Network
Attributes and Technologies
#4

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Network Characterization

- Network impairments
  - The physical environment impacts network protocols
- Network performance criteria
- Basic networking technologies
  - Circuit Switching
  - Packet Switching
  - Virtual Circuit Switching

Network Impairments

- Propagation Delay:
  - ***The Speed of Light Limitation***

    Propagation delay =
    Distance (m)/(Speed of Light m/s)
  - Example: 3000 km fiber link
    Speed of light in fiber = 0.66*($3x10^8$m/s)
    Propagation delay = $3000x10^3$m/ 0.66*($3x10^8$m/s)= 15ms
    Speed of light in free space= 1.0*($3x10^8$m/s)
    Speed of light in coax= 0.88*($3x10^8$m/s)
- Clocking time

Example: Distance = 3000km, Data rate = 1 Mb/s, Packet size = 1000 bits

Source ——— Destination

Packet

Clocking time = L/C = 1 ms

Propagation time = 10 ms

Network Impairments:
Propagation Delay

- Satellite Networks
  - 500ms
- Terrestrial Networks
- PAN: Personal Area Networks [BAN: Body Area Network]
  - 3 m or 10ns
- DAN.: Desk Area Networks
  - 3 m or 10ns
- LAN: Local Area Networks
  - 3 Km or 10us

Network Impairments:
Propagation Delay

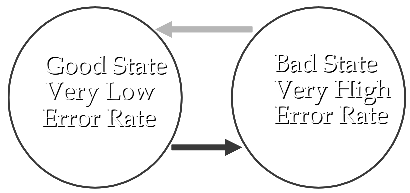
- MAN: Metropolitan Area Networks
  - 300 Km or 1ms
- NAN: National Area Networks
  - 3000 Km or 10ms
- GAN: Global Area Networks
  - 10,000 Km or 30ms
  - NANs and GANs are typically called WANs Wide Area Networks
- Interplanetary Networks

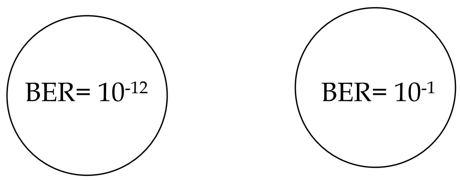
Network Impairments

- Error environment
  - Wired/Fiber/Cable
  - Wireless

Network Impairments: Error Environment

- Random, bit errors are independent
- Bursty, bit errors are correlated and come in groups,





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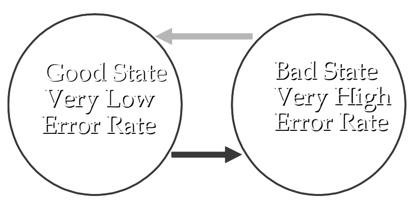
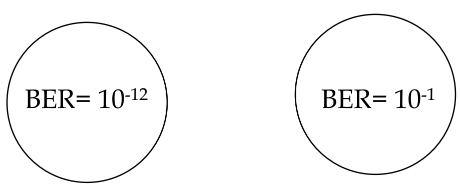




Network Impairments:

- Example: Impact of delay and errors:
  - Link rate 600 Mb/s
  - Free Space
  - Link distance 3000 km ⇒ 10ms
  - Packet size:
    - – Payload 48 bytes
    - – Overhead 5 bytes
    - – Total 53 bytes (424 bits)

Network Impairments:

424 bits/(600Mb/s) = .7us/packet
10ms/(0.7us/packet) = 14,285 packets in flight

Question: How do you cope with packets in error?

Network Impairments:

- Example:
  - Line rate = 600 Mb/s
  - Bit error rate(BER) = 10^{-9}
- What is the time between errors:
  - On average see one error in 10^9 bits
  - 10^9 bits/(600 Mb/s) = 1.66 sec between errors

Network Impairments and Application Types

- Real time interactive applications
  - Require fixed or bounded delays
  - Large delay *"variance"* can degrade performance
  - Some real-time applications can tolerate *some* errors, e.g.,
    - Voice
    - Video

