

EE2 / ISE2 Communications II

Part II: Introduction to Communication Networks

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0. Aims and Objectives

- Learn the basic concepts of communication and computer networks
- Objectives:
 - ◆ Describe communication architectures (OSI, TCP/IP)
 - ◆ Describe different transmission media
 - ◆ Understand multiplexing and switching techniques
- References:
 - ◆ Stallings, *Data and Computer Communications* , PH 2000
 - ◆ Kurose and Ross, *Computer Networking* , AW 2003

Networks

- Interconnected system of nodes and links (e.g. Internet > 30 million nodes)
- Point-to-point communications are not usually practical in the construction of networks:
 - ◆ Devices may be too far apart
 - ◆ May require an impractical number of connections
- Solution:
 - ◆ Share resources (i.e. capacity of links and nodes)

How a Channel can be Shared?

- Divide the channel capacity into “pieces” and allocate each “piece” to a communication:

1. Fixed multiplexing

- ◆ “Pieces” may be idle if not used
- ◆ Types:
 - frequency division multiplexing (FDM) and wavelength division multiplexing (WDM)
 - time division multiplexing (TDM)

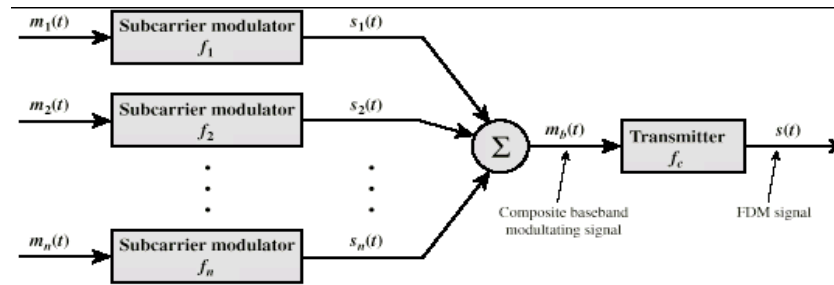
2. Statistical multiplexing

- ◆ Allocates resources on demand
- ◆ Types:
 - Statistical TDM
 - Packets

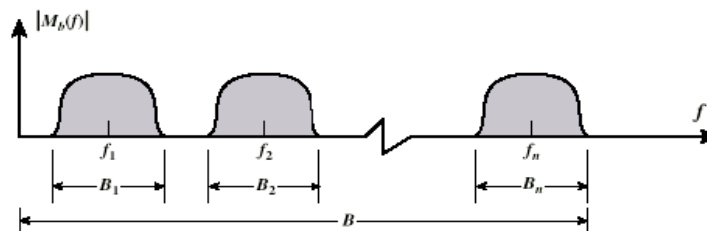
FDM and WDM

- Useful when bandwidth of medium exceeds required bandwidth of channel
- Channel allocated even if no data
- FDM
 - ◆ Each signal is modulated in a different carrier frequency
 - ◆ Carrier frequencies are separated by guard bands
- WDM
 - ◆ Multiple beams of light carried by optical fiber
 - ◆ Each color (wavelength) carries a data channel

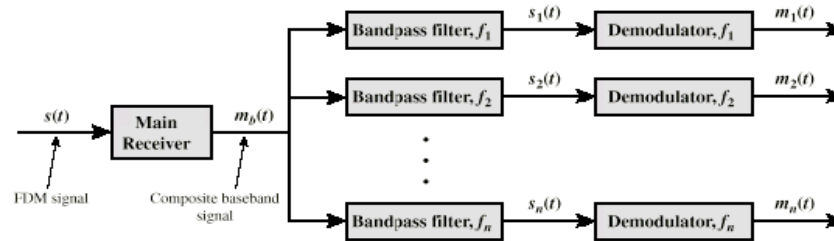
FDM System



(a) Transmitter



(b) Spectrum of composite baseband modulating signal

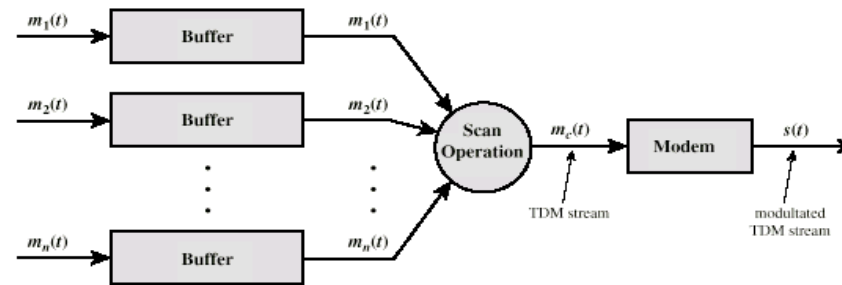


(c) Receiver

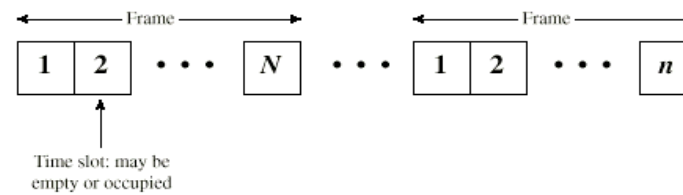
Time Division Multiplexing

- Data rate of medium exceeds data rate of digital signal to be transmitted
- Multiple digital signals are interleaved in time (need synchronism)
- Fixed time slots are pre-assigned to sources
- Time slots allocated even if no data
- Time slots do not have to be evenly distributed among sources

