Lecture 16:
QoS and 802.11

CSE 123: Computer Networks
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Prj2 due for full credit 11:59pm

Lecture 16 Overview

- QoS followup: Packet Scheduling
  - Fair Queueing
  - Fluid Flow

- 802.11 Wireless
  - CSMA/CA
  - Hidden Terminals
  - RTS/CTS

Scheduling

- So far we’ve done flow-based traffic policing
  - Limit the rate of one flow regardless the load in the network

- In general, need scheduling
  - Dynamically allocate resources when multiple flows compete
  - Give each “flow” (or traffic class) own queue (at least theoretically)

- Weighted fair queuing
  - Proportional share scheduling
  - Schedule round-robin among queues in proportion to some weight parameter
(Weighted) Fair Queuing

Maintain a queue for each flow
- What is a flow?

Implements max-min fairness: each flow receives 
\[ \min(r, f) \text{, where} \]
- \( r \) – flow arrival rate
- \( f \) – link fair rate (see next slide)

**Weighted Fair Queuing** (WFQ) – associate a weight with each flow

Fair Rate Computation
- If link congested, compute \( f \) such that
\[
\sum \min(r, f) = C
\]

Fair Queuing

- Implement max-min fairness: each flow receives 
- \( r \) – flow arrival rate
- \( f \) – link fair rate (see next slide)

- **Weighted Fair Queuing** (WFQ) – associate a weight with each flow
TCP vs. UDP

![TCP vs. UDP chart]

TCP vs. UDP w/Fair Queuing

![TCP vs. UDP w/Fair Queuing chart]

Another Example

- Associate a weight $w_i$ with each flow $i$
- If link congested, compute $f$ such that

$$\sum \min(r_i, f \times w_i) = C$$

If $\sum w_i \leq C$, flow $i$ is guaranteed to be allocated a rate $\geq \frac{w_i}{C}$. If $\sum w_i > C$, flow $i$ is guaranteed to be allocated a rate $\geq \frac{w_i}{C}$.
Fluid Flow

- Flows can be served one bit at a time
- WFQ can be implemented using bit-by-bit weighted round robin
  - During each round from each flow that has data to send, send a number of bits equal to the flow's weight

Fluid Flow Example

- Orange flow has packets backlogged between time 0 and 10
- Other flows have packets continuously backlogged
- All packets have the same size

Packet-Based Implementation

- Packet (Real) system: packet transmission cannot be preempted. Why?
- Solution: serve packets in the order in which they would have finished being transmitted in the fluid flow system
Packet-Based Example

Select the first packet that finishes in the fluid flow system

Packet system

Infrastructure vs. Ad hoc

Infrastructure network

Ad hoc network

IEEE 802.11 Infrastructure

Mobile terminal

Fixed terminal

Application
TCP
IP
LLC
802.11 MAC
802.11 PHY

Infrastructure network

Application
TCP
IP
LLC
802.11 MAC
802.11 PHY

IEEE 802.11 PHY
802.11 Frame Format

- Synchronization
  - synch., gain setting, energy detection, frequency offset compensation
- SFD (Start Frame Delimiter)
  - 1111001110100000
- Signal
  - data rate of the payload (0A: 1 Mbit/s DBPSK; 14: 2 Mbit/s DQPSK)
- Service
  - future use, 00: 802.11 compliant
- Length
  - payload length
- HEC (Header Error Check)
  - protection of signal, service and length, x^16+x^5+1

<table>
<thead>
<tr>
<th>bits</th>
<th>description</th>
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<tbody>
<tr>
<td>128</td>
<td>PLCP preamble</td>
</tr>
<tr>
<td>16</td>
<td>SFD</td>
</tr>
<tr>
<td>8</td>
<td>signal</td>
</tr>
<tr>
<td>8</td>
<td>service</td>
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<td>length</td>
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<tr>
<td>16</td>
<td>HEC</td>
</tr>
<tr>
<td></td>
<td>payload</td>
</tr>
</tbody>
</table>

WLAN: IEEE 802.11b

- Data rate
  - 1, 2, 5.5, 11 Mbit/s
  - User data rate max. approx. 6 Mbit/s
- Transmission range
  - 300m outdoor, 30m indoor
  - Max. data rate ~10m indoor
- Frequency
  - Free 2.4 GHz ISM-band