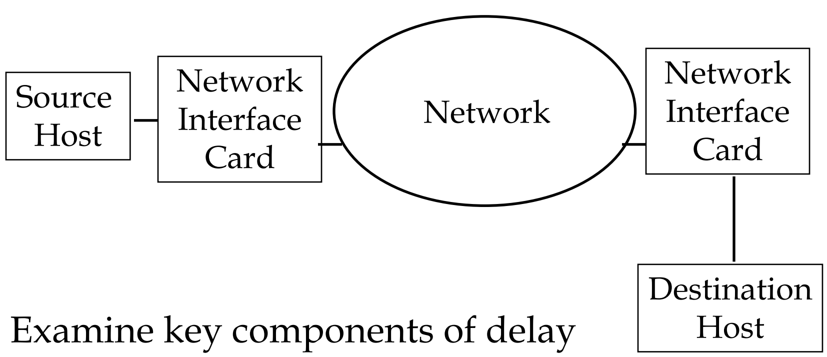
Network Impairments and Application Types

- Non Real time (elastic) applications
  - Can tolerate delay variance
  - Can not tolerate errors
    - E-mail
    - Telnet
    - FTP
    - www
  - Require accurate delivery of information
  - Does not require *'timely'* delivery of data

Network Performance Criteria

Response time T_R: The time to "correctly" transmit a packet from Source to destination.

"correctly" implies Response time includes acknowledgments



Examine key components of delay

Network Performance Criteria: Response Time

- Time from source applications to NIC
- Waiting time in NIC to enter the network: buffering time
- Time to transmit the packet: clock the packet into the network
- Time for the network to deliver the packet to the destination's NIC
- Time for destination's NIC to generate an acknowledgment
- Time for the acknowledgment to reach the source host: repeating the above steps

Network Performance Criteria: Response Time Dependencies

- State of the network
  - Current topology
  - Active nodes
  - Active links
- State of the other users
  - Congestion
- Errors
- State of source/destination host
- Link speeds
- Message sizes
- Message priorities

Network Performance Criteria: Response Time Statistics

- Response time, T_R is a random variable
- Probability density function characterizes T_R
- % packets observed with delays greater than T
- Variance
- Mean

Network Performance Criteria

- Network designers focus on the components of response time that are a function of the network
- Find the one-way delay as a function of:
  - traffic load
  - packet length
  - topology
- Focus on average response time or delay

Network Performance Criteria

- Throughput in b/s, packets/sec, cells/sec
- Normalized throughput

$$S = \frac{R}{C} \text{ where}$$

R = Average error free rate (b/s) passing a reference point in the network

C = Link Capacity (b/s)

S = % time the network is carrying error free packets-goodput

Network Performance Criteria

- Channel (or link) utilization:
  - The % time the channel (or link is busy)
- Channel Efficiency
  - The % time the channel is carrying user information (impact of overhead)

Let

D = # *user data bits / packet*

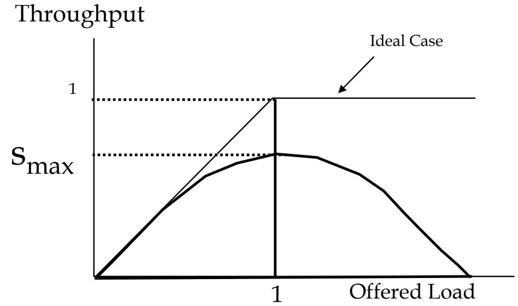
H = # *network overhead bits / packet*

then

$$\text{Channel efficiency} = S\left(\frac{D}{D+H}\right)$$

Network Performance Criteria

- Channel Capacity, Smax, is the maximum obtainable throughput over the entire range of input traffic intensities, i.e., offered load.

