CPE348: Introduction to Computer Networks

Lecture #20: Chapter 6.1

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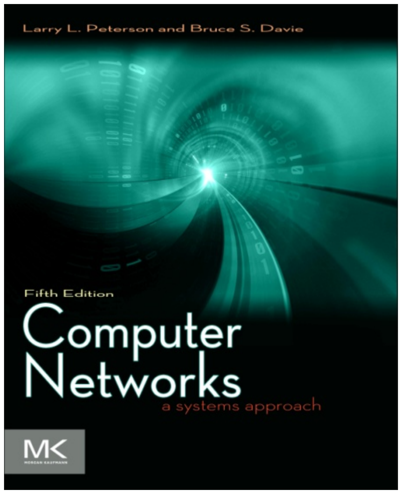


Chapter 6

Congestion Control and Resource Allocation

Problem

- We have seen protocols of Layer 1-4 to understand how data can be transferred among processes across networks;
- Problem: How to *effectively* and *fairly* allocate resources among a collection of network devices?

Chapter Outline

- Issues in Resource Allocation
- Queuing Disciplines
- Quality of Service

- TCP Congestion control/avoidance – We talked it in previous lectures

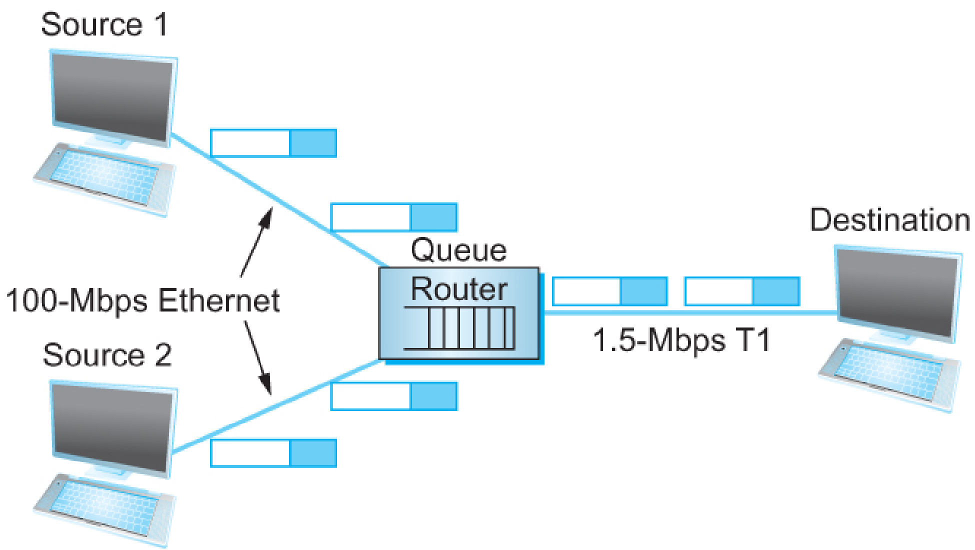
This chapter isn't about any protocols of a OSI layer, but an advanced topic in network design!

Resource Allocation

- What are network resources
  - Bandwidth of the links
  - Buffers at the routers and switches
  - …
- Packets that are cached in a router's queue contend for the use of a link

One Example of Resource Allocation

- Network Model - Packet Switched Network



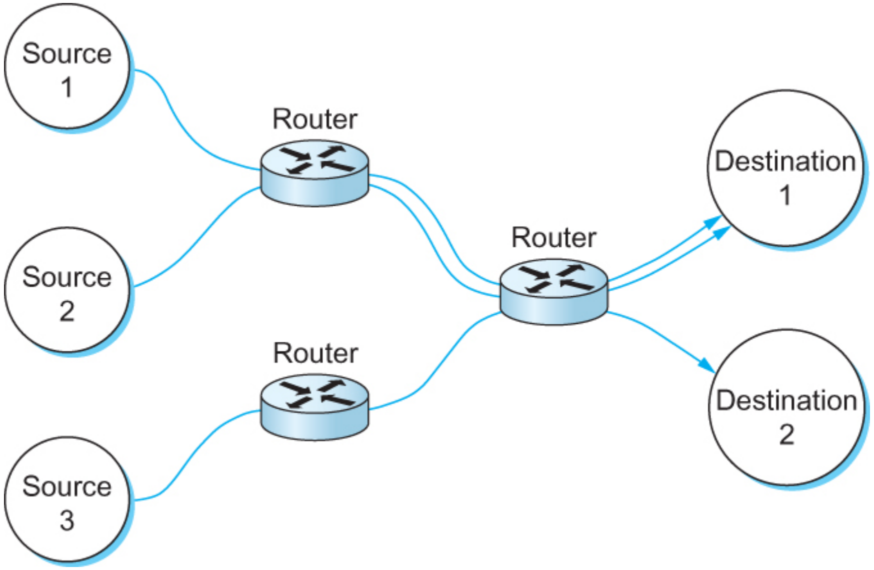
A potential bottleneck router.