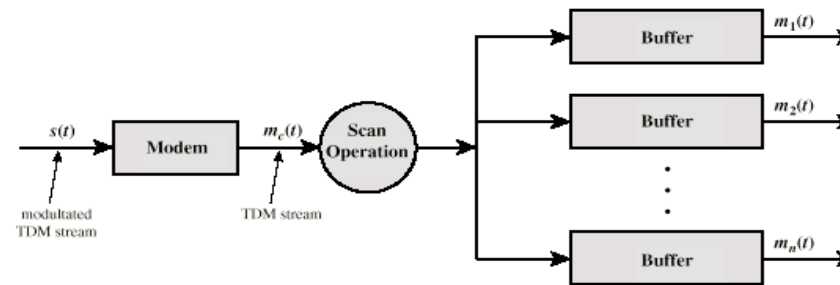
TDM System



(a) Transmitter



(b) TDM Frames



(c) Receiver

Statistical Multiplexing

- Motivation: TDM is not efficient in many cases as idle slots are a waste of time
- Better approach: allocate time slots based on demand (statistical TDM)
- Drawback: additional control is needed (e.g. addresses and access control)
- Advantage: aggregate resource demand may exceed amount available

Statistical Multiplexing with Packets

- Packets are a general form of statistical multiplexing that does not imply synchronism
- Resources are used as needed
- Packets use full link bandwidth when transmitted
- Drawback: resource contention:
 - ◆ Produced when demand exceeds available resources
 - ◆ May lead to congestion

How can a Network be Shared?

- Answer: Switching
- Three different switching technologies:
 - ◆ Circuit switching
 - ◆ Message switching
 - ◆ Packet switching

Circuit Switching

- Developed for voice traffic (telephone)
- A dedicated communications path is established for the duration of a conversation
- Disadvantages:
 - ◆ channels may be idle (uses fixed multiplexing)
 - ◆ Needs time to set up paths
- Advantages:
 - ◆ Communication does need much additional control once established

Message and Packet Switching

- In message switching, the message is sent as one unit (not very popular)
- In packet switching, long messages are split into series of packets
- Need control information (e.g. headers, addressing, etc.)
- Packets are passed from node to node between source and destination
- Packets need to be completely received at a node before proceeding on the next hop (store and forward)

Advantages of Packet vs. Circuit Switching

- Line efficiency
 - ◆ Single node to node link can be shared by many packets over time
 - ◆ Packets queued and transmitted as fast as possible
- Data rate conversion
 - ◆ Each station connects to the local node at its own speed
 - ◆ Nodes buffer data if required to equalize rates
- Packets are accepted even when network is busy
 - ◆ Delivery may slow down
- Simple, good for bursty traffic mainly

Disadvantages of Packet Switching

- May lead to congestion:
 - ◆ Congestion produce severe packet delay and loss
 - ◆ Additional protocols are needed for reliable data transfer and congestion control

Protocols:

- ◆ define format, order of messages sent and received among network entities (nodes, processes, etc)
- ◆ also, define the actions taken on transmission and receipt of messages

Delay and Loss

Delay is the sum of the following factors:

1. Processing delay:

- Process packet headers, determine output link

2. Queueing

- time waiting at output link for transmission
- depends on congestion level

3. Transmission delay: $= L/R$

- R =link bandwidth (bps), L =packet length (bits)

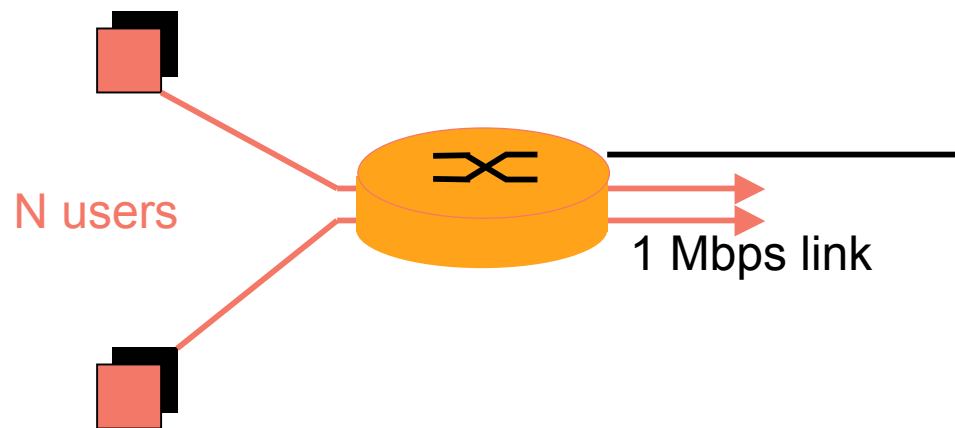
4. Propagation delay: $= d/s$

- d = length of physical link, s = propagation speed in medium ($\sim 2 \times 10^8$ m/sec)

Loss is typically the result of propagation problems (noise, interference, etc.) or the finite capacity of buffers

Packet vs. Circuit Switching Example

- Suppose there is a 1Mbps link and each user transmit at 100 kbps when active, which happens only 10% of the time
- How many users can be served when using circuit switching?
packet switching?

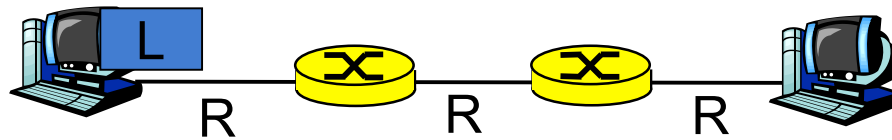


Answer:

