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Lecture 4

Multiple Access (MAC) Protocols and Wired LAN Standards

ELEC 3506/9506
Communication Networks

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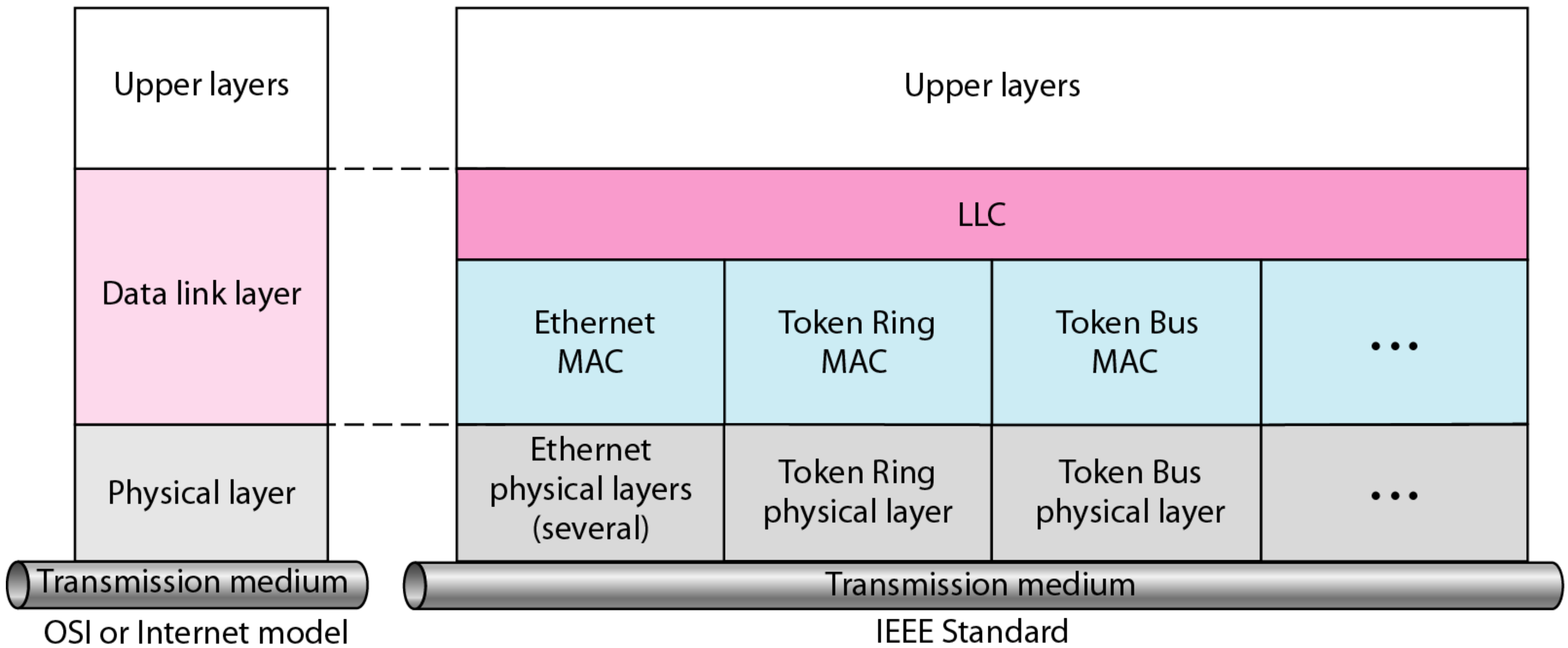
Topics for the Day

- Multiple Access Protocols
  - CSMA/CD
  - CSMA/CA

- LAN Standards
  - Ethernet
  - Token Ring
  - FDDI

IEEE Project 802

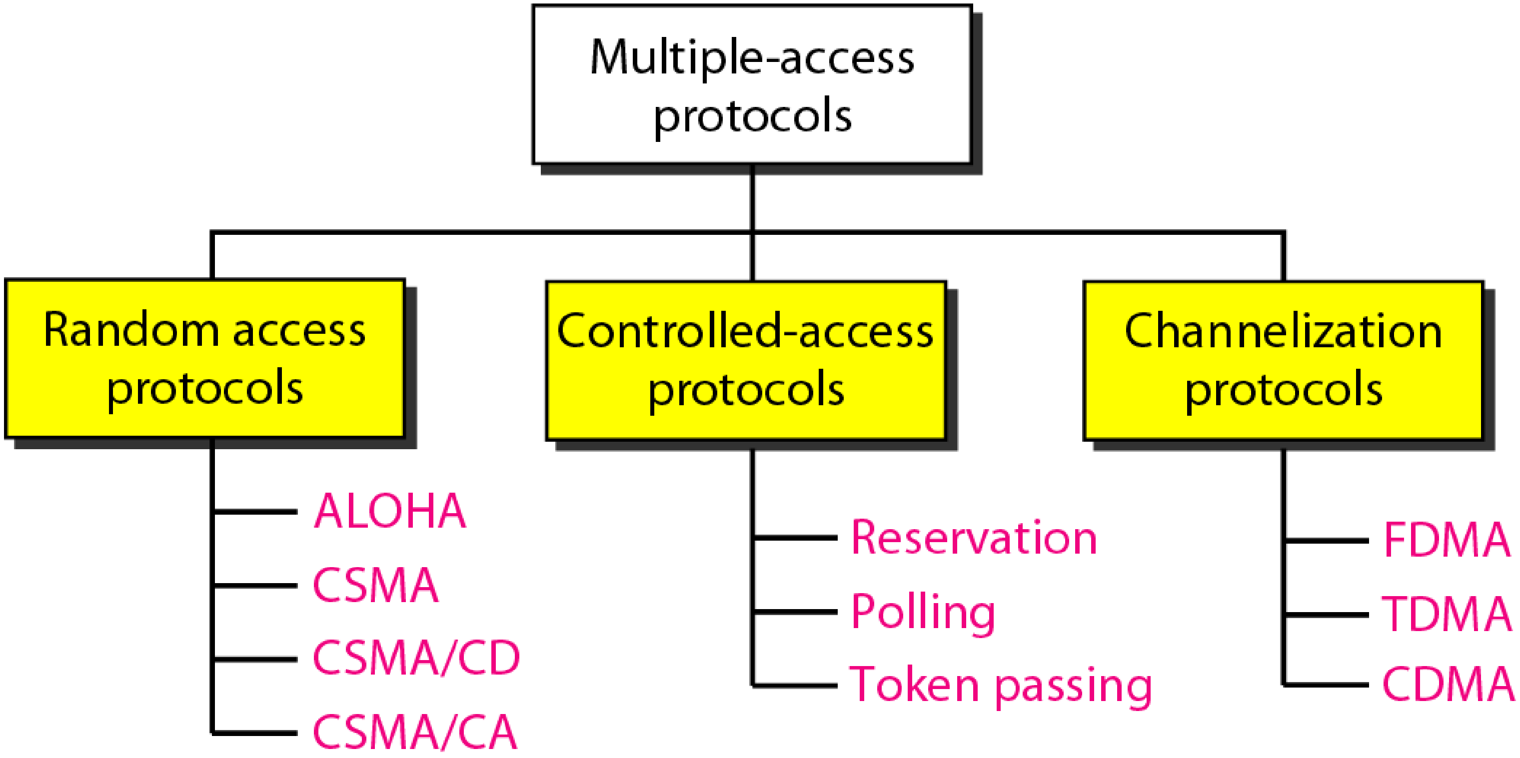
- IEEE started Project 802 to standardize LAN communications in 1985
- Project 802 split the data link layer into two different sub-layers:
  - Logical Link Control (LLC)
  - Media Access Control (MAC)



LLC vs. MAC

- Logical Link Control (LLC) – Provides one single data link control protocol for all IEEE LANs.
  - Flow Control
  - Error Control
  - Framing (partly)
- Media Access Control (MAC) – Defines and specifies the access method for LANs.
  - Different access methods (CSMA/CD, CSMA/CA Token Ring, Token Bus)
  - Framing (partly)

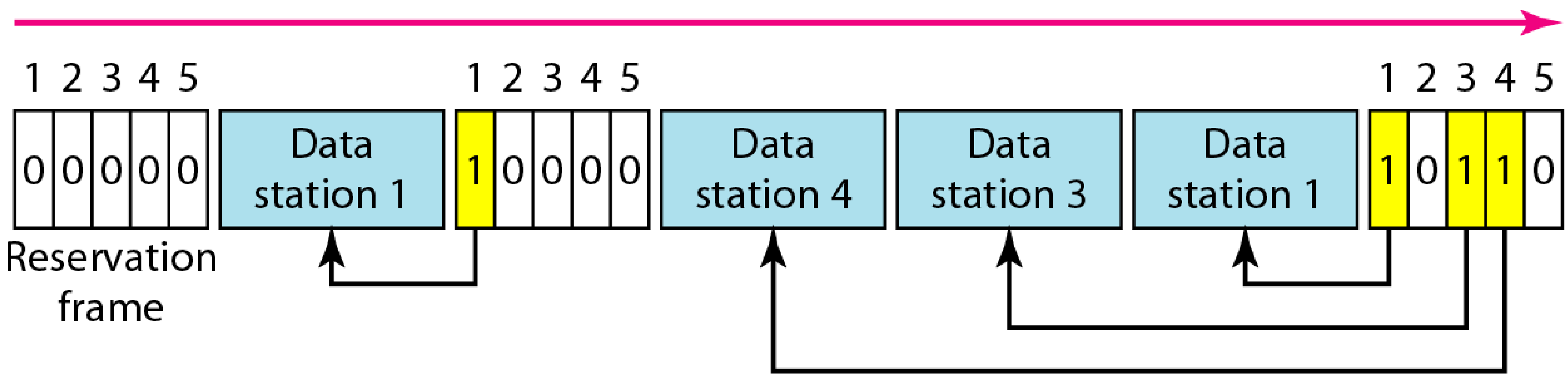
Multiple Access Protocols



Controlled Access Protocols

Reservation

- A station needs to make a reservation before sending data
- A reservation frame to indicate slot allocation precedes the data frames
- Each mini slot in that frame belongs to a station