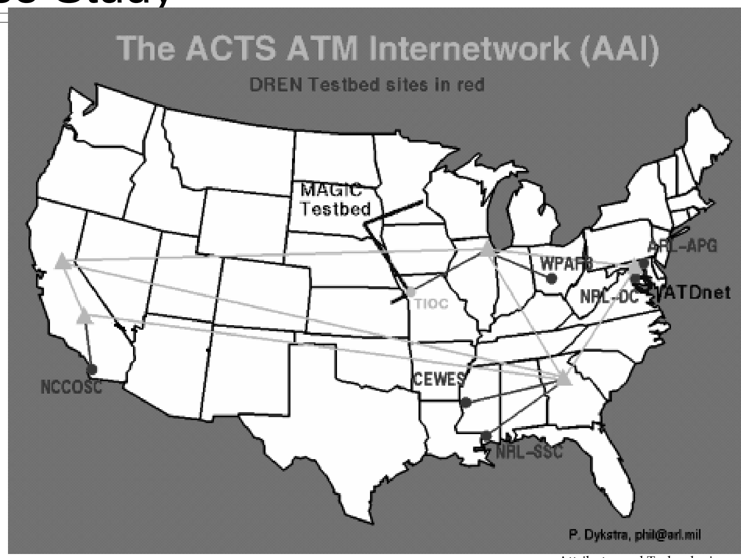


Network Performance Criteria: Other Throughput Metrics

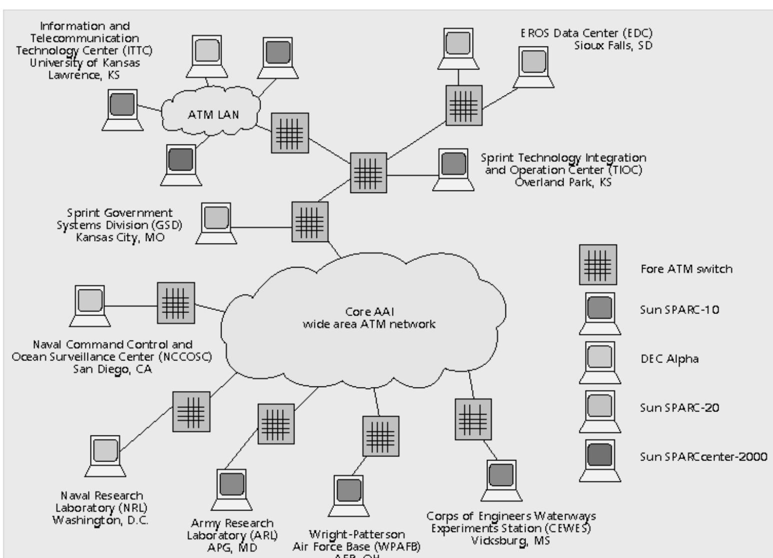
- Maximum lossless throughput
- Peak throughput
- Full load throughput

Transfer from local to remote host memory as fast as possible

Network Performance Criteria: Case Study

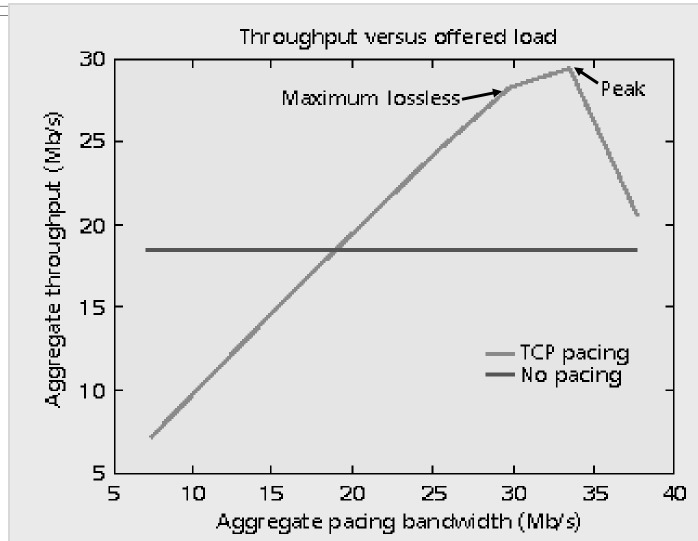


Network Performance Criteria: Case Study



Network Performance Criteria: Case Study

With DS3 Access Lines



Network Performance Criteria

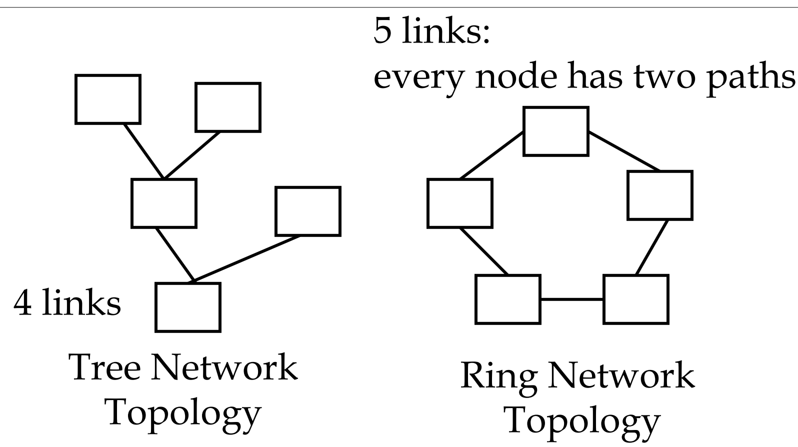
- Blocking Probability
  - Packet
  - Call