circuit-switching:
10 users

packet switching:
with 35 users, probability > 10
active less than .0004

Message Switching Example

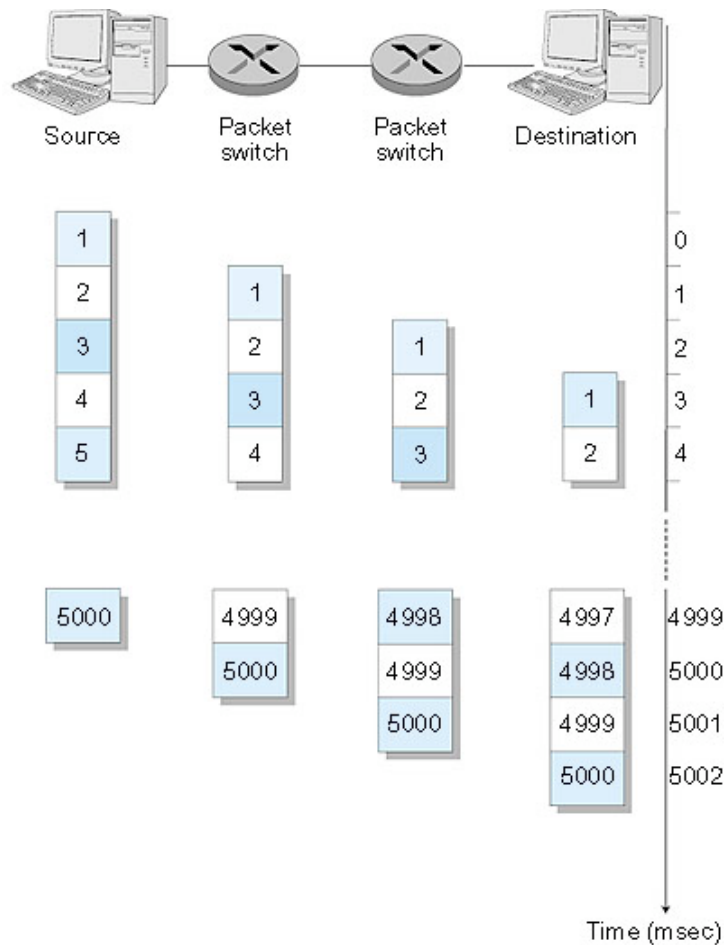


- Assume that we wish to transmit a message of size L over 3 hops
- It takes L/R seconds to transmit a packet of L bits on to link or R bps (assuming no propagation delay)
- Resulting delay = $3L/R$

Example:

- $L = 7.5$ Mbits
- $R = 1.5$ Mbps
- delay = 15 sec

Packet Switching Example



Assume now that we break up the message into 5000 packets

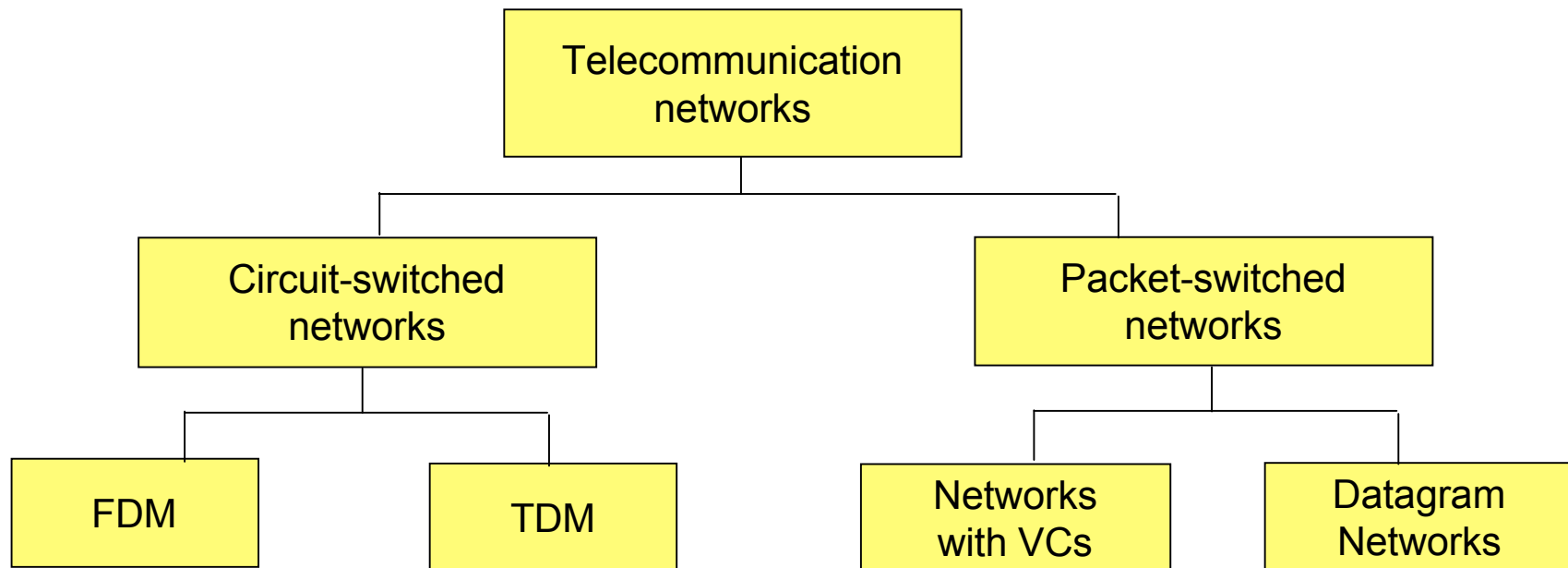
- Each packet 1,500 bits
- 1 msec to transmit packet on one link
- *pipelining*: each link works in parallel
- Delay reduced from 15 sec to 5.002 sec

Packet Switching Techniques

Goal: move packets through nodes from source to destination

Types: datagram network or virtual circuit network

The big picture:



Datagram Network

- Each packet is treated independently
- Packets can take any practical route, which may change during the communication session
- Packets may arrive out of order
- Packets may go missing
- It is up to receiver to re-order packets and recover from missing packets
- Destination address in packet determines next hop
- Analogy: driving, asking directions
- Example: the Internet