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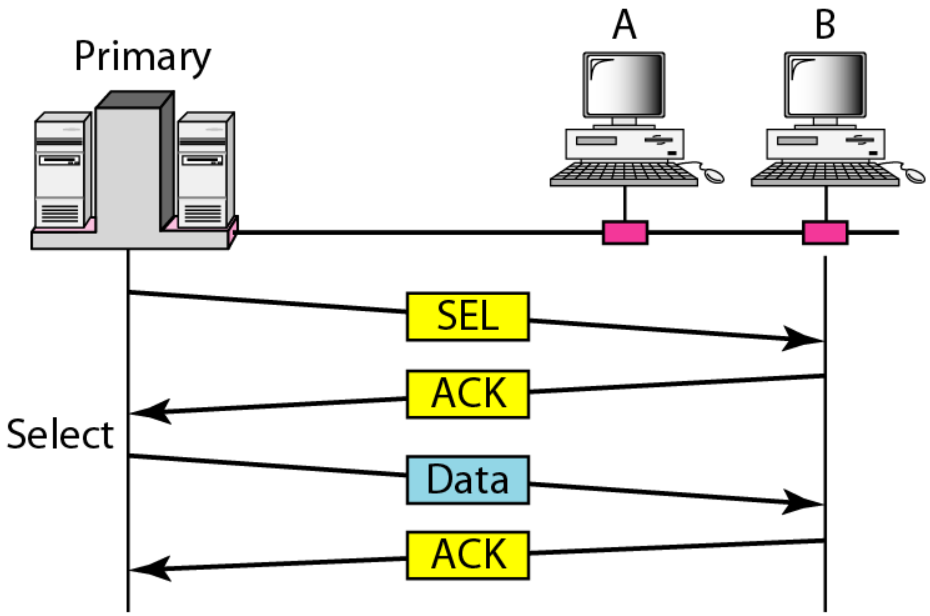
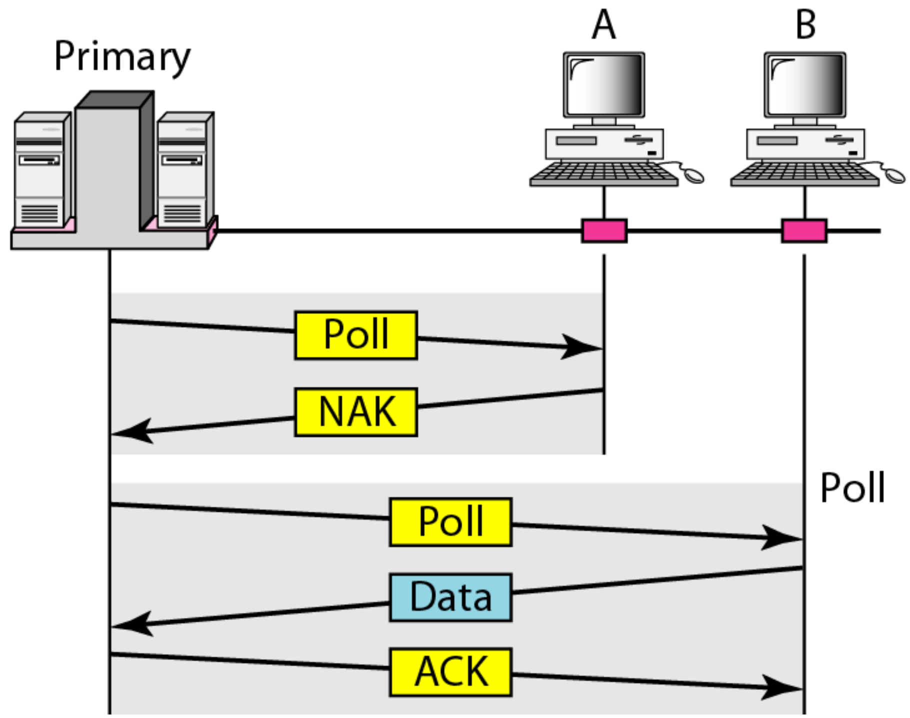
Polling (Select/Poll)

- Works with topologies where one device is designated as a primary station and the other devices are secondary station (Master/Slave)
- The primary station has control of the physical link (initiates the session)



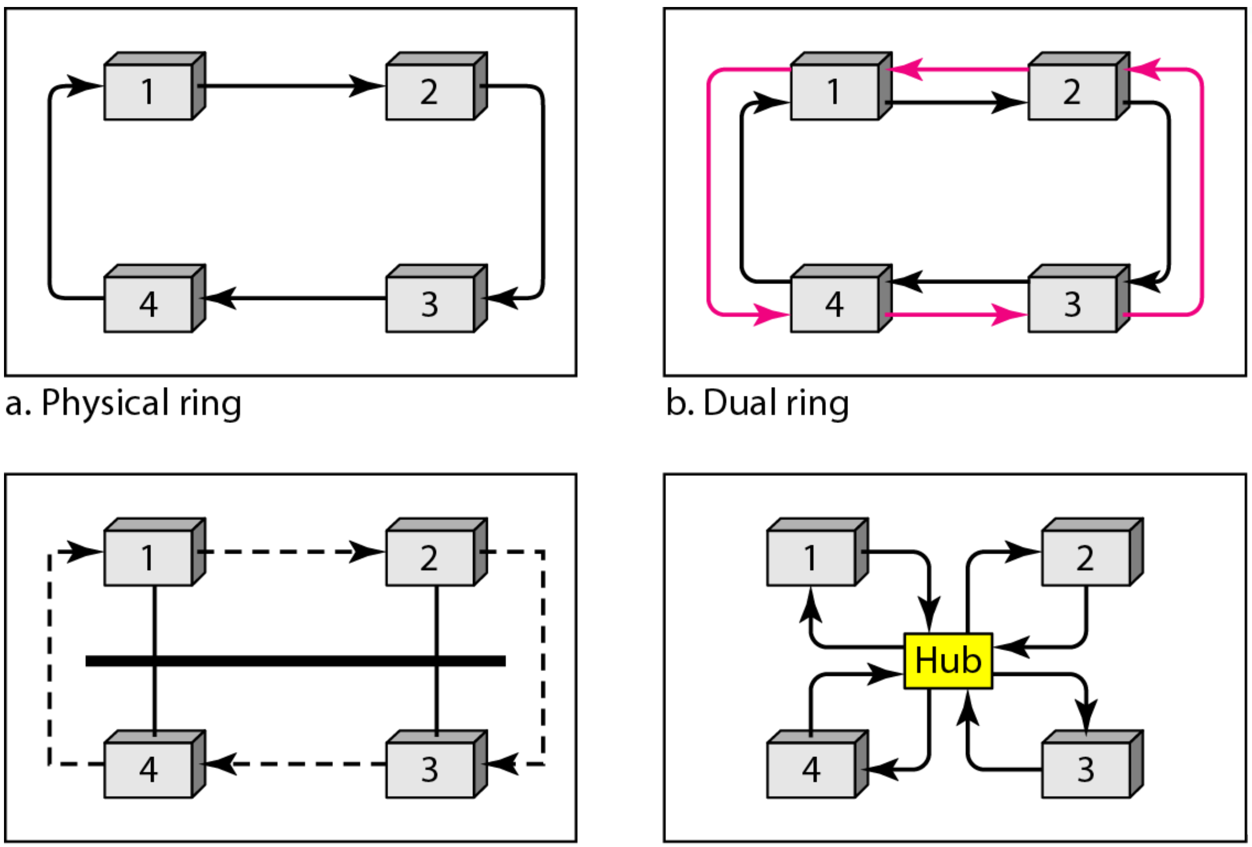


Primary to transmit to B by broadcasting **SEL** containing the address of B
B indicates it is ready to receive by sending **ACK**

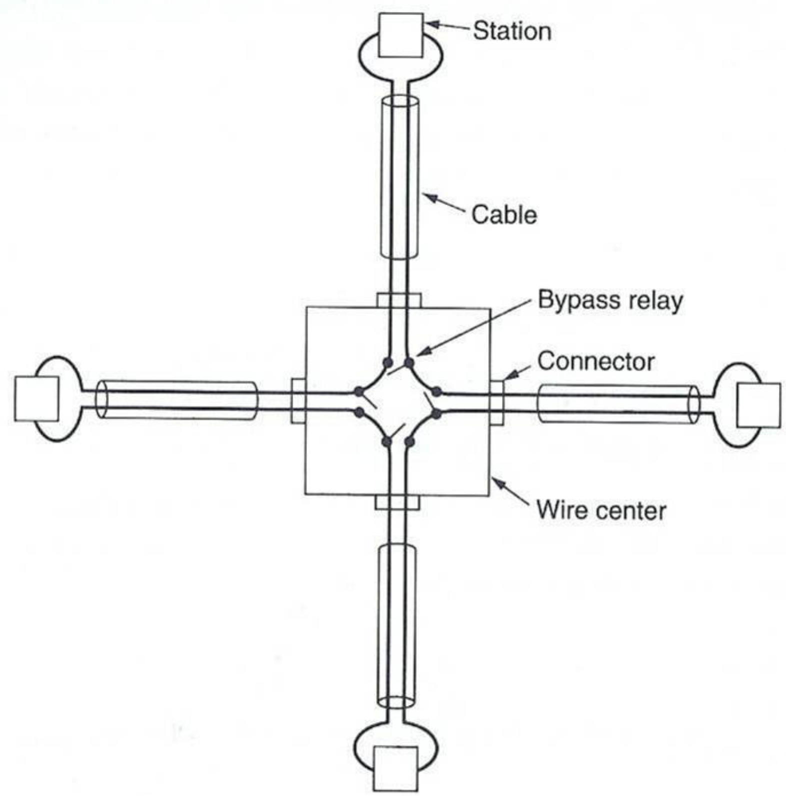
Primary queries A and B 's transmit intention by broadcasting **Poll** to A and B
A and B indicate no and yes by sending **NAK** and data

Logical Ring and Physical Topology

Ring is based on token



a. Physical ring
b. Dual ring
c. Bus ring
d. Star ring



Physical ring: a,b,and d. Predecessor, Successor concepts w/o the need of addresses
Logical ring: c. Predecessor, Successor concepts with the need of addresses

