B)
  - station A decrements its backoff timer before than station B

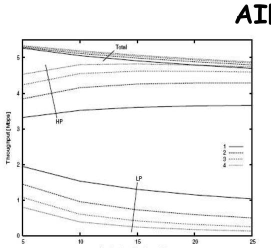


Thanks to its lower AIFS, A starts decrementing its backoff value before than B either after busy channel or idle channel conditions

AIFS Differentiation (2)



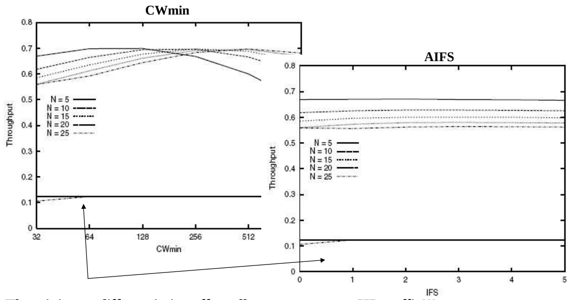
AIFS Differentiation (3)



- Very High differentiation performance
  - Complementary to CWmin case
- @ low loads differentiation performance suffers
  - Collision are few ->
- @ high loads collisions mainly involve LP stations, since HP stations access first
  - Degradations regard LP traffic -> good!
  - HP traffic not affected

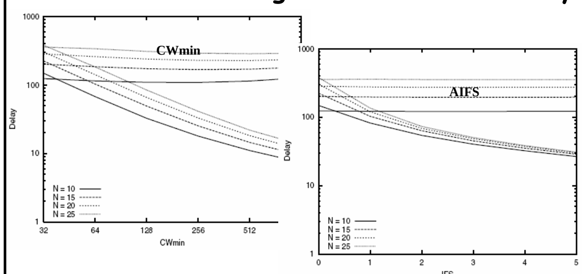
Heterogeneous Sources: Throughput

- Focus on AIFS and CWmin differentiation, seen to be most effective



The minimum differentiation effect allows to guarantee HP traffic!!!

Heterogeneous Sources: Delay



1) CWmin more effective to manage delay behaviour than AIFS (see slopes)

2) AIFS differentiation slightly sensitive to load in terms of delay

3) Joint use: delay requirements satisfied with AIFS, throughput managed via CWmin (because of the maxima)

Conclusions

- Cwmin and AIFS differentiation perform better than PF and CWmax differentiation
  - PF and CWmax differentiation operations allowed only by collisions
- CWmin and AIFS show a complementary behaviour
  - CWmin performance degrades @ high loads
  - AIFS performance degrades @ low loads
- Joint use of CWmin and AIFS
  - AIFS to meet delay requirements
  - CWmin to manage thoughput performance
- Complex parameter setting
- Behavior hardly predictable

Scheduling in 802.11e:
Open-Loop or Closed-Loop?

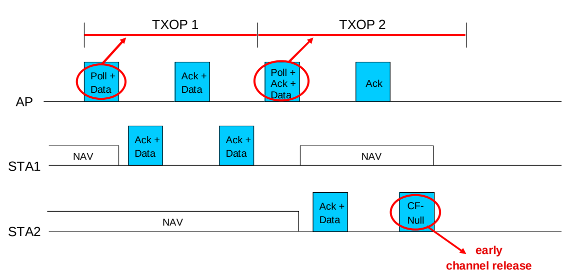
Paolo Larcheri
Renato Lo Cigno

Presented @ WONS 2006

Outline

- Scheduling: The Rules of The Game
- Sample (on the standard) Scheduler
- Equivalent Bandwidth Approach
- Closed Loop Scheduling: A Control Theoretic Approach

MAC 802.11e: HCCA



Resource Scheduling (1)

- Not essential to backward compatibility
  - The standard has just a reference impl. (SS)
- HCF is implemented in the AP
  - HCCA scheduling is a function of HCF
- Requirements of traffic flows are contained in the *Traffic Specifications* (TSPEC):
  - Maximum, minimum and mean datarate
  - Maximum and nominal size of the MSDUs
  - Maximum Service Interval and ***Delay Bound***
  - Inactivity Interval
  - …

Resource Scheduling (2)