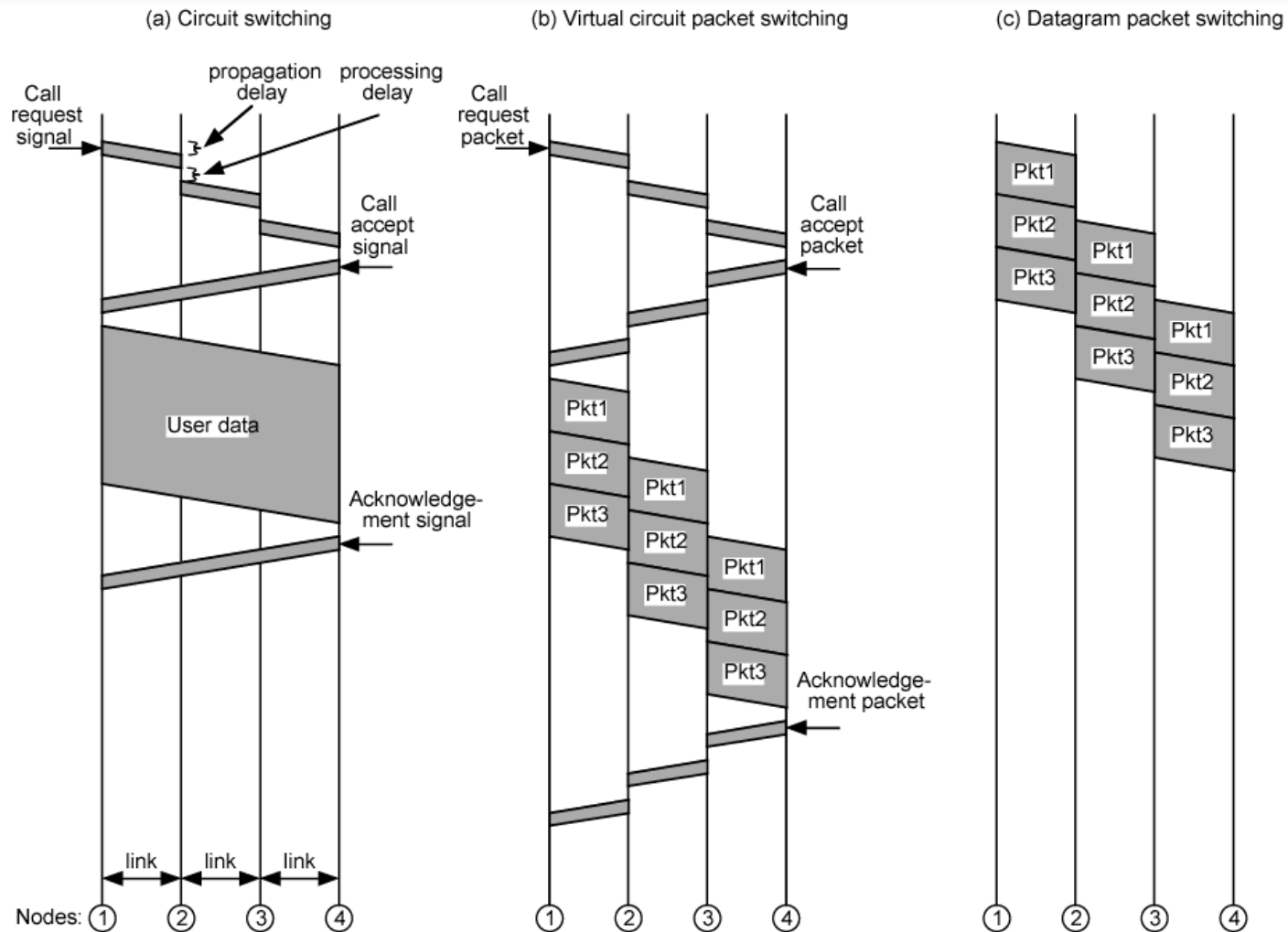
Virtual Circuit

- Preplanned route established before any packets sent (call setup)
- Call request and call accept packets establish connection (handshake)
- Each packet contains a virtual circuit identifier instead of destination address
- Nodes maintain per-call state
- Need a clear request to drop circuit
- Note that this is not circuit switching and therefore there is no dedicated path
- Example: Asynchronous transfer mode networks (ATM)

Virtual Circuits vs. Datagrams

- Virtual circuits
 - ◆ Network can provide sequencing and error control
 - ◆ Packets are forwarded more quickly
 - No routing decisions to make
 - ◆ Less reliable
 - Loss of a node loses all circuits through that node
- Datagram
 - ◆ No call setup phase
 - Better if few packets
 - ◆ More flexible
 - Routing can be used to avoid congested parts of the network

Event Timing of Switching Techniques



2. The Need for a Layered Protocol Architecture

- Network design is too complex to be completed as one system design
- Better idea:
 - ◆ break entire task into subtasks (or modules)
 - ◆ Create an structure of subtasks (stack of layers) that allows an easy identification of relations among pieces and an easy update of the system
- Principles in the design of layers:
 - ◆ Each layer relies on the next lower layer to perform more primitive functions
 - ◆ Each layer provides services to the next higher layer
 - ◆ Changes in one layer should not require changes in other layers
 - ◆ Communication is peer to peer (layer to equivalent layer in destination system)