  Will derive & apply blocking formulas later
- Fairness
- Security
- Reliability

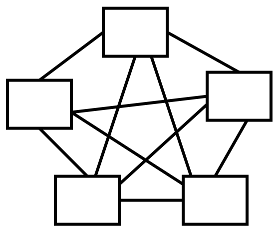
Network Performance Criteria

- Reliability: The reliability of a network can be defined as the probability that the functioning nodes are connected to working links.
  Reliability = 1 - Network Failure
- Here lets assume all nodes are working and analyze simple ring and tree networks

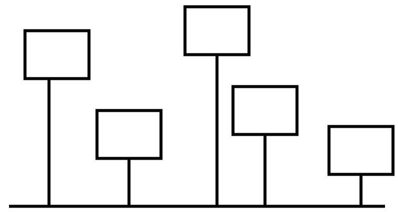
Network Performance Criteria



Other Network Topologies



Full Mesh Network Topology



Bus Network Topology

Network Performance Criteria

- Reliability for a 5 **node tree network**
- Any of the 4 links fail the network is down
- Let p = probability of link failure and failures are statistically independent
- Then Prob[no link failure] = $(1-p)^4$
- Prob[network failure] = $1 - (1-p)^4$

Network Performance Criteria

- But
  $(1-p)^4 = 1 - 4p + 6p^2 - 4p^3 + p^4$
- Prob[network failure] =
  $4p - 6p^2 + 4p^3 - p^4$
- Assuming p is small then
  for 5 node tree network the
  Prob[network failure] $\approx 4p$

Network Performance Criteria

- Reliability for a 5 node ring network
- Ring network has 5 links
- Ring network can have one link failure and still be working, note one more link can fail
- Let $q = 1 - p$=probability of link good
- Prob[network good]=Prob[all good or one failed and 4 good] = $q^5 + 5p\,q^4$

$$\sum_{j=1}^{5} \text{Prob[link j failed and all other links good]} = 5pq^4$$

- So Prob[network failure] =
  $1 - q^5 - 5p\,q^4$

Network Performance Criteria

- Expanding Prob[network failure] =
  $10p^2q^3 + 10p^3q^2 + 5p^4q + p^5$
- The dominant term (assuming p small) is $10p^2q^3$

Network Performance Criteria

Network Failure Probabilities

	Tree	Ring
p	4p	$10p^2q^3$
0.01	0.04	0.00097
0.001	0.004	10^{-5}
10^{-5}	$4x10^{-5}$	10^{-9}
10^{-7}	$4x10^{-7}$	10^{-13}

Network Performance Criteria: Example

Traffic Data Type	Network Service	Typical Message Size	QoS	SoS
Battle Command Data	IP Unicast & Mulitcast	100-500 Bytes	>95%	0.5sec
Situation Awareness	IP Broadcast	<100 Bytes	>95%	5 sec

QoS = Quality of Service = % IP packets successfully delivered

(for this RFP)

SoS = Speed of Service = Average time to deliver error free packets

From: DoD Proposal RFP October 1997

Network Performance Criteria: Example

Generic service type	**Virtual bandwidth**	**Tolerable error rate**	**Acceptable maximum delay**	**Tolerable delay variation**
Real time video	**> 4Mb/s**	**$< 10^{-6}$**	**~100 ms**	**<5 ms**
Web browsing	**>250 Kb/s**	**$< 10^{-5}$**	**~100 ms**	**<10 ms**
Multiparty network games	**> 100 Kb/s**	**$< 10^{-5}$**	**~50 ms**	**<5 ms**
Tele-commuting	**>1 Mb/s**	**$< 10^{-4}$**	**~1 sec**	**<500 ms**

From: IEEE Network Maginze, Jan/Feb 1997, pp 59.

