AOT LAB

Agent and **O**bject **T**echnology **Lab**
Dipartimento di Ingegneria dell'Informazione
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Computer Network

Local Area Network

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LAN Properties

- Properties characterizing LAN
  - High throughput
  - Relatively low cost
  - Limited to short distance
  - Different kinds of topology
    - Bus
    - Ring
    - Star
- Media Access Control (MAC) policy mainly determines LAN properties (e.g., efficiency, fairness, …)

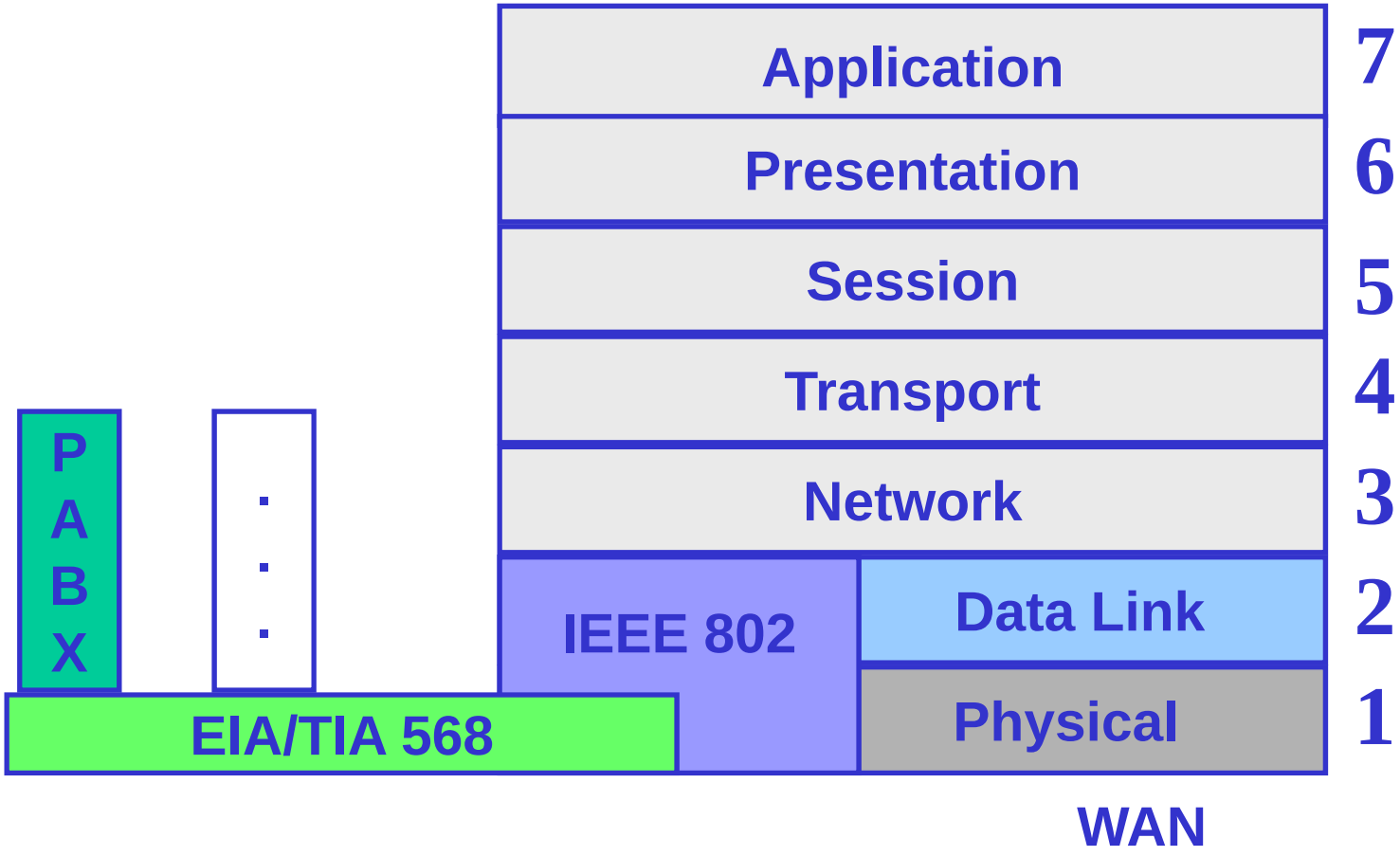
IEEE 802

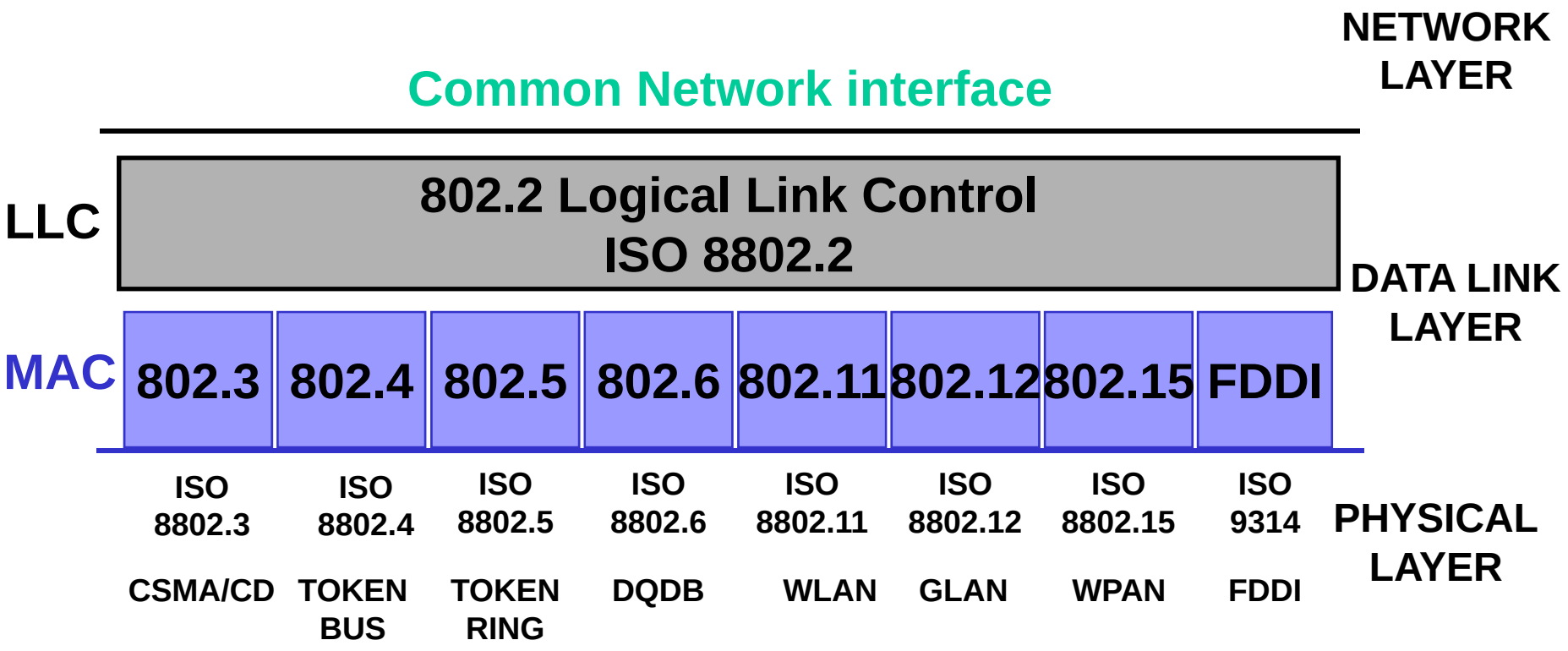
- IEEE 802 standardize the access to the network layer from the different kinds of LAN transmission technologies
- IEEE 802 is composed of different parts
  - 802.1 mainly covers the problems of addressing, internetworking and network management
  - 802.2 supports multi-access and fits LANs into the general OSI framework
  - 802.3, 802.4, … define different media access and additional LAN services

IEEE 802

- 802.3 CSMA/CD LAN
- 802.4 Token Bus LAN
- 802.5 Token Ring LAN
- 802.6 DQDB
- 802.7 Broadband LAN
- 802.8 Fiber Optic LAN
- 802.9 Isochronous LAN
- 802.10 Security
- 802.11 Wireless LAN
- 802.12 Demand Priority
- 802.14 Cable Modem
- 802.15 Wireless PAN
- 802.16 Broadband Wireless
- 802.17 Resilient Packet Ring
- 802.18 Radio Regulatory WG
- 802.19 Coexistence TAG
- 802.20 Mobile Broadband Wireless
- 802.21 Media Independent Handoff
- 802.22 Wireless Regional Area Networks

ISO/OSI, IEEE 802, EIA/TIA 568





Different Transmission Technologies

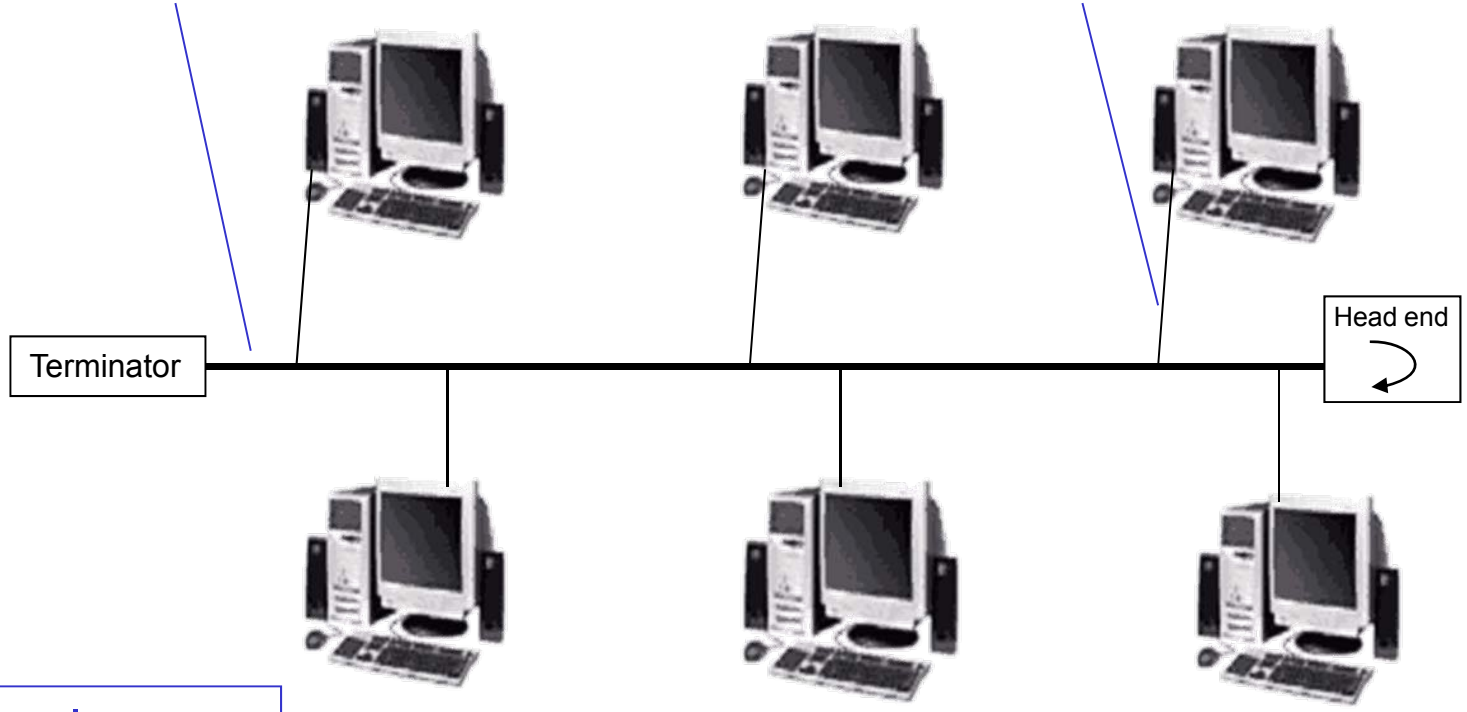
Network LAN Topologies

- LANs can have different kinds of topology
  - Bus
  - Ring
  - Star
- Moreover, different kinds of network can be combined
  - Tree

Bus

Shared medium among the computers

Each computer has a connection to the medium



Examples are:

- Ethernet
- Localtalk

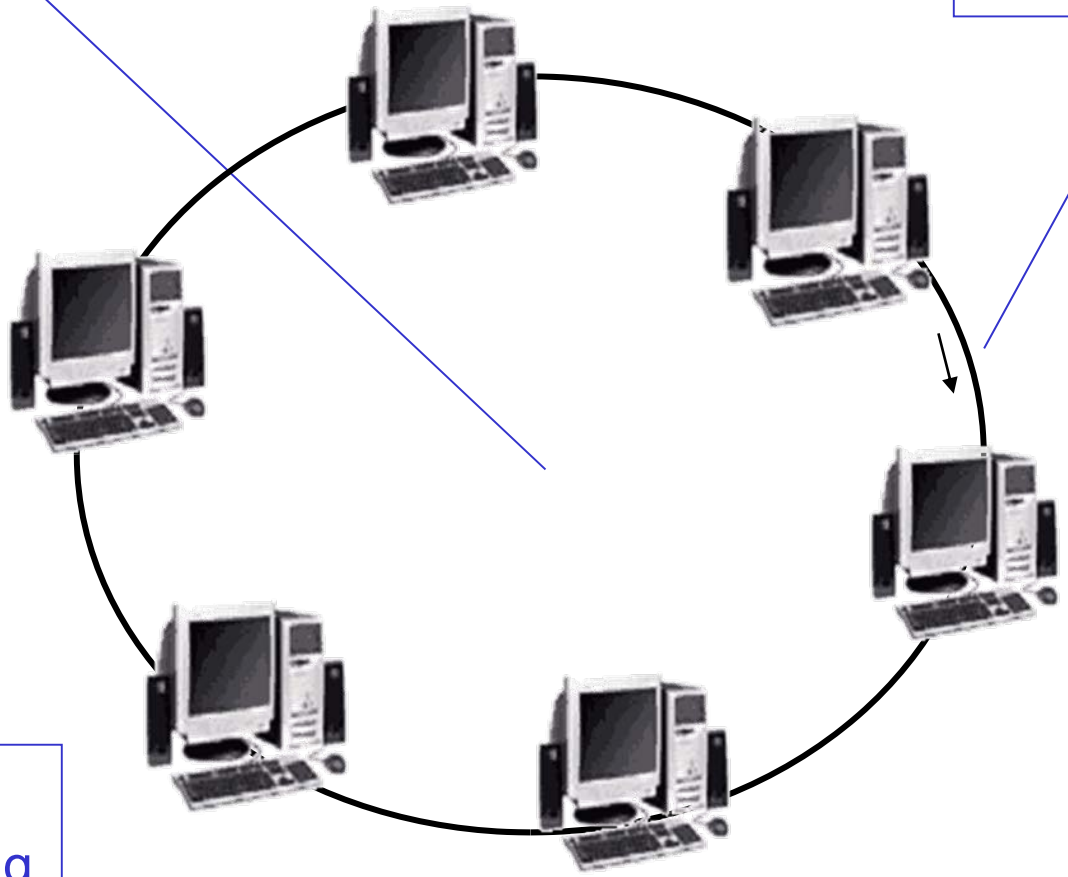
Advantages & Disadvantages

- Advantages
  - Easy to connect a computer or peripheral to a linear bus
  - Requires less cable length than a star topology
  - Well suited for temporary networks (quick setup)
  - Typically the cheapest topology to implement
  - Failure of one station does not affect others
- Disadvantages
  - Entire network shuts down if there is a break in the main cable
  - Difficult to identify the problem if the entire network shuts down
  - Difficult to administer/troubleshoot
  - Limited cable length and number of stations
  - Performance degrades as additional computers are added