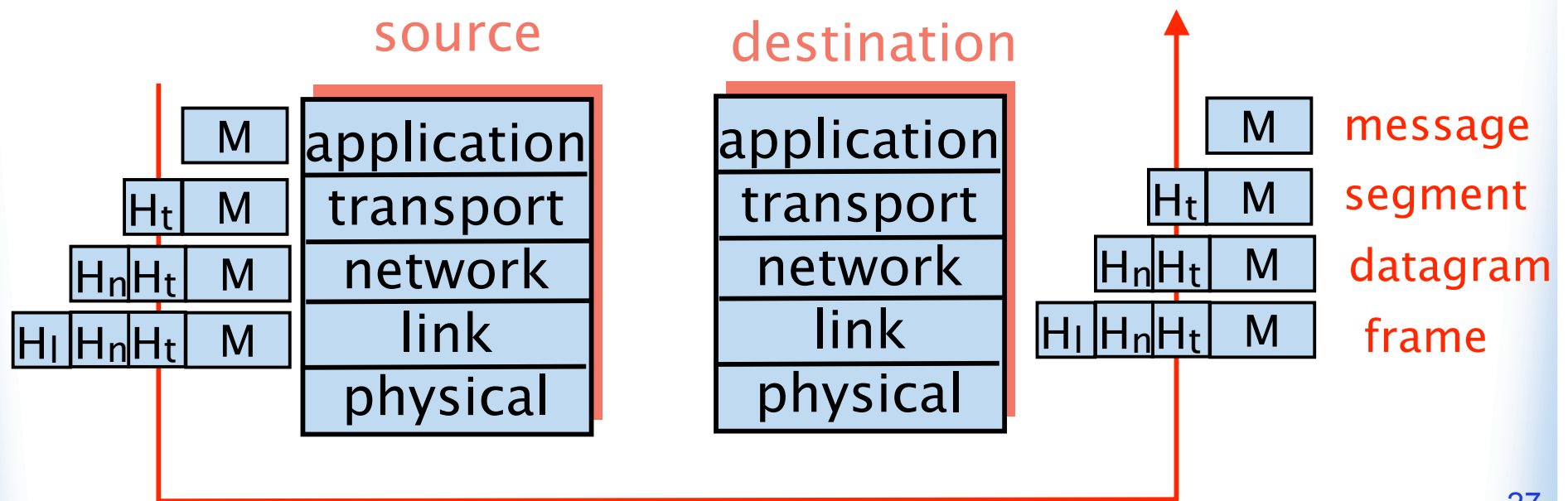
TCP/IP Protocol Architecture

- Application layer
 - ◆ Support for user applications
- Transport layer
 - ◆ Connection oriented and connectionless services
 - ◆ Reliable delivery of data
 - ◆ Ordering of delivery
- Internet layer
 - ◆ Routing functions across multiple networks
- Network Access or Data Link layer
- Physical layer

Protocol Layering and Data

Each layer takes data from above

- adds header information to create new data unit
- passes new data unit to layer below



TCP vs. UDP

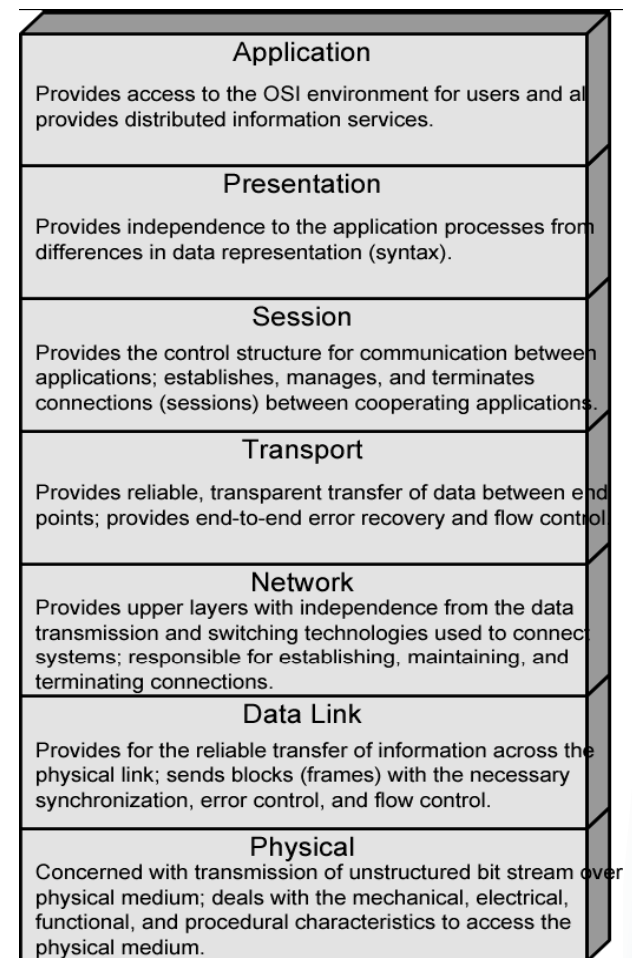
- **UDP**
 - ♦ *best effort* service (no guarantees), UDP segments may be:
 - lost
 - delivered out of order to application
 - ♦ *connectionless*:
 - no handshaking between UDP sender, receiver
 - Each UDP segment is handled independently of others
- **TCP**
 - ♦ **Reliable service**:
 - Retransmit on packet loss
 - Implements flow and congestion control
 - Deliver packets in order to application
 - ♦ **connection oriented**
 - Handshake between TCP sender and receiver

OSI Model

Open Systems Interconnection Model
developed by the International Organization
for Standardization (ISO)

Theoretical system delivered too late!
TCP/IP continues to be the de facto standard

OSI	TCP/IP
Application	Application
Presentation	
Session	
Transport	Transport (host-to-host)
Network	Internet
Data Link	Network Access
Physical	Physical



3. Physical Layer

Goal: Move bits from transmitter to receiver(s):

- Define transmission media
- Format of bits, modulation, timing, etc.
- Characteristics of interfaces (electrical, mechanical, etc.)