Token Passing

- When no station is transmitting a data frame, a special token frame circles a logical ring.
- This special token frame (with addresses) is repeated from station to station until arriving at a station that needs to transmit data.
- When a station needs to transmit data, it retains the token (successor) and transmits a data frame.
- Nobody else can transmit during this time.
- When the receiving station receives data, it then sends an ACK back to the sending station.
- Once the sending station receives the ACK, it (predecessor) releases the token back to the ring and passes it to the next station (successor).
- No Contention and No Collision in the ring

Token Management

- If an error occurs, a special station referred to as the *Active Monitor* detects the problem and removes and/or reinserts tokens as necessary.
- On 4 Mbit/s Token Ring, only one token may circulate; on 16 Mbit/s Token Ring, there may be multiple tokens.
- The special token frame consists of three bytes.
- Stations with a high-priority transmission may request priority access to the token (priority token access)

Random Access

CSMA/CD

- Carrier Sense Multiple Access with Collision Detection (CSMA/CD) is a random access/contention based access method
- No station superior or controls others
- No scheduled time to transmit (random access)
- No rules specify who sends next
- Stations compete with each other to access the medium (contention based)
- If more than one station transmit frames, collisions may take place

Ethernet CSMA/CD algorithm

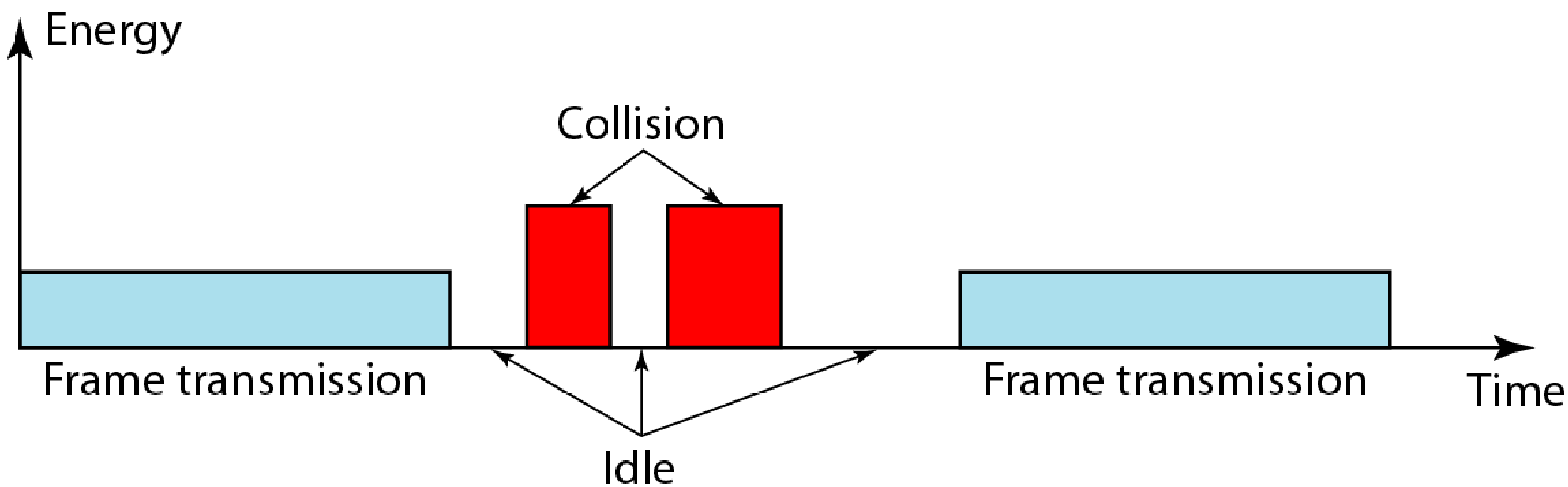
1. NIC receives datagram from network layer, creates frame
2. If NIC senses channel:

   if idle: start frame transmission.

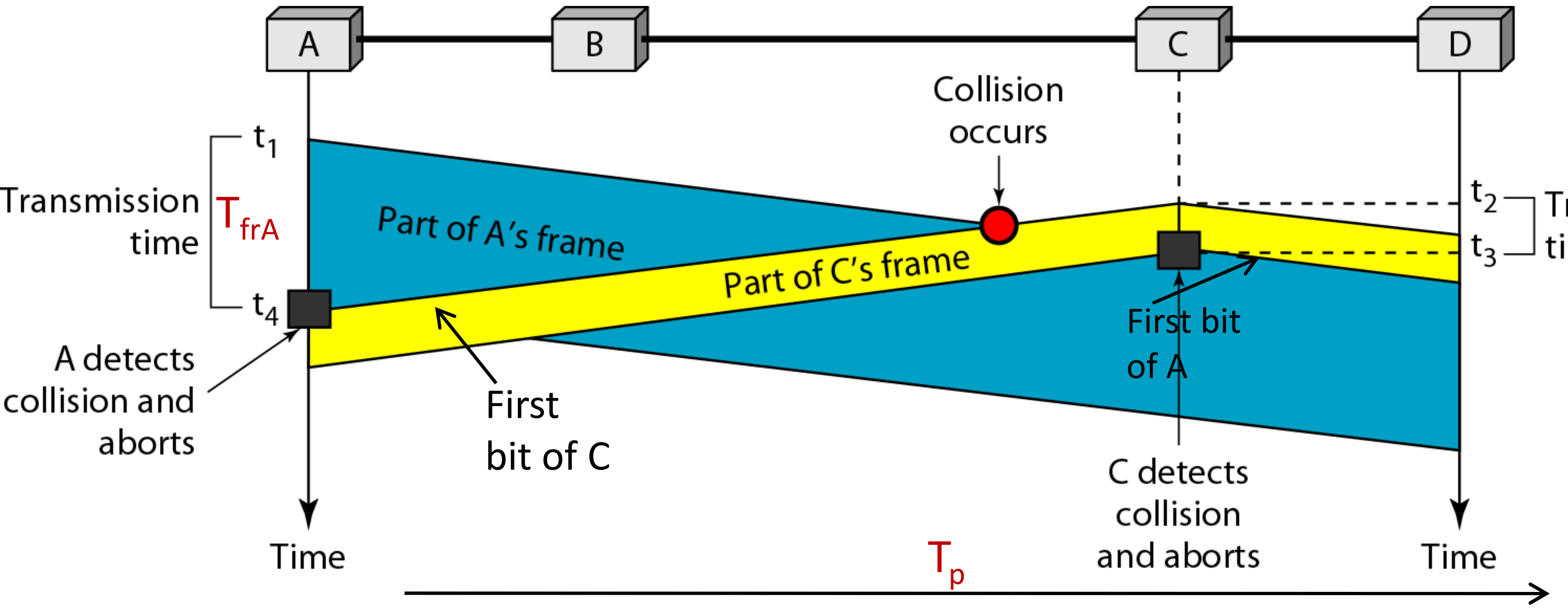
   if busy: wait until channel idle, then transmit
3. If NIC transmits entire frame without collision, NIC is done with frame !
4. If NIC detects another transmission while sending: abort, send jam signal
5. After aborting, NIC enters *binary (exponential) backoff:*
   - after *m*th collision, NIC chooses *K* at random from $\{0,1,2, \ldots, 2^m-1\}$. NIC waits $K \cdot 512$ bit times, returns to Step 2
   - more collisions: longer backoff interval
   - m is the number of collisions
   - Spread future transmission in time to reduce collusion

Energy Level Sensing

- Three values of energy:
  - Zero – the channel is idle
  - Normal level – a station is successfully transmitting a frame
  - Abnormal level – there is a collision and the level of energy is twice the normal level



Collision and Abortion in CSMA/CD



- Before sending the last bit of the frame, the sending station must detect a collision.
- Therefore, frame transmission time (T_{fr}) must be at least two times the maximum propagation time (T_p)
- If two stations involved in a collision are at maximum distance apart, the signal from the first takes time T_p to reach the second, and the effect of the collision takes another T_p to return to the first.
- So, the requirement is that the first station must still be transmitting after $2T_p$.
- Successful transmission happens when A does not sense a collision

Minimum Frame Size

Example:

- For a network using CSMA/CD that has a bandwidth of 10 Mbps, if the maximum propagation time T_p (from one end to the other) is 25.6 μs. What is the minimum size of the frame?
- The frame transmission time (slot time) $T_{fr} = 2 * T_p = 51.2$ μs.
- Therefore, the minimum frame size is 10 Mbps * 51.2 μs = 512 bits or 64 bytes.
- If the first 512 bits are successfully transmitted, it is guaranteed that a collision will not happen during the transmission of this frame.
- So, the sender only needs to listen for a collision during the first 512 bits.
- The slot time is the time required for a station to transmit 512 bits; for 10Mbps traditional Ethernet it is 51.2 μs

- What will happen if the frame size < (51.2 μs or 2 T_p)?

Maximum Collision Domain Size

- The maximum length of the network (collision domain)

  = Propagation Speed * maximum propagation time (T_p)

  = $(2*10^8) * (25.6*10^{-6}) = 5120$ m

- Considering delay time at repeaters/hubs and network interfaces, the max length of a traditional (10 Mbps) Ethernet network is reduced to 2500 m (48% of the theoretical calculation)

- The max length for a 100 Mbps Ethernet network with a minimum frame size of 512 bits is 250 m

- Electrical signal in a copper wire travels at approximately 2/3 of the speed of light

CSMA/CA

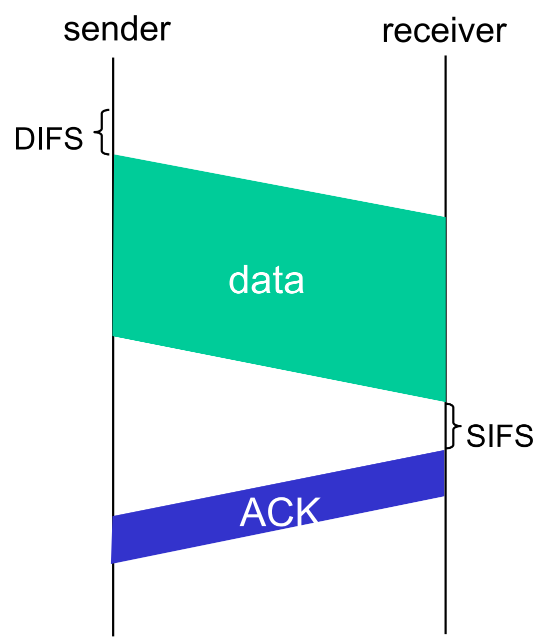
- CSMA/CD cannot be used in a wireless medium because:
  - In a wireless network, collisions do not add enough energy for stations to effectively detect them
  - Collisions may not be detected because of hidden node problem
  - Distance between stations may be great and signal fading could prevent a station at one end from hearing a collision at the other end
  - Unlike non-wireless mediums, the received signal power is not known
  - Signal fade significantly in wireless medium
- Therefore, collisions to be avoided by CSMA/CA strategy