One Example of Resource Allocation

- What is a Flow?
  - A sequence of packets sent between a source / destination pair and following a route through the network
  - Important abstraction in the context of resource allocation

Issues in Resource Allocation

- Network Model
  - Connectionless Flows



Multiple flows passing through a set of routers

Issues in Resource Allocation

- Evaluation Criteria - Fair Resource Allocation
  - The effective utilization of network resources is not the only criterion for judging a resource allocation scheme.
  - We must also consider the issue of fairness. *However,* what exactly constitutes fair resource allocation.

What is fairness?

  - An example
    - A video stream could receive 1 Mbps across some link
    - While a file transfer receives only 10 Kbps over the same link.

Issues in Resource Allocation

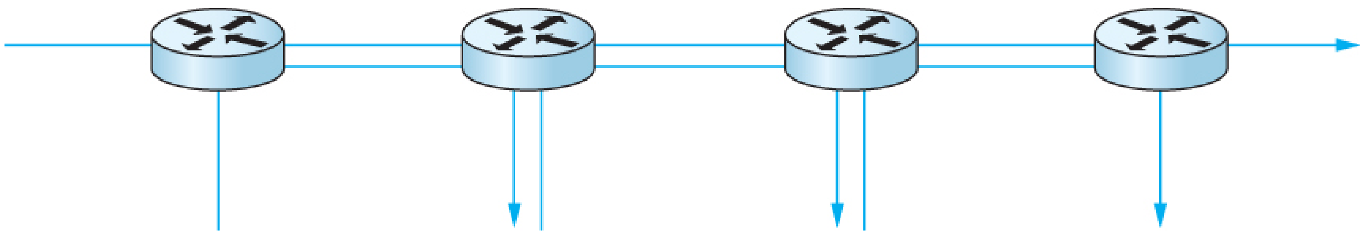
- Evaluation Criteria - Fair Resource Allocation
  - When several flows share a particular link, we would like for each flow to receive an equal share of the bandwidth.
  - This definition presumes that a *fair share of bandwidth means an equal share of bandwidth.*

But equal shares may not equate to fair shares!

  - Should we also consider the length of the paths being compared? (Example on next slide)

Issues in Resource Allocation

- Evaluation Criteria - Fair Resource Allocation



One four-hop flow competing with three one-hop flows

If we are considering path length, what is fair allocation for this situation?

Issues in Resource Allocation

- Evaluation Criteria - Fair Resource Allocation
  - Assuming that fair implies equal and that all paths are of equal length,
  - Networking researcher Raj Jain proposed a metric that can be used to *quantify* the fairness of a congestion-control mechanism.
  - Jain's fairness index is defined as follows: Given a set of flow throughputs (x_1, x_2, . . . , x_n) (measured in consistent units such as bits/second), the following function assigns a fairness index to the flows:

$$f(x_1, x_2, \ldots, x_n) = \frac{\left(\sum_{i=1}^{n} x_i\right)^2}{n \sum_{i=1}^{n} x_i^2}$$

    - The fairness index always results in a number between 0 and 1, with 1 representing greatest fairness.
    - Indicates the fairness of the flows

Queuing Disciplines

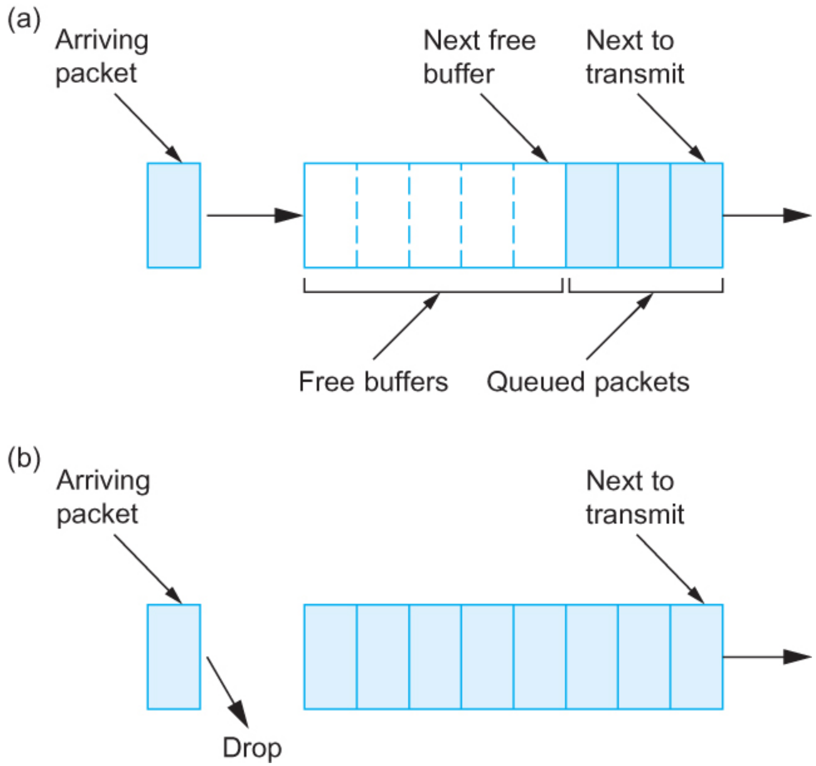
- **First in First out (FIFO)** queuing, also called first-come-first-served (FCFS) queuing – single queue
- **Priority Queuing** – utilizes FIFO queuing
- **Fair Queuing (FQ)** – each flow has its own queue
- **Weighted Fair Queuing (WFQ)** – variation on FQ