Key concerns are data rate and distance

Types of transmission media:

1. unguided media (wireless):

signals propagate freely: radio, infrared

2. guided media (wired):

signals propagate in solid media: twisted pair, coaxial cable, optical fiber

Unguided Media

- Signal carried in electromagnetic spectrum
- Affected by:
 - ◆ propagation environment
 - ◆ reflection
 - ◆ objects
 - ◆ Interference
 - ◆ etc.
- Examples:
 - ◆ Terrestrial microwave: directional transmission using parabolic dish and typically used for long haul communications. Requires line of sight
 - ◆ Satellite microwave

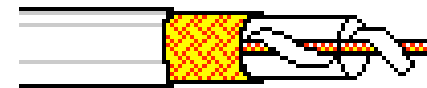
Twisted Pair Cable

- Two insulated copper wires twisted together
- Applications:
 - ♦ telephone (between house and local exchange or PBX)
 - ♦ local area networks (LAN)
- Cheap, easy to work with
- Low data rate, short range
- Analog:
 - ♦ Amplifiers every 5km to 6km
- Digital:
 - ♦ repeater every 2km or 3km
- Very susceptible to interference, crosstalk and noise



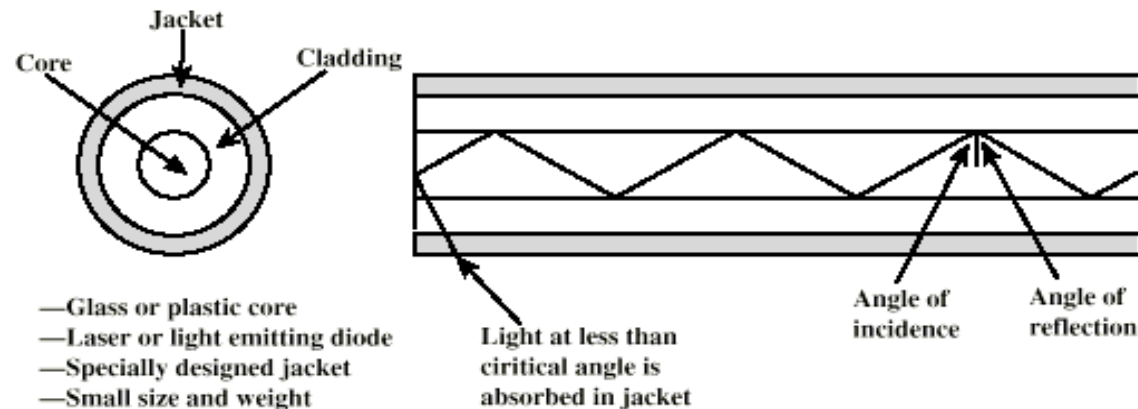
Coaxial Cable

- Two concentric copper conductors, bidirectional
- Baseband: single channel on cable (e.g. Ethernet)
- Broadband: multiple channels on cable
- Analog
 - ◆ Amplifiers every few km, closer if higher frequency
 - ◆ Up to 500MHz
- Digital
 - ◆ Repeater every 1km, closer for higher data



Optical Fiber

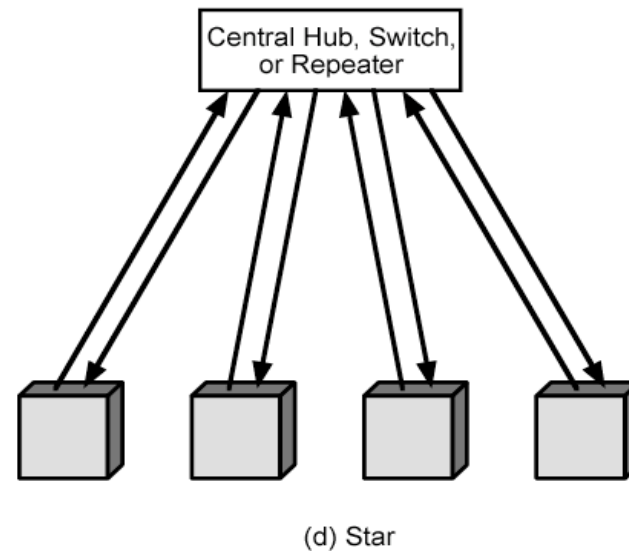
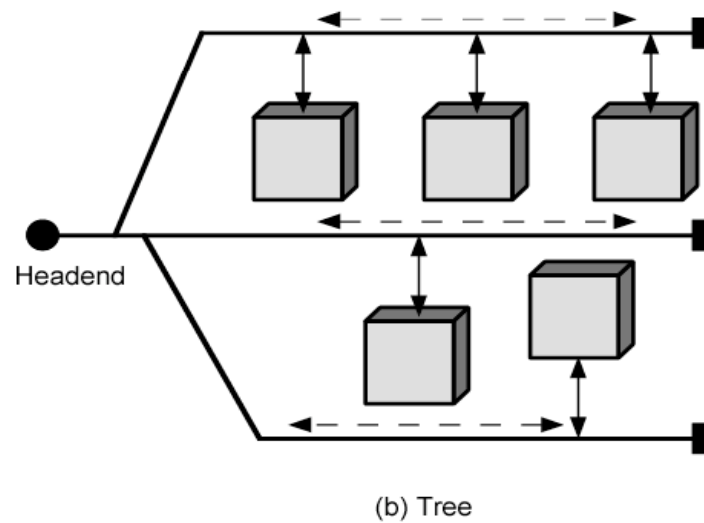
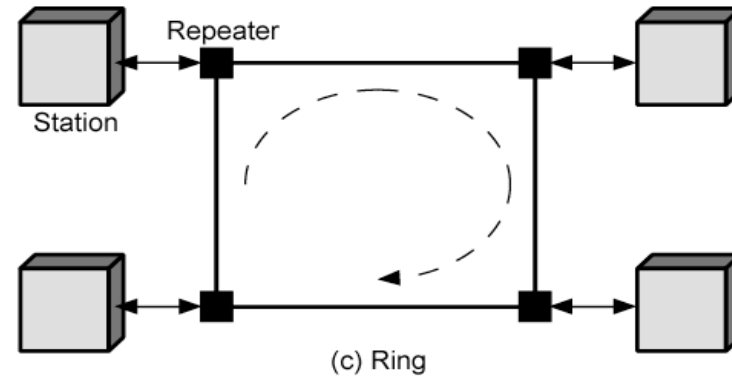
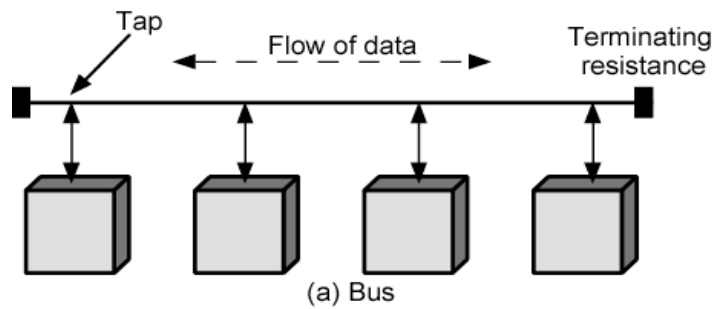
- OF is a thin flexible medium capable of guiding an optical ray
- Great capacity: data rates of hundreds of Gbps
- Smaller size and weight, low attenuation, and electromagnetic isolation
- Repeater spacing 10s of km at least



