IEEE 802.11e : EDCA

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Mobile Communication Networks
What is the WLAN cell performance with bidirectional TCP traffic?
DCF (Distributed Coordination Function)

- Without the RTS/CTS handshake.

- The BO time (backoff) is slotted in “empty slots” of duration $\sigma$ [seconds]
Exercise 1

- Markov Chain (K=4)

- Traffic load: $A = 4.5 \times 0.2 = 0.9$ Erlangs
- Balance Equations:

  - Steady-state probabilities:
    - $p(0)=2.4419e-01$  $p(1)=2.1977e-01$  $p(2)=1.9780e-01$  $p(3)=1.7802e-01$  $p(4)=1.6022e-01$
  - $EQ = 1.79$ frames
Exercise 1

\[ A = 1, \quad B = \frac{1}{K+1} \]
Exercise 1

![Graph showing the relationship between delay and arrival rate in mobile communications networks. The x-axis represents the arrival rate (frames/second) ranging from 0 to 8, and the y-axis represents delay ranging from 0.2 to 0.65. The graph illustrates an increasing trend as the arrival rate increases.]
Exercise 2

- Assumptions: Poisson arrivals / Exponentially distributed service times.
- Real case:

Statistical characterization of the service time in saturated IEEE 802.11 networks
Zanella, A. De Pellegrini, F.
Communications Letters, IEEE
Publication Date: March 2005
Exercise 3 (a)
Exercise 3 ($\rho=1$)
Exercise 3 ($\rho=1$)
Exercise 3 ($\rho=0.4$)
Exercise 3 ($\rho=0.4$)
Exercise 4 & 5

4) Difficult to answer (non-linear).
   - \( n \uparrow \): p, N, X, alfa, rho, tau, p, N, ...
   - \( B \uparrow \): rho, tau, p, N, X, alfa, rho, ...

\[ p = 1 - (1 - \tau)^n, \tau = f(B) \]
- Impact of \( n \uparrow \) > \( \tau \uparrow \)
- In terms of performance, it is better to have few nodes.

5) For example, a fixed-point approach.
   - Others?
EDCA
VoIP over WLANs

- **Voice over IP**
  - *Economical* alternative to traditional telephony.

- **Wireless LANs**
  - *Broadband* access network to internet.

- **VoIP over WLANs.**
  - A market opportunity.
    - Complement/Substitute of current cellular networks.
  - Technical limitations.

August 2003

178,000 new Skype users *per day*!

Projected Worldwide PWLAN Locations

VoIP over WLANs

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  - Economical alternative to traditional telephony.

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VoIP over WLANs

• Limitations for VoIPoWLAN (and other real-time services)
  – Protocol overheads.
  – Capacity-varying channels (multi-rate).
  – Random Access MAC.
    • Bandwidth penalty due to the distributed access.
  – Unfairness Downlink/Uplink.
    • Difficult coexistence between heterogeneous (rigid and elastic) flows.
  – Hand-off / Roaming between WLANs.
VoIP over WLANs

Example: \( R_{data} = 2 \text{ Mbps}, R_{basic} = 1 \text{ Mbps}, \) VoIP codec: G.729 (8 Kbps)

- Downlink/Uplink TCP flows \( \uparrow \rightarrow \) simultaneous VoIP calls \( \downarrow \)

IEEE Solution: *EDCA (Enhanced Distributed Access)*

- Traffic differentiation at MAC layer + CAC optional.

- **EDCA is too conservative.**
- Static Traffic Differentiation without Admission Control.
Multimedia Traffic Flows

• General Classification (*queue occupation*).
  – Elastic flows (TCP-based):
    • use all available bandwidth, fair with other elastic flows.
    • saturated source/queue with: \( B \approx \frac{L}{X}, \rho = 1 \)
  – Streaming/Rigid flows (UDP-based):
    • use only the bandwidth required.
    • finite-load (un-saturated) source/queue with: \( B \approx \rho \frac{L}{X}, \rho \leq 1 \)

Rigid Traffic (UDP)

User Perception

- Good
- Bad

Minimum Bandwidth

B

Multimedia

Elastic Traffic (TCP)

User Perception

- Better
- Worst

B

- Video/audio streaming
- Voice over IP
- Web (HTTP)
- FTP, e-mail, ...
The DCF/EDCA model
The scenario

MN and AP share the channel using a random access MAC protocol.
IEEE 802.11 MAC Model (DCF)

• Each node is modelled by a M/M/1/K queue with packet arrival rate $\lambda_k$ ($\alpha = \lambda$) and service time $X$.
  
  – Assumption: Poisson arrivals and service time exponentially distributed.
  
