Supporting QoS in IEEE 802.11e Wireless LANs

IEEE TRANSACTIONS ON WIRELESS COMMUNICATIONS, 2006

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24 January 2007

Outline

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Introduction

- Channel Access methods in IEEE 802.11e:
  - Hybrid Coordination Function (HCF)
    - Enhanced Distributed Channel Access (EDCA)
      - Contention-based
    - HCF controlled channel access (HCCA)
      - Polling-bsed
- The EDCA cannot guarantee strict QoS required by real-time services without proper network control mechanisms.

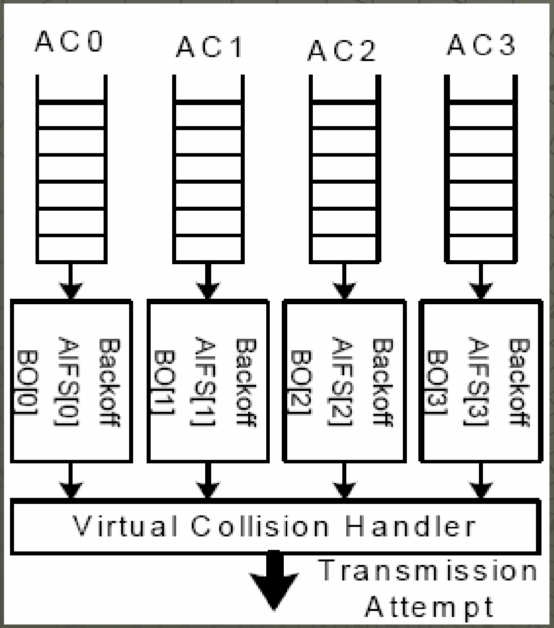
Introduction (Cont.)

- To overcome this deficiency, the author proposes
  - *Aalytical model*
    - to derive an average delay estimate for the traffic of different priorities in the unsaturated 802.11e WLAN
  - *Two call admission control schemes*
  - *A rate control scheme*
    - relies on the average delay estimates and the channel busyness ratio

Introduction (Cont.)

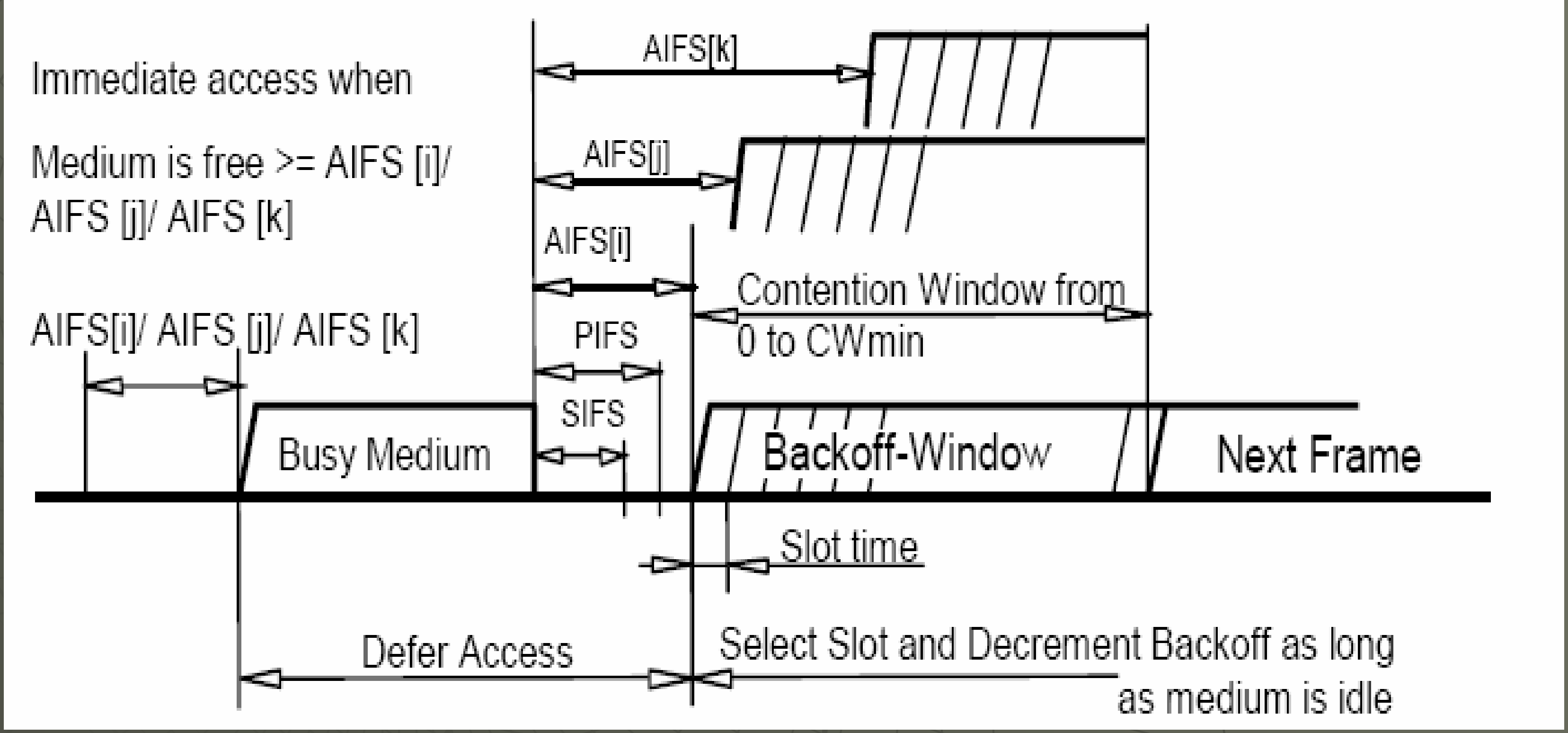
- Key idea:
  - When accepting a new real-time flow, the admission control algorithm considers its effect on the channel utilization and the delay experienced by existing real-time flows.
  - At the same time, the rate control algorithm allows the best effort traffic to fully use the residual bandwidth left by the real-time traffic, thereby achieving high channel utilization.