4. The Data Link Layer

- Goal: Move packets from transmitter to receiver(s):
 - ◆ Take care of error detection, correction
 - ◆ Determine how to share broadcast channels (multiple access), determine addressing
 - ◆ Implement reliable data transfer, flow control
- Local Area Networks (LAN) are typically defined here
- Broadcast (shared) vs. point-to-point (dedicated) channels

LAN Topologies



Multiple Access Protocols

- Probably the most salient task of this layer is that of multiple access control
- Defines a distributed algorithm that determines how nodes share a broadcast channel, i.e., determine when a node can transmit (note that only one node can transmit successfully at a time)
- The communication about channel sharing may use the channel itself!

Ideal Multiple Access Protocol

Assuming a Broadcast channel of rate R bps

1. When one node wants to transmit, it can send at rate R .
2. When M nodes want to transmit, each can send at average rate R/M
3. Fully decentralized:
 - ◆ no special node to coordinate transmissions
 - ◆ no synchronization of clocks, slots
4. Simple

MAC Protocols: a taxonomy

Three broad classes:

1. Channel Partitioning

- ◆ divide channel into smaller “pieces” (time slots, frequency)
- ◆ allocate piece to node for exclusive use

2. Random Access

- ◆ channel not divided, allow collisions
- ◆ “recover” from collisions

3. “Taking turns”

- ◆ tightly coordinate shared access to avoid collisions

Random Access Protocols

- When node has packet to send
 - ◆ transmit at full channel data rate R .
 - ◆ no a priori coordination among nodes
- two or more transmitting nodes = “collision”
- random access MAC protocol specifies:
 - ◆ how to detect collisions
 - ◆ how to recover from collisions (e.g., via delayed retransmissions)
- Examples of random access MAC protocols:
 - ◆ slotted ALOHA. ALOHA
 - ◆ CSMA, CSMA/CD, CSMA/CA

CSMA/CD (Carrier Sense Multiple Access / Collision Detection)

CSMA: listen before transmit:

- ◆ If channel sensed **idle**: transmit entire frame
- ◆ If channel sensed **busy**, defer transmission

CSMA/CD:

- ◆ collisions *detected* within short time
- ◆ colliding transmissions aborted, reducing channel wastage
- ◆ collision detection:
 - easy in wired LANs: measure signal strengths, compare transmitted, received signals
 - difficult in wireless LANs: receiver shut off while transmitting

CSMA without CD

With pure CSMA collisions *can* occur:

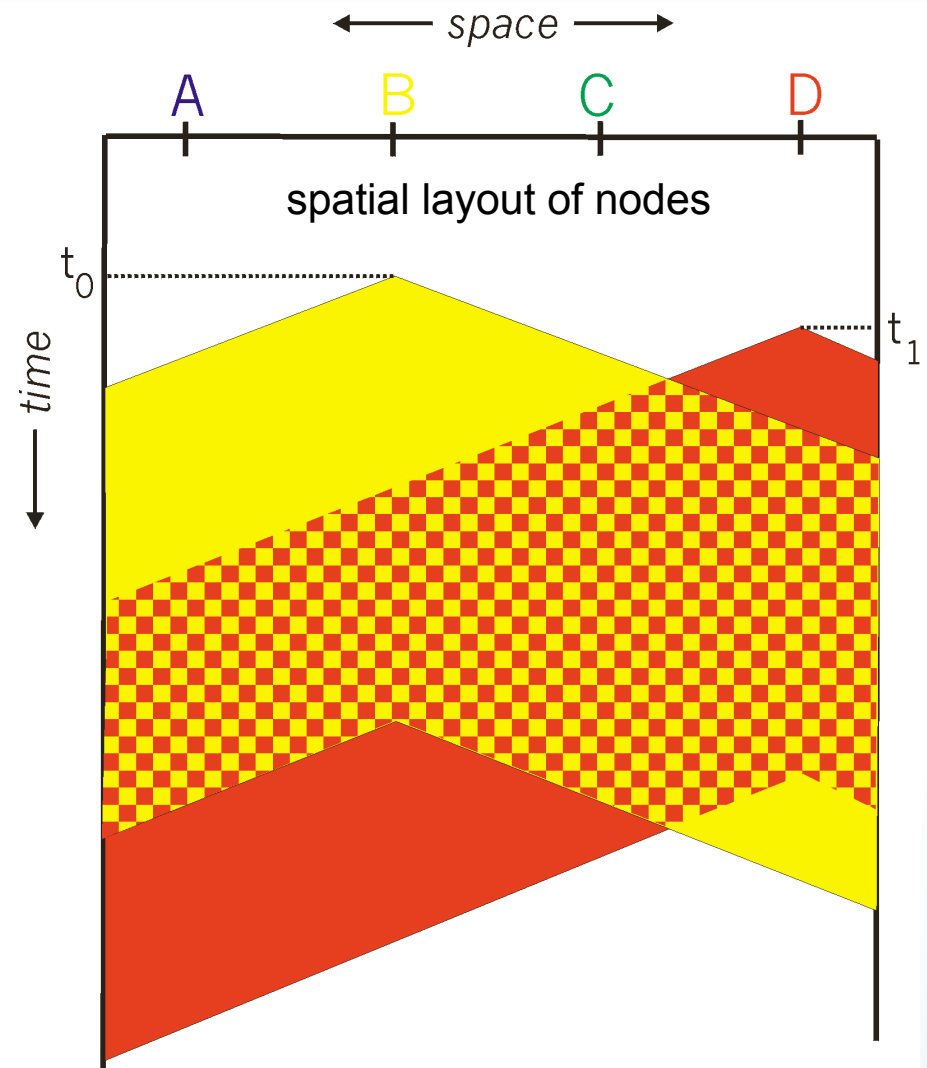
propagation delay means two nodes may not hear each other's transmission