- *Scheduling Discipline* – determines order in which packets are transmitted
- *Drop Policy* – determines which packets are dropped

Queuing Disciplines

- FIFO queuing:
  - Simple to implement - the first packet that arrives is the first packet to be transmitted
  - The amount of buffer space at each router is finite, if a packet arrives and the queue (buffer space) is full, then the router discards that packet
    - Discarding is done without regard to the flow the packet belongs to
    - Discarding is done without regard to the importance of the packet
    - Called *tail drop, since packets that arrive at* the tail end of the FIFO queue are dropped
  - FIFO is a *scheduling discipline*—it determines the order in which packets are transmitted.
  - Tail drop is a *drop policy* — it determines which packets get dropped

Queuing Disciplines



(a) FIFO queuing; (b) tail drop at a FIFO queue.

Queuing Disciplines

- Priority Queuing
- A simple variation on basic FIFO queuing
- Each packet is marked with a priority; the mark could be carried, for example, in the IP header.
- The routers implement multiple FIFO queues, one for each priority class.
- Routers always transmit packets out of the highest-priority queue first. As higher priority queues are emptied, lower priority queue packets are transmitted
- Within each priority, packets are still managed in a FIFO manner.
- High-priority queue can dominate transmission time
- Users have to use self-control on setting the priorities

Queuing Disciplines

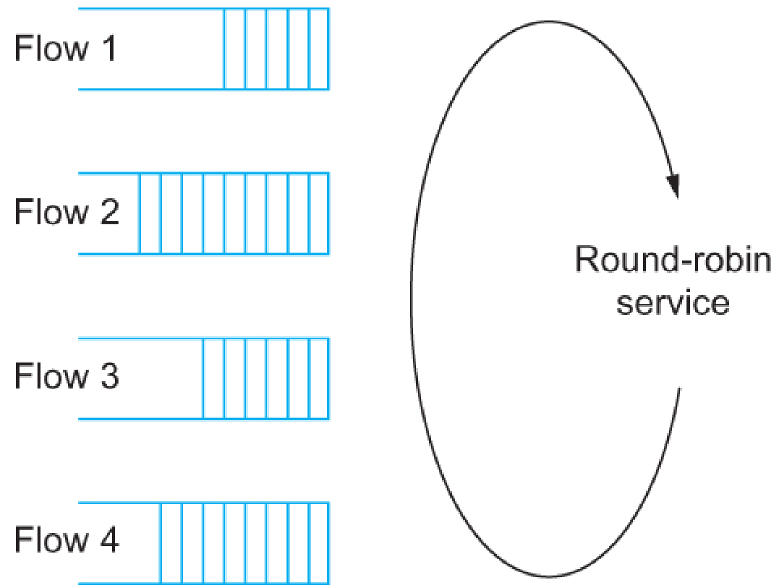
- FIFO queuing: Main problems with FIFO
  - FIFO queuing does not discriminate between different traffic sources
  - FIFO queuing does not separate packets according to the flow to which they belong.

Queuing Disciplines

- Fair Queuing – Addresses FIFO main problems
  - Fair queuing (FQ) maintains a separate queue for each flow currently being handled by the router.
  - Routers service these queues using a round-robin methodology.
  - Tail drop is used on each queue – prevents any given source from increasing its share of network capacity
  - FQ is designed to be used with end-to-end congestion control methods

Queuing Disciplines

- Fair Queuing



Round-robin service of four flows at a router
Each flow is given an opportunity to have a packet transmitted

Queuing Disciplines

- Fair Queuing – main complication
  - In Fair Queuing the packets being processed at a router are not necessarily the same length.
  - To truly allocate the bandwidth of the outgoing link in a fair manner packet length must be considered.
  - A router is managing two flows using simple round-robin servicing
    - One with 1000-byte packets receives 2/3 of the link BW
    - The other with 500-byte packets receives 1/3 of the link BW

Queuing Disciplines

- Fair Queuing – solution to complication
  - What we really want is bit-by-bit round-robin; that is, the router transmits a bit from flow 1, then a bit from flow 2, and so on.
  - Clearly, it is not feasible to interleave the bits from different packets.
  - The FQ mechanism simulates bit-by-bit round-robin
    - First FQ determines when a given packet would finish transmitting based on bit-by-bit round-robin
    - This finish time is used to sequence the packets for transmission.