Network Performance Perspective: User-Oriented

- Minimum application response time (Delay guarantee)
- Maximum application throughput (Throughput (b/s) guarantee)
- Low loss (Maximum packet loss guarantee)
- Highly reliable (Availability guarantee)
- Very flexible
- Secure
- Low cost

Network Performance Perspective: Network Manager/Provider

- Maximum throughput for all users
- Effective congestion control
- Power = Throughput/Delay
- **Easy of management**
- Highly reliable
- Fairness
- Ease of billing
- Low cost

Network Performance Perspective:

Network Designer/Developer/Vendor

- Simple design
- Robust
- **Scales**
  - **Number of users**
  - **Geographical distribution**
  - **Speed**
- Efficient use of resources, CPU, links and memory
- Evolvable

Network Performance: What Can the Network Guarantee?

- Quality of Service (QoS)-

  Absolute/Contractual performance guarantees

  Examples:
  - Sustainable rate
  - Peak rate
  - Packet delay (average and standard deviation)
  - Packet/Cell loss rate
- Network must reserve resources to provide QoS
- ATM is designed to provide QoS

Network Performance: What Can the Network Guarantee?

- Class of Service (CoS)-Relative performance guarantees
  Examples:
  - Best Effort (lowest priority) **[Current Internet is Best Effort]**
    - e-mail
    - ftp
  - Gold (medium priority)
    - Point of sales transaction
    - Telnet
  - Platinum (highest priority)
    - Voice
    - Video
- Network performs packet 'labeling' and priority queueing to provide CoS
- Differential Services (IP-DiffServ) provides CoS in the Internet

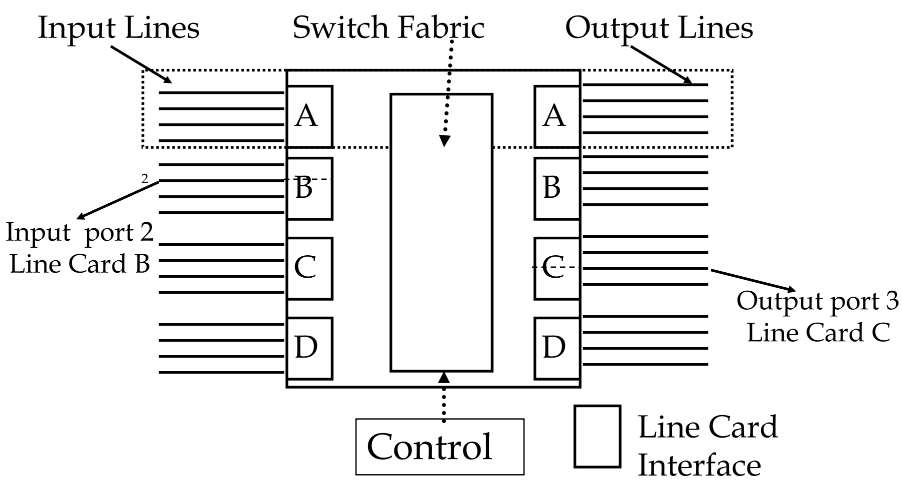
Network Performance: What Can the Network Guarantee?

- Network engineering issues:
  - QoS
    - Reserving resources implies per connection processing and saving flow state information for each flow
    - Reserving resources implies call set-up
    - Reserving resource thus implies complex per flow processing in each switch
  - CoS
    - Relative services implies simplified router processing only look at a label and queue appropriately
    - Relative services implies no unique per flow processing
  - Hybrids
    - QoS in the enterprise and CoS on the Core

Network Switching Technologies

- Circuit Switching
- Message Switching
- Packet Switching
  - Datagram
  - Virtual Circuit Switching
  - Cell Switching