EDCA



AC	CWmin	CWmax	AIFSN
AC_BK	aCWmin	aCWmax	7
AC_BE	aCWmin	aCWmax	3
AC_VI	(aCWmin+1)/2 – 1	aCWmin	2
AC_VO	(aCWmin+1)/4 – 1	(aCWmin+1)/2 – 1	2

EDCA (Cont.)


Immediate access when
Medium is free >= AIFS [i]/
AIFS [j]/ AIFS [k]
AIFS[i]/ AIFS [j]/ AIFS [k]
AIFS[k]
AIFS[j]
AIFS[i]
PIFS
SIFS
Contention Window from
0 to CWmin
Busy Medium
Backoff-Window
Next Frame
Slot time
Defer Access
Select Slot and Decrement Backoff as long
as medium is idle

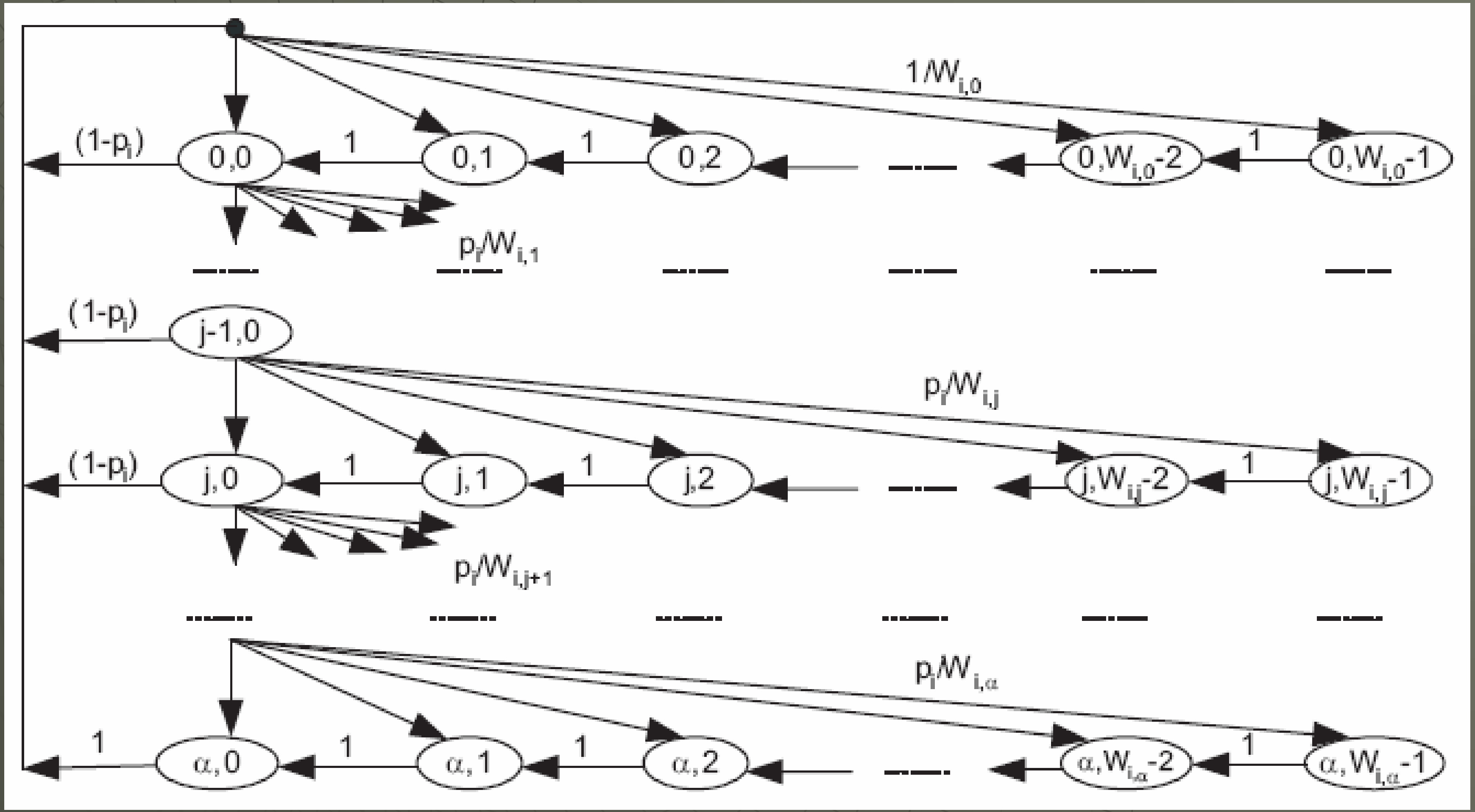
Markov Chain Model for the IEEE 802.11e

- Define Wi,0 = CWi,min.
- At different backoff stage j $\in$ (0, α), where α is the maximum number of retransmissions, the contention window size

$$W_{i,j} = \begin{cases} 2^j W_{i,0} & if\ 0 \leqslant j \leqslant m \\ 2^m W_{i,0} & if\ m < j \leqslant \alpha. \end{cases}$$

- Let pi denote the probability of collision seen by a transmitted packet from queue i.
- We define b(i, t) as a stochastic process representing the value of the backoff counter at time t, and s(i, t) as a stochastic process representing the backoff stage j, where $0 \leq j \leq \alpha$.

