Networks and Distributed Systems

Lecture 16 – Congestion Control and Resource Allocation

Problem

- We have seen enough layers of protocol hierarchy to understand how data can be transferred among processes across heterogeneous networks

- Problem
  - How to *effectively* and *fairly* allocate resources among a collection of competing users?

Outline

- Issues in Resource Allocation
- Queuing Disciplines
- TCP Congestion Control
- Congestion Avoidance Mechanism
- Quality of Service

Congestion Control and Resource Allocation

- Resources
  - Bandwidth of the links
  - Buffers at the routers and switches

- Packets contend at a router for the use of a link, with each contending packet placed in a queue waiting for its turn to be transmitted over the link

Congestion Control and Resource Allocation

- When too many packets are contending for the same link
  - The queue overflows
  - Packets get dropped
    - Network is congested!
- Network should provide a congestion control mechanism to deal with such a situation

Congestion Control and Resource Allocation

- Congestion control and Resource Allocation
  - Two sides of the same coin
- If the network takes active role in allocating resources
  - The congestion may be avoided
  - No need for congestion control

Congestion Control and Resource Allocation

- Allocating resources with any precision is difficult
  - Resources are distributed throughout the network
- On the other hand, we can always let the sources send as much data as they want
  - Then recover from the congestion when it occurs
  - Easier approach but it can be disruptive because many packets many be discarded by the network before congestions can be controlled

Congestion Control and Resource Allocation

- Congestion control and resource allocations involve both hosts and network elements such as routers

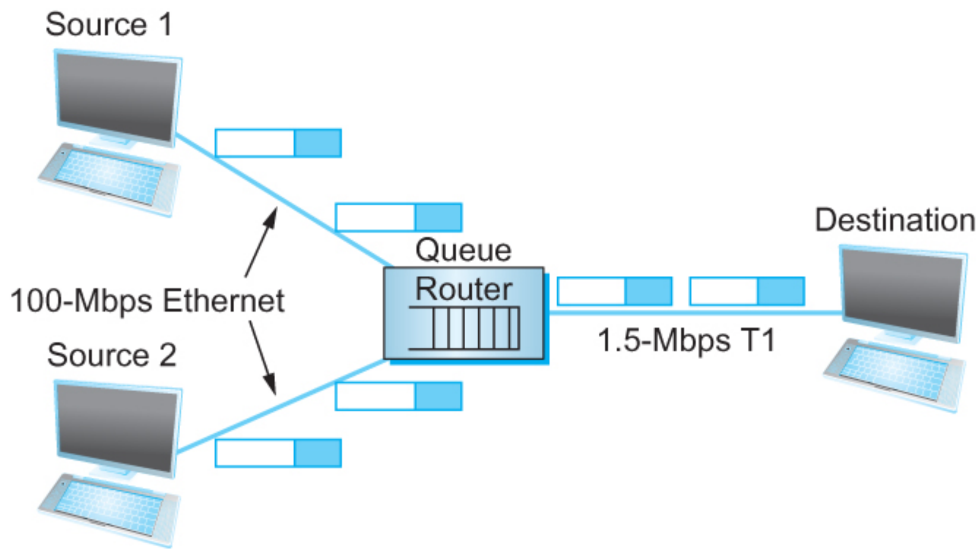
- In network elements
  - Various queuing disciplines can be used to control the order in which packets get transmitted and which packets get dropped
- At the hosts' end
  - The congestion control mechanism paces how fast sources are allowed to send packets

Issues in Resource Allocation

- Network Model: Packet Switched Network
  - We consider resource allocation in a packet-switched network (or internet) consisting of multiple links and switches (or routers).
  - In such an environment, a given source may have more than enough capacity on the immediate outgoing link to send a packet, but somewhere in the middle of a network, its packets encounter a link that is being used by many different traffic sources

