BLG 337E- Principles of Computer Communications

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-Medium Access Layer-

References:

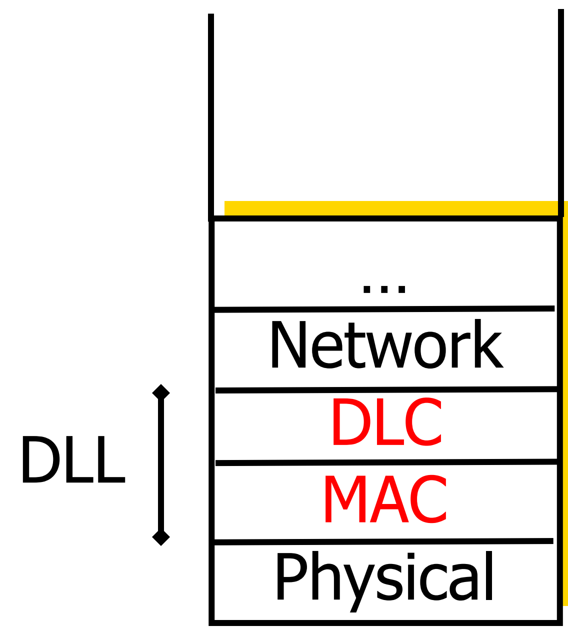
Data and Computer Communications, William Stallings, Pearson-Prentice Hall, 9th Edition, 2010.

-*Computer Networking, A Top-Down Approach Featuring the Internet*, James F.Kurose, Keith W.Ross, Pearson-Addison Wesley, 6th Edition, 2012.

-Google!

The Channel Allocation Problem

- Allocate a single broadcast channel among competing users
  - Static Channel Allocation
    - TDM, FDM
  - Dynamic Channel Allocation
    - Multiple Access Protocols: ALOHA, CSMA etc.



DLL: Data Link Layer
DLC: Data Link Control
MAC: Medium Access Control

Dynamic Channel Allocation

- Key assumptions for formulating the allocation problem:
  - *Station Model:*
    - N independent stations (computers, phones, PDAs etc.) each generating frames for transmission with a mean rate of λ frames/sec.
  - *Single Channel Assumption:*
    - A single channel is available for all communication.
  - *Collision Assumption:*
    - If two frames are transmitted simultaneously, they overlap in time and the resulting signal is garbled → COLLISION.
    - All stations can detect collision and collided frame must be retransmitted

Dynamic Channel Allocation

- *<u>Continuous Time:</u>* Frame transmission can begin at any instant, no master clock dividing time into discrete intervals
- *<u>Slotted Time:</u>* Time is divided into discrete slots (intervals), frame transmission always begin at the start of a slot
- *<u>Carrier Sense:</u>*
  - Stations can detect if the channel is busy or not.
  - If busy, no station will attempt until it goes idle.
- *<u>No Carrier Sense:</u>*
  - Stations cannot detect the channel status → They go ahead and transmit
  - Later they determine if the transmission was successful or not

Multiple Access Protocols

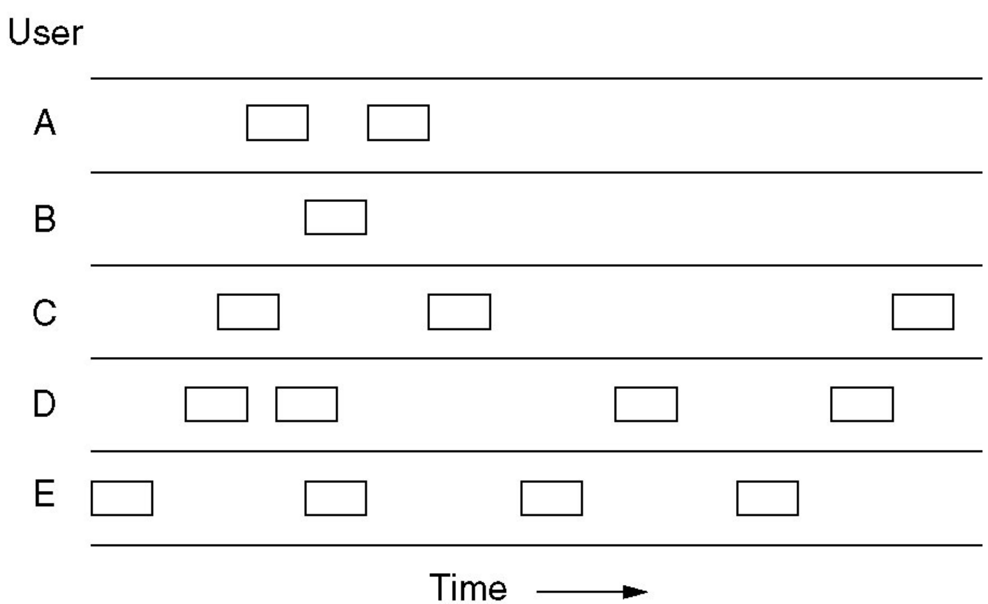
- ALOHA
- Carrier Sense Multiple Access Protocols
- Collision-Free Protocols
- Limited-Contention Protocols
- Wavelength Division Multiple Access Protocols
- Wireless LAN Protocols