Markov chain for the 802.11e backoff procedure



Markov Chain Model for the IEEE 802.11e (Cont.)

- The probability that a node of priority i transmits in a random slot, given that the queue is not empty:

$$\tau_i = \sum_{j=0}^{\alpha} b_{j,0} = \begin{cases} \dfrac{2(1-2p_i)(1-p_i^{\alpha+1})}{W_{i,0}(1-(2p_i)^{\alpha+1})(1-p_i)+(1-2p_i)(1-p_i^{\alpha+1})} & \alpha \leqslant m \\ \dfrac{2(1-2p_i)(1-p_i^{\alpha+1})}{W_{i,0}(1-(2p_i)^{m+1})(1-p_i)+(1-2p_i)(1-p_i^{\alpha+1})+W_{i,0}2^m p_i^{m+1}(1-2p_i)(1-p_i^{\alpha-m})} & \alpha > m \end{cases}$$

- The probability of collision seen by a transmitted packet from queue i:

$$p_i = 1 - \prod_{l=0}^{i-1}(1-(1-P_{l,0})\tau_l)^{n_l}(1-(1-P_{i,0})\tau_i)^{n_i-1}\prod_{l=i+1}^{3}(1-(1-P_{l,0})\tau_l)^{n_l}$$

G/G/1 Queue Model to Estimate Mean Delay

- We model a priority i queue as a G/G/1 system.
- An upper bound for the average waiting time in the queue:

$$W_i \leqslant \frac{\lambda(\sigma_{A_i}^2 + \sigma_{B_i}^2)}{2(1-\rho_i)}$$

ρ_{i} - traffic intensity

σ_{Ai}^2 - variances of the interarrival time

σ_{Bi}^2 - variances of service time

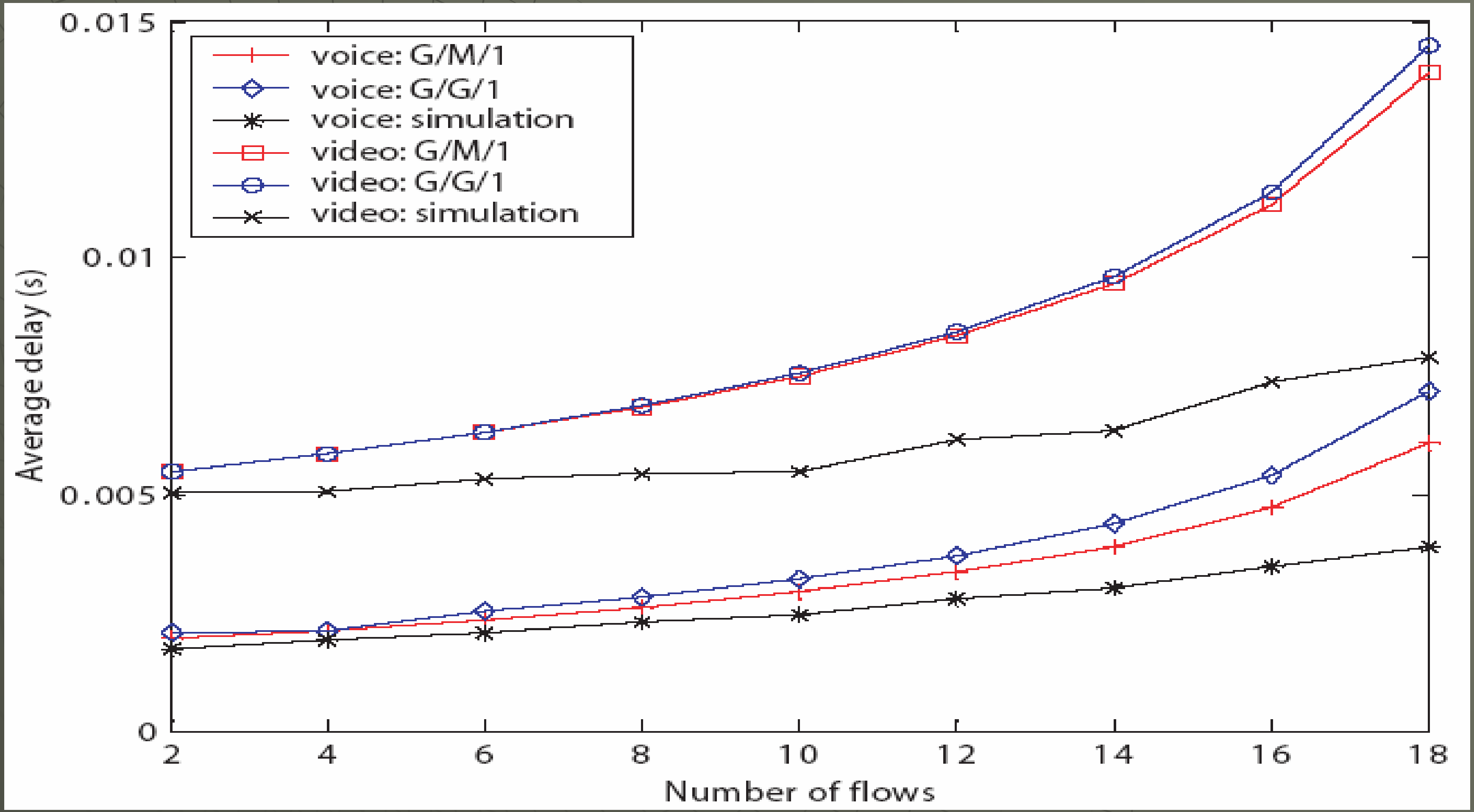
- Average packet delay = average waiting time + average MAC service time

$$T_i = \frac{\lambda_i(\rho_i^2\sigma_{A_i}^2 + \sigma_{B_i}^2)}{2(1-\rho_i)} + 1/\mu_i$$