Ring

No central facility

Bits flow in single direction



Examples are:

- IBM Token Ring
- FDDI

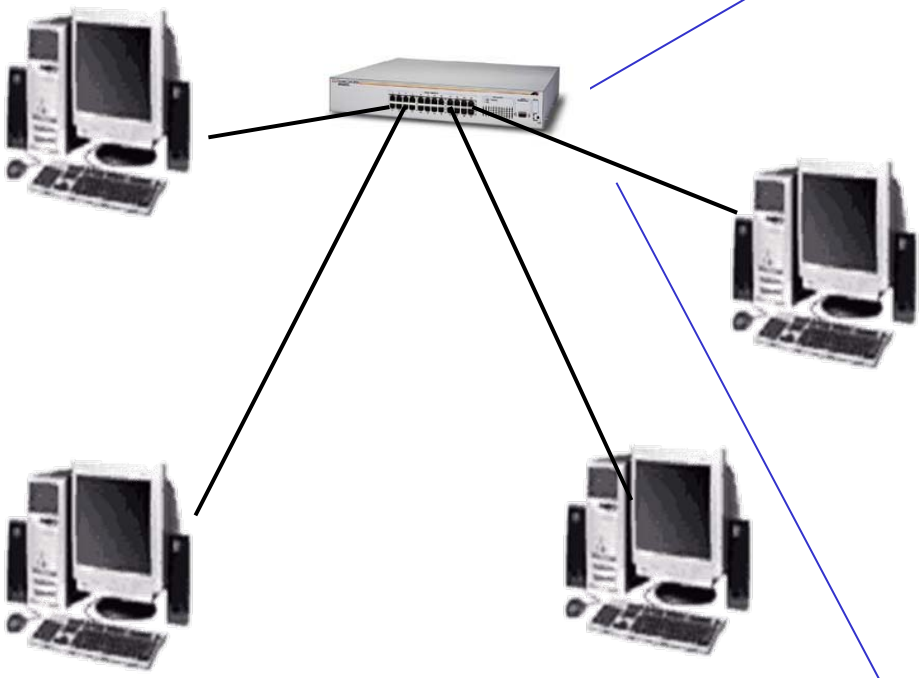
Advantages & Disadvantages

- Advantages
  - Growth of the system has minimal impact on performance
  - All stations have equal access
  - Each node on the ring acts as a repeater
    - Ring networks to span greater distances than other physical topologies

- Disadvantages
  - Often the most expensive topology
  - Failure of one computer may impact others

Star

Central component of network usually known as hub / switch



Examples are:

- ATM
- Ethernet

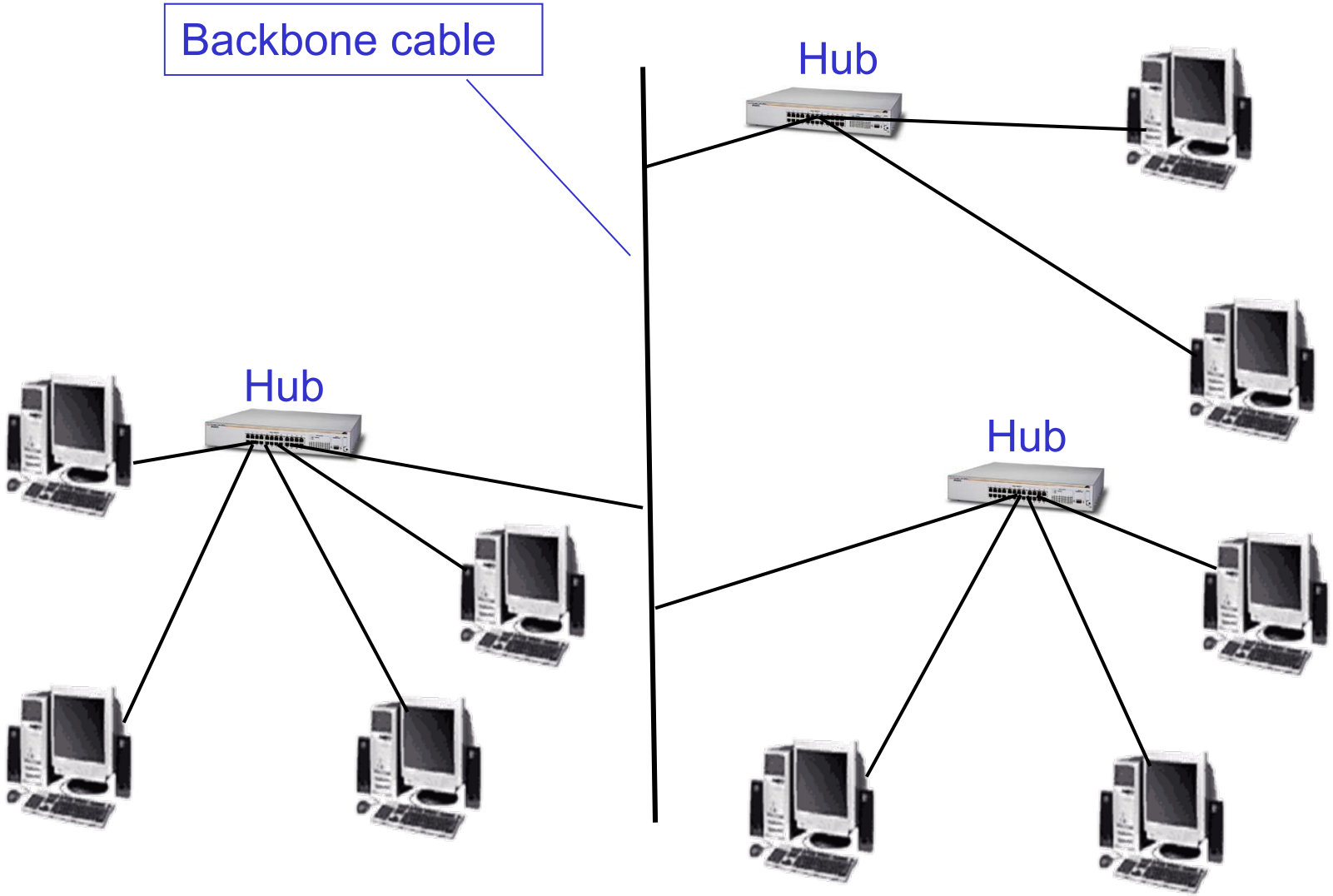
Each computer has separate connection to hub or other hardware device

Advantages & Disadvantages

- Advantages
  - Easy to install and wire
  - No disruptions to the network while connecting or removing devices
  - Easy to detect faults and to remove parts
  - Well suited for temporary networks (quick setup)

- Disadvantages
  - Performance degrades as additional computers are added
  - Requires more cable length than a linear topology
  - If the hub or concentrator fails, nodes attached are disabled
  - More expensive than linear bus topologies because of the cost of the concentrators

Tree



Advantages & Disadvantages

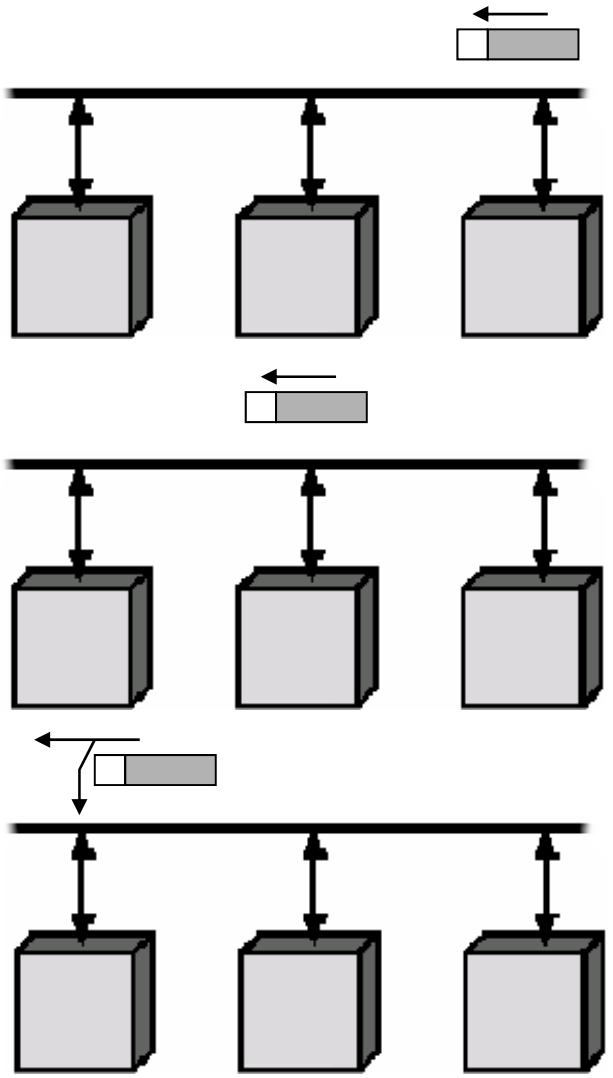
- Advantages
  - Point-to-point wiring for individual segments
  - Supported by several hardware and software vendors
- Disadvantages
  - Overall length of each segment is limited by the type of cabling used
  - If the backbone line breaks, the entire segment goes down
  - More difficult to configure and wire than other topologies

Ethernet / IEEE 802.3

- Most popular LAN
- Several generations
  - Some frame formats
  - Different data rates
  - Different wiring schemes
- Shared medium used for all transmissions (bus)
- Media Access Control (MAC) policy ensures fairness
- Operates at 10 Mbps

Media Access on a Bus

- Only one station transmits at any time
- Signal propagates across entire cable
- All stations receive transmission



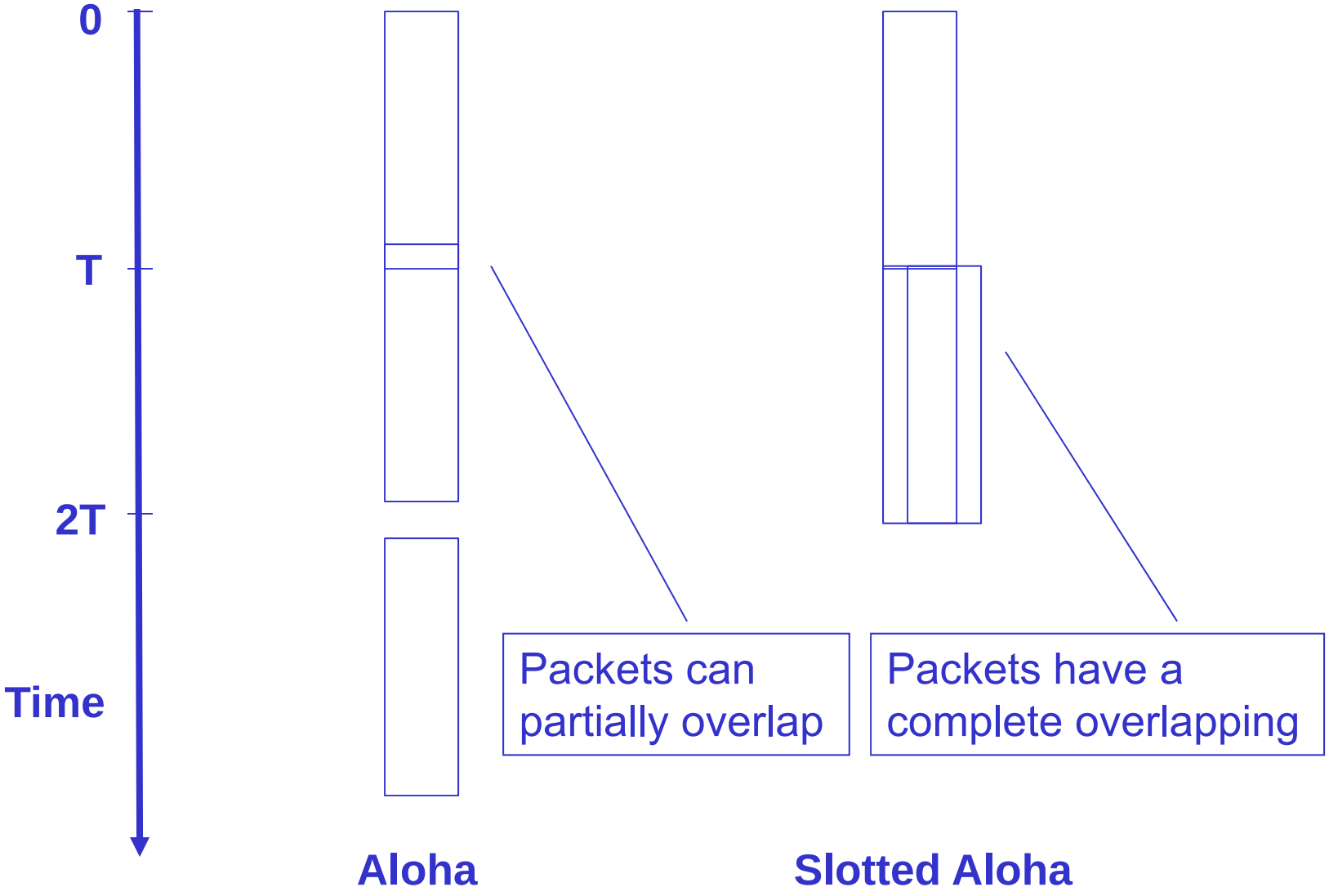
Aloha

- Node sends the message when it has data to send
- If it receives an acknowledgment
  - It considers the transmission completed
  - Otherwise it retransmits after a random delay
- Simple, distributed protocol, but not very efficient:
  - 18% maximum utilization