ALOHA

- Developed by Norman Abramson in Hawaii and it allowed multiple uncoordinated users access to a shared channel (ground based radio broadcasting)
- Ideas used in the protocol are applicable to any single shared channel with uncoordinated users or computers competing to transmit messages.
- Contention-based channel access (random access), i.e., multiple users share a common channel in a way that they contend for the channel and lead to conflicts.
- Two types were developed:
  - Pure ALOHA
  - Slotted ALOHA

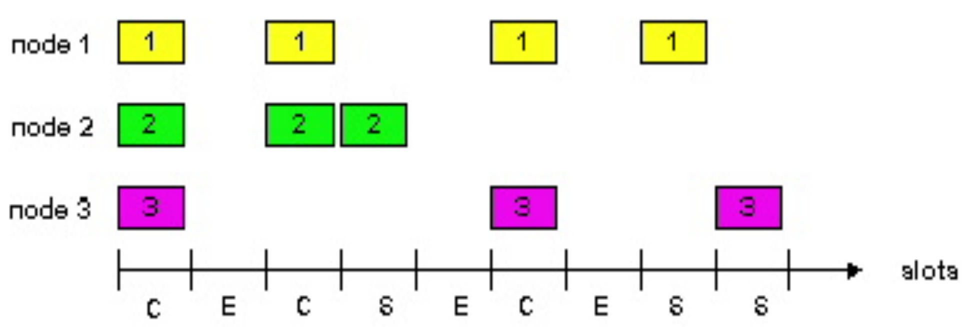
Pure ALOHA

- Each station transmits whenever it wants (i.e., whenever a frame is generated)
- Frames are transmitted at completely arbitrary times
- There will be collisions, and collisions will be detected when they occur
- When collision, sender waits for a random amount of time and sends it again. (Why random??)



Slotted ALOHA

- A method for doubling the capacity of ALOHA
- Divide up time into intervals, each interval corresponding to one frame
- Senders must agree on the slot boundaries → requires synchronization
  - Can be achieved by a special station emitting a short frame at the start of each slot interval (similar to a clock tick)
- Sender is not allowed to transmit until the start of a slot (after the clock tick)
  - a newly arriving station transmits at the beginning of the next slot
- If collision occurs, sender retransmits the packet in future slot with probability p, until successful



Success (S),
Collision (C),
Empty (E) slots

Problems with Pure/Slotted ALOHA

- Pure ALOHA
  - Transmit whenever a message is ready
  - Retransmit when there is a collision
- Slotted ALOHA
  - Time is divided into equal time slots
  - Transmit only at the beginning of a time slot
  - Avoid partial collisions
  - Increase delay, and require synchronization

They do not listen to the channel !!!

Carrier Sense Multiple Access (CSMA) Protocols

- In Local Area Networks, it is possible for computers to detect whether other computers are transmitting or not
- Unlike ALOHA, stations listen for a carrier (i.e., transmission) and act accordingly
- These protocols have a much better throughput rate (% of successfully transmitted frames) compared to ALOHA.
- Protocols in which computers listen for a carrier (signal on the medium) and act accordingly are called **carrier sense** protocols.
  - **1-persistent** CSMA
  - **nonpersistent** CSMA
  - **p-persistent** CSMA

1-persistent CSMA

1. When a station has data to send, it first listens to the channel to see if it is busy
2. If channel busy
   → *the station waits until it becomes idle*
3. When the station detects an idle channel
   → *it transmits a frame*
4. While transmitting the frame, station listens to channel to see if collision
5. If collision
   → *station waits a random amount of time and attempts to transmit again (starts all over again)*

The protocol is called 1-persistent because the station transmits with a probability of 1 whenever it finds the channel idle.

1-persistent CSMA

```
while (frame exists) do
begin
    listen to channel (idle);
    if idle then
      repeat
            xmit (frame);
            check (collision);
            if collision then wait (random);
      until (not collision);
end
```

1-persistent CSMA

- Collision still possible e.g., due to propagation delay
  - The time it takes for the electrical signal to propagate over the medium is known as the **propagation delay**.
  - Possible (slightly) that after a station begins sending, another one becomes ready to send and senses the channel
  - If the first station's signal has not reached the second one, then the second will sense an idle channel, begin sending→ COLLISION
  - *The longer the propagation delay, the worse this effect is*

- Even if propagation delay is zero, there will still be collisions
  - Two stations become ready to transmit during another computers transmission
  - Both will wait until channel idle and then begin sending → COLLISION

1-persistent CSMA is much better than Pure ALOHA because at least stations wait until there are no transmissions before attempting to transmit !

nonpersistent CSMA

- In this protocol, an attempt is made to be less greedy than 1-persistent CSMA
- Before sending, a station senses the channel
  - If channel idle → begins sending
  - If busy → wait a random time before listening again
  - If idle → it transmits its frame.
- *Advantage:* Instead of waiting for the channel to become idle as in the 1-persistent case, on detecting that the channel is busy, a station waits a random time before listening again.