- KEY notions are
  - Service Interval - SI(j): The maximum amount of time between successive polling to a station j
  - Transmission Opportunities - TXOP(j): The amount of resources (time) assigned to station j in a single polling
- Goals of scheduling:
  - Find suitable values of SIs and TXOPs
  - Fully exploit resources
  - Guarantee quality and differentiation of the TSPECs

Reference Implementation (SS)

Service Interval

$$m = \min_i (MaximumServiceInterval_i)$$

$$SI = \max(x) \text{ t.c. } x < m \text{ e } BI \bmod x = 0$$

TXOP

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

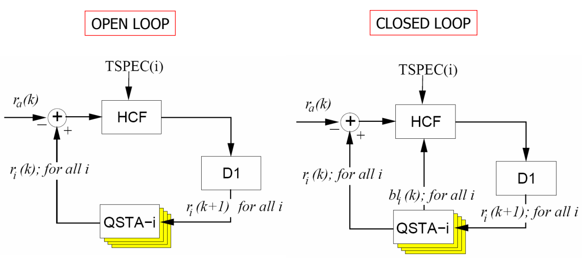
$$T_i = \max\left(\frac{N_i \times L_i}{R} + O, \ \frac{M_i}{R} + O \right)$$

ρ_i	Mean datarate
L_i	Nominal MSDU size
M_i	Maximum MSDU size
R	TX rate
O	Overhead (Ack, SIFS,…)

Feedback Information ... or not?

- SS Schedules is open-loop:
  - Uses only TSPEC info
  - Assigns the mean rate: not suited for VBR ...
  - ... but you can assign a rate based on an **Equivalent Bandwidth** approach
- 802.11e has a field to feedback information about backlog (bytes or frames in queue)
  - Use this info for prediction or
  - Use this info for **closed-loop control**?

Open/Closed Loop Scheduling



Equivalent Bandwidth

- Well known approach
  - Conceptually simple, just assign resources such that

$$P\left[\frac{\rho}{SI} > \frac{EB(p)}{SI}\right] = p$$

  - EB(p) is the assignment that guarantees p frame loss probability
  - ρ is the actual (time-depended) offered traffic
  - **But** ... requires full stochastic knowledge of the traffic ☹

Closed-loop Scheduling: Basics

- Discrete time modeling
  - Just throw away time (creates a lot of problems)
  - The system evolves in cycles of SIs: 1,2,3…,k
- Goal: equalize (to zero) all queues
- Max/Min fair approach
  - Only resources above the minimum guarantee are “controlled”
- Assumption: There is a CAC function ensuring long-term stability
  - Can use large loop gains without oscillation risks

Closed-loop Scheduling: Formulae

$$\frac{1}{K}\sum_{k=1}^{K} r_a(k) > \sum_{i=1}^{N_{QS}} \overline{r_i}$$

CAC based long term stability: the average available resources over a finite time K are larger than the average assigned resources

$$r_j(k) = r_j^{\min}(k) + r_j^{+}(k)$$

$$r_j^{+}(k+1) = \frac{B_j(k)}{\sum_{j=1}^{N_{TS}} B_j(k)}\left[r_a(k+1) - \sum_{j=1}^{N_{TS}} r_j^{\min}(k+1)\right]$$

Closed-loop Scheduling: Formulae

$$\frac{1}{K}\sum_{k=1}^{K} r_a(k) > \sum_{i=1}^{N_{QS}} \overline{r_i}$$

Max/Min Fairness
r

$r^{\min}$ are guaranteed and not subject to control
r^{+} is strictly non negative

$$r_j(k) = r_j^{\min}(k) + r_j^{+}(k)$$

$$r_j^{+}(k+1) = \frac{B_j(k)}{\sum_{j=1}^{N_{TS}} B_j(k)}\left[r_a(k+1) - \sum_{j=1}^{N_{TS}} r_j^{\min}(k+1)\right]$$

Closed-loop Scheduling: Formulae

$$\frac{1}{K}\sum_{k=1}^{K} r_a(k) > \sum_{i=1}^{N_{QS}} \bar{r}_i$$

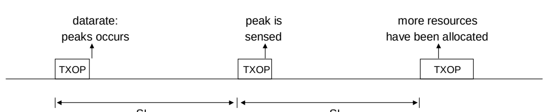
Simple proportional controller splitting excess resources among all the flows that are backlogged

$$r_j(k)=r_j^{\min}(k)+r_j^{+}(k)$$

$$r_j^{+}(k+1) = \frac{B_j(k)}{\sum_{j=1}^{N_{TS}} B_j(k)}\left[r_a(k+1) - \sum_{j=1}^{N_{TS}} r_j^{\min}(k+1)\right]$$

Details ... the real doom!