CSMA/CA

Sender

1 if sense channel idle for **DIFS** then
transmit entire frame (no CD)

2 if sense channel busy then
start random backoff time
timer counts down while channel idle
transmit when timer expires
if no ACK, increase random backoff interval, repeat 2



Receiver

if frame received OK
return ACK after **SIFS** (ACK needed due to hidden terminal problem)

DIFS=distributed inter frame space
SIFS=short inter frame space

Avoiding collisions (more)

idea: sender "reserves" channel use for data frames using small reservation packets

- sender first transmits *small* request-to-send (RTS) packet to BS using CSMA
  - RTSs may still collide with each other (but they're short)
- BS broadcasts clear-to-send CTS in response to RTS
- CTS heard by all nodes
  - sender transmits data frame
  - other stations defer transmissions

CA: If the channel is busy, use CW/back-off and decrement if the channel is idle

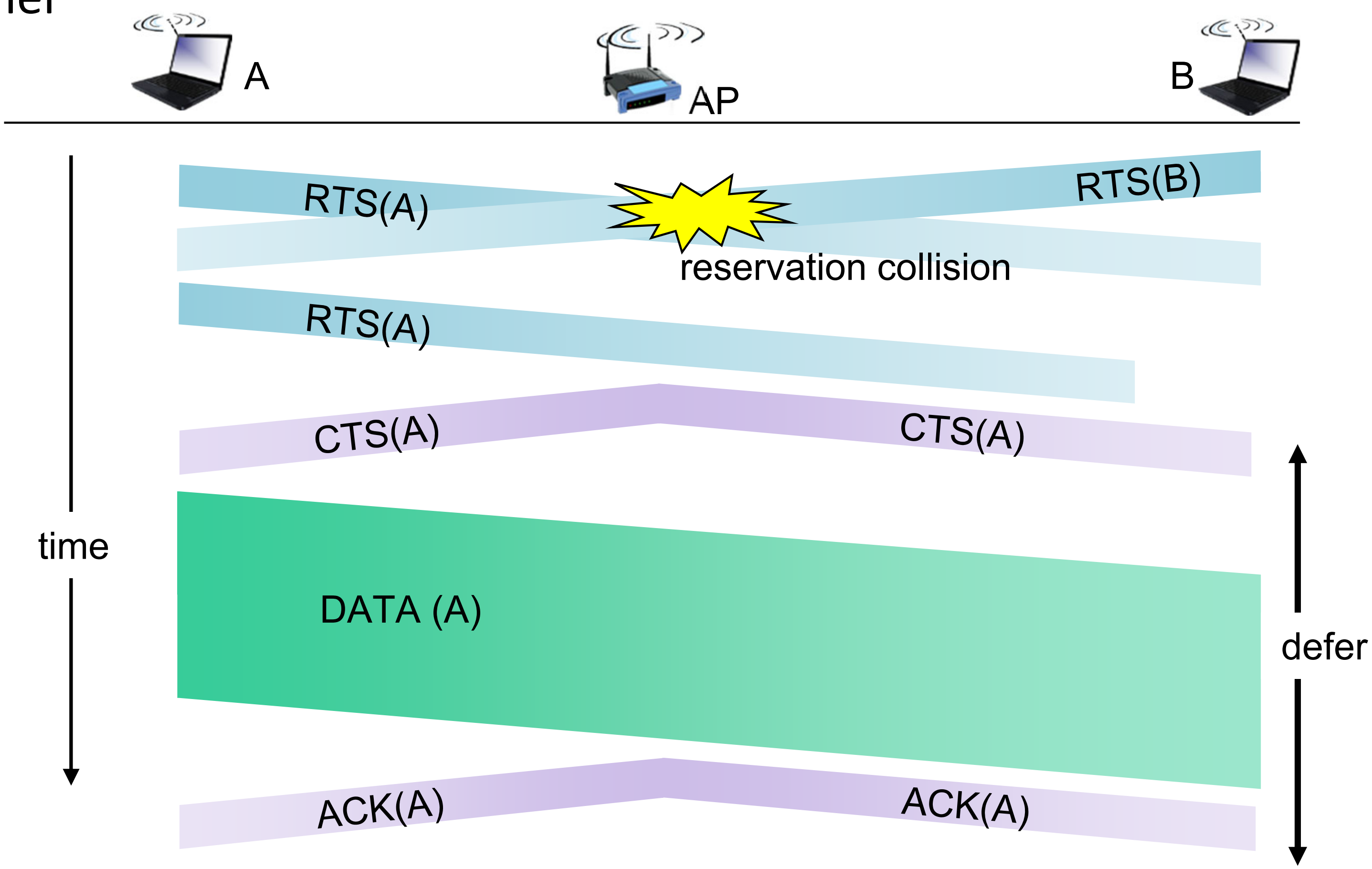
No CD: transmit completely and rely on ACK for collision

DIFS, SIFS and a time slot are 50µs, 20µs and 10µs, followed by CA

Hidden Node Problem

RTS contains info on the time required to transmit data and is used with CTS to reserve the wireless channel

RTS and CTS are short control packets

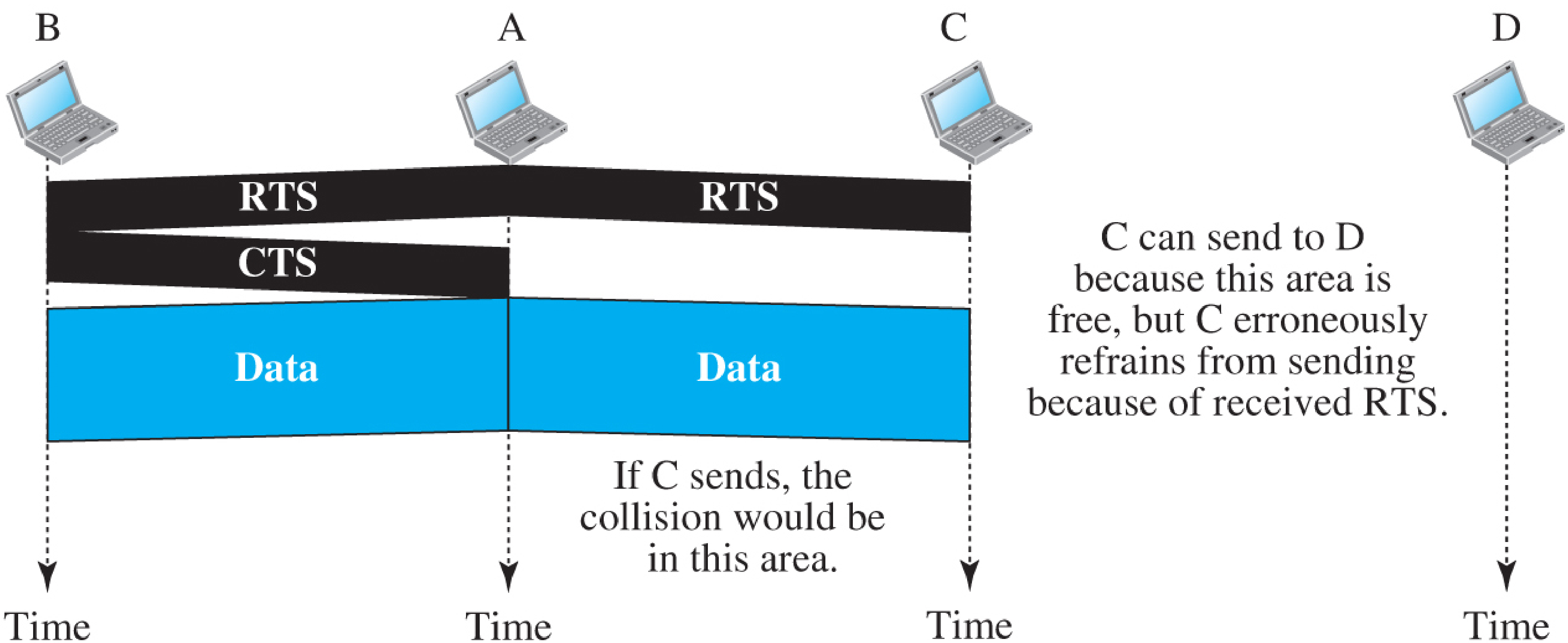


Hidden node problem happens when B and A are simultaneously transmitting to AP → A is hidden from B (during handshake)

Network Allocation Vector (NAV)

- How is collision avoidance accomplished?
  - When a station sends a RTS/CTS frame, it includes the duration of time that it needs to occupy the channel.
  - Other stations that are affected create a timer called a Network Allocation Vector (NAV) to defer based on the information in RTS/CTS frame
  - The NAV shows the time that must pass before these stations are allowed to check/sense the channel for idleness
  - Each time a station access the system and sends a RTS frame, other stations start their NAV.
- Collision during handshake
  - Two or more stations may try to send RTS frames at the same time and these may collide
  - Sender assumes that there may have been a collision since it does not receive a CTS frame
  - Revert back to CW and the back-off strategy is employed,sender tries again

Exposed Node Problem



Exposed node problem happens when A are transmitting to B → C is exposed to A

Summary

- CSMA/CA address collision in the wireless medium by using
  - backoff/persistent methods to spread transmission in time
  - NAV to ensure all stations are aware of on-going transmissions
  - ACK to ensure the sender are aware transmission is successful or not