Issues in Resource Allocation

- Network Model
  - Packet Switched Network



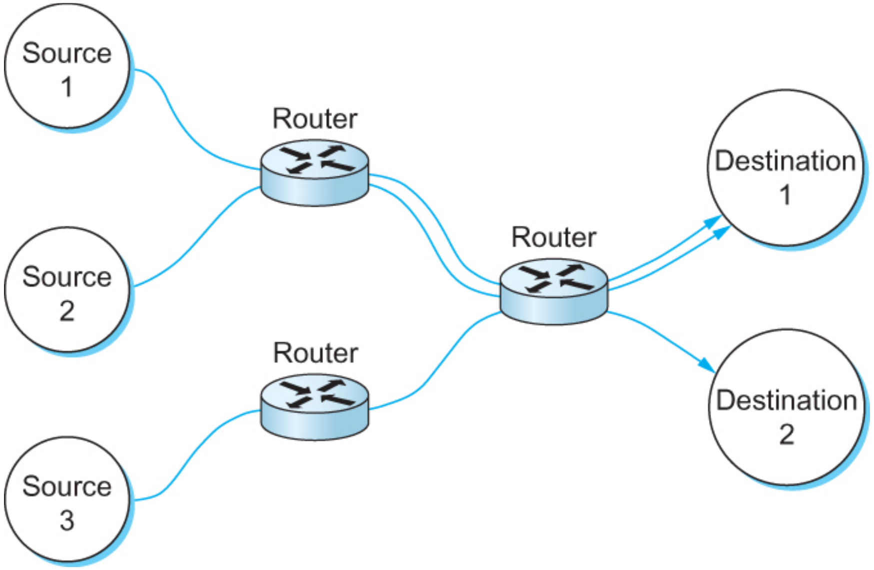
A potential bottleneck router.

Issues in Resource Allocation

- Network Model: Connectionless Flows
  - Assuming that the network is connectionless, with a connection-oriented service implemented in the transport protocol
    - We need to qualify the term "connectionless"
    - In particular, the assumption that all datagrams are completely independent in a connectionless network is too strong.
    - The datagrams are certainly switched independently, but it is usually the case that a stream of datagrams between a particular pair of hosts flows through a particular set of routers

Issues in Resource Allocation

- Network Model
  - Connectionless Flows



Multiple flows passing through a set of routers

Issues in Resource Allocation

- Network Model: Connectionless Flows
  - Flows can be defined at different granularities. e.g., a flow can be host-to-host (i.e., have the same source/destination host addresses) or process-to-process (i.e., have the same source/destination host/port pairs).
  - In the latter case, a flow is essentially the same as a channel. The reason we introduce a new term is that a flow is visible to the routers inside the network, whereas a channel is an end-to-end abstraction.

Issues in Resource Allocation

- Network Model: Connectionless Flows
  - Because multiple related packets flow through each router, it sometimes makes sense to maintain some state information for each flow, information that can be used to make resource allocation decisions about the packets that belong to the flow. This state is sometimes called soft state.
  - The main difference between soft state and "hard" state is that soft state need not always be explicitly created and removed by signalling.

Issues in Resource Allocation

- Network Model: Connectionless Flows
  - Soft state represents a middle ground between a purely connectionless network that maintains no state at the routers and a purely connection-oriented network that maintains hard state.
  - The operation of the network does not depend on soft state being present (each packet is still routed correctly without regard to this state), but when a packet happens to belong to a flow for which the router is currently maintaining soft state, then the router is better able to handle the packet.

Router-centric vs. Host-centric

- In a router-centric design, each router takes responsibility for deciding when packets are forwarded and selecting which packets are to dropped, as well as for informing the hosts that are generating the network traffic how many packets they are allowed to send.

- In a host-centric design, the end hosts observe the network conditions (e.g., how many packets they are successfully getting through the network) and adjust their behavior accordingly.

- Note that these two groups are not mutually exclusive.

Reservation-based vs. Feedback-based

- In a reservation-based system, the end host asks the network for a certain capacity to be allocated for a flow.
  - Each router then allocates enough resources (buffers and/or percentage of the link's bandwidth) to satisfy this request.
  - If the request cannot be satisfied at some router, because doing so would overcommit its resources, then the router rejects the reservation.

Reservation-based vs. Feedback-based

- In a feedback-based approach, the end hosts begin sending data without first reserving any capacity and then adjust their sending rate according to the feedback they receive.
  - This feedback can either be *explicit (i.e., a congested router sends a "please* slow down" message to the host)
  - Or it can be *implicit (i.e., the end host adjusts its sending* rate according to the externally observable behavior of the network, such as packet losses).

Window-based vs. Rate-based

- Window advertisement is used within the network to reserve buffer space.
- Control sender's behavior using a rate, how many bit per second the receiver or network is able to absorb.