Network Switching Technologies



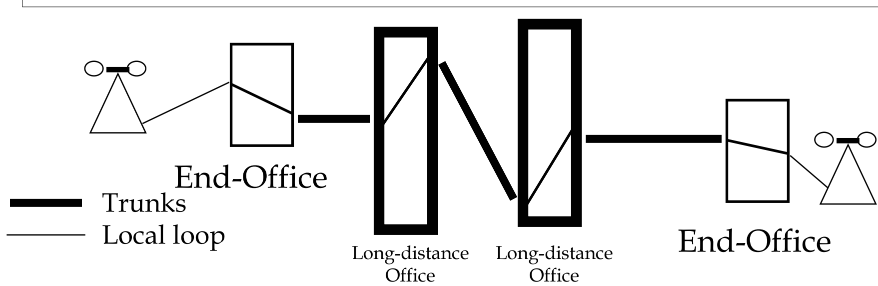
Network Switching Technologies

- Switching transfers information from input ports to output ports

Input port 2
Line Card B → **Output port 3**
Line Card C

- Elements of Switches
  - Line cards (multiple interfaces/card)
  - Switch fabric
  - Control (mappings)
  - Management
  - Billing

Network Switching Technologies: Circuit Switching



- **<u>On demand</u>** call set up
- Dedicated path
- Fixed network resources held for call duration

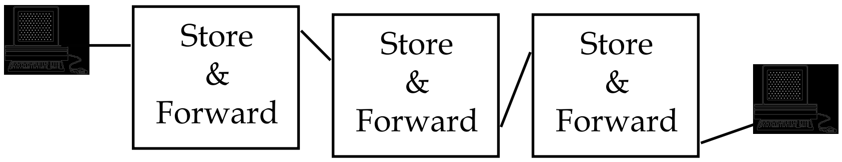
Network Switching Technologies: Circuit Switching

- Phases of a call
  - Call establishment
  - Information transfer
  - Call disconnect
- If no network resources are available the call blocks (fast busy signal)
- Network resources can be easily defined: e.g., *"Voice line"*

Network Switching Technologies: Circuit Switching

- The Public Switched Telephone Network (PSTN)
- DWDM Optical Networks
- Dial-up modems
- Customers can not use idle channels, that is unused capacity is wasted

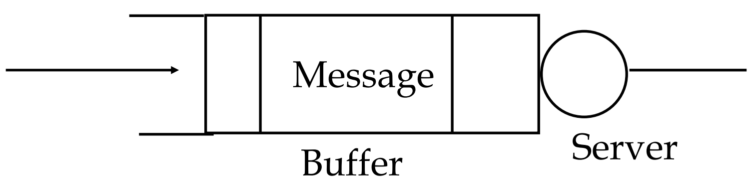
Network Switching Technologies: Message Switching



- No Dedicated path
- Address information is added to the message
- Store if output port is busy
- Trade off delay for blocking
- If message is corrupted then retransmit entire message

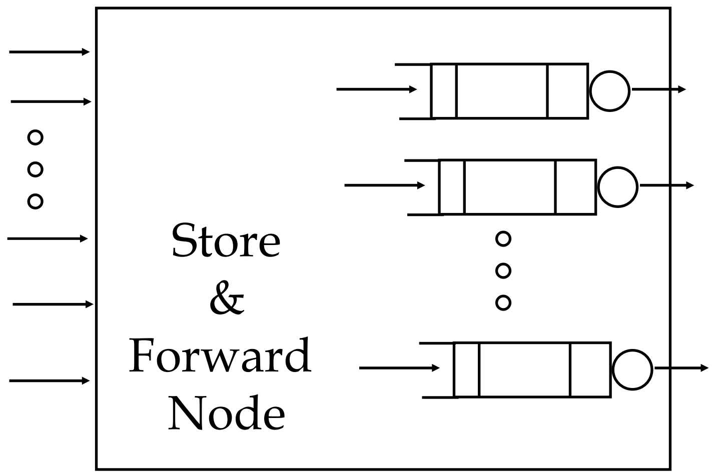
Network Switching Technologies: Message Switching

- If message arrives to empty system then it is transmitted at the **FULL LINE RATE**
- Transmission at the **FULL LINE RATE is shared among the all the users**
- If a message arrives to a busy system it waits



This is called a Statistical Multiplexer

Network Switching Technologies: Message Switching



Network Switching Technologies: Packet Switching

- Break up messages into smaller units: **Packets**
- The process of *"breaking up"* larger information units into smaller parts is called: **Segmentation or Fragmentation**
- The process of *"putting together"* smaller parts into larger information units is called: **Reassembly**
- **Segmentation and Reassembly (SAR) can happen multiple times to the same information stream, or flow**