Slotted Aloha

- Time is divided into equal size slots
- Node sends the message only at the beginning of a time slot
- If it receives an acknowledgment
  - It considers the transmission completed
  - Otherwise it retransmits at the beginning of a future time slot after a random delay
- More complex distributed protocol, but also more efficient because it reduces chances of collision:
  - 37% maximum utilization

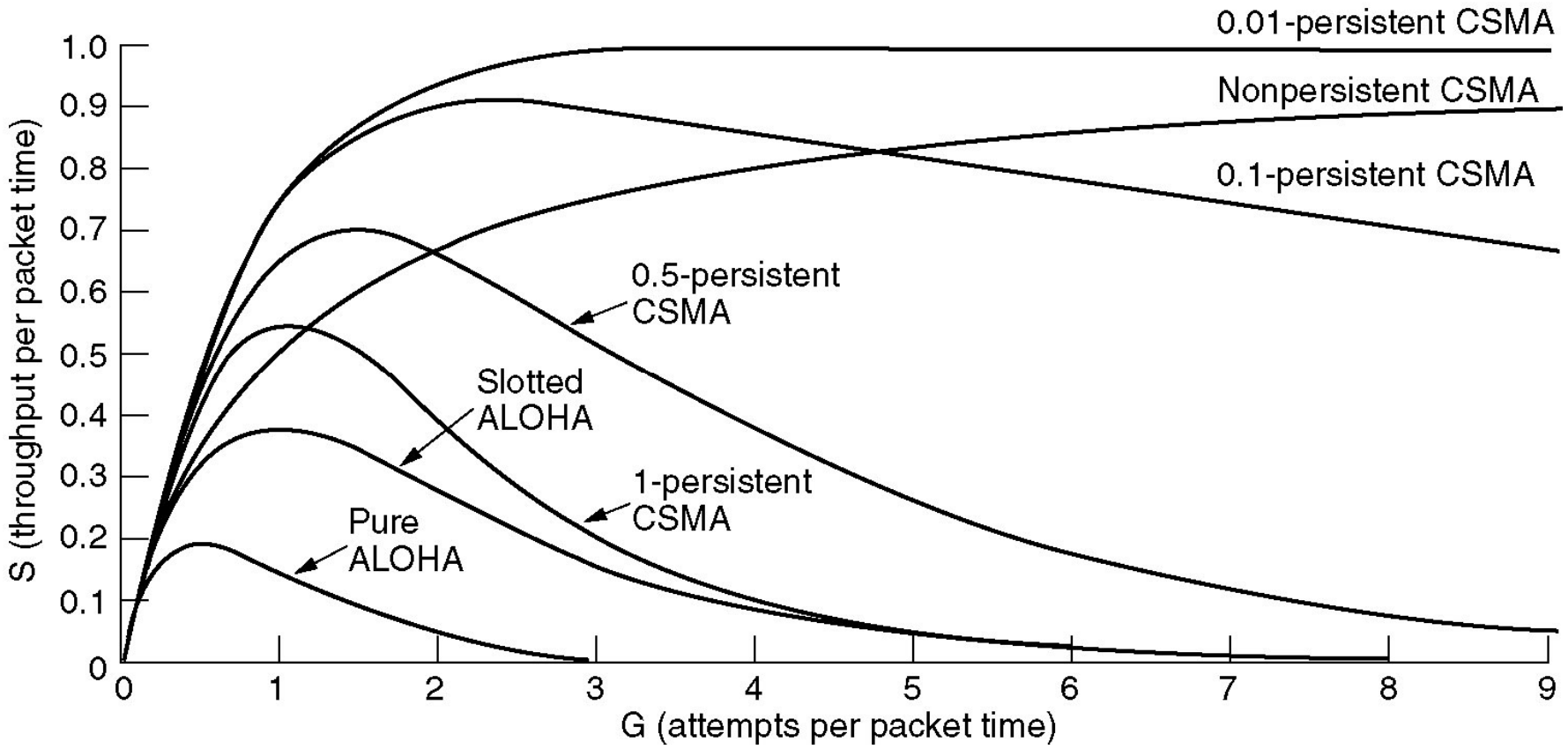
Aloha & Slotted Aloha Utilization



CSMA

- CSMA: listen before transmit
  - If channel sensed idle, transmit entire packet
  - If channel sensed busy, defer transmission
- Persistent CSMA
  - Retry immediately with probability p when channel becomes idle (may cause instability)
- Non-persistent CSMA
  - Retry after random interval
- Human analogy: don’t interrupt others!

Aloha and CSMA Performances

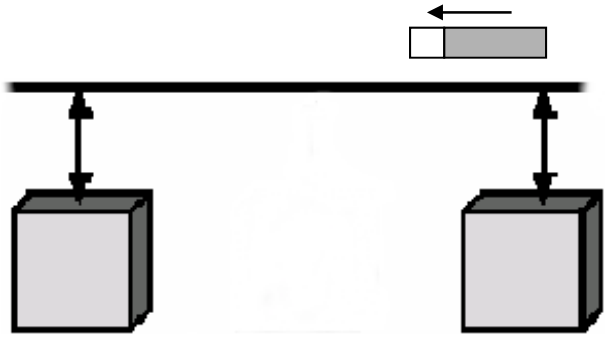


CSMA/CD

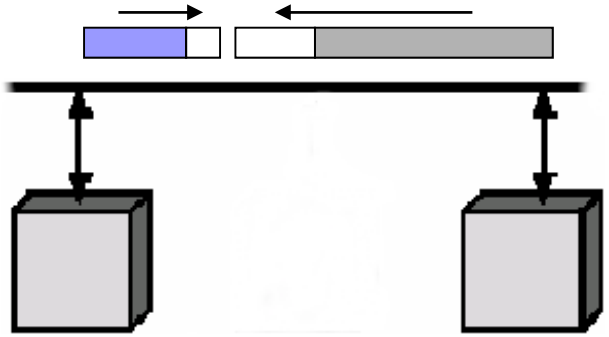
- CSMA/CD: listen before and when transmit
  - if a collision is detected within short time, then the transmission is aborted, reducing channel wastage
- Human analogy: the polite conversationalist
- Collision detection is easy in wired LANs:
  - Measure signal strengths, compare transmitted, received signals
- Collision detection is difficult in wireless LANs:
  - receiver shut off while transmitting

CSMA/CD

- Two simultaneous transmissions
  - Interfere with one another
  - Called collision



- CSMA plus Collision Detection (CD)
  1. Listens to medium during transmission
  2. Detects whether another station signal interferes



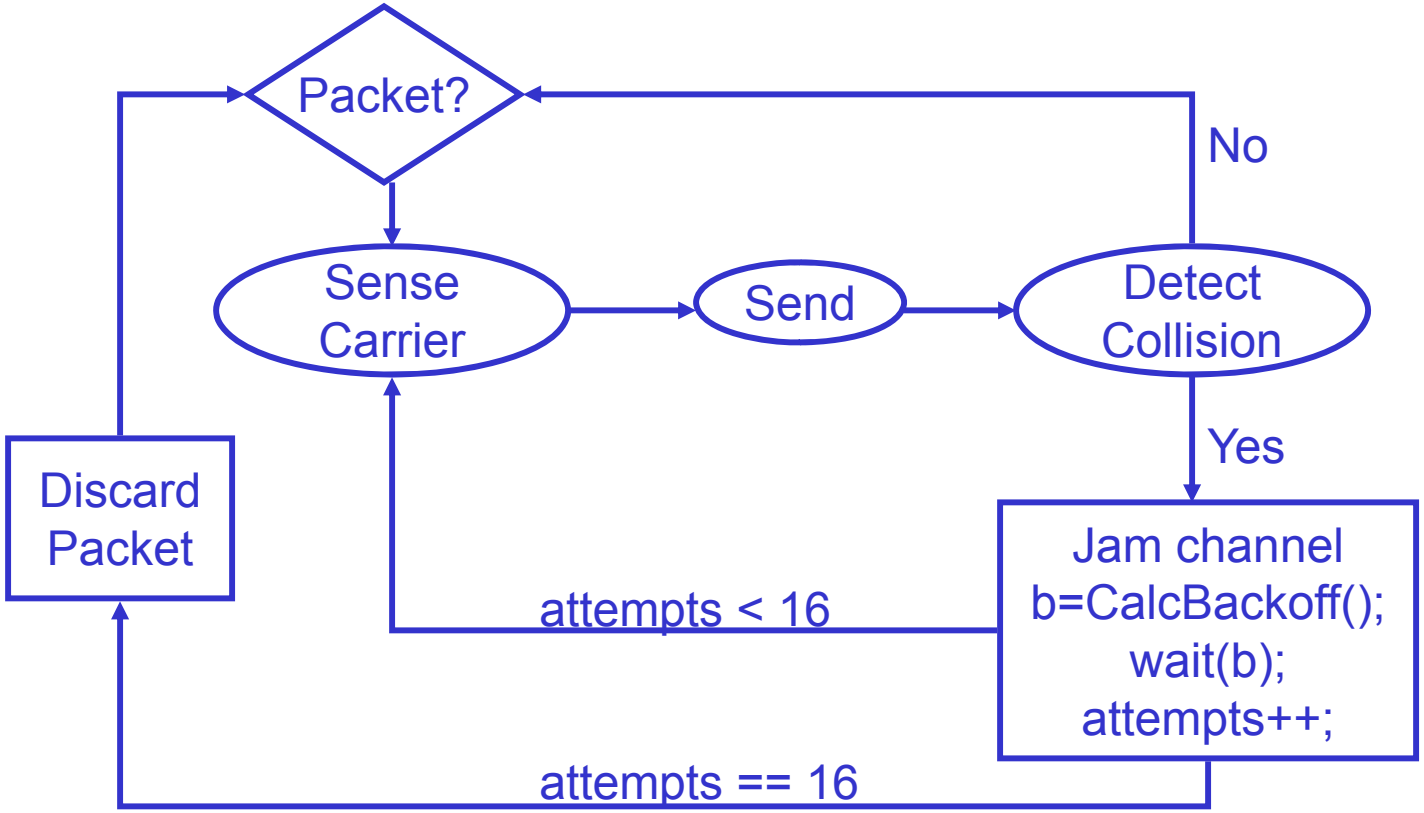
CSMA/CD

- Back off from interference and try again
- When collision occurs
  1. Waits random time T, $0 \leq T \leq d$
  2. Uses CSMA and try again
- If second collision occurs
  - Waits random time T, $0 \leq T \leq 2d$
- Double range for each successive collision
- Called exponential backoff

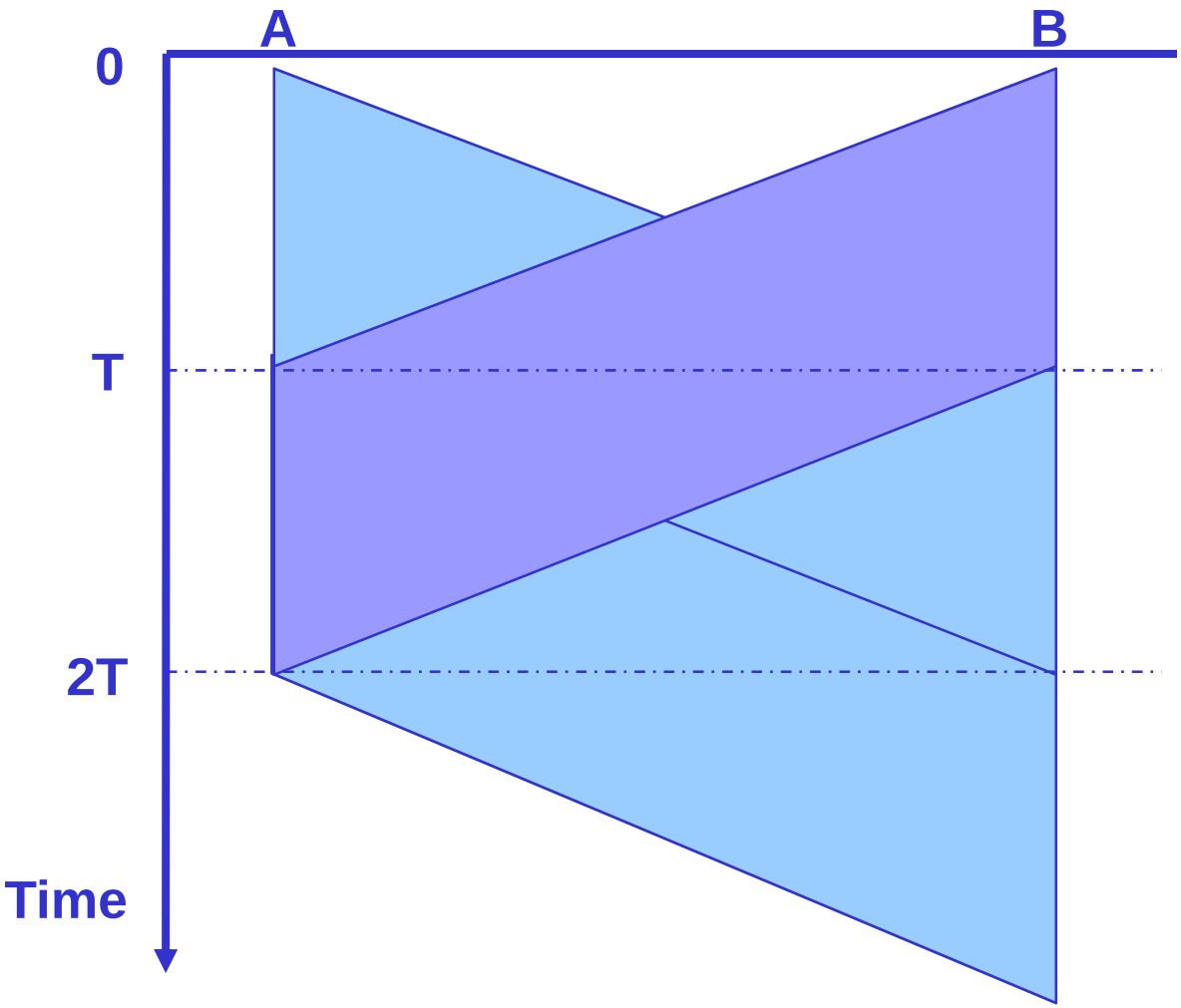
Backoff Calculation

- Exponentially increasing random delay
  - Wait time increases with the number of messages that collide
- Delay is K x 512 bit transmission times
- First collision
  - Choose K from {0,1}
- After second collision
  - Choose K from {0,1,2, …, 2^C - 1}
    - Where C is the number of collisions
- After ten or more collisions
  - Choose K from {0,1,2,3,…,1023}