Model Validation – Simulation Setting

- 100 mobile nodes
- Channel rate: 2 Mb/s
- Voice Traffic (VBR)
  - On/off source with exponentially distributed on and off periods of 300 ms average each
  - Packet generating rate: 32 kb/s
  - Packet size: 160 bytes
  - Inter-packet time: 40 ms
- Video Traffic (CBR)
  - Packet generating rate: 64 kb/s
  - Packet size: 1000 bytes
- AIFS[2] = 60 μ s, AIFS[3] = 50 μ s, $W_{2,0}$ = 32, and $W_{3,0}$ = 16

Model Validation



Average Delay Model

- As specified in [1] [2], when we keep the network working in the unsaturated case, the delays for both traffic classes are sufficiently small to satisfy their QoS requirements
  - Unsaturated case
    - Not all the nodes are contending for the channel at the same time.
    - Low collision probability
  - One way transmission delay for VoIP
    - 150ms, and must be less than 400ms

Call Admission & Rate Control

Traffic Type	Delay Requirement	Bandwidth Usage	Traffic Control Mechanism
Real-time	strict	not greedy	Call admission control (CAC)
Non-real-time	tolerable	greedy	Rate control (RC)

Channel Utilization

- Denoted by *cu*
- Defined as the portion of the time that the channel is used for successful transmissions in an observation period

Call Admission Control I

- Three parameters are used to characterize the bandwidth requirement of a real-time flow
  - *Rmean:* average data rate
  - *Rpeak:* peak data rate (bit/s)
  - *PKl:* average packet length (bits)
- A successful transmission time, denoted by *Tsuc*, is obtained by
  - *Tsuc = RTS + CTS + DATA + ACK +3SIFS + AIFS, where DATA is the average packet transmission time for the packet of length PKl*

Call Admission Control I (Cont.)

- The channel utilization *cu* corresponding to a flow's bandwidth requirement as follows:

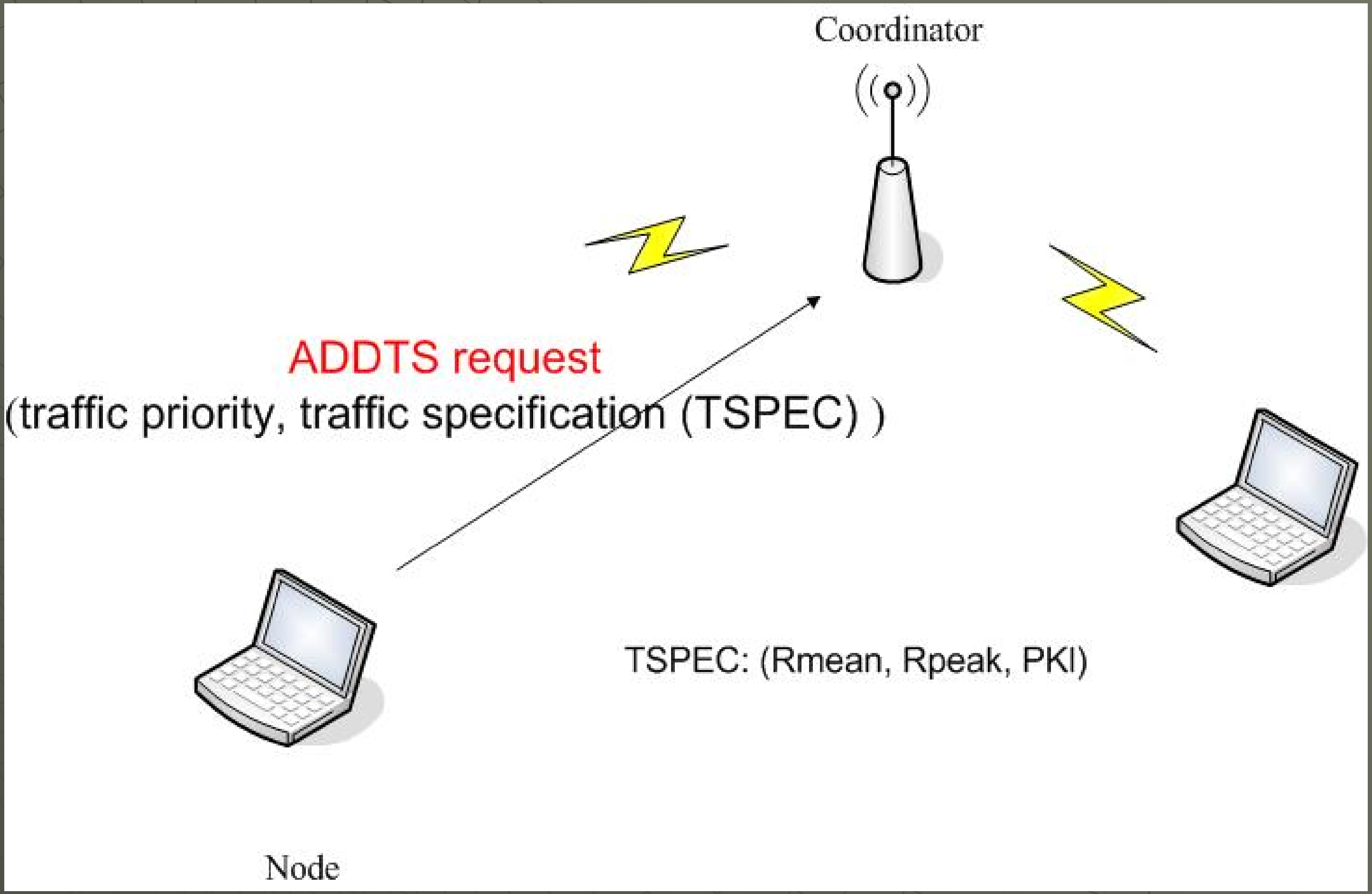
$$cu = \mathcal{U}(R) = \frac{R}{PK_l} \times T_{suc}$$

  where U is the mapping function from the traffic rate to the channel utilization
- Thus, a flow's bandwidth requirement can be translated into *(cumean, cupeak)*, where cumean = U(Rmean) and cupeak = U(Rpeak).

