CS 5224
High Speed Networks and Multimedia Networking

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School of Computing
National University of Singapore

Organization

- Lecturer:
  - Dr. Chan Mun Choon (chanmc@comp.nus.edu.sg)
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- Course Information
  - Web-site: http://www.comp.nus.edu.sg/~cs5224
  - IVLE
  - Class Venue: S16 #04-05 (SR1)
  - Class Time: 6:30pm – 8:30pm, Wednesday
  - ***Office Hours: 3:30pm – 5:30pm Wednesday***

Course Description

- Introduce graduate students to fundamental networking problems and concepts
  - For students interested in the area of networking, this course will be rewarding
- Emphasis on problem solving and performance evaluation (queuing theory, graph algorithms etc.)
- Long homework
- Midterm + Finals

Course Pre-requisites

- Assume students have taken undergraduate networking classes like CS2105/CS3103
- Basic background on probability and algorithms
- Textbooks:
  - S. Keshav, "An Engineering Approach to Computer Networking", Addison-Wesley.
- Reference Books
  - Bertsekas and Gallager, "Data Networks", 2nd Edition, Prentice Hall

(Tentative) Outline/Schedule

1	10/8	Introduction and basic concepts	
2	17/8	Multiplexing, Queuing Theory	
3	24/8	Traffic Engineering	(HW1 Assign)
4	31/8	Simulation	(HW1 Due)
5	7/9	Scheduling and Buffer Management	(Hw 2 Assign)
6	14/9	Scheduling and Buffer Management	(HW 2 Due)
	21/8	Mid-Semester Break	
7	28/9	Midterm Exam	
8	5/10	Routing	
9	12/10	Routing	(HW3 Assign)
10	19/10	End-to-end Performance	(HW3 Due)
11	26/10	Transport	
12	2/11	Wireless Networks	(HW4 Assign)
13	9/11	Access/High Speed Networks	
	16/11	Reading Day	(HW 4 Due)

(Tentative) Grading Policy

- Homework 35% (4 Assignments)
- Class Participation 5%
- Mid-Term Exam 25%
- Final Exam 35%

Introduction and Basic Concepts

Outline

- **Types of Communication Networks**
- Quality of Service Measure and Classes
- Design issues/principles

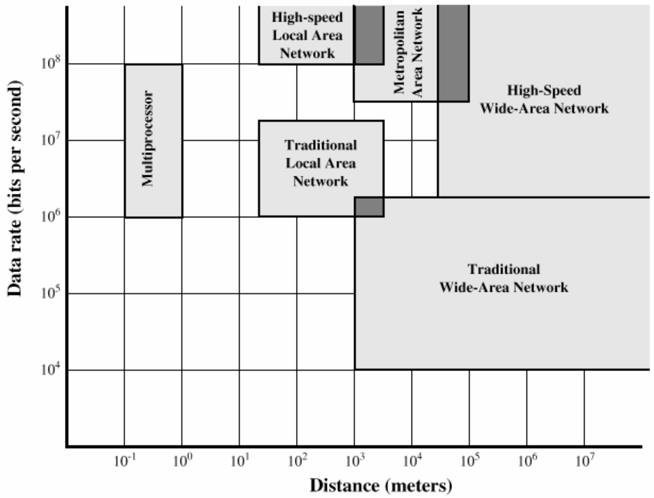


Figure 3.1 Comparison of Multiprocessor Systems, LANs, MANs, and WANs

Characteristics of WANs

- Covers large geographical areas
- Circuits provided by a common carrier
- Consists of interconnected switching nodes
- Legacy WANs provide modest connection capacity
  - 64 kbps were common
  - Business subscribers uses **T1 (1.544Mbps)**
- **Current WAN connections**
  - Higher-speed WANs use optical fiber and transmission technique known as asynchronous transfer mode (ATM) or SONET
  - **T1/DS3(45Mbps)/OC3(155Mbps)/OC12, Ethernet**
  - 10, 100 of Mbps or more are common

Characteristics of LANs

- Like WAN, LAN interconnects a variety of devices and provides a means for information exchange among them
- Legacy LANs
  - Provide data rates of 1 to 20 Mbps
- High-speed LANS
  - Provide data rates of 100 Mbps to 10 Gbps