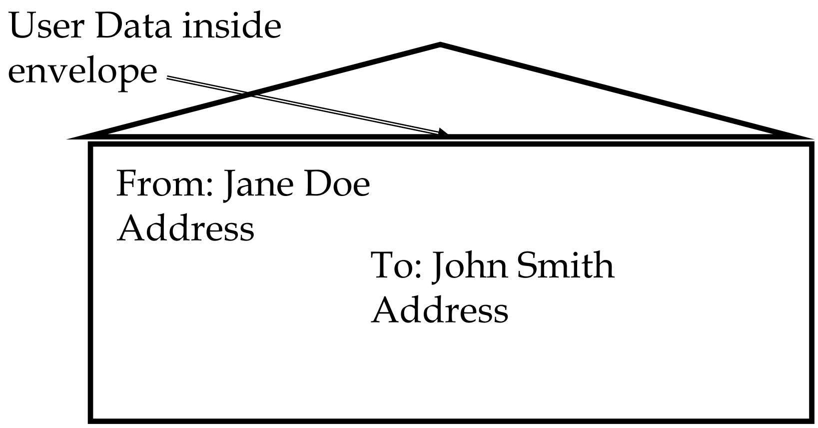
Network Switching Technologies: Packet Switching: Methods

- Datagram Packet Switching
  - Conectionless
- Virtual Circuit Packet Switching
  - Connection-oriented

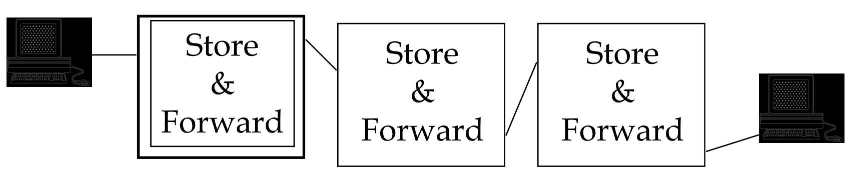
Network Switching Technologies: Packet Switching --> Datagrams

- Each packet is treated independently
- Packets with same destination may take different routes through the network
- Each nodes makes independent routing decisions
- No call set up is required
- Nodes keep no “state” information
- No QoS is guaranteed

Network Switching Technologies: Packet Switching -->Datagrams



Network Switching Technologies: Packet Switching --> Datagrams



Data	Destination Address	Source Address

Network Switching Technologies: Packet Switching --> Datagrams

- Datagram is an example of a connectionless service
- Internet Protocol (IP) provides a connectionless service

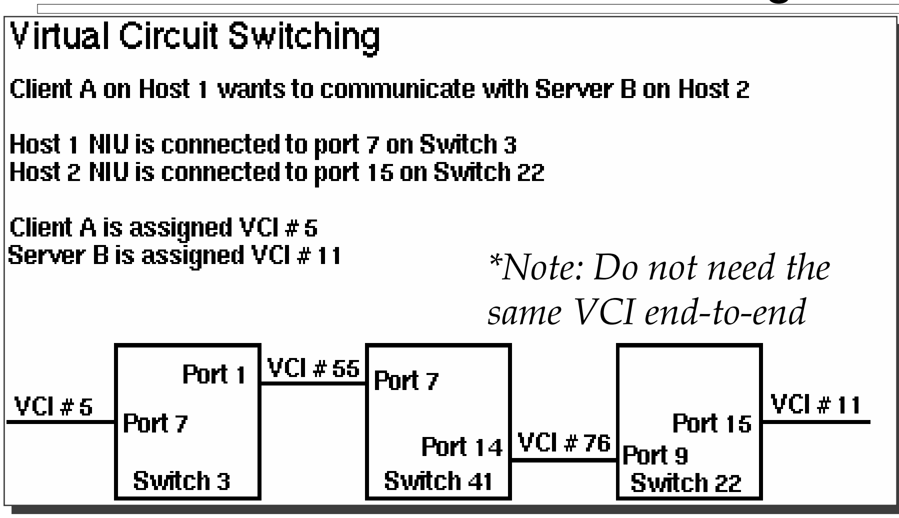
Network Switching Technologies: Virtual Circuit Packet Switching

- Virtual circuit packet switch is: **connection oriented**
- Connection oriented does not imply virtual circuits
- A *"logical connection"* is established between the source and destination
- All packets flow over the same route through the network
- Packets still *"statistically share"* link

