Lecture 24: Scheduling and QoS

CSE 123: Computer Networks
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HW 4 due Wednesday
Lecture 24 Overview

- Scheduling
  - (Weighted) Fair Queuing

- Quality of Service basics
  - Integrated Services
  - Differentiated Services
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-robbins among queues in proportion to some weight parameter
Our Previous Example

1 UDP (10 Mbps) and 31 TCPs sharing a 10 Mbps line
TCP vs. UDP w/Fair Queuing

![Graph showing throughput vs flow number for Fair Queuing (FQ)]
(Weighted) Fair Queuing

I/P

Flow 1
Flow 2
Flow n

O/P

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

Implements **max-min fairness**: each flow receives $\min(r_i, f)$, where
  - $r_i$ – flow arrival rate
  - $f$ – link fair rate (see next slide)

**Weighted Fair Queuing** (WFQ) – associate a weight with each flow
If link congested, compute $f$ such that

$$\sum_{i} \min(r_i, f) = C$$

$\min(8, 4) = 4$
$\min(6, 4) = 4$
$\min(2, 4) = 2$

$f = 4$: $\min(8, 4) = 4$
$\min(6, 4) = 4$
$\min(2, 4) = 2$
Another Example

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

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

$(w_1 = 3) 8$
$(w_2 = 1) 6$
$(w_3 = 1) 2$

$f = 2$:
- $\min(8, 2\times3) = 6$
- $\min(6, 2\times1) = 2$
- $\min(2, 2\times1) = 2$

Flow $i$ is guaranteed to be allocated a rate $\geq wi/\left(\sum_k w_k\right)$

If $\sum_k w_k \leq C$, flow $i$ is guaranteed to be allocated a rate $\geq w_i$
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
Select the first packet that finishes in the fluid flow system.
Quality of Service (QoS)

- So far, we have assumed all traffic is equal and provided best effort delivery
  - Perhaps with enforcement to throttle non-responsive senders

- Not always best model. Why?
  - Application demands
    - I want low-delay low-loss for phone service
  - Market differentiation
    - I want to sell better service for more money
  - Bandwidth management
    - Don’t let BitTorrent eat up all UCSD bandwidth
Multimedia Applications

- Basic idea
  - Sample signal, packetize, transmit
  - Repeat in reverse at receiver

- Network Requirements (@ given load)
  - Delay
  - Jitter (variation in delay)
  - Packet loss
  - Exact parameters a function of interactivity demands, buffer capacity, retransmission time and loss tolerance
  - However… as a rule they want *more*
Different Demands

- **Elastic**: Utility increases with Bandwidth.
- **Delay-adaptive**: Utility increases with Bandwidth until it plateaus.
- **Hard real-time**: Utility is constant regardless of Bandwidth.

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Packet Classification

- Want to treat some traffic better/worse than others
  - How to identify the more important traffic?
  - How much better do we want to treat it?
  - How do we actually treat it better?

- Router **classifies** based on packet header
  - Aggregates
    » From particular network (IP src address)
    » For particular protocol (e.g., port 80 traffic)
  - Individual network flows
    » 5-tuple (src, dst, src port, dst port, protocol)
  - Special header field that indicates traffic “type”
Service Classes

- **Best-effort**
  - Vanilla IP

- **Differentiated services**
  - Bronze, Silver, Gold, etc… (effectively priorities, up to some amount of bandwidth per time)
  - E.g., best service up to 10Mbps, then best effort

- **Predicted service (soft real-time)**
  - Network guarantees good performance on average
  - Application promises only send as fast as negotiated

- **Guaranteed service (hard real-time)**
  - Network guarantees good performance always
  - Application promises only send as fast as negotiated
How to Specify?

- Kind of service (service class)
- Specify “flowspec” for data flow limits
  - Tspec: describes the flow’s traffic characteristics
    » Average bandwidth + burstiness (contract with ISP)
  - Rspec: describes the service requested from the network (e.g., delay target)
- Interface can be interactive (ask network) or via business interface (ask salesman)
  - Can say no
  - If yes, then use scheduling mechanisms in routers (not FIFO anymore) to deliver
More Complicated Routers

Routing Messages

Routing

Signaling

QoS Control messages

Control Plane

Data In

Dest Lookup

Forwarding Table

Per Flow QoS Table

Data Out

Classifier

Scheduler

Admission Control?
Network-wide QoS

- **Integrated services**
  - Motivated by need for end-to-end guarantees
  - On-line negotiation of per-flow requirements
  - End-to-end per-router negotiation of resources
  - Complex

- **Differentiated services**
  - Motivated by economics (multi-tier pricing)
  - No per-flow state
  - Not end-to-end and not guaranteed services
  - Simple
Integrated Services

- Example: guarantee 1MBps and < 100 ms delay to a flow
Integrated Services

- Allocate resources - perform per-flow admission control
Integrated Services

- Install per-flow state
Integrated Services

- Install per flow state
IntServe: Data Path

- Per-flow classification

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IntServe: Data Path

- Per-flow buffer management
IntServe: Data Path

- Per-flow scheduling
Differentiated Services

- **Edge router**
  - Shape & police traffic
  - Mark “class” of traffic in DS header field (e.g., gold service)
- **Core router**
  - Schedule aggregates according to marks in header
  - Drop lower-class traffic first during congestion

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Summary

- Routers manage their own resources
  - Buffer management may entail marking/dropping
  - Scheduling discipline determines outgoing packet order

- Token bucket and RED
  - Mechanisms to control traffic flowing through routers

- Networks can provide quality of service
  - Combines per-router traffic policing with network signaling
  - IntServ and DiffServ are contrasting approaches
For next time…

- Read Ch. 2.7 in P&D
- Wrap up Project 2!