- RTS and CTS solve hidden node but not exposed node problems

Local Area Networks

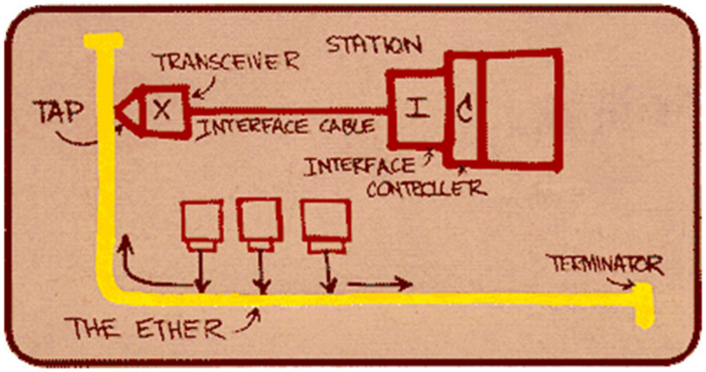
Local Area Networks

- A data communication system that allows a number of independent devices to communicate directly with each other in a limited geographic area
- Three most popular LAN standards
  - Ethernet
  - Token ring
  - FDDI

Ethernet

"dominant" wired LAN technology:

- first widely used LAN technology
- simpler, cheap
- kept up with speed race: 10 Mbps – 400 Gbps
- single chip, multiple speeds (e.g., Broadcom BCM5761)



Metcalfe's Ethernet sketch

https://www.uspto.gov/learning-and-resources/journeys-innovation/audio-stories/defying-doubters

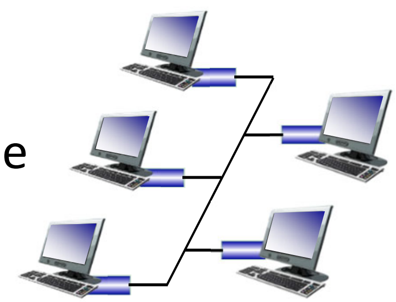
Ethernet (IEEE 802.3)

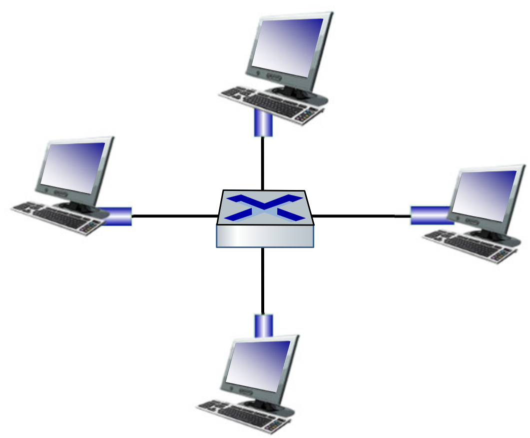
- It is a simple LAN architecture with very little management overhead.
- Access method - CSMA/CD
- Cabling is either twisted pair, fiber, thick or thin coaxial cable.
- Cable and connection types are known as 10BaseT, 10BaseF, 10Base5, 10Base2.
- Bits are coded using Manchester encoding.
- Traditional Ethernet is Half Duplex.

Ethernet: physical topology

- bus: popular through mid 90s
  - all nodes in same collision domain (can collide with each other)
- switched: prevails today
  - active link-layer 2 *switch* in center
  - each "spoke" runs a (separate) Ethernet protocol (nodes do not collide with each other)

bus: coaxial cable





switched

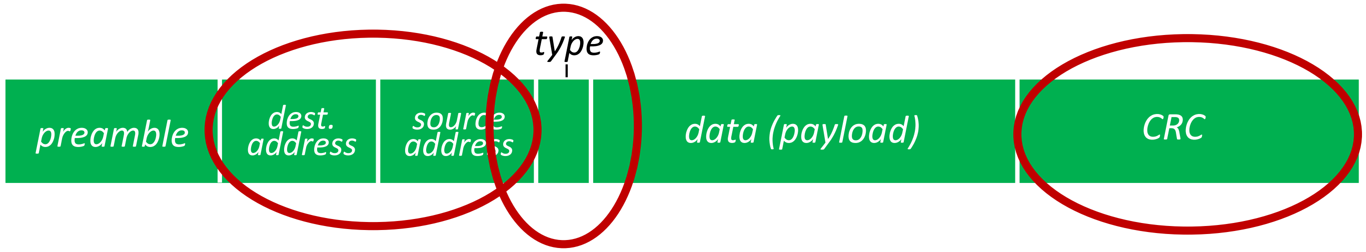
Ethernet frame structure

sending interface encapsulates IP datagram (or other network layer protocol packet) in Ethernet frame

preamble:

- used to synchronize receiver, sender clock rates
- 7 bytes of 10101010 followed by one byte of 10101011

Ethernet frame structure (more)



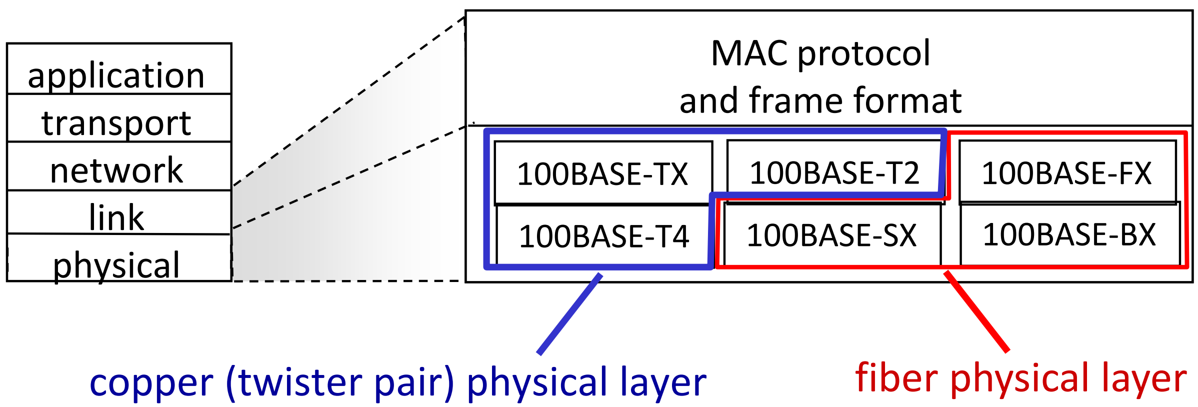
- addresses: 6 byte source, destination MAC addresses
  - if adapter receives frame with matching destination address, or with broadcast address (e.g., ARP packet), it passes data in frame to network layer protocol
  - otherwise, adapter discards frame
- type: indicates higher layer protocol
  - mostly IP but others possible, e.g., Novell IPX, AppleTalk
  - used to demultiplex up at receiver
- CRC: cyclic redundancy check at receiver
  - error detected: frame is dropped

Ethernet: unreliable, connectionless

- connectionless: no handshaking between sending and receiving NICs
- unreliable: receiving NIC doesn't send ACKs or NAKs to sending NIC
  - data in dropped frames recovered only if initial sender uses higher layer rdt (e.g., TCP), otherwise dropped data lost
- Ethernet's MAC protocol: unslotted CSMA/CD with binary backoff

802.3 Ethernet standards: link & physical layers

- *many* different Ethernet standards
  - common MAC protocol and frame format
  - different speeds: 2 Mbps, 10 Mbps, 100 Mbps, 1Gbps, 10 Gbps, 40 Gbps
  - different physical layer media: fiber, cable



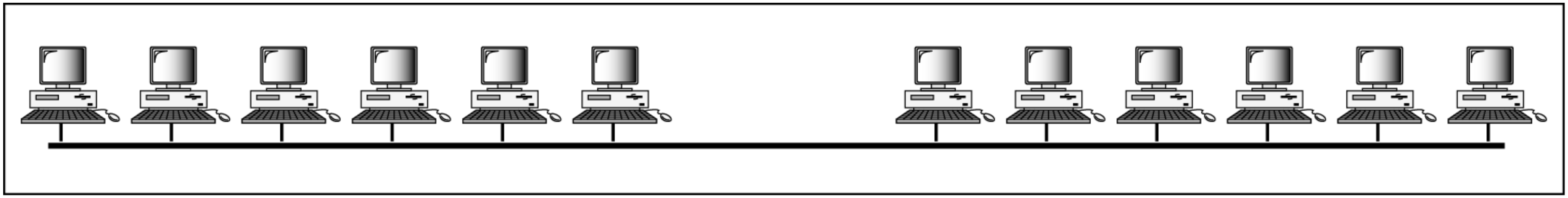
Bridged Ethernet

- The first step in the Ethernet evolution was the division of a LAN by bridges.

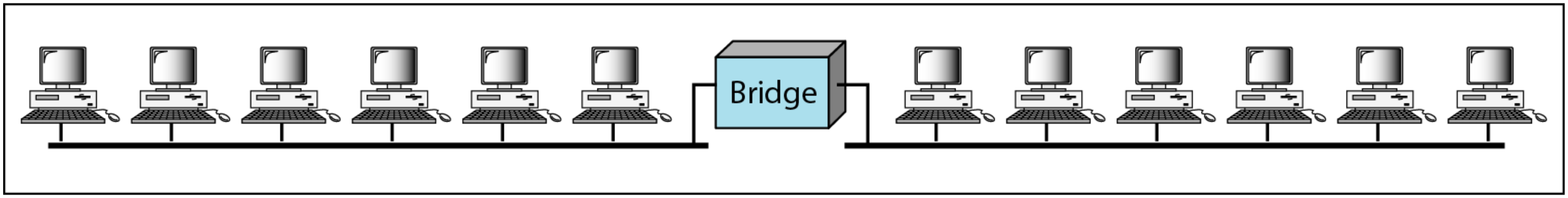
- Bridges have two effects on an Ethernet LAN:
  - Raise the bandwidth
  - Separate collision domains

Raising the Bandwidth

- In an unbridged Ethernet network, the total capacity (say 10 Mbps) is shared among all stations.
- A bridge can divide the network into two or more segments and bandwidth-wise each network becomes independent