Network Switching Technologies: Virtual Circuit Packet Switching

- Forwarding decisions are made based on a <u>*"virtual circuit identifier"*</u> not on the full address
- Packet share transmission facilities
- Switches save state/connection
- State is saved for duration of the connection
- QoS can be guaranteed

Network Switching Technologies: Virtual Circuit Packet Switching



Network Switching Technologies:
Virtual Circuit/Datagram Trade-offs

Example:

Find the time to transmit a 1 Kbyte message
coast-to-coast is the USA (3000Km)
on a 600 Mb/s link

a) Using Datagrams:

1*8000/(600Mb/s) + 10 ms ~ 10ms
(13 us)

b) Using Virtual Circuits

30ms

Call Set-up

A B

Data Transmission

Network Switching Technologies:
Virtual Circuit/Datagram Trade-offs

Example:

Find the time to transmit a 37.5 Mbyte message
coast-to-coast is the USA (3000Km)
on a 600 Mb/s link

a) Using Datagrams:

510ms

b) Using Virtual Circuits

530ms

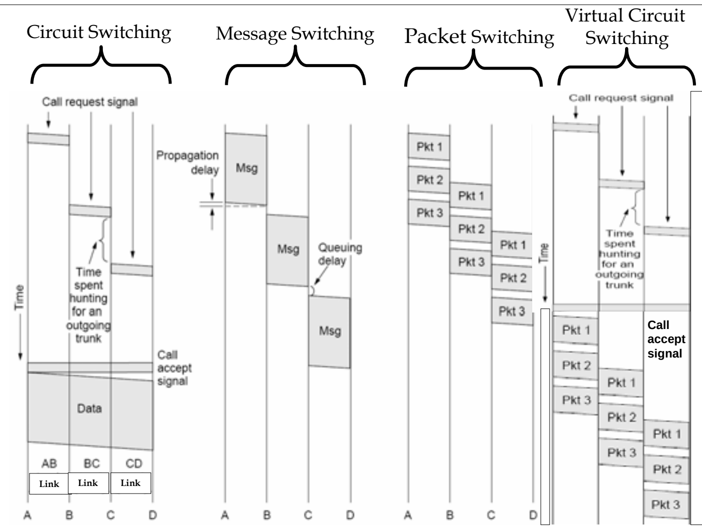
Call Set-up

A B

Data Transmission

Key issue is holding time relative to call set-up time

Comparison



Modified from: Computer Networks, A. S. Tannenbaum, 4th Ed, Prentice Hall, 2003

Network Switching Technologies:

- Permanent Virtual Circuits (PVC)
  - VC numbers assigned by management, usually manual
- Permanent Virtual Circuits are always up

Network Switching Technologies:

- Switched Virtual Circuits (SVC)
- Automatic user initiated call set-ups
- Call set up is on-demand

Network Switching Technologies: Switch State

- Circuit switched networks
  - Switches have "hard" state, they save knowledge of the connection throughout the duration of the call
- Pure datagram networks
  - Routers (switches) have no state of each connection or "flow".
  - Can use a *'label'* inside the packet for priority queuing

Network Switching Technologies: Soft state

- Often multiple related flows pass through a network element
- Implicit identification of what datagrams constitute a flow can be done based on source/destination addresses
- The states can be used for resource management --
  RSVP (Resource Reservation Protocol)
- State of flows are temporarily saved
- Unused soft state is cleared by time outs

Network Switching Technologies: Attributes of datagram transmission

- Decentralized control
- Simple hosts and switches
- No call processing
- Difficult to provide QoS
- Difficult to bill for services
- Difficult to manage resources to control congestion, note if no congestion then not an issue

Network Switching Technologies: Attributes of Virtual Circuit Connection Oriented Networks

- Provides QoS
- Accommodates billing
- Centralized control
- Follows well known model of the PSTN
- Simpler switching
- Complex control
- Soft state is trying to give connectionless systems attributes of an connection oriented network

Network Switching Technologies: Cell Switching

- Packets tend to be variable size
- Variable size packets increase hardware complexity
- Variable size packets increase difficulty of providing integrated services with QoS
- Solution: Small fixed length packets called **"Cells"**
- ATM is based on cell switching with:
  - 5 byte headers
  - 48 byte payloads