Physical Channels

- 12 channels available for use in the US
  - Each channel is 22 MHz wide
  - Only 3 orthogonal channels
  - Using any others causes interference
Carrier Sense Multiple Access

**CSMA:** listen before transmit:
- If channel sensed idle: transmit entire pkt
- If channel sensed busy, defer transmission
  - Persistent CSMA: retry immediately with probability $p$ when channel becomes idle (may cause instability)
  - Non-persistent CSMA: retry after random interval

Hidden Terminal Problem

- B can communicate with both A and C
- A and C cannot hear each other
- Problem
  - When A transmits to B, C cannot detect the transmission using the carrier sense mechanism
  - If C transmits, collision will occur at node B
- Solution
  - Hidden sender C needs to defer

CSMA/CA

- Cannot detect collision w/half-duplex radios
- Wireless MAC protocols often use collision avoidance techniques, in conjunction with a (physical or virtual) carrier sense mechanism
- Collision avoidance
  - Nodes negotiate to reserve the channel.
  - Once channel becomes idle, the node waits for a randomly chosen duration before attempting to transmit.
RTS/CTS (MACA)

- When A wants to send a packet to B, A first sends a Request-to-Send (RTS) to B
- On receiving RTS, B responds by sending Clear-to-Send (CTS), provided that A is able to receive the packet
- When C overhears a CTS, it keeps quiet for the duration of the transfer
  - Transfer duration is included in both RTS and CTS

Backoff Interval

- **Problem:** With many contending nodes, RTS packets will frequently collide
- **Solution:** When transmitting a packet, choose a backoff interval in the range [0, CW]
  - CW is contention window
  - Wait the length of the interval when medium is idle
    - Count-down is suspended if medium becomes busy
    - Transmit when backoff interval reaches 0
- Need to adjust CW as contention varies

Non-symmetric ranges
802.11 MAC Modes

- Distributed Coordination Function (DCF) CSMA/CA
  - collision avoidance via randomized "back-off" mechanism
  - minimum distance between consecutive packets
  - ACK packet for acknowledgements (not for broadcasts)

- DCF w/ RTS/CTS
  - Distributed Foundation Wireless MAC
  - avoids hidden terminal problem

- Point Control Function (PCF) - optional
  - Access point polls terminals according to a list
  - We’re not going to discuss…

IEEE 802.11 DCF

- DCF is CSMA/CA protocol
  - Uses a Network Allocation Vector (NAV) to implement collision avoidance

- DCF suitable for multi-hop ad hoc networking

- Optionally uses RTS/CTS exchange to avoid hidden terminal problem
  - Any node overhearing a CTS cannot transmit for the duration of the transfer

- Uses ARQ to provide reliability

IEEE 802.11
IEEE 802.11

**NAV** = remaining duration to keep quiet

**RTS** = Request-to-Send

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**CTS** = Clear-to-Send

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**NAV** = 8

IEEE 802.11
IEEE 802.11

- DATA packet follows CTS. Successful data reception acknowledged using ACK.

IEEE 802.11

- When a node fails to receive CTS in response to its RTS, it increases the contention window
  - CW is doubled (up to an upper bound)
  - More collisions $\Rightarrow$ longer waiting time to reduce collision

- When a node successfully completes a data transfer, it restores CW to $CW_{min}$

Binary Exponential Backoff
802.11 Backoffs

- **SIFS (Short Inter Frame Spacing)**
  - highest priority, for ACK, CTS, polling response
- **PIFS (PCF IFS)**
  - medium priority, for time-bounded service using PCF
- **DIFS (DCF, Distributed Coordination Function IFS)**
  - lowest priority, for asynchronous data service

DCF Example

B1 = 25  \hspace{1cm} B1 = 5
\[ \begin{array}{c}
\text{medium busy} \hspace{1cm} \text{wait} \hspace{1cm} \text{data} \\
\text{data} \hspace{1cm} \text{wait} \hspace{1cm} \text{data}
\end{array} \]
B2 = 20  \hspace{1cm} B2 = 10
\[ \begin{array}{c}
\text{contention} \hspace{1cm} \text{contention} \\
\text{contention} \hspace{1cm} \text{contention}
\end{array} \]
cw = 31
B1 and B2 are backoff intervals at nodes 1 and 2

Fragmentation

\[ \begin{array}{c}
\text{sender} \hspace{1cm} \text{receiver} \hspace{1cm} \text{other stations}
\end{array} \]