CSMA/CD


Packet?
No
Sense Carrier
Send
Detect Collision
Yes
Discard Packet
attempts < 16
Jam channel
b=CalcBackoff();
wait(b);
attempts++;
attempts == 16

Collision Detection Problem



Collision Detection Problem

- There must be a mechanism to insure retransmission on collision
  - If T is the propagation time between the two network end-points
  - Then a sender must still be transmitting at 2T

- It follows that minimum packet size (MPS) and network maximum length have a limit and the are dependent
  - If the minimum packet size is 64 bytes
  - Then we can compute the network maximum length (ML)

ML ≈ minimum packet size * light speed / 2 * bandwidth

= 8 *64 * $2*10^8$ / 2 * 10^7 = 5.12 km

Destination Identification

- All stations on shared media LAN may receive all transmissions
- Sender must specify destination
  - Unique number is assigned to each station known as station address
  - Each frame contains destination address

Ethernet Addressing

- Standardized by IEEE
- Unique 48-bit address is assigned to each station
- Address is usually assigned when interface card (NIC) is manufactured

Ethernet Address Recognition

- Each frame contains destination address
- All stations receive a transmission
- Station discards any frame addressed to another station
- Address check is not performed by software, but by interface hardware

Possible Destinations

- Packet can be send to
  - Single destination (unicast)
  - All stations on network (broadcast)
  - Subset of stations (multicast)
- Address is used to distinguish different alternatives
- Address alternatives increase interaction efficiency

Broadcast on Ethernet

- Broadcast address is a special address where the value of all the bits is “1”
- Sender
  1. Places broadcast address in frame
  2. Transmits frame
- Receiver always accepts frame that contains
  - Station unicast address
  - Broadcast address

Multicast on Ethernet

- Half of addresses are reserved for multicast
- Network interface card
  - Always accepts unicast and broadcast addresses
  - Can accept zero or more multicast addresses
- Software
  - Determines multicast addresses to accept
  - Informs network interface card

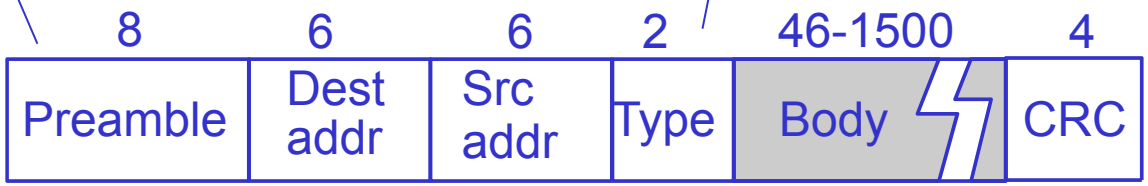
Promiscuous Mode

- Network interface card accepts all the frames that appear on the net
  - Used for debugging/testing
  - Available on most of interface hardware

Ethernet Frame Format

Sequence of 8 bytes, each set to “10101010”

Value	Description
0800	IPv4
0806	ARP
86DD	IPv6
880B	PPP

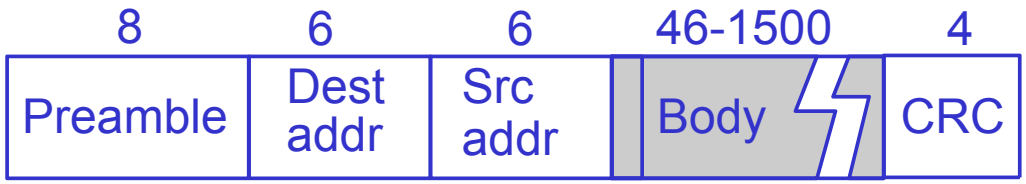


De-multiplexing key used to determine which higher level protocol the frame should be delivered to

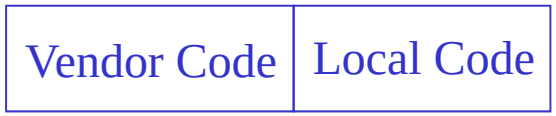
Ethernet Frame Format

Some hardware does not include type

Stations must agree to only send one type of data or to manage their type



Ethernet type for the frame (backwards compatibility)



Information type is put in the first bytes of the message body

Logical Link Control

Sub-Network Access Protocol

LLC type

Destination Service Access Point: pointer to a memory buffer in the receiving station

Source Service Access Point: pointer to a memory buffer in the sending station

Demultiplexing on Type

- Network interface hardware
  1. Receives copy of each transmitted frame
  2. Examines address and either discards or accepts
  3. Passes accepted frame to system software

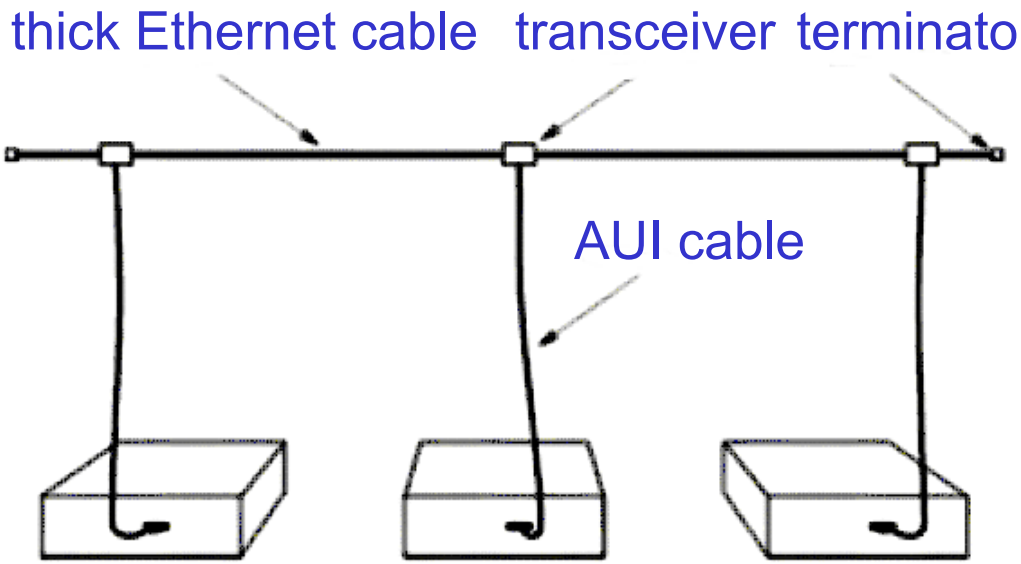
- Network device software
  1. Examines frame type
  2. Passes frame to correct software module

Ethernet Wiring

- Three schemes
  - Correspond to three generations
  - All use the same frame format
- Original Ethernet used bus topology
- Modern Ethernet is called star-shaped bus
  - Physical star
  - Logical bus

Original Ethernet Wiring

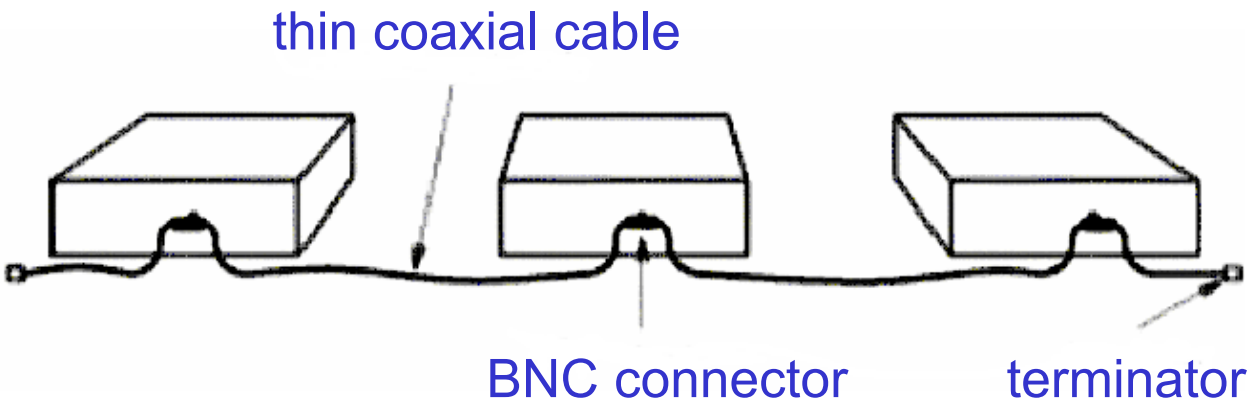
Formally named 10Base5, but called thicknet



Uses heavy coaxial cable called thin Ethernet cable

2nd Generation Ethernet Wiring

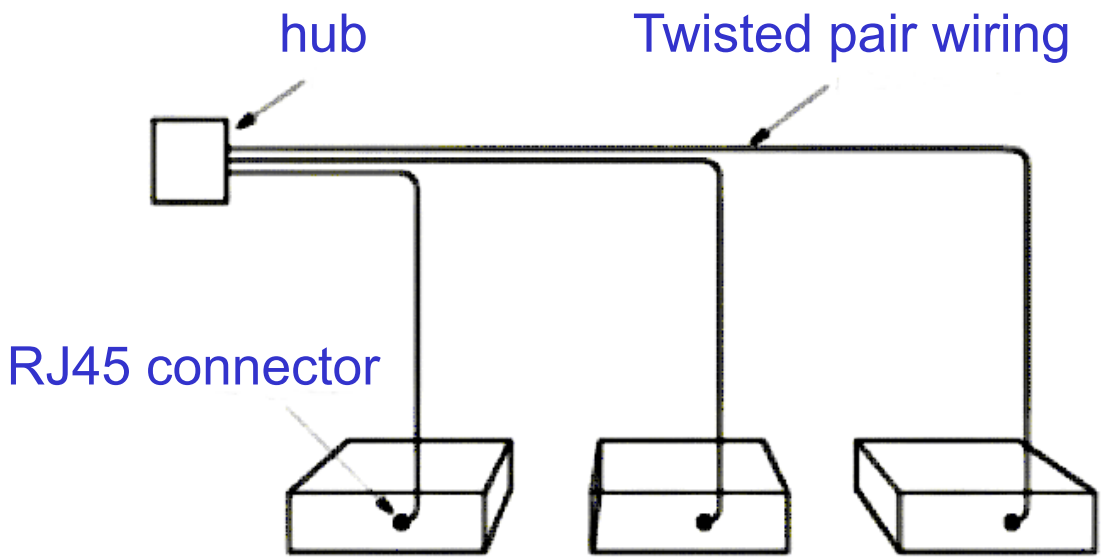
Formally named 10Base2, but called thinnet



Uses thinner coaxial cable called thin Ethernet cable

Modern Ethernet Wiring

Formally named 10Base-T,
but called twisted pair Ethernet



Uses hub and twisted pairs

Fast Ethernet

- Apply original CSMA/CD medium access protocol at 100 Mbps
- Must change either minimum frame or maximum diameter:
  - Change diameter
- Fast Ethernet three wiring standards
  - Star-wired topology with a central switch
  - 2 twister pairs, 2 optical fibers, 4 twister pairs

Gigabit Ethernet

- Apply original CSMA/CD medium access protocol at 1 Gbps
- Provides both half-duplex and full-duplex transmission
- Adds flow control to deal with congestion
- Gigabit Ethernet four wiring standards
  - Star-wired topology with a central switch
  - Two optical fibers (multi-mode), 1 optical fiber (single-mode), 2 shielded twister pairs, 4 twister pairs

Fast & Gigabit Ethernet

	Ethernet	Fast Ethernet	Giga Ethernet
Speed	10 Mbps	100 Mbps	1000 Mbps
IEEE Standard	802.3	802.3u	802.3z
Media Access Protocol	CSMA/CD	CSMA/CD	CSMA/CD
Frame format	IEEE 802.3	IEEE 802.3	IEEE 802.3
Signal representation	Manchester code	4B/5B code, …	8B/10B code, …
Topology	Bus or star	Star	Star
Cable support	Coax, UTP, fiber	UTP, fiber	UTP, fiber
Network diameter (max)	2,500 meters	210 meters	200 meters
UTP link distance (max)	100 meters	100 meters	100 meters

Code Efficiency Vs Clock Synchronization

- Manchester code
  - a good clock synchronization between sender and receiver (a value change in each transmitted bit)
  - A bad code efficiency (50%)
- NRZ, NRZ-I
  - A bad clock synchronization between sender and receiver (when long sequences of 0 or 1 are sent)
  - An optimal code efficiency (100%)
- 4B/5B
  - Uses NRZ-I
  - Encodes sequences of 4 bits in five bits for increasing synchronization