Evaluation Criteria

- Effective Resource Allocation
  - Metrics of networking: throughput and delay.
    - We want as much throughput and as little delay as possible.
    - Unfortunately, these goals are often somewhat at odds with each other.
    - One sure way for a resource allocation algorithm to increase throughput is to allow as many packets into the network as possible, so as to drive the utilization of all the links up to 100%.
    - The problem with this strategy is that increasing the number of packets in the network also increases the length of the queues at each router. Longer queues, in turn, mean packets are delayed longer in the network

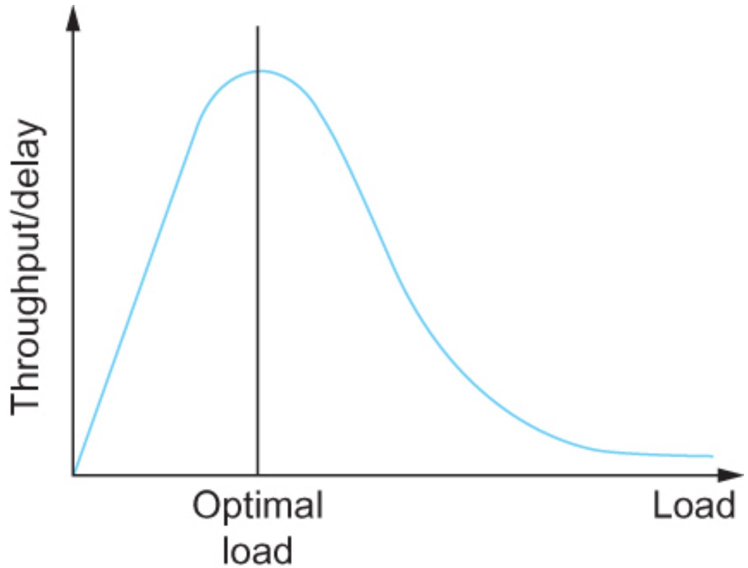
Evaluation Criteria

- Effective Resource Allocation
  - To describe this relationship, some network designers have proposed using the ratio of throughput to delay as a metric for evaluating the effectiveness of a resource allocation scheme.
  - This ratio is sometimes referred to as the *power of the network.*

Power = Throughput/Delay

Evaluation Criteria

- Effective Resource Allocation



Ratio of throughput to delay as a function of load

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, we quickly get into murky waters when we try to define what exactly constitutes fair resource allocation.
  - For example, a reservation-based resource allocation scheme provides an explicit way to create controlled unfairness.
  - With such a scheme, we might use reservations to enable a video stream to receive 1 Mbps across some link while a file transfer receives only 10 Kbps over the same link.

Evaluation Criteria

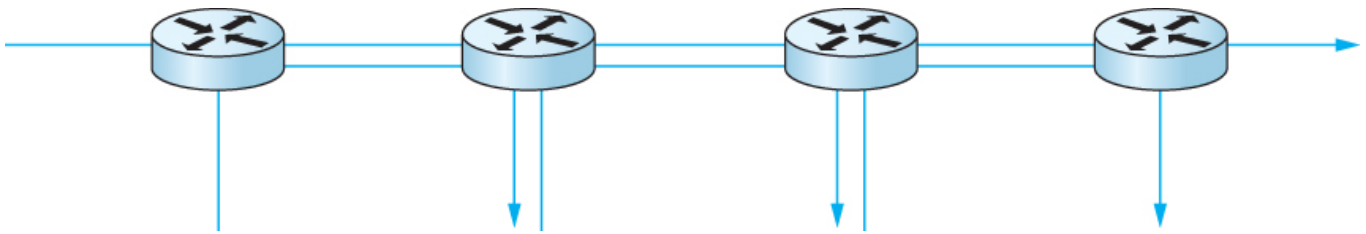
- Fair Resource Allocation
  - In the absence of explicit information to the contrary, when several flows share a particular link, we would like for each flow to receive an equal share of the bandwidth.
  - This definition presumes that a *fair share of bandwidth means an equal share of bandwidth.*

Evaluation Criteria

- Fair Resource Allocation
  - But even in the absence of reservations, equal shares may not equate to fair shares.
  - Should we also consider the length of the paths being compared?

Evaluation Criteria

- Fair Resource Allocation



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

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 $(x_1, x_2, \ldots, x_n)$ (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.