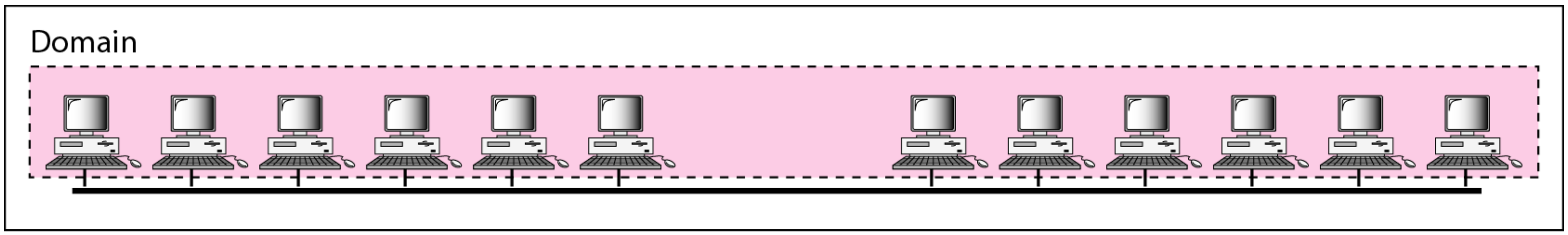
a. Without bridging



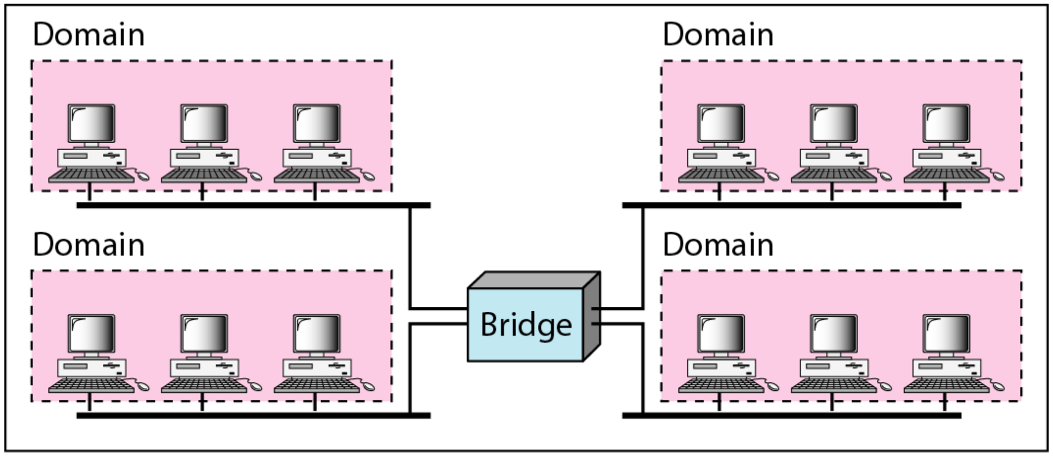
b. With bridging

Separating Collision Domains

- A bridge can separate a collision domain
- Collision domains becomes much smaller and the probability of collisions are reduced tremendously



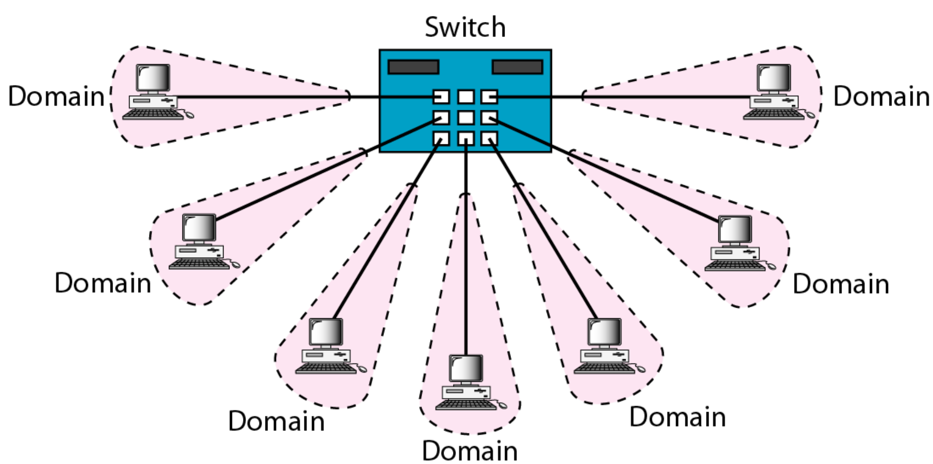
a. Without bridging



b. With bridging

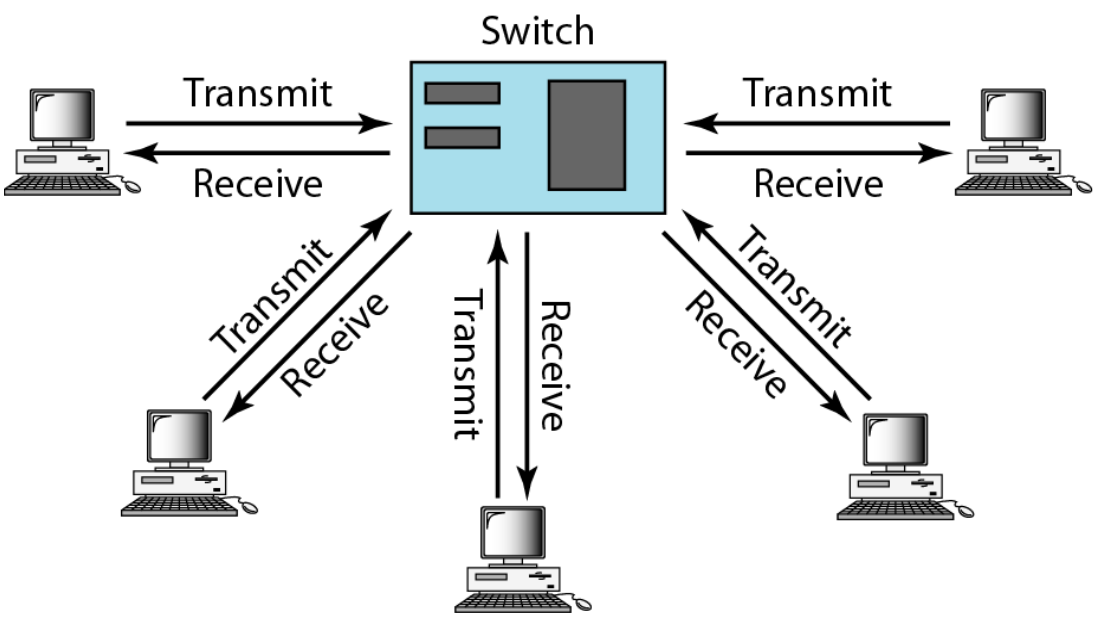
Switched Ethernet

- A switch is a multiple-port bridge
- Instead of having 2-4 networks, why not have N networks, where is the number of nodes in the LAN?
- So an N-port switch can be used
- Bandwidth is shared only between the station and the switch (10/2 = 5 Mbps each)
- The single collision domain is divided into N domains

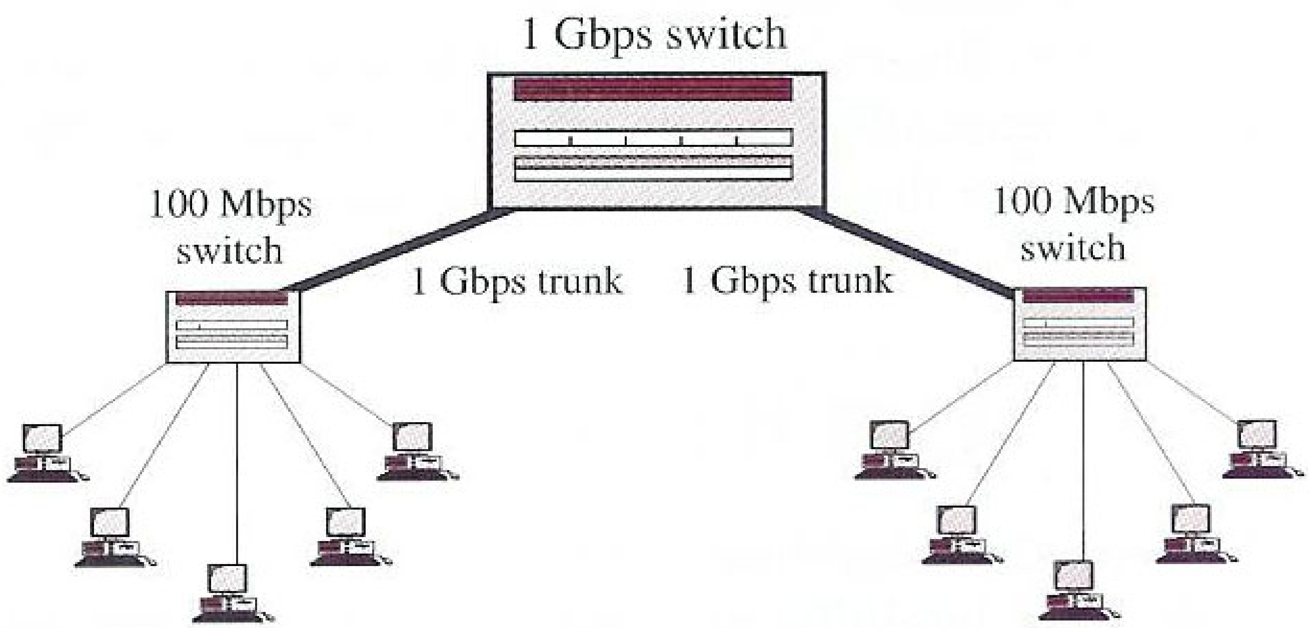


Full-Duplex Ethernet

- Traditional Ethernet (10Base5, 10Base2) is half-duplex
- 10BaseT is full-duplex
- Increases the capacity from 10 to 10000 Mbps
- Two separate links for transmitting and receiving are used between the station and the switch
- No need for CSMA/CD



Gigabit (1Gbps) Ethernet



Implementation	*Medium*	*Medium Length(m)*	*Wires*	*Encoding*
1000Base-SX	Fiber S-W	550 m	2	8B/10B + NRZ
1000Base-LX	Fiber L-W	5000 m	2	8B/10B + NRZ
1000Base-CX	STP	25 m	2	8B/10B + NRZ
1000Base-T4	UTP	100 m	2	4D-PAM5