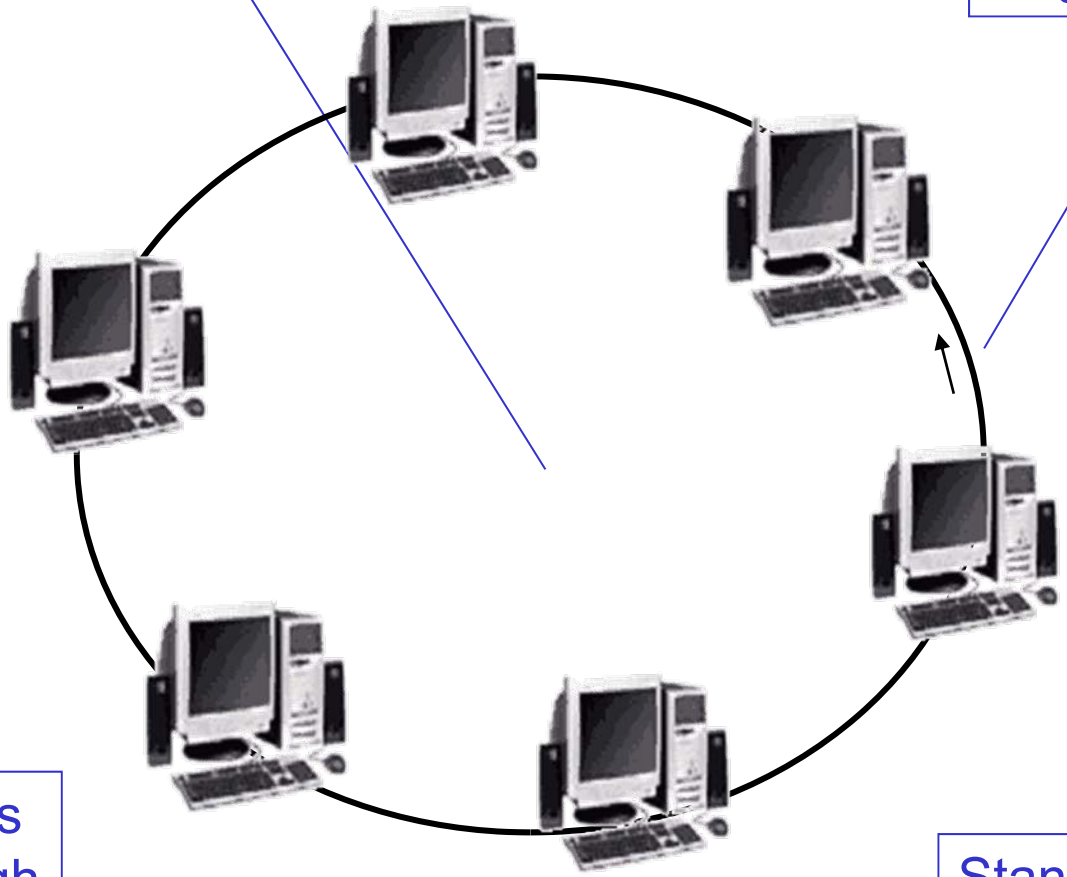
4B/5B Encoding

Data	Encoding	Data	Encoding
0000	11110	1000	10010
0001	01001	1001	10011
0010	10100	1010	10110
0011	10101	1011	10111
0100	01010	1100	11010
0101	01011	1101	11011
0110	01110	1110	11100
0111	01111	1111	11101

Token Ring

No central facility

Bits flow in single direction



Access control is managed through token passing

Standardized by IEEE with 802.5

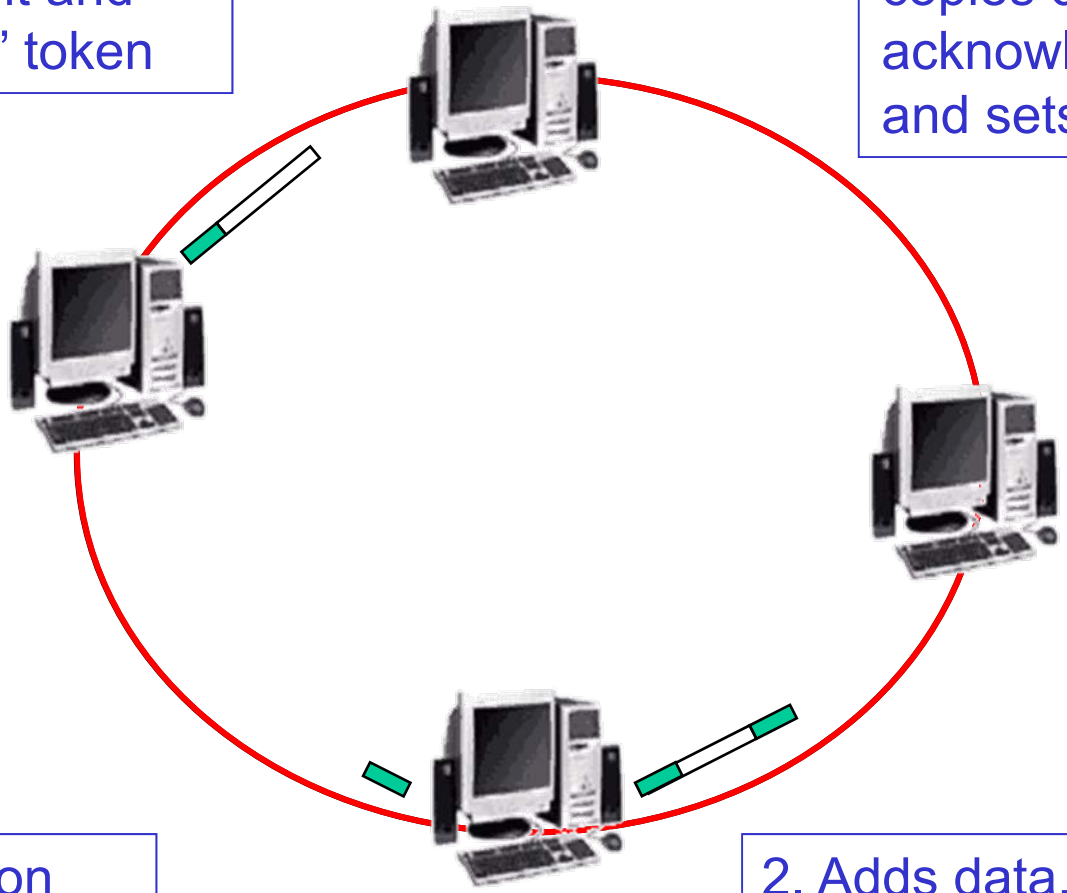
Token Passing

- Token passing guarantees fair access in ring
- Token is a special (reserve) small (a few bits) message
- Sender
  1. Waits for token to arrive
  2. Transmits one packet around ring
  3. Transmits token around ring
  4. Receives its transmission
- When no station has data to send
  - Token circulates continuously

Token Passing

4. Sending station check acknowledgment and generates “free” token

3. Receiving station copies data, adds acknowledgment and sets “copied bit”



1. Sending station waits for “free” token

2. Adds data, addresses and sets token as “busy”

Token Failure Problem

Token loss

- The token crashes before being transmitted
  - Lost a free token
- A computer in the ring crashes
  - Lost a busy token

- A token is always busy or duplicated

Token Failure Problem Solution

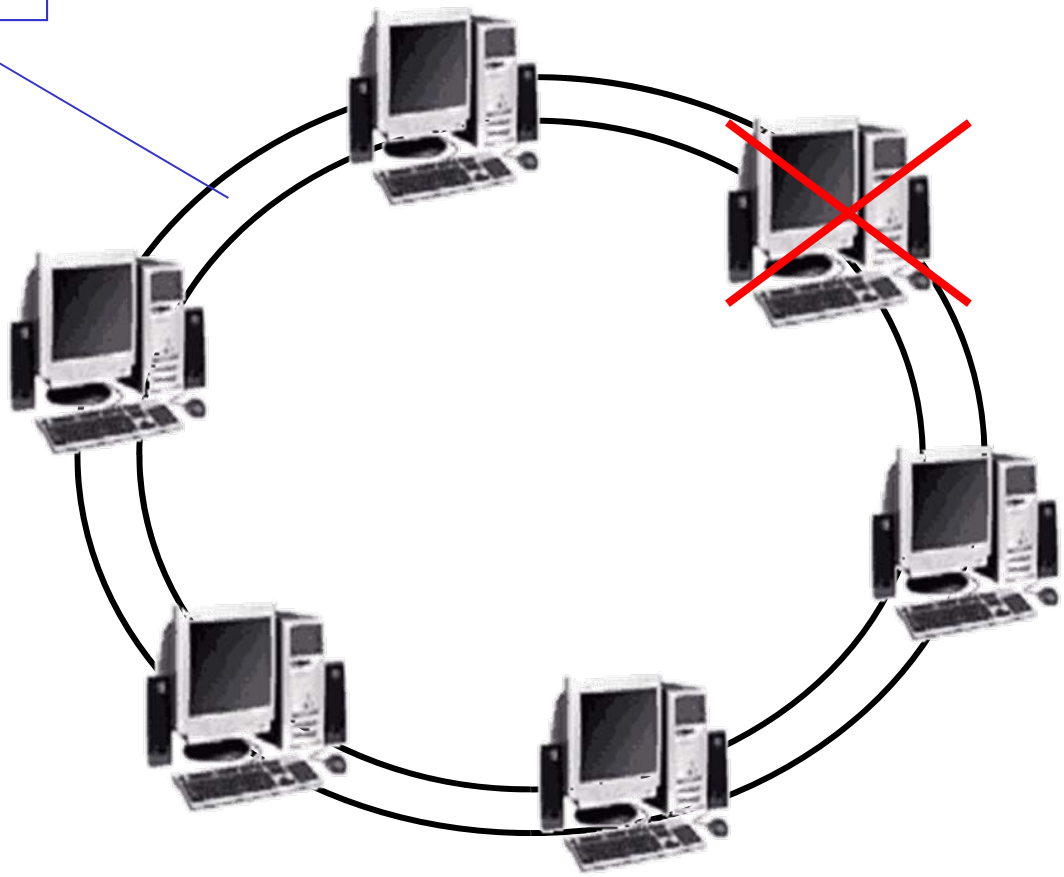
- Designate one computer to be the token monitor and another computer to be a backup token monitor
- If no token circulated through the network for a certain length of time or if a (busy) token circulates too often, then the token monitor if necessary:
  - Creates a new free token
  - Destroys the busy or duplicated token

Strengths & Weaknesses

- Strengths
  - Easy detection of
    - Broken ring
    - Hardware failure
    - Interference
  - Very efficient and fair for high traffic
- Weaknesses
  - Broken wire disables entire ring
  - Point-to-point wiring
    - Awkward in office environment
    - Difficult to add/move stations
  - Low efficient for low traffic

Failure Recovery

Two rings

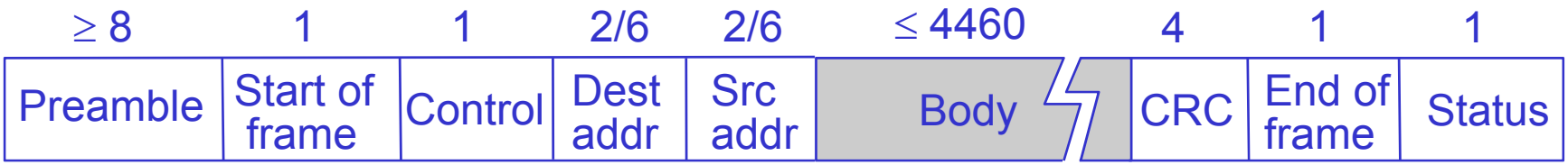


Automatic failure recovery algorithm

FDDI

- Fiber Distributed Data Interconnect (FDDI) uses a ring topology of multimode or single mode optical fiber transmission links
  - High reliability
  - Immune to interferences
- Operates at 100 Mbps
- Spans up to 200 Km
- Permits up to 500 stations
- Token is absorbed by station and released as soon as it completes the frame transmission
  - More than a packet on the ring

FDDI Frame Format



FDDI

- Uses two rings:
  - Normal traffic is on primary ring
  - Secondary “counter-rotating” ring is redundant
- There are two types of station:
  - Dual Attached Stations (DAS)
    - Connected to both rings
  - Single Attached Stations (SAS)
    - Attached only to the primary ring through a Dual-Attachment Concentrator (DAC)
- a Dual-Attachment Concentrator (also called FDDI concentrator) is the building block of an FDDI network
  - Attaches directly to both the primary and secondary rings
  - Ensures that the failure or power-down of any SAS does not bring down the ring

FDDI Behavior

- During normal operation, only the primary ring is used, the secondary ring remains in readiness
- If the ring breaks, the other one (also called protection ring) can be used
- If both rings break or if a station precipitates, the rings can be combined into only one, which has double length