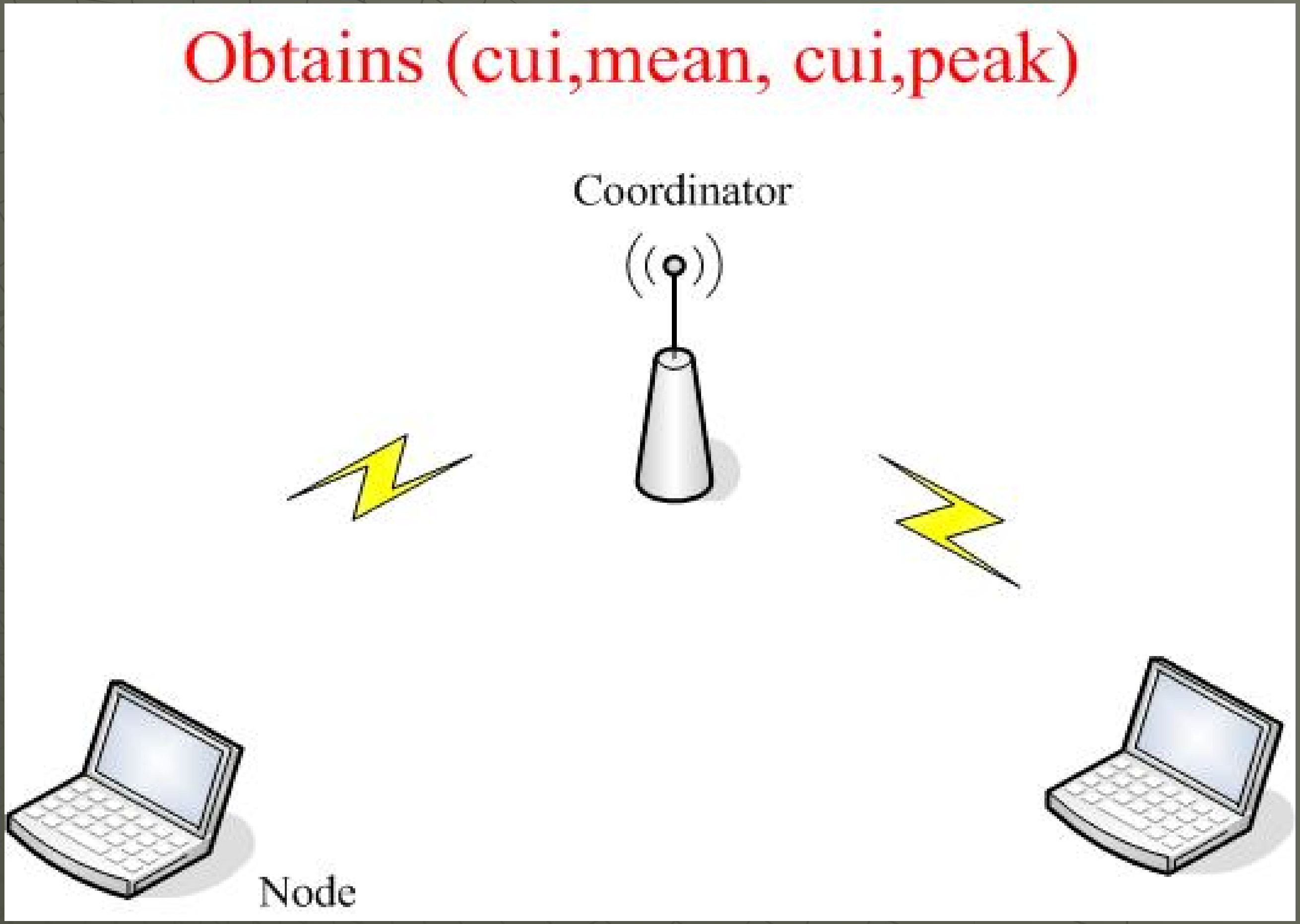
Call Admission Control I (Cont.)

- The coordinator records the total channel utilization due to all admitted real-time flows into two parameters (cuA,mean, cuA,peak), i.e., the aggregate (cumean, cupeak).
- Meanwhile, the coordinator maintains the number of flows belong to AC i, denoted by *ni*.

Call Admission Control I (Cont.)



Call Admission Control I (Cont.)



Call Admission Control I (Cont.)