- Highly quantized resource assignment
  - A minimum assignment of one maximum size segment is mandatory ... what if the station transmits at low rate?
  - "Fragments" of frames might lead to waste resources
- Reaction of the controller can be slugghish



In the worst case the response time is about 2*SI

Closed-loop Schedulers

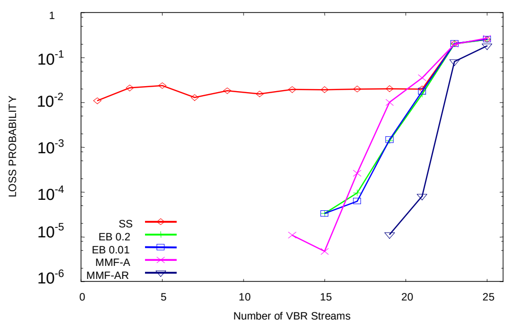
- MMF-A
  - Implements the formulae above
  - Have quantization and response problems
- MMF-AR
  - Dynamically changes the SI 'on-demand' ☺
  - Reassign spare resources at the end of the CFP
  - Violates proportional assignment to avoid quantization problems

Simulations

- Schedulers implemented in ns2
- ns2 adapted to drat 11.0 of 802.11e standard
- 2 and 3 state VBR sources implemented as MMDP processes
- EB(p) exact computation for the MMDP sources
- The package use for simulations is available at http://twelve.unitn.it/tools.html

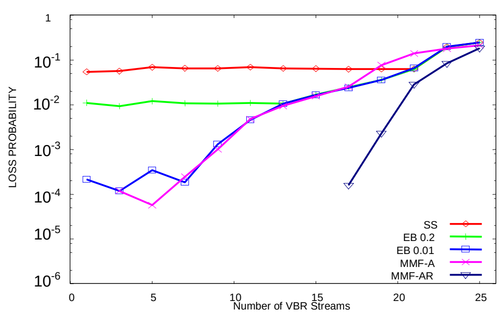
Results

Traffic VBR-3: both packet size and interarrival time change
Delay Bound = ∞ Buffer Size = 50 pck Service Interval = 50 *ms*



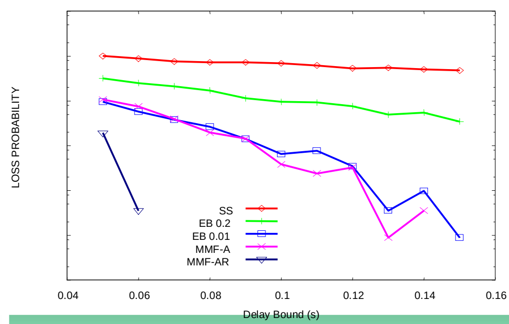
Results

Traffic VBR-3: both packet size and interarrival time change
Delay Bound = 100ms Buffer Size = 50 pck Service Interval = 50 *ms*



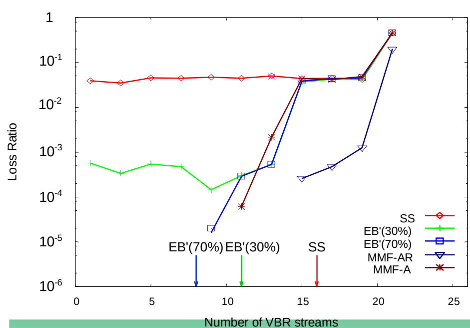
Results

Sorgenti VBR-3: both packet size and interarrival time change
Buff. = 50pck #stream = 8 Service Interval = 50 *ms*



Results

Real Video Traces: h.263 codec → **EB???**
Delay bound = 150ms Service Interval = 100 *ms*



Conclusions

- Different HCCA scheduling explored
- HCCA complexity is manageable, performances are better than EDCA, configuration is easier
- Closed-loop scheduling:
  - Viable alternative to open-loop or predictive scheduling
  - Complexity much simpler and effective than Equivalent Bandwidth approaches
- The BIG problem are details
  - Quantization, Normalization, Spare Resource Collection, ...