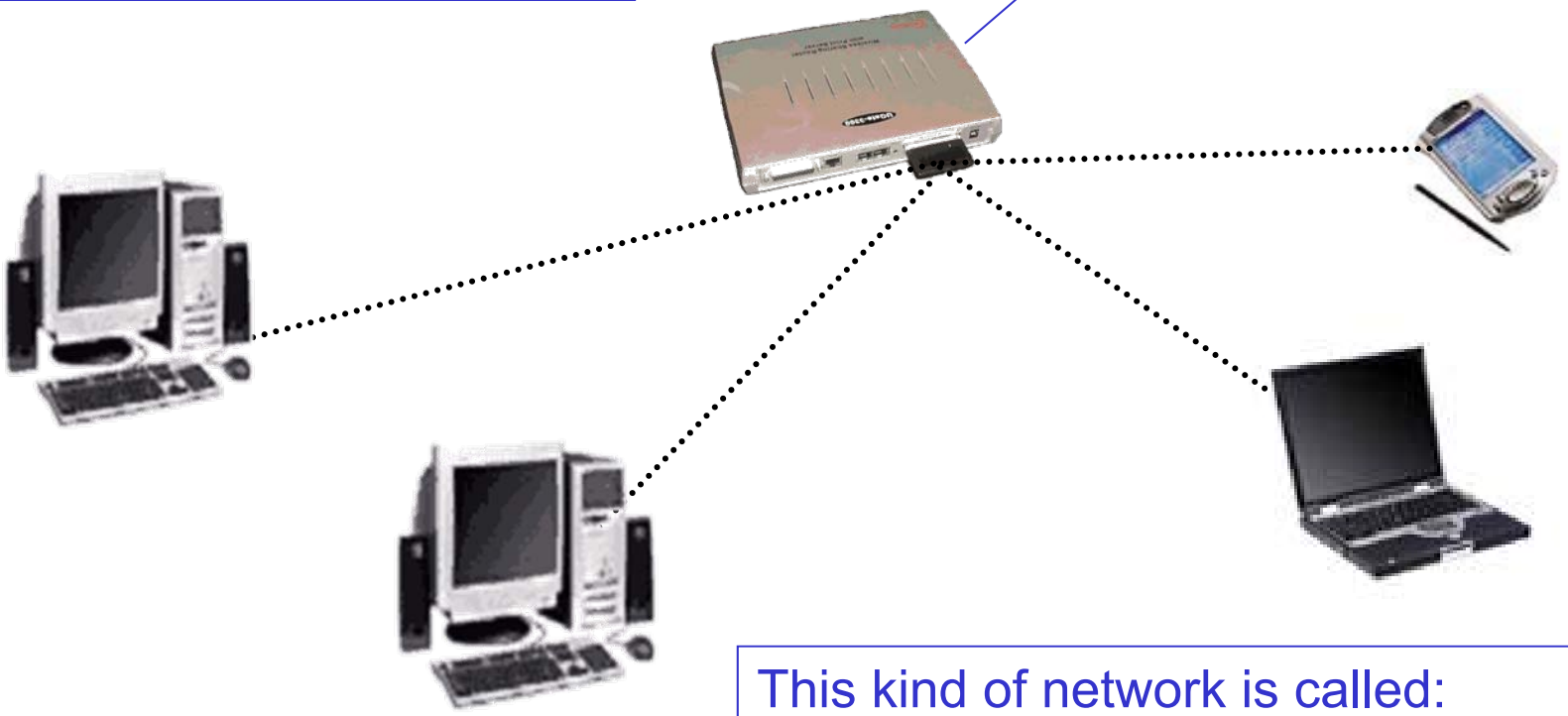
FDDI

- Wiring variant
  - CDDI: FDDI over copper
  - Less noise immunity
- Scheme variant
  - Stations attached to hub
  - Called star-shaped ring

Wireless LANs

Transmit data through the air (space) rather than through wire or cable

Central component of network usually known as base station



This kind of network is called:

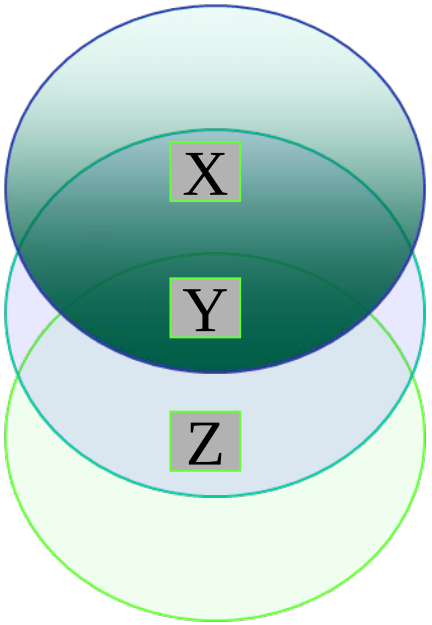
- WLAN (Wireless LAN)
- LAW (Local Area Wireless Network)

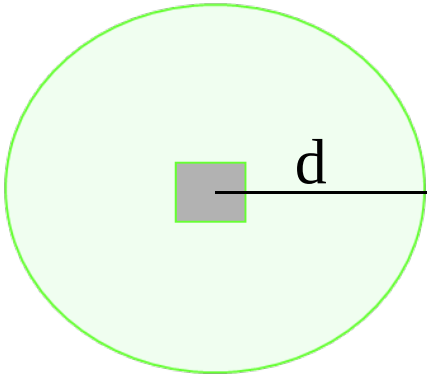
Wireless LANs

- LAN extension
  - Wireless network connected to a main wire-based network
- Cross-building interconnect
  - Point-to-point link between networks in separate buildings
- Nomadic access
  - Wireless link between a LAN hub and a mobile data terminal
- Ad hoc networks
  - Peer-to-peer network (no centralized server) set up temporarily to meet some immediate need

Media Access on a Wireless Net

- Limited range
  - Not all the stations receive all transmissions
  - Cannot use CSMA/CD
- If the range is d for the station X, Y and Z
- Station X and Z do not receive each other transmissions

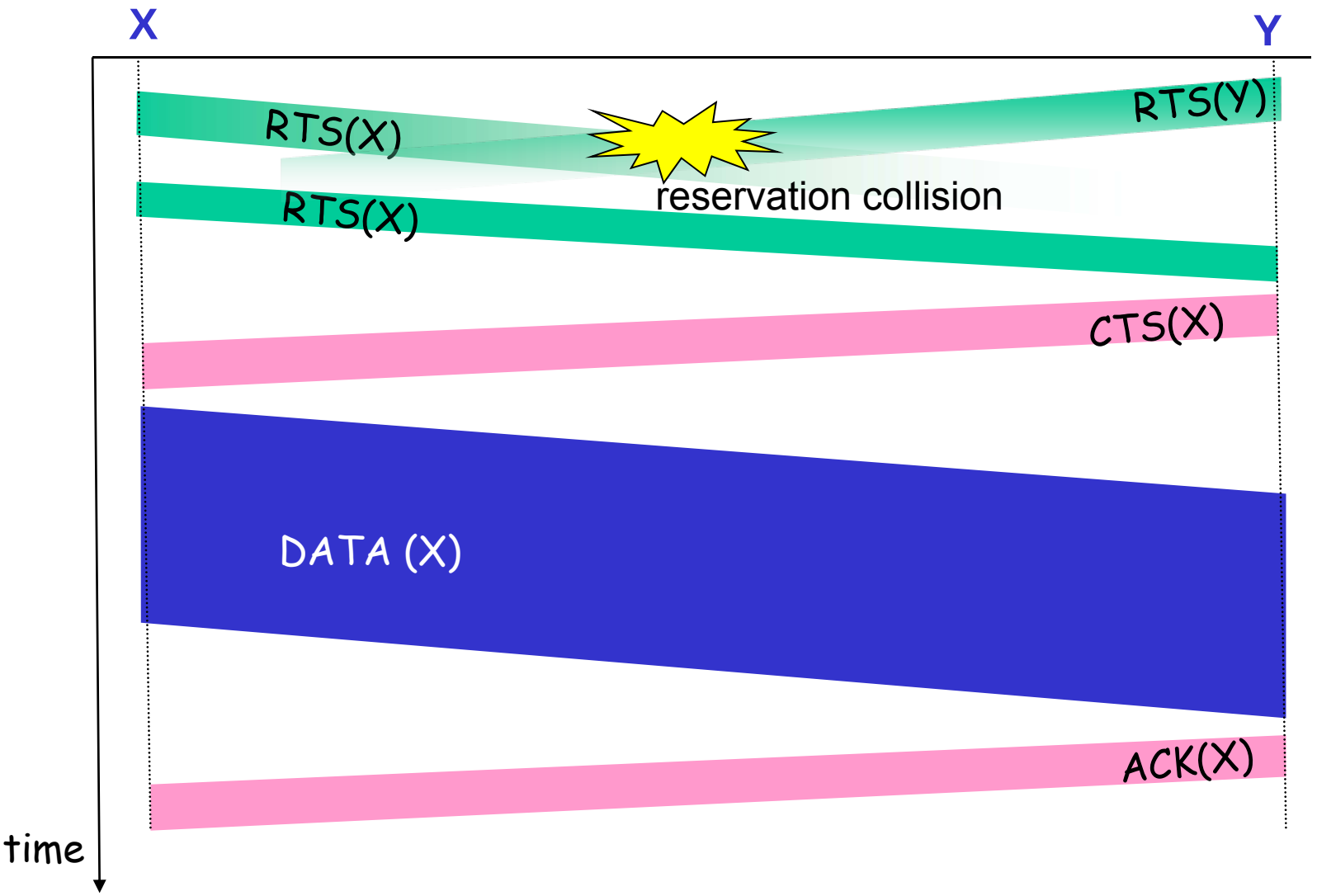




CSMA/CA

- CSMA plus Collision Avoidance (CA) is used for wireless networks
- Both sides send small messages followed by data transmission
  1. “X is about to send to Y” Request To Send (RTS)
  2. “Y is about to receive from X” Clear To Send (CTS)
  3. Data frame sent from X to Y
- All stations in range of X or Y are informed before transmission
- Collision happens only for RTS and CTS messages

CSMA/CA


X
Y
RTS(X)
RTS(Y)
reservation collision
RTS(X)
CTS(X)
DATA (X)
ACK(X)
time

IEEE 802.11

- IEEE 802.11 standard is likely to be the dominant standard for wireless LAN
- IEEE 802.11 LANs can be easily connected to Ethernet wired LANs
  - So, the are usually called wireless Ethernet
- Same topology as traditional Ethernet
  - Both a physical star and a logical bus
  - A central wireless access point (AP) is a radio transceiver that plays the role of hub
  - The maximum range is 100-500 feet depending on interference

Access Point

- Base station has different purposes:
  - Connects mobiles into wired network
  - Connect mobiles to a dedicated host that:
    - May perform authentication
    - Runs DHCP to assign IP address in AP's subnet

IEEE 802.11

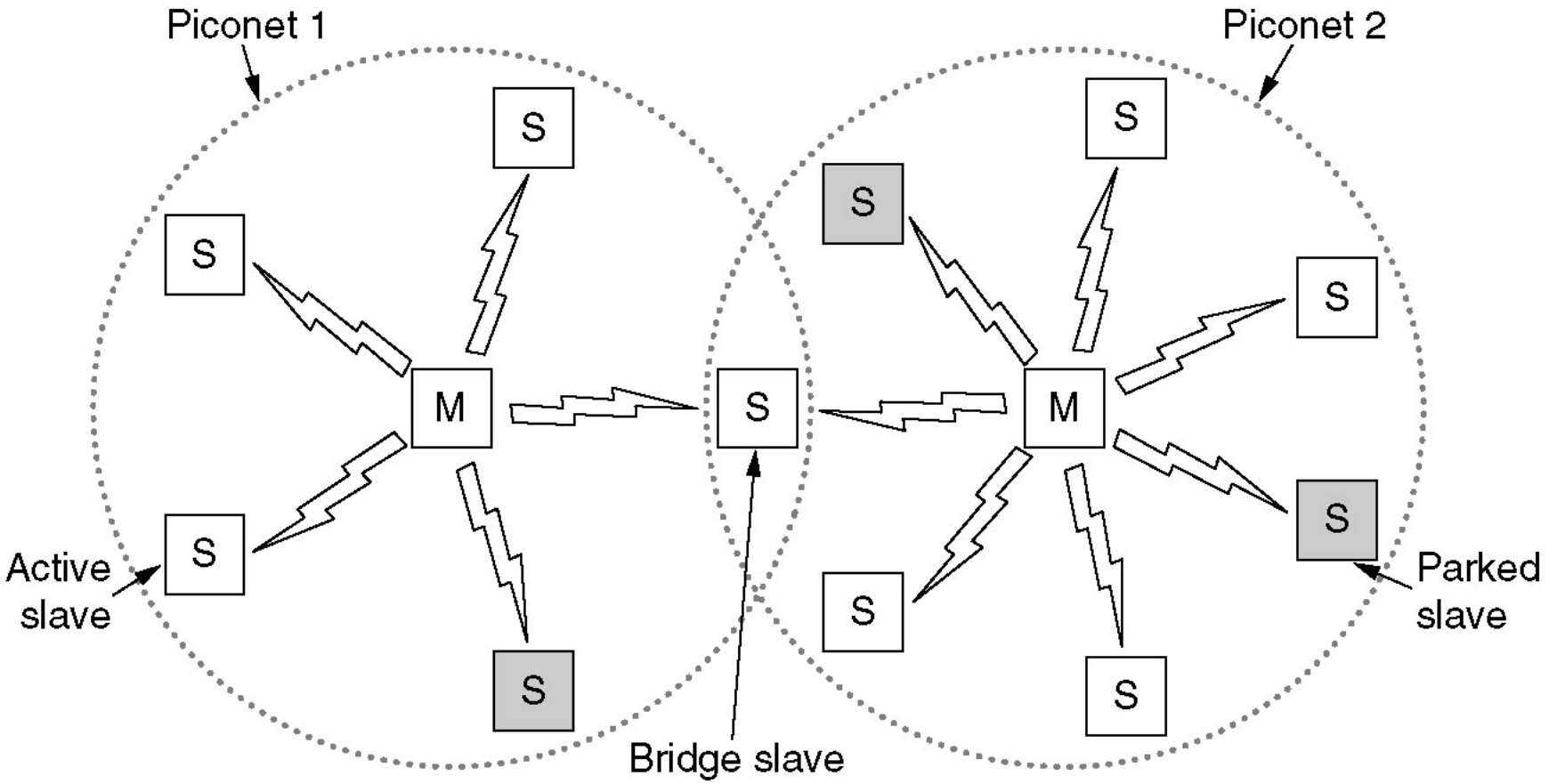
- Access control is usually managed by CSMA/CA
- Encrypts data to offer an equivalent level of privacy to insecure wired LAN
  - Wired Equivalent Privacy (WEP) security
- Four versions of the standard
  - IEEE 802.11b
    - Operates at 2.4 GHz up to 11 Mbps
  - IEEE 802.11a
    - Operates at 5 GHz up to 54 Mbps
  - IEEE 802.11g
    - Operates at 2.4 GHz up to 54 Mbps
  - IEEE 802.11n
    - Operates at 2.4 GHz up to 600 Mbps

Personal Area Network

- Usually less than 10 m diameter
- Usually used as replacement for cables between different devices of the same system (mouse, keyboard, headphones)
- Ad hoc network (no infrastructure) based on master/slaves interaction
  - Slaves request permission to send (to master)
  - Master grants requests

- Also called Bluetooth
  - Operates at 2.4 GHz
  - Offering symmetric traffic up to185.6 kbps
  - Offering asymmetric traffic up to 721 kbps
  - In a range of 10-100m
- Piconet is the name of both the master and the network
- Several devices can be connected to a piconet (up to 7 active simultaneously)
- Piconets can be connected together to form ad-hoc network called, multiple piconet structure or scatternet