- Then, it determines if the flow can be admitted using the following tests:
  - First,

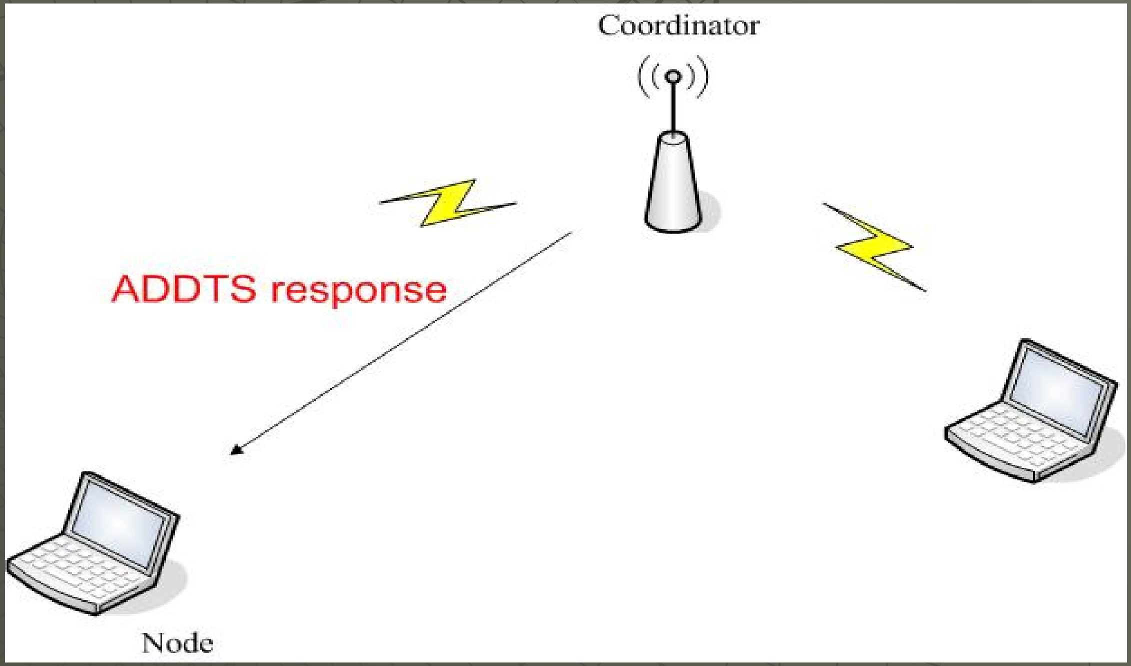
$$\left\{ \begin{array}{l} \text{cuA,mean} + \text{cui,mean} \; ?= \; \text{CUrt} \\ \text{cuA,peak} + \text{cui,peak} \; ?= \; \text{CUmax} \end{array} \right.$$

  - Second, estimate the average delay using the G/G/1 model.

$$\overline{D_i} \leqslant D_i \quad i = 2, 3$$

Call Admission Control I (Cont.)

- If both of the above conditions are satisfied, the new flow is admitted, otherwise it is rejected.



Remark

- When making admission decisions, CAC scheme I takes into account both the peak rate and mean rate for the real-time traffic.
- While this ensures that the network will not be congested in the worst-case scenario, in which all the VBR real-time traffic transmits at its peak rate.
- Problem
  - When many real-time flows with the ratio Rpeak/Rmean is large are admitted, channel utilization will be low.

Call Admission Control II

- The coordinator grants admission if the following test is passed:

$$cu_{A,mean} + cu_{i,mean} < CU_{rt}$$

Remark on Call Admission Control

- It can be seen that there exists a tradeoff between strict QoS guarantee and the number of real-time flows that can be accepted.
- A better balance is to obtain the knowledge about the rate-changing pattern of VBR flows.
  - It is very hard.

Channel Busyness Ratio

- Denoted by *rb* $\in$ [0, 1]
- Defined as the portion of the time that the channel is busy in an observation period
- cu $\leq$ rb

Rate Control

- Each node needs to monitor the channel busyness ratio rb during a period of Trb.
- The node thus adjusts Rbe after each Trb according to the following:

$$R_{be_{new}} = R_{be_{old}} \times \frac{CU_{max} - r_{br}}{r_b - r_{br}}$$

  - *Rbe:* the data rate of the best effort traffic
  - *rbr:* real-time rb
- The node increases the rate of the best effort traffic if rb < CUmax and decreases the rate otherwise.

Rate Control (Cont.)

- To estimation of *rbr*, each mobile node needs to decode the MAC header part.
  - The observed channel busyness ratio *rb* comprises
    - *rb*1:from the best effort traffic with a decodable MAC header
    - *rb*2:from the real-time traffic with a decodable MAC header
    - *rb*3:all the traffic with an undecodable MAC header due to collision

Rate Control (Cont.)

- Give an upper bound and a lower bound for *rbr* as follows:

$$r_{b2} \leqslant r_{br} \leqslant r_{b2} + r_{b3}$$

- To enforce a conservatively increasing and aggressively decreasing law, we thus set rbr as follows:

$$r_{br} = \begin{cases} r_{b2}, & if\ r_b < CU_{max} \\ r_{b2} + r_{b3}, & if\ r_b > CU_{max} \end{cases}$$