Queuing Disciplines

- Fair Queuing – single flow bit-by-bit round-robin
  - To understand the algorithm for approximating bit-by-bit round robin, consider the behavior of a single flow
  - For a single flow, let
    - P_i : denote the length of packet *i (in bits)*
    - S_i: time when the router starts to transmit packet *i*
    - F_i: time when router finishes transmitting packet *i*
    - Then, for a single flow $F_i = S_i + P_i$
    - P_i is expressed in how many clock ticks it takes to transmit packet ***i*** – one clock tick is the time it takes for a flow to get 1 bits worth of service(transmission time).

Queuing Disciplines

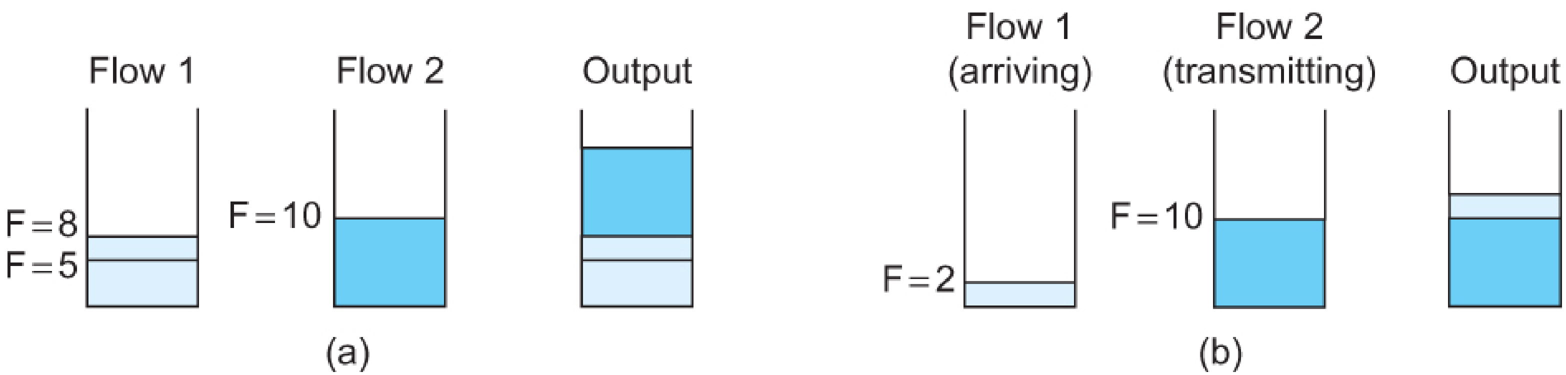
- Fair Queuing - single flow bit-by-bit round-robin
  - When do we start transmitting packet *i*?
    - Depends on whether packet i arrived before or after the router finishes transmitting packet ***i*-1** for the flow
  - Let A_i denote the time that packet ***i*** arrives at the router
  - **Then $S_i = \max(F_{i-1}, A_i)$**
  - **So $F_i = S_i + P_i = \max(F_{i-1}, A_i) + P_i$**

Queuing Disciplines

- Fair Queuing - multiple flow bit-by-bit round-robin
  - Now for every flow, calculate F_i for each packet that arrives using the formula $F_i = \max(F_{i-1}, A_i) + P_i$
  - For clocking A_i advances one clock tick after each active flow transmits a bit
  - Then treat all the F_i as timestamps
  - Next packet to transmit is always the packet that has the lowest timestamp
    - The packet that should finish transmission before all others
    - New arriving packets cannot preempt a packet that is being transmitted
    - Shorter packets that arrive can jump ahead of longer packets waiting to be transmitted

Queuing Disciplines

- Fair Queuing



Example of fair queuing in action: (a) packets with earlier finishing times are sent first; (b) sending of a packet already in progress is completed

Queuing Disciplines

- Weighted Fair Queuing (WFQ)
  - A weight is assigned to each flow(queue)
  - The weight indicates how many bits are transmitted each time – FQ assigns a value of 1 to all queues
  - Flows could be considered as different classes of traffic
  - WFQ is moving toward a reservation-based resource allocation
  - Now for every flow, calculate $\mathbf{F_i}$ for each packet that arrives using the formula $\boldsymbol{F_i = \max(F_{i-1}, A_i) + P_i/weight}$