  – The model accounts for: queuing delays, packet losses.

\[ P_{b,i} = \frac{A_i^{K_i}}{\sum_{j=0}^{K_i} A_i^j} \quad EQ_i = \frac{\sum_{j=0}^{K_i} jA_i^j}{\sum_{j=0}^{K_i} A_i^j} \quad ED_i = \frac{EQ_i}{\alpha_i(1 - P_{b,i})} \]
IEEE 802.11 MAC Model (DCF)

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  - Assumption: Poisson arrivals and service time exponentially distributed.
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$$X_i = (M_i - 1) \left( E B_i \gamma_i + E T_{c,i}^{ba} \right) + E B_i \gamma_i + T_{s,i}$$

<table>
<thead>
<tr>
<th>MN1</th>
<th>MN2</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Diagram" /></td>
<td><img src="image" alt="Diagram" /></td>
</tr>
</tbody>
</table>

- Packet arrival (HOL)
- Packet arrival (queued)
- Packet departure
- Packet departure
- Queue empty
- Backoff suspension

**MN1:**
- BO
- DATA
- ACK
- BUSY
- COLLISION

**MN2:**
- BO
- DATA
- ACK
- BUSY
- COLLISION

**EQ:** Queueing delay

**Time:** $t$
DCF → EDCA

- Packet arrival (HOL)
- Packet arrival (queued)
- Packet departure
- Packet departure

Variables:
- $1/\lambda_1$, $X_1$, $X_2$
- Queue empty
- Empty slot
- Backoff suspension (coll.)
- Backoff suspension (succ.)

Key Events:
- $E_{Q_1}$, Queueing delay
- Data transmission
- Acknowledgment

MN1, MN2, MN3

- AIFS
- BEB
- TXOP

Mobile Communications Networks
IEEE 802.11e MAC Model (EDCA) : TXOP

- Multiple packet transmission each time a MN/AP gets the channel
  - The overall network throughput increases ($S = \text{Data/Time [bps]}$)
  - Less wasted time in random access.

$$X^b_i = (M_i - 1) \left( \zeta_i \gamma_i + E(T_{c,i}^{ba}) \| rts \right) + \zeta_i \gamma_i + E(T_{s,i}^{b_i,ba} \| rts)$$
IEEE 802.11e MAC Model (EDCA) : TXOP

- Each user is modeled as an M/G\text{[\[i,B\]}{1} queue (bulk service time queue)
  - TXOP (Burst length): maximum consecutive number of frames transmitted at each successful attempt.

- Departure distribution.
- Average TXOP length
- Average TXOP duration

\[ A_{i,B} = \int_{t=0}^{\infty} f_0(h,t)f_0(B,t)dt = \int_{t=0}^{\infty} \frac{(\alpha t)^h}{h!} e^{-\alpha t} \beta^B e^{-\beta t} dt \]

- Stationary (equil.) distribution.
- Blocking Probability.
- Queue occupation.
- Queuing delay.
IEEE 802.11e MAC Model (EDCA): AIFS

- **AIFS**

\[ X_i^b = (M_i - 1) \left( \zeta_i \gamma_i + ET_{c,i}^{b_i,a||r_i} \right) + \zeta_i \gamma_i + ET_{s,i,b_i,a||r_i} \]

\[ \tau_i = \lim_{t \to \infty} Pr(Q_i(t) > 0) \]

Extra blocked slots due to AIFS

Aggregate load from other nodes

Service Time \(\uparrow\)

Transmission Prob. \(\downarrow\)
IEEE 802.11e MAC Model (EDCA): $EB, p$

- Expected BackOFF slots
  \[ EB_i = \frac{1 - p_i - p_i(2p_i)^m_i}{1 - 2p_i} \frac{CW_{min,i}}{2} - \frac{1}{2} \]

- Cond. Collision Probability
  \[ p_i = 1 - \prod_{j \neq i} (1 - \tau_j) \]

- Prioritizing a flow:
  - $TXOP \uparrow$
  - $AIFS \downarrow$
  - $CW\text{min} \downarrow$

- This model is able to capture the impact of the other flows with different MAC parameters.
Wireless Scenario

- No hidden-terminals and ideal channel-conditions.
- Channel access based on the DCF (BA and RTS/CTS).
- Two types of flows: **streaming** (UPD-like) and **elastic** (TCP-like).
Results

- Single-cell WLAN (ad-hoc)
  - Two types of flows:
    - S1 (streaming ~ unsaturated)
      - $B_s = 100$ Kbps
      - $L = 400$ bytes
    - E1 (elastic ~ saturated)
      - $B_e$ (network dependant)
      - $L = 1500$ bytes

- Default WLAN MAC parameters
  - 0 S1 flows.

- Solution (1):
  - AIFS ↑ (elastic flows, A=3)
    - 8 S1 flows
    - The TCP throughput is reduced.
Model Validation

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      - $L = 400$ bytes
    - E1 (elastic ~ saturated)
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      - $L = 1500$ bytes

- Solution (2):
  - TXOP S1 $\uparrow$ (=4)
    - 7 S1 flows.
  - CWmin,E1 $\uparrow$ (=64)
    - 6 S1 flows.
Call Admission Control
Problem statement: Providing QoS

- Flow-level Admission Control.
- Adaptive selection of MAC parameters.
Problem statement: Providing QoS

- Flow-level Admission Control.
- Adaptive selection of MAC parameters.

random access MAC
(Performance) = f(MAC parameters, number of nodes, traffic profile each node)

non-linear relation

QoS constraints

Service Requests → Admission Control → Positive Response
- Negative Response
  - Suggest new specs.
  - Block the new request.
  - Drop existent flows.