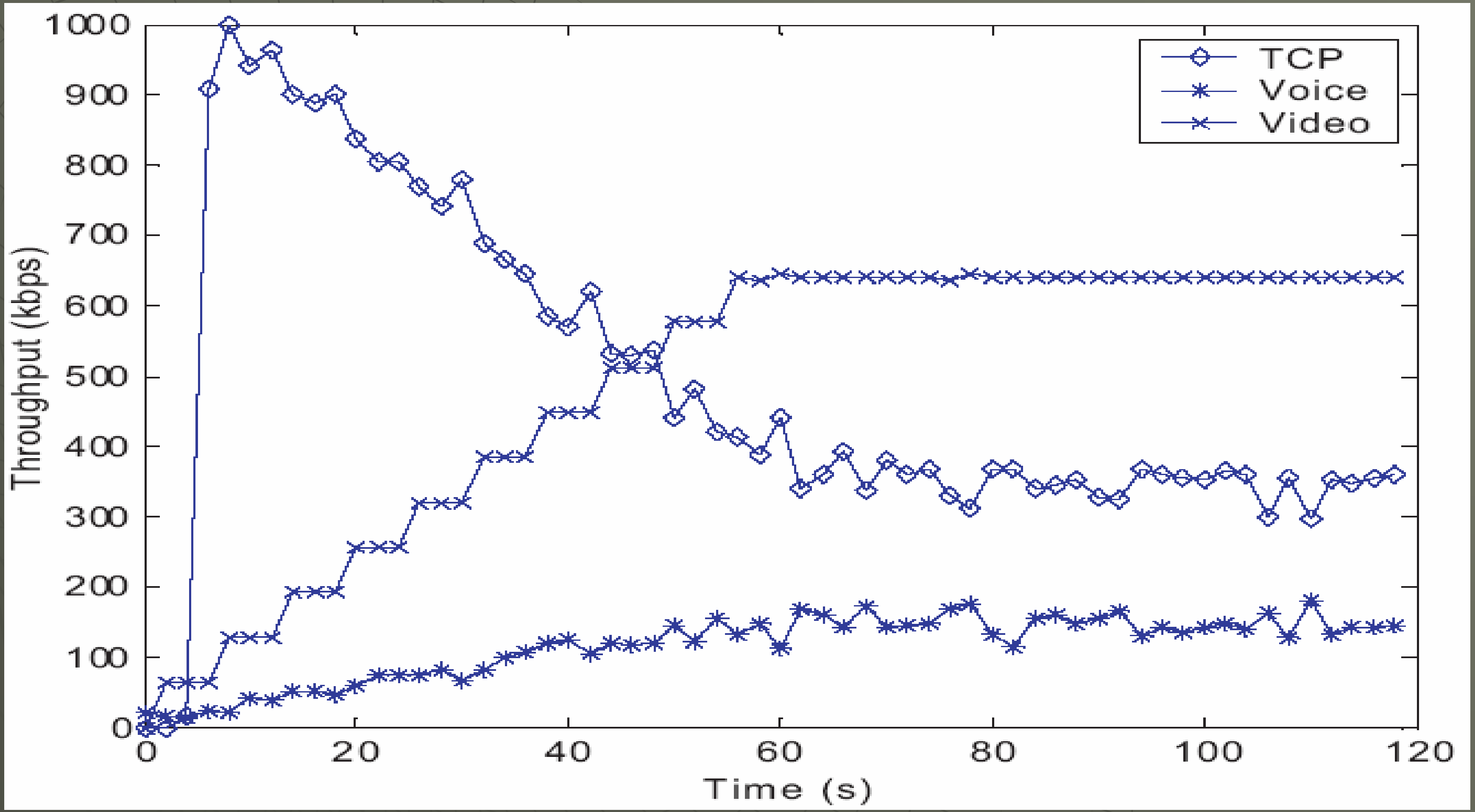
Simulation

- 100 mobile nodes
- Channel rate: 2 Mb/s
- CUmax = 0.93
- CUrt =

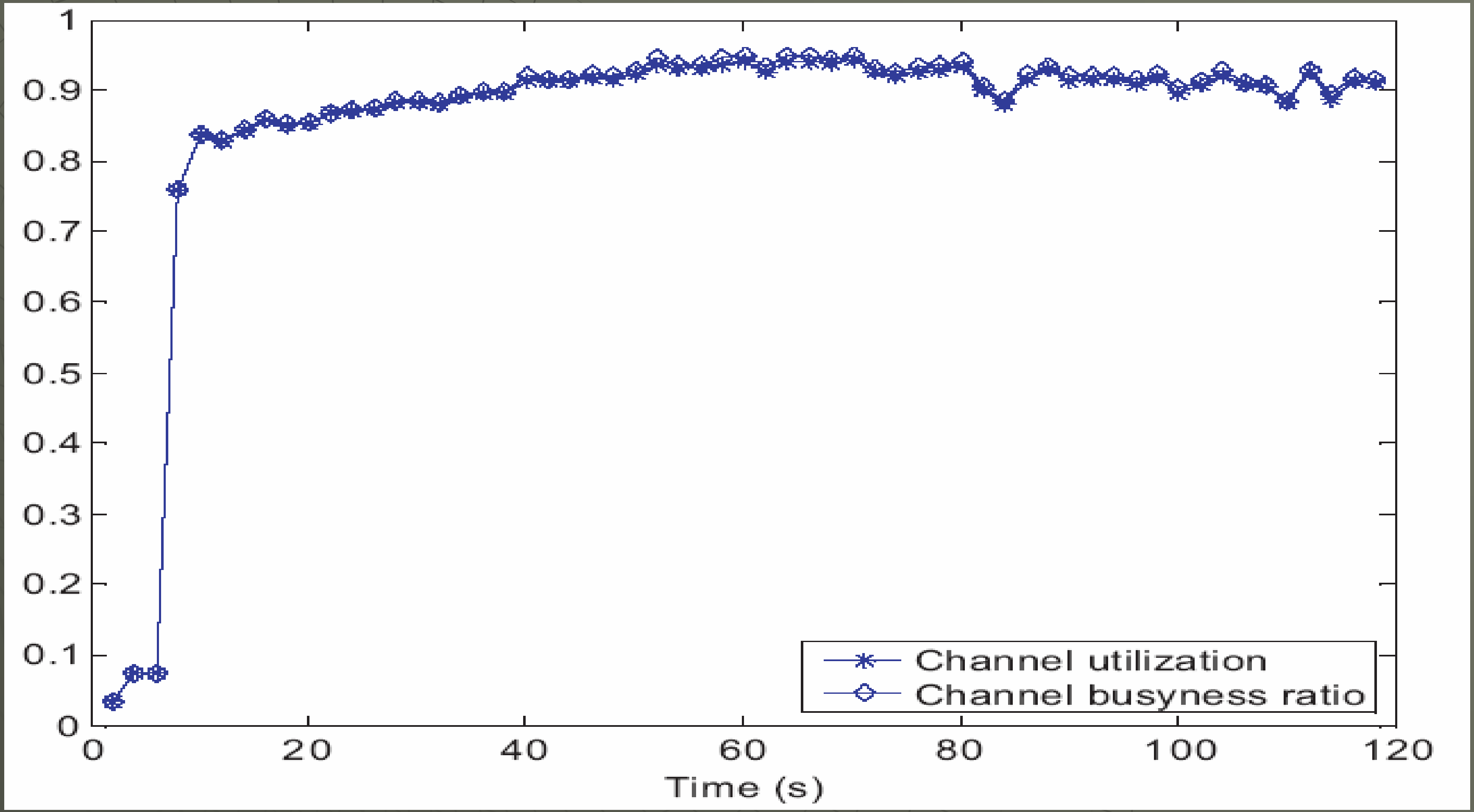
  CUmax ∗ 80% = 0.744
- Trb = 2s
- D2 = 200ms, D3 = 100ms

