Lecture 18:
Buffering & Scheduling

Homework 3 due FRIDAY
Lecture 18 Overview

- Queues in routers & switches
- Buffer management and scheduling disciplines
  - RED
Third Generation Routers

Shared interconnect (frequently crossbar)

Centralized scheduler

Full forwarding table in line card

Fixed cells
Output queuing

- Output interfaces buffer packets

- Pro
  - Simple algorithms
  - Single congestion point

- Con
  - N inputs may send to the same output
  - Requires speedup of N
    » Switch fabric must be N times faster than input line rate
Input queuing

- Input interfaces buffer packets

- Pro
  - Single congestion point
  - Simple to design algorithms

- Con
  - Must implement flow control
  - Low utilization due to Head-of-Line (HoL) Blocking
How many time units will it take to send the remainder of the packets?

A. 3  
B. 4  
C. 5  
D. 8
IQ + Virtual Output Queuing

- Input interfaces buffer packets in per-output virtual queues

- **Pro**
  - Solves blocking problem

- **Con**
  - More resources per port
  - Complex arbiter at switch
  - Still limited by input/output contention (scheduler)
Virtual Output Queues

How many time units will it take to send the remainder of the packets?

A. 2
B. 3
C. 4
D. 5
Switch scheduling

- Problem
  - Match inputs and outputs
  - Resolve contentions, no packet drops
  - Maximize throughput
  - Do it in constant time…

- If traffic is uniformly distributed its easy
  - Lots of algorithms (approximate matching)

- Seminal result (Dai et al, 2000)
  - Maximal size matching + speedup of two guarantees 100% utilization for most traffic assumptions
Typical high-performance router

- IQ + VoQ + OQ
  - Speedup of 2
  - Central scheduler
  - Fixed-sized internal cells
- Pro
  - Can achieve utilization of 1
  - Can scale to > Tb/s
- Con
  - Multiple congestion points
  - Complexity

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Key Router Challenges

- **Buffer management**: which packet to drop when?
  - We only have finite-length queues
- **Scheduling**: which packet to transmit next?
Basic Buffer Management

- **FIFO + drop-tail**
  - Simplest choice
  - Used widely in the Internet
- **FIFO (first-in-first-out)**
  - Implies single class of traffic
- **Drop-tail**
  - Arriving packets get dropped when queue is full regardless of flow or importance
- **Important distinction:**
  - FIFO: scheduling discipline
  - Drop-tail: drop policy (a.k.a. buffer management)
FIFO/Drop-Tail Problems

- Leaves responsibility of congestion control completely to the edges (e.g., TCP)
- Does not separate between different flows
- No policing: send more packets → get more service
- Synchronization: end hosts react to same events
Active Queue Management

- Design active router queue management to aid congestion control

- Why?
  - Router has unified view of queuing behavior
  - Routers see actual queue occupancy (end hosts have difficulty distinguishing between queuing delay and propagation delay)
  - Routers can decide on transient congestion, based on workload
Design Objectives

- Keep throughput high and delay low
  - High power (throughput/delay)

- Accommodate bursts

- Queue size should reflect ability to accept bursts rather than steady-state queuing

- Improve TCP performance with minimal hardware changes in router
Random Early Detection

- Detect incipient congestion
- Assume hosts respond to lost packets
- Avoid window synchronization
  - Randomly mark packets
- Avoid bias against bursty traffic
RED Algorithm

- Maintain running average of queue length in router

- If $\text{avg} < \text{min}_{th}$ do nothing
  - Low queuing, send packets through

- If $\text{avg} > \text{max}_{th}$, drop packet
  - Protection from misbehaving sources

- Else drop/mark packet in a manner proportional to queue length
  - Notify sources of incipient congestion
  - Dropping vs Marking tradeoff (Explicit Congestion Notification)

Is RED a scheduling discipline or a buffer management policy?

A. Scheduling discipline
B. Buffer management policy
C. Both
D. Neither
RED Operation

Min thresh

Max thresh

Average Queue Length

$P(\text{drop})$

$1.0$

$max_P$

$\min_{th}$

$max_{th}$

Avg queue length

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For next time…

- Homework due Friday
- Read Ch. 6.2 in P&D
- Surprise guest lecturer Friday