Switching Terms

- Switching Nodes:
  - Intermediate switching device that moves data
  - Not concerned with content/payload of data
  - Switch based on timing or header information
- Stations:
  - End devices that wish to communicate
  - Each station is connected to a switching node
- Communications Network:
  - A collection of switching nodes

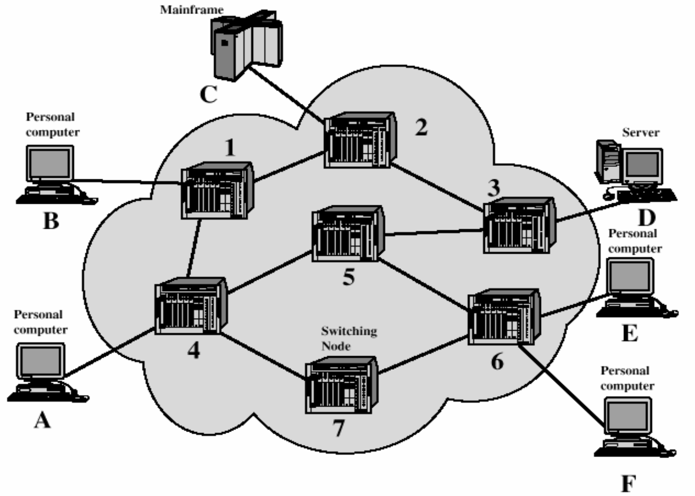


Figure 3.3 Simple Switching Network

Observations of Figure 3.3

- Some nodes connect only to other nodes (e.g., 5 and 7)
- Some nodes connect to one or more stations
- Node-station links usually dedicated point-to-point links
- Node-node links usually multiplexed links
  - Shared among difference source-destination pairs
- Not a direct link between every node pair
- Directly connecting all pairs requires N(N-1) or $O(N^2)$ links

Techniques Used in Switched Networks

- Circuit switching
  - Dedicated communications path between two stations
  - E.g., public telephone network
- Packet switching
  - Message is broken into a series of packets
  - Each node determines next leg of transmission for each packet

Phases of Circuit Switching

- Circuit establishment
  - An end to end circuit is established through switching nodes
- Information Transfer
  - Information transmitted through the network
  - Data may be analog voice, digitized voice, or binary data
- Circuit disconnect
  - Circuit is terminated
  - Each node deallocates dedicated resources

Characteristics of Circuit Switching

- Can be inefficient
  - Channel capacity dedicated for duration of connection
  - Utilization not 100%
  - Delay prior to signal transfer for establishment
- Once established, network is transparent to users
- Information transmitted at fixed data rate with only (fixed) propagation delay
- Best known circuit switched network is the Public Switch Telephone Network (PSTN)

How Packet Switching Works

- Data is transmitted in blocks, called packets
- Before sending, the message is broken into a series of packets
  - Packets consists of a portion of data plus a packet header that includes control information
- At each node en route, packet is received, stored briefly and passed to the next node
- The store and forward mode of operation incurred both (variable) queuing delay and propagation delay

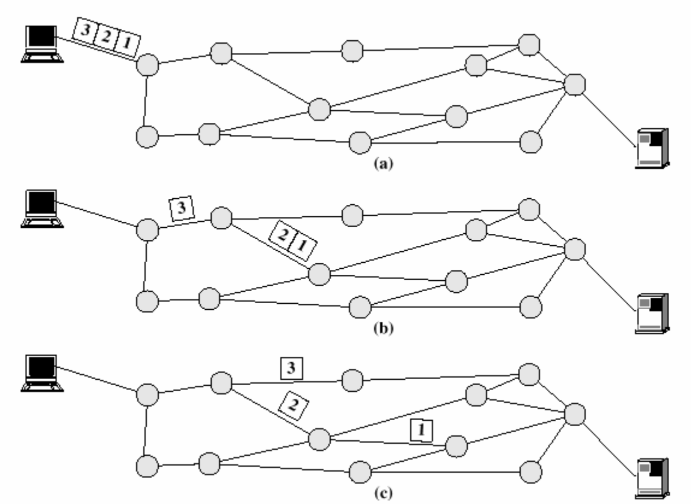


 Figure 3.7 Packet Switching: Datagram Approach

Packet Switching Advantages

- Line efficiency is greater
  - Many packets over time can dynamically share the same node to node link
- Packet-switching networks can carry out data-rate conversion
  - Two stations with different data rates can exchange information
- Unlike circuit-switching networks that block calls when traffic is heavy, packet-switching still accepts packets, but with increased delivery delay
- Priorities can be used at the packet level