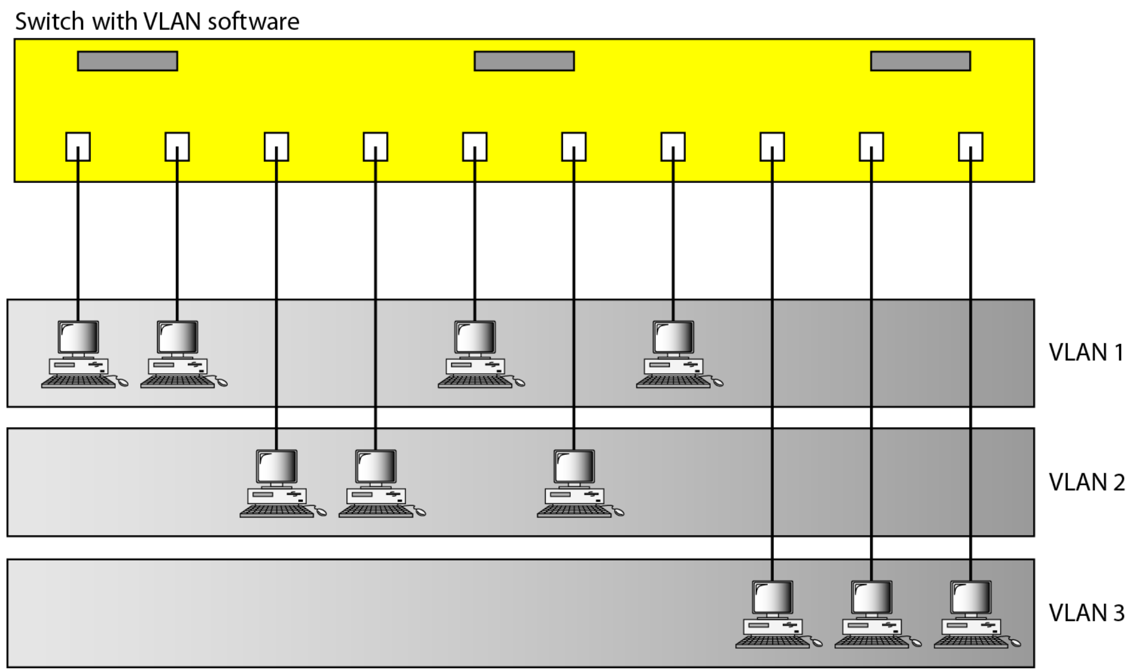
10-Gigabit Ethernet

- IEEE Standard 802.3ae
- operates only in full-duplex mode, no contention; no CSMA/CD
- Four implementations are the most common: 10GBase-SR, 10GBase-LR, 10GBase-EW, and 10GBase-X4.

Implementation	*Medium*	*Medium Length*	*Number of wires*	*Encoding*
10GBase-SR	Fiber 850 nm	300 m	2	64B66B
10GBase-LR	Fiber 1310 nm	10 km	2	64B66B
10GBase-EW	Fiber 1350 nm	40 km	2	SONET
10GBase-X4	Fiber 1310 nm	300 m to 10 km	2	8B10B

Virtual LAN (VLAN)

- A VLAN is a LAN configured by software and not by physical wiring
- A single physical LAN can be divided into several logical LANs
- VLANs create separate broadcast domains
- Stations are grouped based on: port #, IP addresses, MAC addresses, or a combination



Token Ring – IEEE 802.5

- Token Ring has become the IEEE standard 802.5.
- It was developed by IBM for STP, IBM Type 1 cabling.
- TR is available for speeds of 4 Mbps and 16Mbps.
- Bits are Encoded using Differential Manchester Encoding.
- The typical maximum frame size is 4500 bytes.
- Some implementations allow larger frame sizes.
- Each TR card has a unique 48-bit address similar to Ethernet.

FDDI (Fiber Distributed Data Interface)

Specifications:

- FDDI is a token ring network designed to run over fiber optic cabling (Multimode Fiber).
- The data transfer rate is 100Mbps.
- It has a maximum circumference of 200km (Both Rings)
- Topology – Ring based token bus network (not token ring)
- Access Control Method – A timed token protocol
- More than one frame is transmitted before releasing the token
- Hence, FDDI has higher throughput than 802.5

FDDI (Fiber Distributed Data Interface)

Specifications:

- Consists of two rings (Primary and Secondary Rings)
- Each ring should be limited to 500 nodes and 100km of cable.
- Repeater is required every 2Km or less

Mechanism of Operation:

- Two counter rotating dual rings are used. Two similar data streams flow around the two counter rotating rings
- Traffic usually flows on the primary ring and if this ring fails FDDI automatically reconfigures the network so the data flows on to the secondary ring in the opposite direction.
- Advantage is Redundancy.
- This automatic reconfiguration is called as self-healing.
- Stations can be dual (Class A) or single (Class B) attached.
- When there is network failure Class A stations reconfigures but not Class B stations.

FDDI Self Healing

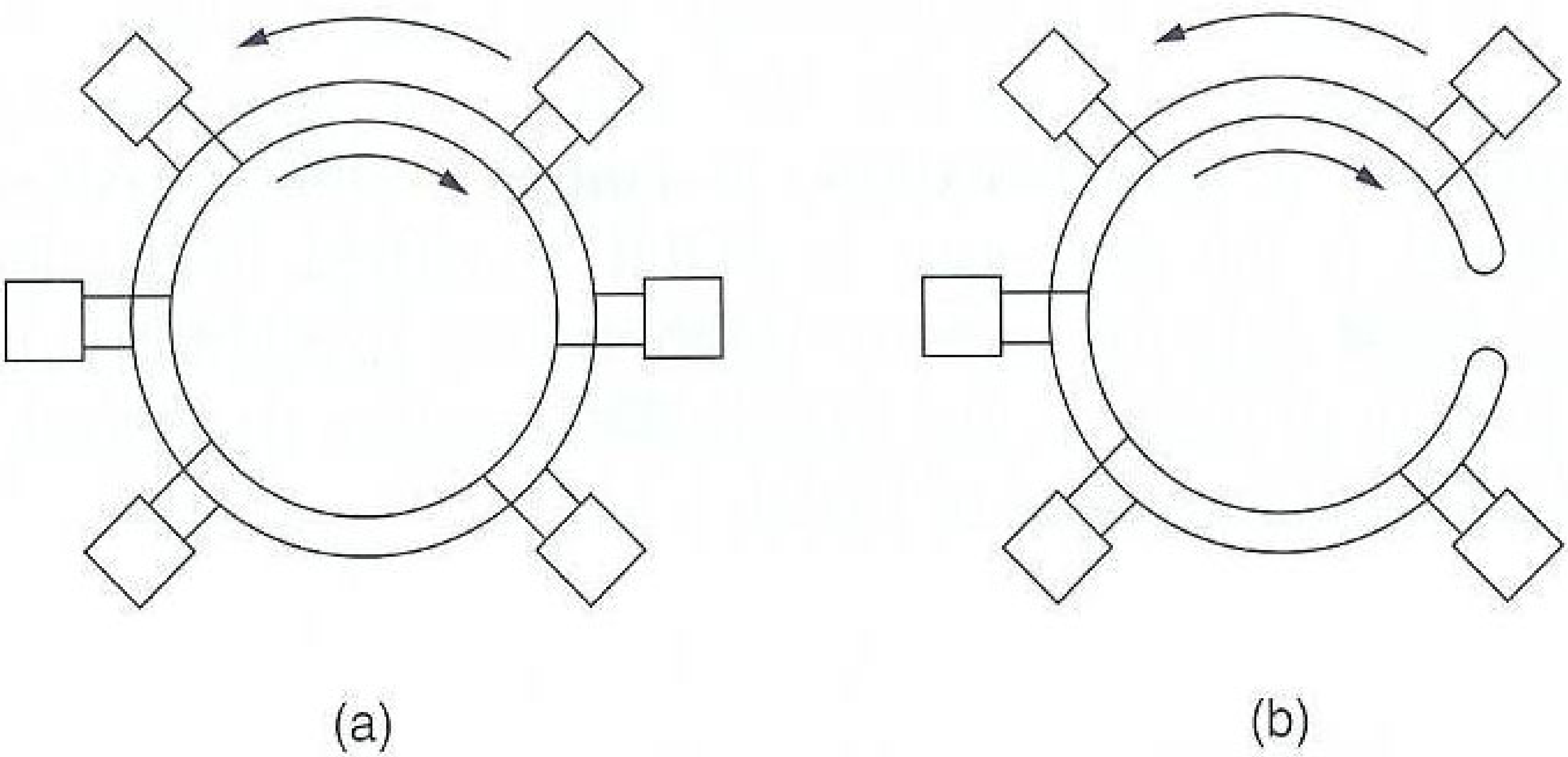
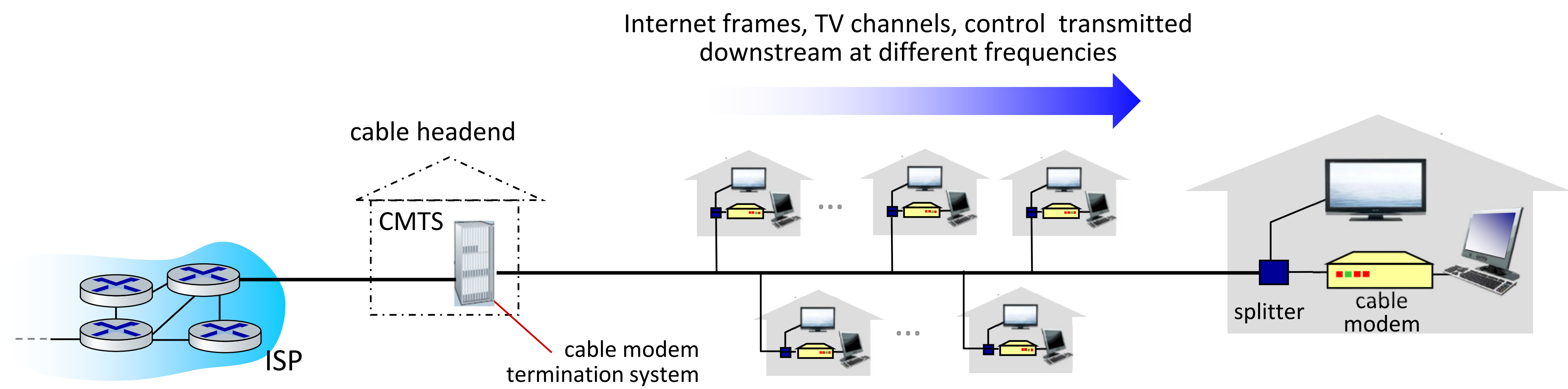