collision:

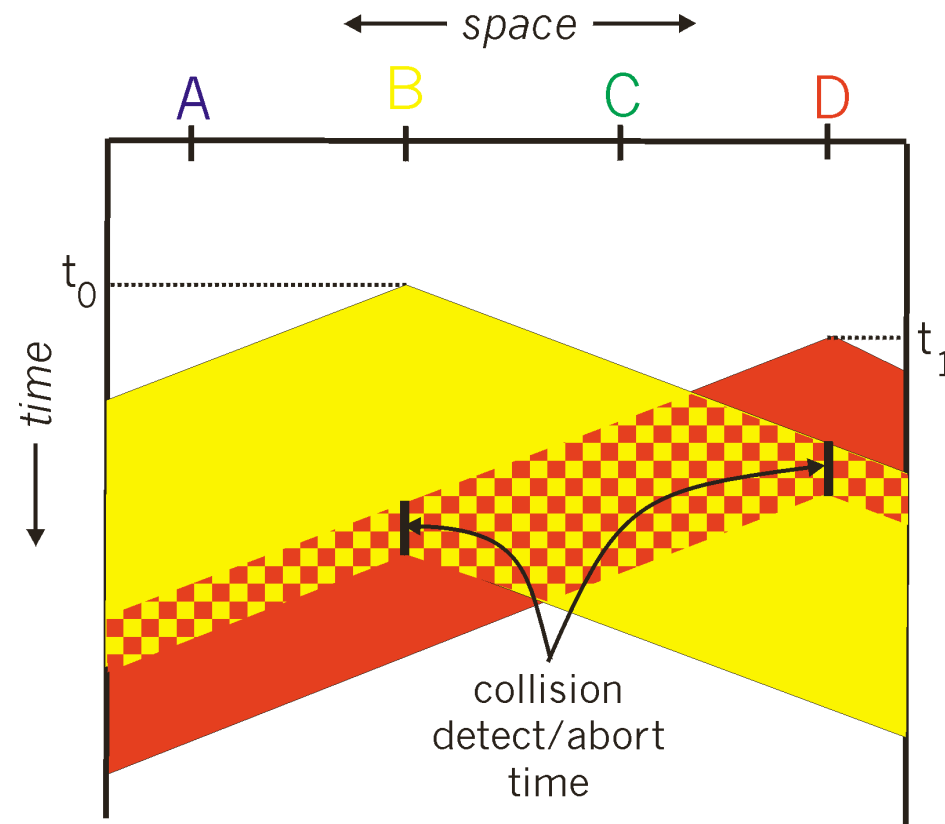
entire packet transmission time wasted

note:

1. role of distance & propagation delay in determining collision probability
2. Attenuation and distance



CSMA/CD collision detection



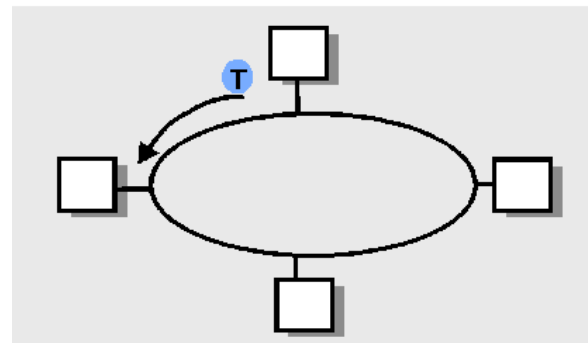
“Taking Turns” MAC protocols

Polling:

- master node “invites” slave nodes to transmit in turn
- concerns:
 - ◆ polling overhead
 - ◆ latency
 - ◆ single point of failure (master)

Token passing:

- control **token** passed from one node to next sequentially.
- token message
- concerns:
 - ◆ token overhead
 - ◆ latency
 - ◆ single point of failure (token)



5. Network (Internet) Layer

Goal: Transport packets network wide from sending to receiving nodes (hosts)

Three functions:

- *Routing*: determine the path for packets from source to destination
- *Forwarding*: move packets from router's input to appropriate router output
- *Call setup*: some network architectures require router call setup along path before data flows

IP Addresses

- **IP address**: 32-bit identifier for node's interface
- **Interface**: connection between host/router and physical link
- Every IP address is associated with a **netmask**, which determines the network and host part of the address
- Example: 255.255.255.0 indicates that the first 24 bits of the IP address correspond to the network part and the last 8 bits to the host part
- What's a network ? (from IP perspective)
 - ♦ device interfaces with same network part of IP address
 - ♦ can physically reach each other with a single hop

Forwarding

- An IP datagram contains information about its ultimate destination
- A datagram is **unchanged**, as it travels from source to destination
- At every hop a forwarding table is consulted to determine the next hop for the packet

forwarding table in router

Dest. Net	router	Nhops	interface
223.1.1	-	1	223.1.1.4
223.1.2	-	1	223.1.2.9
223.1.3	-	1	223.1.3.27