Disadvantages of Packet Switching

- Each packet switching node introduces a delay
- Overall packet delay can vary substantially
  - This is referred to as jitter
  - Caused by differing packet sizes, routes taken and varying delay in the switches
- Each packet requires overhead information
  - Includes destination and sequencing information
  - Reduces communication capacity
- More processing required at each node

Packet Switching Networks - Virtual Circuit

- Preplanned route established before packets sent
- All packets between source and destination follow this route
- Routing decision not required by nodes for each packet
- Emulates a circuit in a circuit switching network but is not a dedicated path
  - Packets still buffered at each node and queued for output over a line

Packet Switching Networks – Virtual Circuit

- Advantages:
  - Packets arrive in original order
  - Packets arrive correctly
  - Packets transmitted more rapidly without routing decisions made at each node
- This is how ATM network works

Packet Switching Networks - Datagram

- Each packet treated independently, without reference to previous packets
- Each node chooses next node on packet's path
- Packets don't necessarily follow same route and may arrive out of sequence
- Exit node restores packets to original order
- Responsibility of exit node or destination to detect loss of packet and how to recover

Packet Switching Networks – Datagram

- Advantages:
  - Call setup phase is avoided
  - Because it's more primitive, it's more flexible
  - Datagram delivery is more "reliable"
- This is how the Internet works

Example

- Imagine a postal system implemented in the following ways:
  - 1. All mails coming from zip code 123456 will be delivered to 654321. This is ____________
  - 2. The zip code of all mails coming from zip code 123456 will be changed to 654321 and sent to the post office in Kent Ridge. This is ____________
  - 3. The zip code of all mails coming from zip code 123456 will be delivered to Kent Ridge. This is ____________

Recap: different types of networks

- A network is defined by its "switching mode" and its "networking mode"
- Circuit switching vs. packet switching
  - Circuit-switching: switching based on position (space, time, λ) of arriving bits
  - Packet-switching: switching based on information in packet headers
- Connectionless vs. connection-oriented networking:
  - CL: Packets routed based on address information in headers
  - CO: Connection set up (resources reserved) prior to data transfer

Switching modes \ Networking modes	Connectionless		Connection-oriented
Packet-switching	IP, SS7	MPLS IP + RSVP	ATM, X.25
Circuit-switching			Telephone network, SONET/SDH, WDM

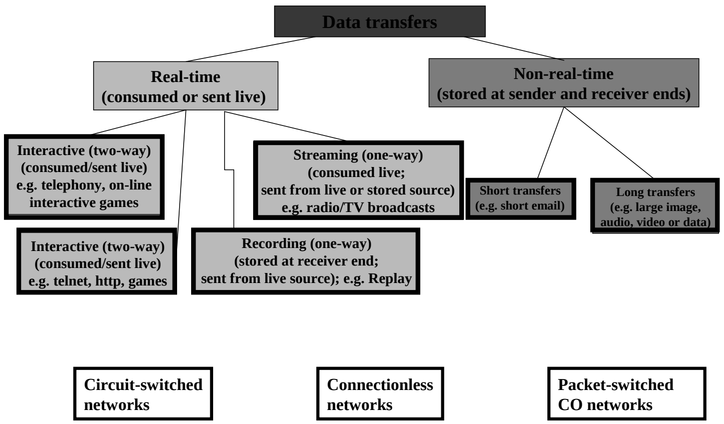
Types of data transfers

An application could consist of different types of data transfers

— **An http session has an interactive component, but could also have a non-real-time transfer**

Sending end \ Consuming end	Live	Stored
Live	**Interactive/ Live streaming**	**Recording**
Stored	**Stored streaming**	**File transfers**

Matching applications & networks



Outline

- Types of Communication Networks
- **Quality of Service Measure and Classes**
- Design issues and Scalability Requirements of Networks