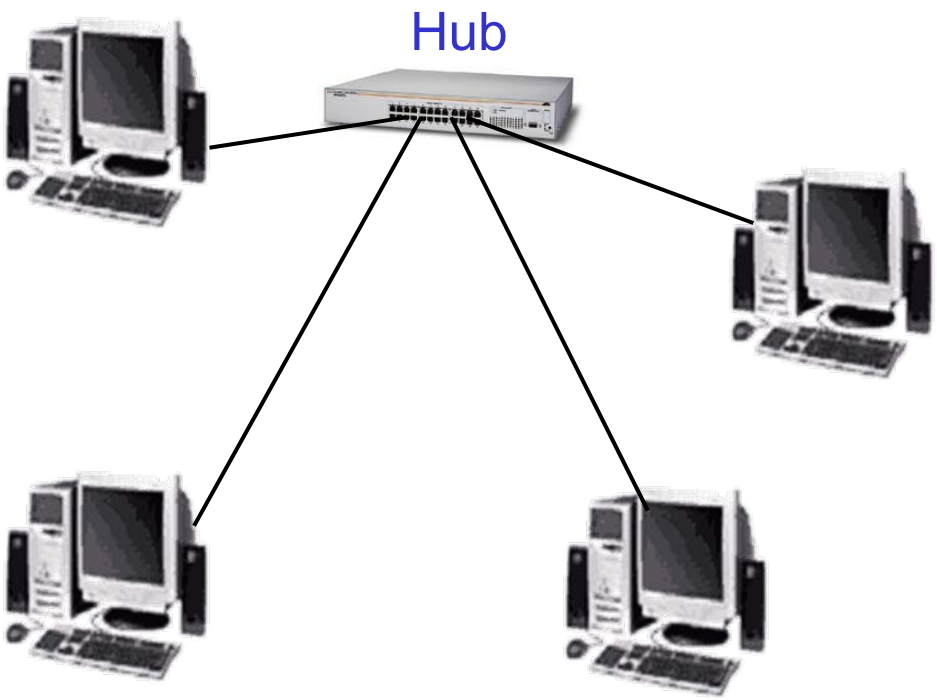
Scatternet Architecture



Extending a LAN Network

- Each LAN technology has a distance limitation (e.g., 500 meters for Ethernet)
  - Limited delay
  - Limited energy
- However
  - Companies can be very wide
  - Users desire arbitrary distance connections
- LANs can be extended through the use of special hardware

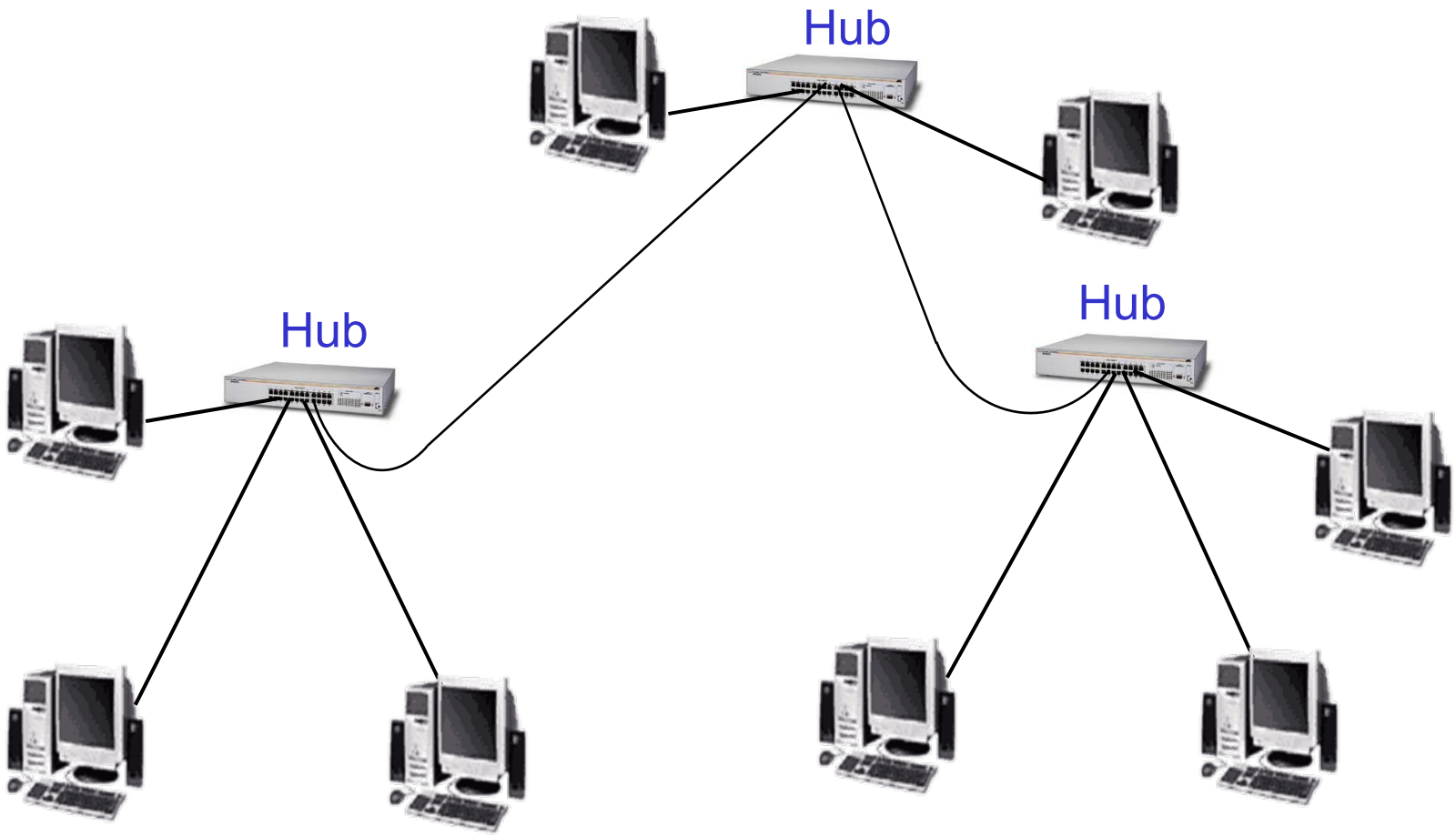
Hub



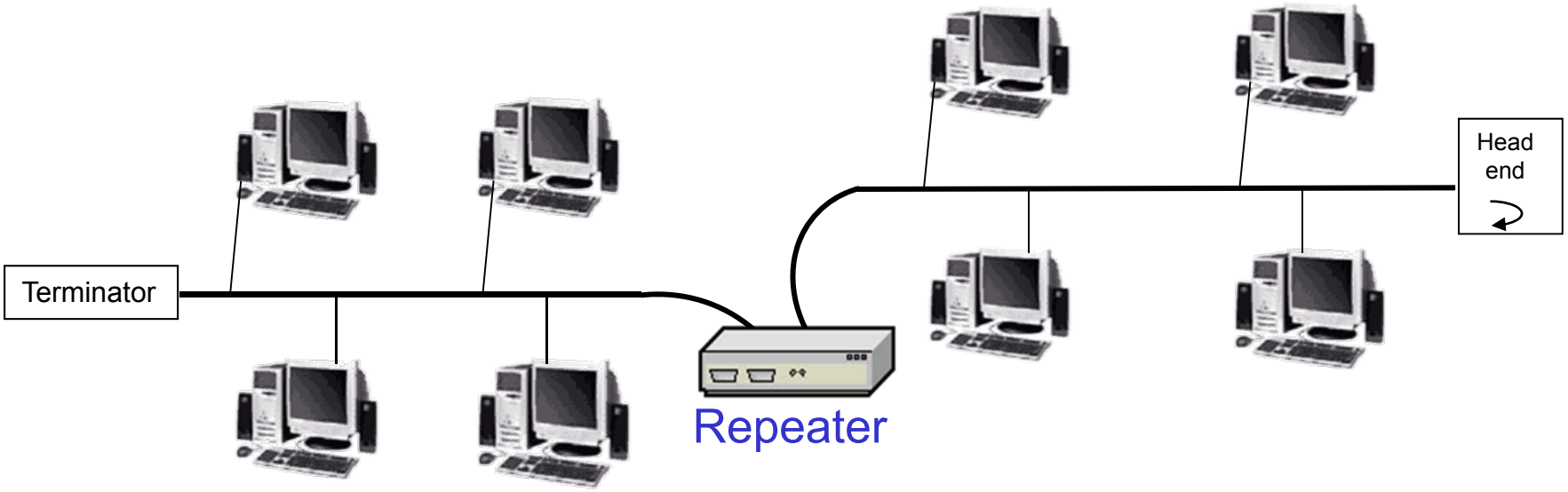
Hub

- Connects several computers (e.g., 4 or 20)
- Acts as central element of the star layout
- Operates at the physical layer (on signals)
- When a single station transmits, the hub repeats the signal on the outgoing line to each station
- Physically a star, logically a bus
- Connect different types of cable, but use the same data link and network protocol

Hierarchical Configuration



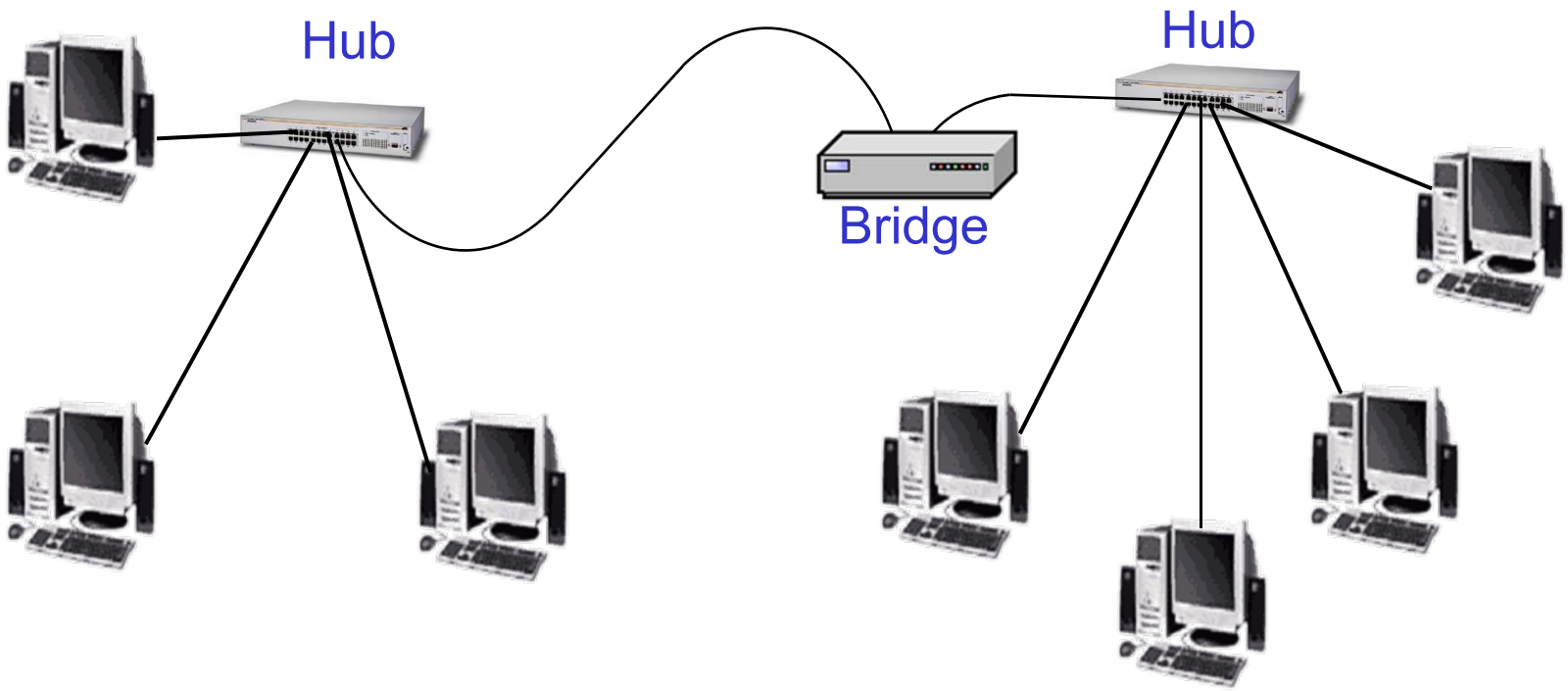
Repeater



Repeater

- Connects two LANs
  - Using identical physical, link and network layer protocols
- Amplifies and sends all electrical signals between segments
  - Collisions are amplified and propagated
- Stations do not know whether a repeater separates them
- IEEE 802.3 sets to 4 the maximum number of repeaters between any two stations