Traffic Type	Voice	Video	TCP
AC i	3	2	0
AIFS (us)	50	60	80
Wi,0	16	32	128

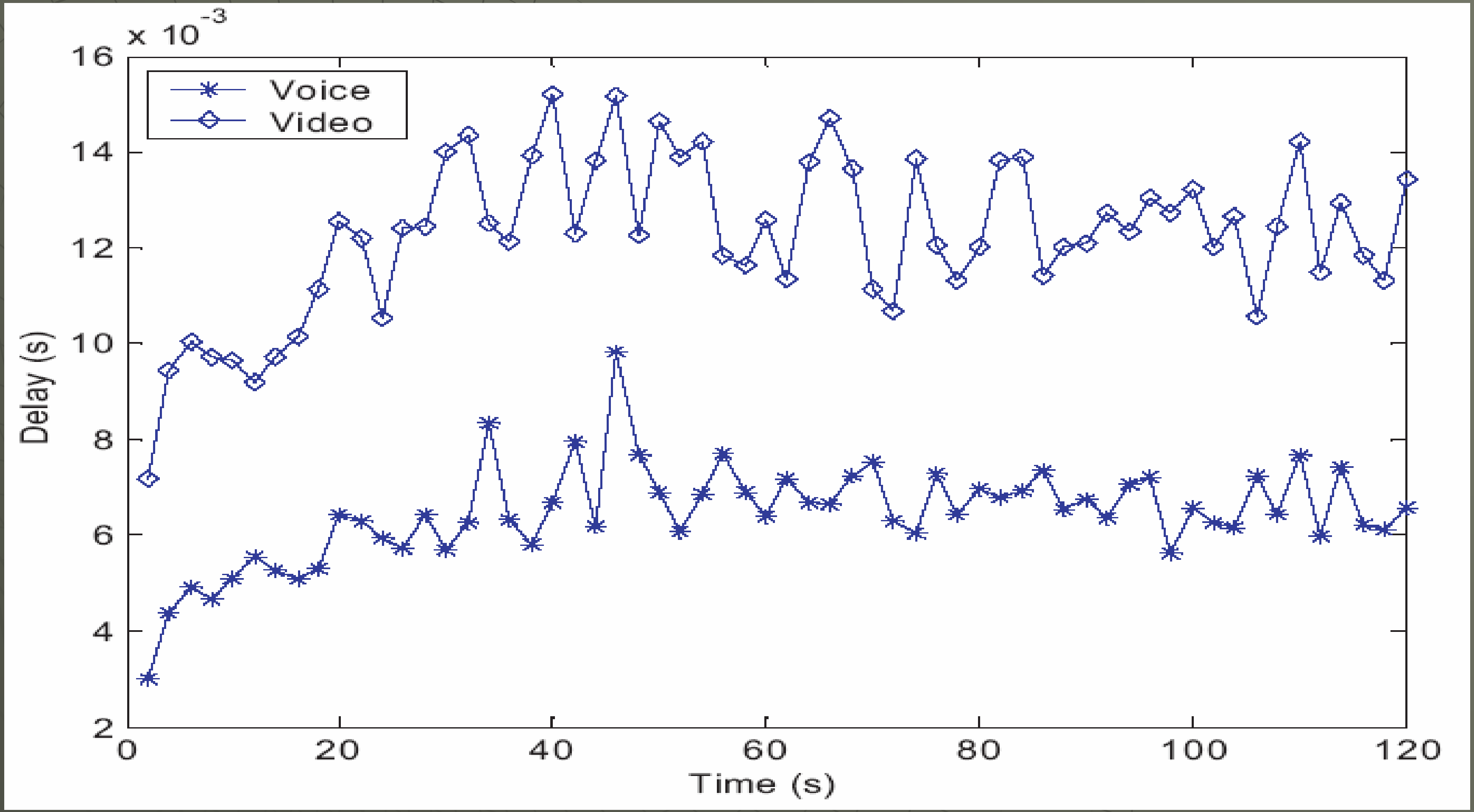
Aggregate Throughput



Channel busyness ratio & Channel utilization



Average Delay



Conclusion

- In this paper, we enhance the 802.11e by proposing two call admission schemes and a rate control scheme.

- Finally, the simulation results show that the proposed schemes successfully guarantee stringent QoS requirements of real-time services, while achieving high channel utilization.

References

- [1] ITU-T G.114. One-way transmission time, 1996.
- [2] ITU-T G.1010. End-user multimedia QoS categories, 2001.