"Quality of Service" Measure

- How is level of service measured in the network?
- Measure can be *deterministic* or *statistical*
- Common parameters are
  - bandwidth
  - delay
  - delay-jitter
  - loss

Bandwidth

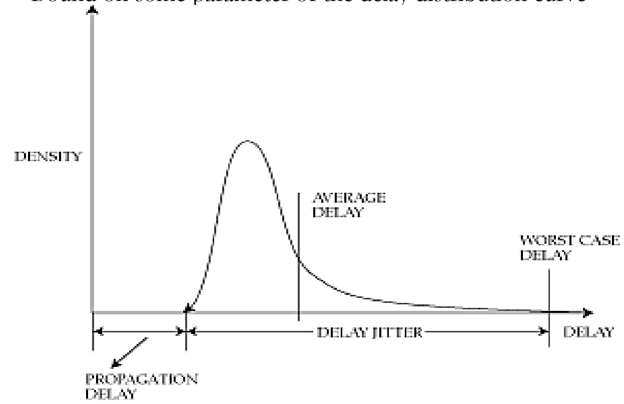
- Specified as minimum bandwidth measured over a pre-specified interval
- E.g. > 5Mbps over intervals of > 1 sec
- Meaningless without an interval!
- Can be a bound on average (sustained) rate or peak rate
- Peak is measured over a 'small' inteval
- Average is asymptote as intervals increase without bound

Packet Loss

- Specified ratio of packet loss over some interval
- Like bandwidth, meaningless without some reference to a measurement interval
- Common to use an average loss rate measured over a "sufficiently long" interval
- Consecutive packet loss can be of interest to some applications, e.g. those with error-correction capability

Delay and delay-jitter

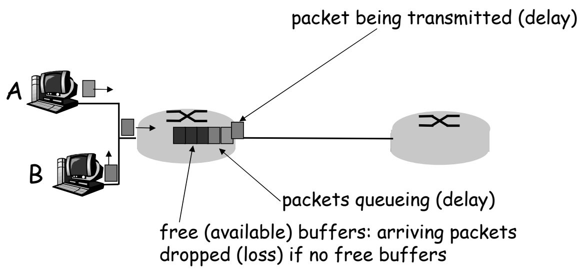
- Bound on some parameter of the delay distribution curve



How do loss and delay occur?

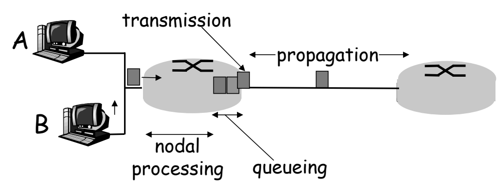
Packets *queue* in router buffers

- packet arrival rate to link exceeds output link capacity
- packets queue, wait for turn



Four sources of packet delay

- 1. nodal processing:
  - check bit errors
  - determine output link
- 2. queueing
  - time waiting at output link for transmission
  - depends on congestion level of router

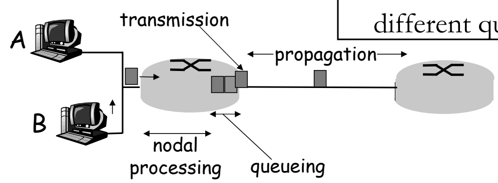


Delay in packet-switched networks

3. Transmission delay:
- R=link bandwidth (bps)
- L=packet length (bits)
- time to send bits into link = L/R

4. Propagation delay:
- d = length of physical link
- s = propagation speed in medium (~$2x10^8$ m/sec)
- propagation delay = d/s

Note: s and R are *very* different quantities!



Nodal delay

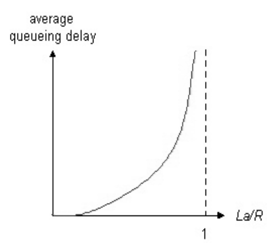
$$d_{\text{nodal}} = d_{\text{proc}} + d_{\text{queue}} + d_{\text{trans}} + d_{\text{prop}}$$

- d_{proc} = processing delay
  - typically a few microsecs or less
- d_{queue} = queuing delay
  - depends on congestion
- d_{trans} = transmission delay
  - = L/R, significant for low-speed links
- d_{prop} = propagation delay
  - a few microsecs to hundreds of msecs

Queueing delay (revisited)

- R=link bandwidth (bps)
- L=packet length (bits)
- a=average packet arrival rate

traffic intensity = La/R



- La/R ~ 0: average queueing delay small
- La/R -> 1: delays become large
- La/R > 1: more "work" arriving than can be serviced, average delay infinite!