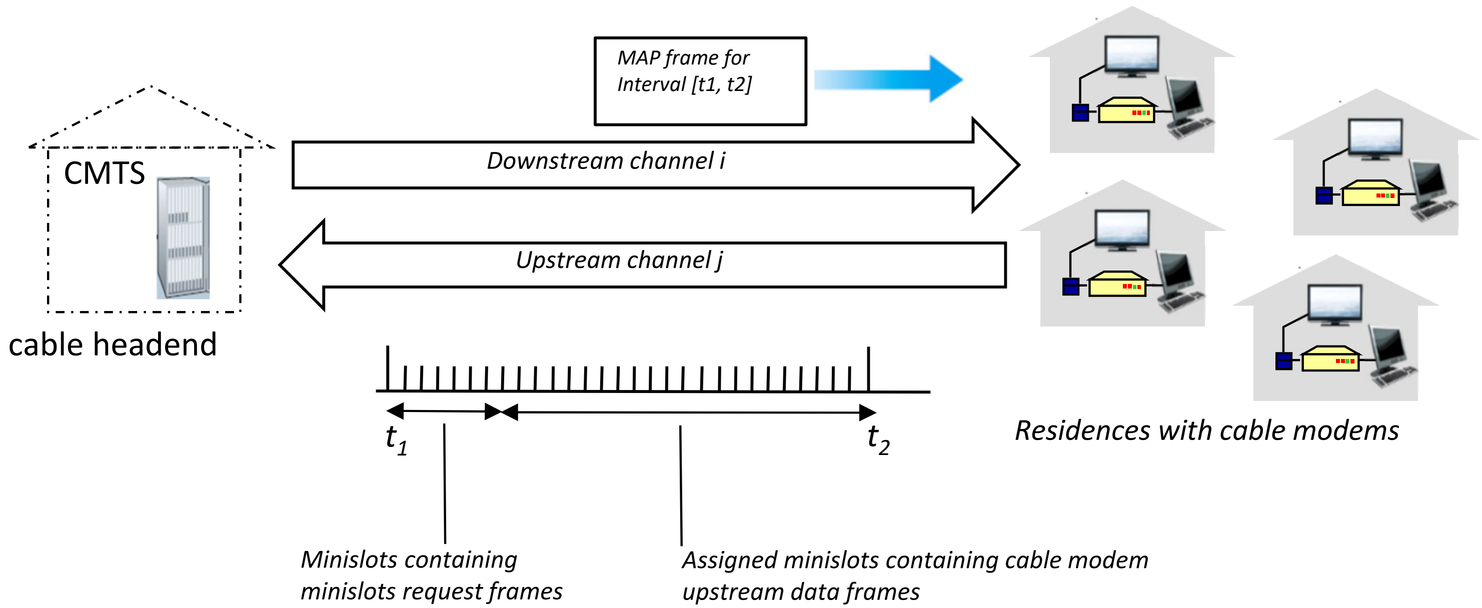
Fig. 4-45. (a) FDDI consists of two counterrotating rings. (b) In the event of failure of both rings at one point, the two rings can be joined together to form a single long ring.

Cable access network: FDM, TDM *and* random access!



- multiple downstream (broadcast) FDM channels: up to 1.6 Gbps/channel
  - single CMTS transmits into channels
- multiple upstream channels (up to 1 Gbps/channel)
  - multiple access: all users contend (random access) for certain upstream channel time slots request; others assigned TDM
  - Persistent method and Binary Exponential Back-off to resolve collision

Cable access network: FDM, TDM *and* random access!



DOCSIS: data over cable service interface specification

- FDM over upstream, downstream frequency channels
- TDM upstream: some slots assigned, some have contention
  - downstream MAP frame: assigns upstream slots
  - request for upstream slots (and data) transmitted random access (binary backoff) in selected slots

Datacenter networks

10's to 100's of thousands of hosts, often closely coupled, in close proximity:

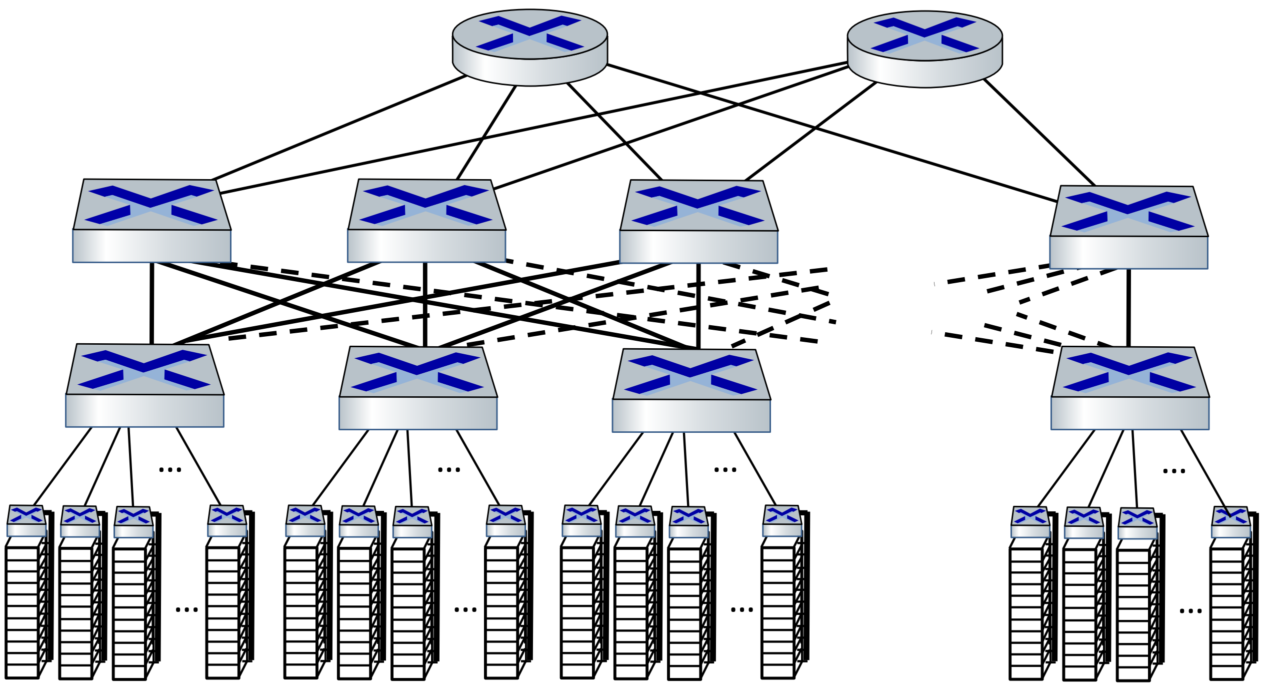
- e-business (e.g. Amazon)
- content-servers (e.g., YouTube, Akamai, Apple, Microsoft)
- search engines, data mining (e.g., Google)

challenges:

- multiple applications, each serving massive numbers of clients
- reliability
- managing/balancing load, avoiding processing, networking, data bottlenecks

Inside a 40-ft Microsoft container, Chicago data center

Datacenter networks: network elements



Border routers

- connections outside datacenter

Tier-1 switches

- connecting to ~16 T-2s below

Tier-2 switches

- connecting to ~16 TORs below

Top of Rack (TOR) switch

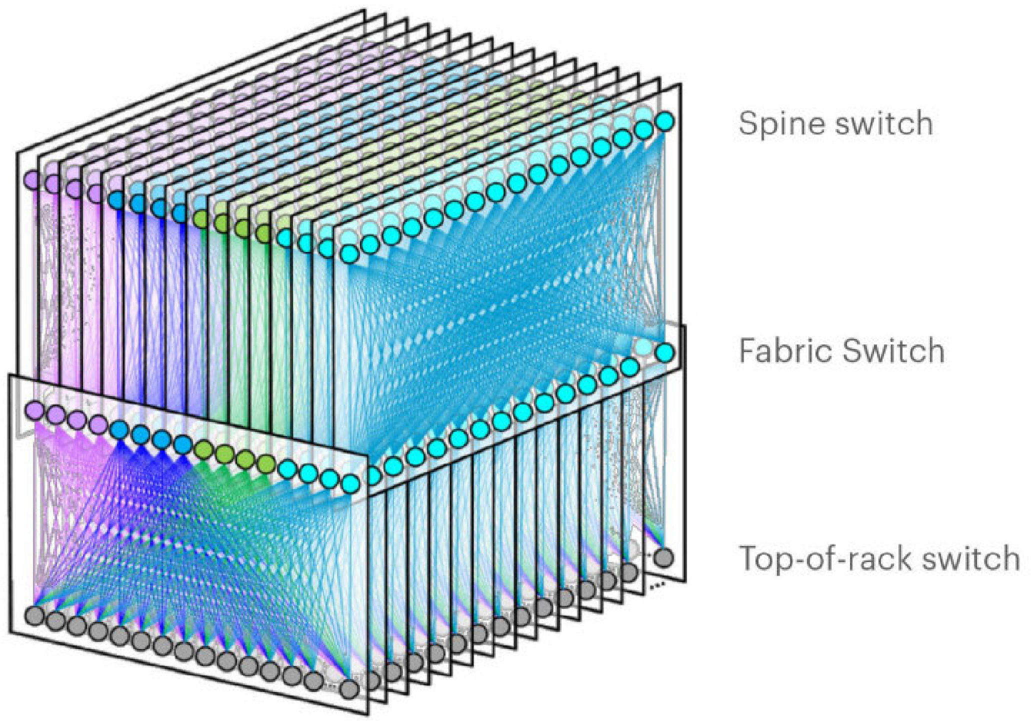
- one per rack
- 40-100Gbps Ethernet to blades

Server racks

- 20- 40 server blades: hosts

Datacenter networks: network elements

Facebook F16 data center network topology:



https://engineering.fb.com/data-center-engineering/f16-minipack/ (posted 3/2019)

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Recommended Reading

- Behrouz A. Forouzan, Data Communications and Networking with TCP/IP Protocol Suite, 6th ed., 2022, Chapters 3 and 4

- J. F. Kurose and K. W. Ross, Computer Networking: A Top-Down Approach, 8th ed., 2022, Chapter 6