Bridge

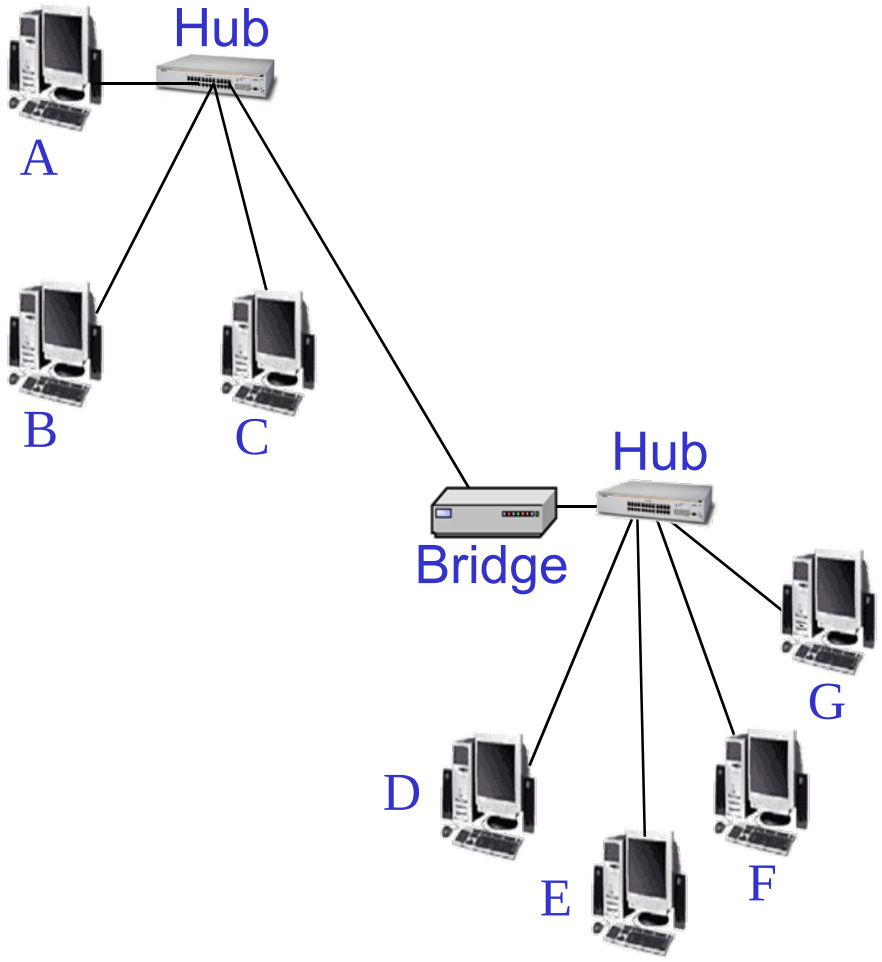


Bridge

- Connects two LANs
  - Using identical physical and link layer protocols
- Allow connections between LANs and to WANs
- Operates at the data link layer
  - Forwards frames
  - Does not forward noise and collisions
- Learns addresses and filters
  - Only forwards if necessary
  - Always forwards broadcast/multicast
- Provide a number of advantages
  - Reliability: creates self-contained units
  - Performance: less contention
  - Security: not all data broadcast to all users
  - Geography: allows long-distance links

Addresses Learning

Event	List1	List 2
Bridge boots	[]	[]
A sends D	[A]	[]
E send C	[A]	[E]
G sends E	[A]	[E,G]
D broadcasts	[A]	[D,E,G]
C sends G	[A,C]	[D,E,G]
B sends A	[A,B,C]	[D,E,G]
F sends B	[A,B,C]	[D,E,F,G]

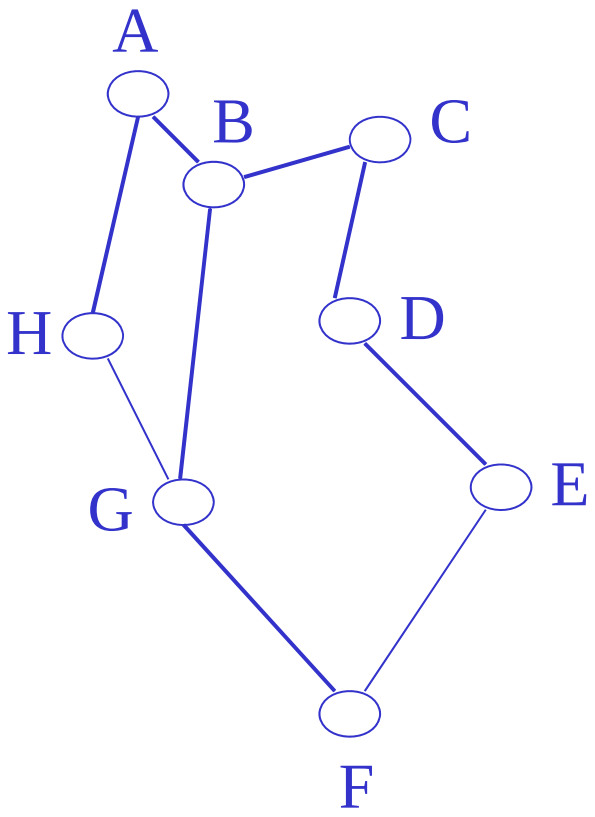


Bridges Cycle

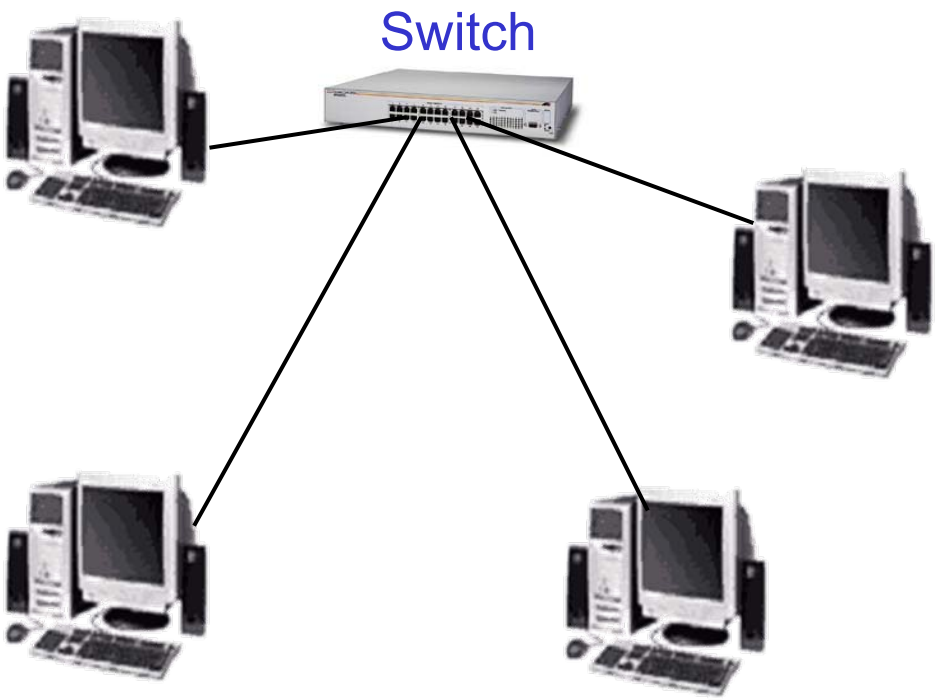
- Complex bridge connections may introduce a cycle
  - Incorrect propagation of frames (e.g., broadcast frame)
- Bridges use Distributed Spanning Tree algorithm
  - Discovers one another
  - Breaks cycles

Spanning Tree Algorithm

- Each bridge has a unique identifier
- Bridge with smallest identifier becomes the root
- Each bridge calculates the distance of the shortest path to the root bridge
- Each LAN identifies a designated bridge, the bridge closest to the root. It will forward packets to the root
- Each bridge determines a root port, which will be used to send packets to the root



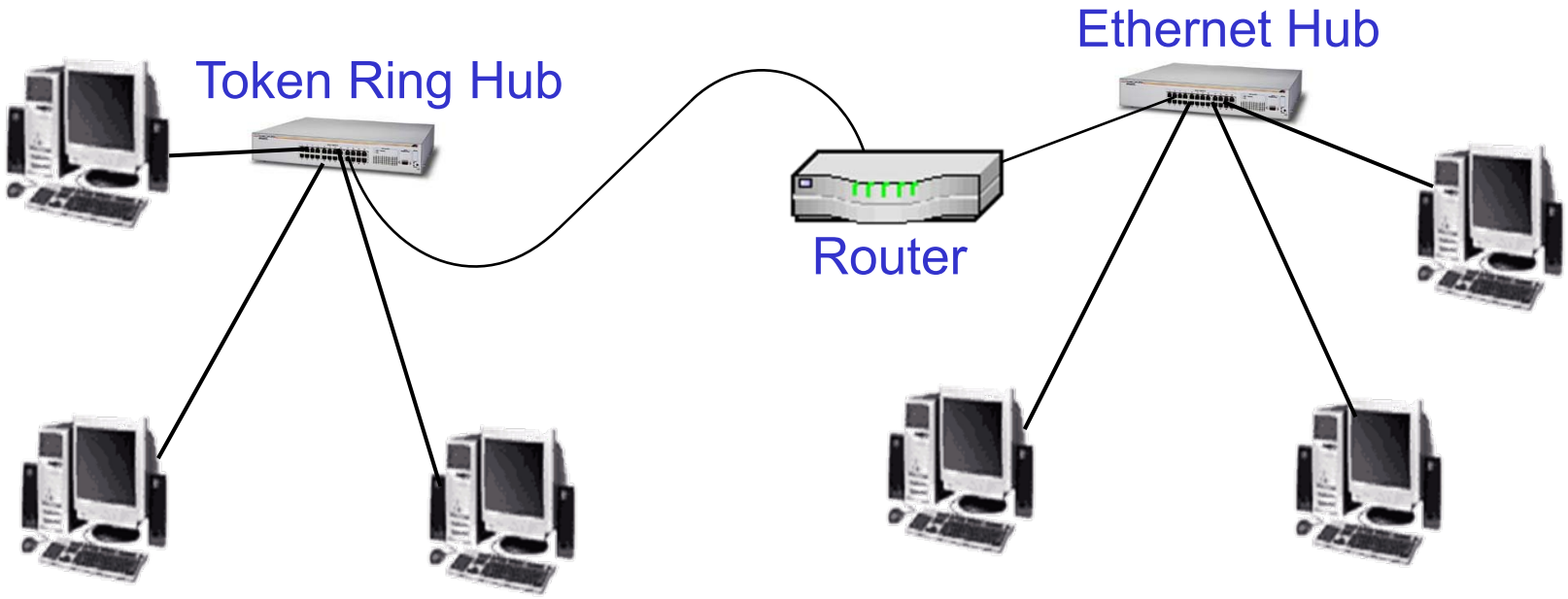
Switch



Switch

- Physically similar to hub
- Logically similar to bridge
  - Operates on packets
  - Understands addresses
  - Only forwards when necessary
- Permits separate pair of computers to communicate at the same time
- Higher cost than hub

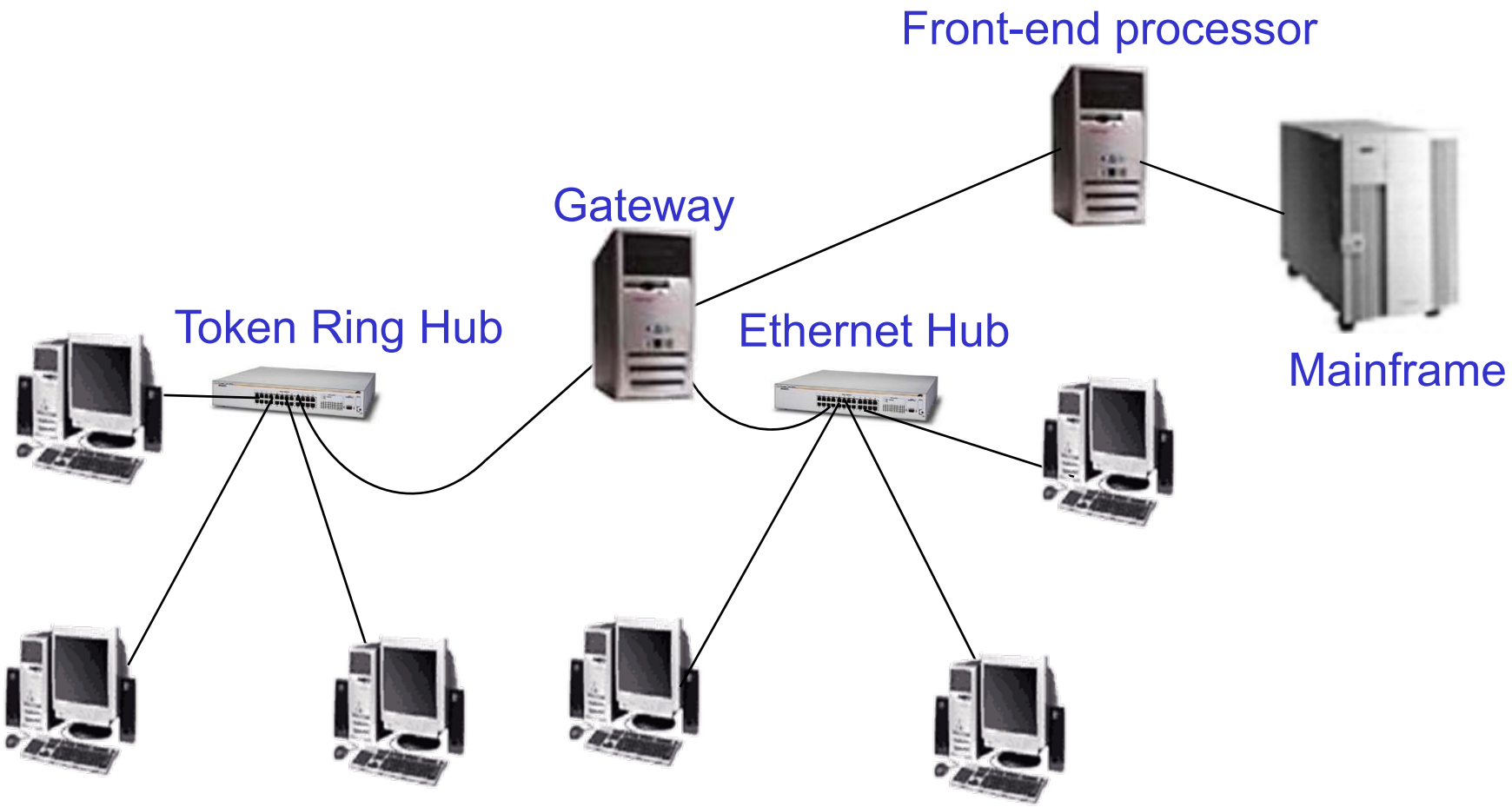
Router



Router

- Connects two or more LANs
  - Using the same or different data link protocols
  - But the same network protocol
- Operates at the network layer
- A router performs more processing on each message than a bridge
  - Operate more slowly
- But
  - Can choose the best route
  - Can connect networks using different data link layer protocols
    - Are able to change data link layer packets
  - May split a message into several smaller messages for transmission

Gateway


Front-end processor
Gateway
Token Ring Hub
Ethernet Hub
Mainframe

Gateway

- Connects two or more LANs
  - Using the same or different (usually different) data link and network protocols
  - Using the same or different kinds of cable
- Operates at the network layer
  - Translates one network protocol into another
  - Translates data formats
  - Opens sessions between application programs

  Thus overcoming both hardware and software incompatibilities
- May be a stand-alone microcomputer or even a special circuit card in the network server