Set new operation parameters

Input Traffic → System → Output Traffic

maximize performance (under the QoS)
The available bandwidth estimation problem

... how to decide if a flow can be admitted? We have to compute or to test if the new flow is possible.

\[ B_a - B_r \geq 0 \]

... the bandwidth penalty due to the distributed access depends on the number of flows active and the traffic profile of each flow.

\[ B_a - (B_r + B_o) \geq 0 \]
Multi-rate Problems on VoIP capacity
Transmission Rates

- **PHY Rate:**
  - The PHY Preamble and Header are transmitted at this rate (lowest)

- **Basic Rate:** Maximum rate common to all STAs
  - Control frames are transmitted at BASIC rate.
  - MAC Headers are transmitted at BASIC rate.

- **Multiple Data Rates:** Rate at which data is transmitted
  - Based on the channel conditions of the STA / AP.
    - Good: Higher rates (less redundancy bits, higher modulations)
    - Bad: Lower rates (more redundancy bits, lower modulations)
Multi-rate transmission (Multiple data rates)

- Direct relationship between communication rate and the channel quality required for that rate
- As distance increases, channel quality decreases
- Therefore: tradeoff between communication range and link speed
- Multi-rate provides flexibility to meet both consumer demands
  - Coverage
  - Speed (high data rates)
Efficiency

Rate (Mbps) vs. Medium Time (milliseconds)

- 11.0 Mbps
- 5.5 Mbps
- 2.0 Mbps
- 1.0 Mbps

- MAC Overhead
- Data
Auto Rate Protocols

- Selects the rate to use for a packet
- ARF
  - Adaptive based on success/failure of previous packets
  - Simple to implement
  - Doesn’t require the use of RTS CTS or changes to 802.11 spec
- Receiver Based Auto Rate (RBAR)
  - Uses SNR measurement of RTS to select rate
  - Faster & more accurate in changing channel
  - Requires some tweaks to the header fields
- Opportunistic Auto Rate (OAR)
  - Adds packet bursting to RBAR
  - Allows nodes to send more when channel conditions are good
  - Implements temporal fairness instead of packet fairness
# IEEE 802.11a Rates

<table>
<thead>
<tr>
<th>Data rate (Mbits/s)</th>
<th>Modulation</th>
<th>Coding rate (R)</th>
<th>Coded bits per subcarrier ($N_{BPSC}$)</th>
<th>Coded bits per OFDM symbol ($N_{CBPS}$)</th>
<th>Data bits per OFDM symbol ($N_{DBPS}$)</th>
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</thead>
<tbody>
<tr>
<td>6</td>
<td>BPSK</td>
<td>1/2</td>
<td>1</td>
<td>48</td>
<td>24</td>
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<tr>
<td>9</td>
<td>BPSK</td>
<td>3/4</td>
<td>1</td>
<td>48</td>
<td>36</td>
</tr>
<tr>
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<td>2</td>
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<td>1/2</td>
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<td>4</td>
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<td>144</td>
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<td>192</td>
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<td>54</td>
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<td>3/4</td>
<td>6</td>
<td>288</td>
<td>216</td>
</tr>
</tbody>
</table>
IEEE 802.11a

Ideal “rate”, acceptable BER
Multirate wireless

etc…
Multirate wireless

11Mbps

AP

1Mbps

11Mbps

11Mbps

etc...
Problem Statement

While total cell capacity is around 12 calls when all of them transmit at 11Mbps...

...this capacity falls with any change from fast to slow flows.

Distribution of VoIP flows in a cell (G.711 codec)
Multihop (Mesh) Networks
VoIP capacity
Hidden Terminal Problem

(a) A transmits data frame

(b) C transmits data frame & collides with A at B

C senses medium, station A is hidden from C
CSMA with Collision Avoidance (RTS/CTS)

(a) A requests to send

(b) B announces A ok to send

(c) A sends

C remains quiet
CSMA/CA (optional)

RTS

CTS

Data

Ack

SIFS

DIFS

NAV (RTS)

NAV (CTS)

NAV (Data)

Defers access
VoIP Capacity in a mesh network

MP

MP

MP

MP

VoIP calls (G.279)

Channel Contention (MAC)

hidden nodes

Single channel

2 Mbps

D. Niculescu. S. Ganguly, K. Kim, R. Izmailov;
VoIP Capacity in a mesh network

A

Multiple channels (Two channels)

B

Multiple channels (Three channels)
VoIP Capacity in a mesh network