Packet loss

- queue (aka buffer) preceding link in buffer has finite capacity
- when packet arrives to full queue, packet is dropped (aka lost)
- lost packet may be retransmitted by previous node, by source end system, or not retransmitted at all

Outline

- Types of Communication Networks
- Quality of Service Measure and Classes
- **Design issues/principles**

Common design techniques

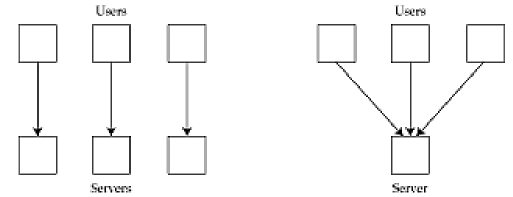
- Key concept: *bottleneck*
  - the most constrained element in a system
- System performance improves by removing bottleneck
  - but creates new bottlenecks
- In a *balanced* system, all resources are simultaneously bottlenecked
  - this is optimal
  - but nearly impossible to achieve
  - in practice, bottlenecks move from one part of the system to another

Top level goal

- Use unconstrained resources to alleviate bottleneck
- How to do this?
- Several standard techniques allow us to trade off one resource for another

Multiplexing

- Another word for sharing
- Trades time and space for money
- Users see an increased response time, and take up space when waiting, but the system costs less
  - economies of scale



Multiplexing (contd.)

- Examples
  - multiplexed links
  - shared memory
- Another way to look at a shared resource
  - *unshared virtual resource*
- *Server* controls access to the shared resource
  - uses a *schedule* to resolve contention
  - choice of scheduling critical in proving quality of service guarantees

Statistical multiplexing

- Suppose resource has capacity C
- Shared by N identical tasks
- Each task requires capacity c
- If Nc <= C, then the resource is underloaded
- If at most 10% of tasks active, then C >= Nc/10 is enough
  - we have used statistical knowledge of users to reduce system cost
  - this is *statistical multiplexing gain*

Statistical multiplexing (contd.)

- Two types: spatial and temporal
- Spatial
  - we expect only a fraction of tasks to be simultaneously active
- Temporal
  - we expect a task to be active only part of the time
    - e.g silence periods during a voice call

Example of statistical multiplexing gain

- Consider a 100 room hotel
- How many external phone lines does it need?
  - each line costs money to install and rent
  - tradeoff
- What if a voice call is active only 40% of the time?
  - can get both spatial and temporal statistical multiplexing gain
  - but only in a packet-switched network (why?)
- Remember
  - to get SMG, we need good statistics!
- Will cover statistical multiplexing in more detail in the queuing theory section

Optimizing the common case

- 80/20 rule
  - 80% of the time is spent in 20% of the code
- Optimize the 20% that counts
  - need to measure first!
  - RISC
- How much does it help?
  - Amdahl's law
  - Execution time after improvement = (execution affected by improvement / amount of improvement) + execution unaffected
  - beyond a point, speeding up the common case doesn't help

Hierarchy

- Recursive decomposition of a system into smaller pieces that depend only on parent for proper execution
- No single point of control
- Highly scaleable
- Leaf-to-leaf communication can be expensive
  - shortcuts help
- Most network naming schemes are hierarchical

More…

- Extensibility
  - Always a good idea to leave hooks that allow for future growth
  - Examples: version field in header, Modem negotiation
- Separation of Control and Data Path
  - Divide actions that happen once per data transfer from actions that happen once per packet
  - Can increase throughput by minimizing actions in data path

Acknowledgements

- Slides are taken from the following sources:
  - W. Stallings, "Wireless Communications and Networks", Chapter 3
  - S. Keshav, "An Engineering Approach to Computer Networking"
  - Kurose and Ross, "Computer Networking: A Top-Down Approach Featuring the Internet", Chapter 1