Intuitively, it has better channel utilization and longer delays than 1-persistent CSMA.

nonpersistent CSMA

```
while (frame exists) do
begin
      collision=true;
      repeat
         listen to channel (idle);
         if idle then begin
                  collision=false;
                  xmit (frame);
                  check (collision);
         end;
         wait (random);
      until (not collision);
end
```

If collision occurs,
collision=true

p-persistent CSMA

- This protocol applies to slotted channels
- When a station is ready to transmit, it senses the channel
  - If the channel is idle

    → the station either transmits with a probability p or waits a further slot with probability q=1 - p
  - If the channel still idle during this slot

    → then again it either transmits or defers with probabilities p or q
  - This is repeated until either the frame is transmitted or another station has begun transmitting
    - If the channel is busy (another station transmitting), station acts as if collision → waits a random time and starts again
  - If the channel is initially busy

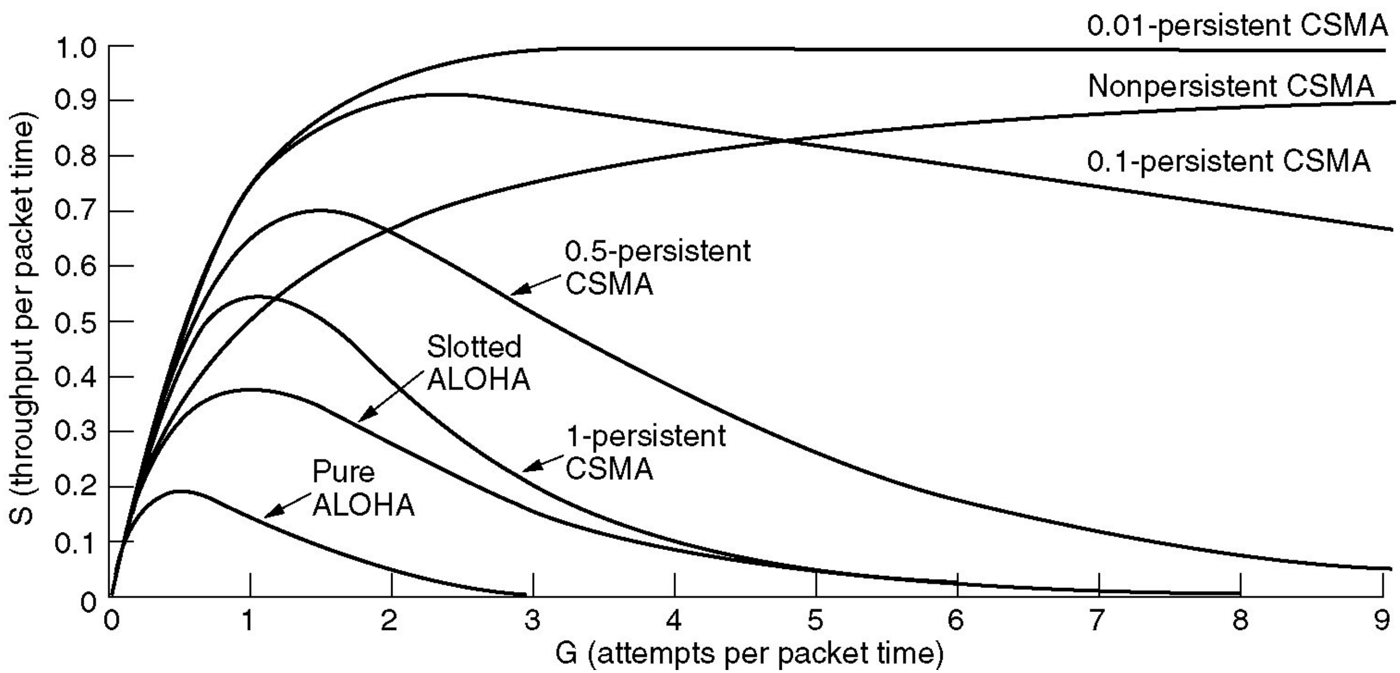
    → it waits until the next slot and applies above algorithm

p-persistent CSMA

```
while (frame exists) do
begin
      collision=true;
      repeat
         listen to channel (idle);
         if idle then
                  if (rand <p) then begin
                           collision=false;
                           xmit (frame);
                           check (collision);
                           if collision then wait (random)
                  end;
         until (not collision);
end
```

Persistent and Nonpersistent CSMA

- Comparison of the channel utilization versus load for various random access protocols.
- CSMA has better channel utilization (and longer delays than ALOHA)



CSMA/CD (Collision Detection)

- CSMA an improvement over ALOHA because no station transmits when it senses the channel busy

- Another improvement: *stations abort their transmissions as soon as they detect a collision*
  - if two stations sense the channel idle and begin transmission simultaneously they will both detect the collision immediately
  - Rather than finishing transmitting their frames, which will be corrupted, stop transmitting frames as soon as collision detected

    Quickly terminating damaged frames saves time and bandwidth!

- This protocol is called CSMA/CD (Carrier Sense Multiple Access with Collision Detection).

CSMA/CD (Collision Detection)

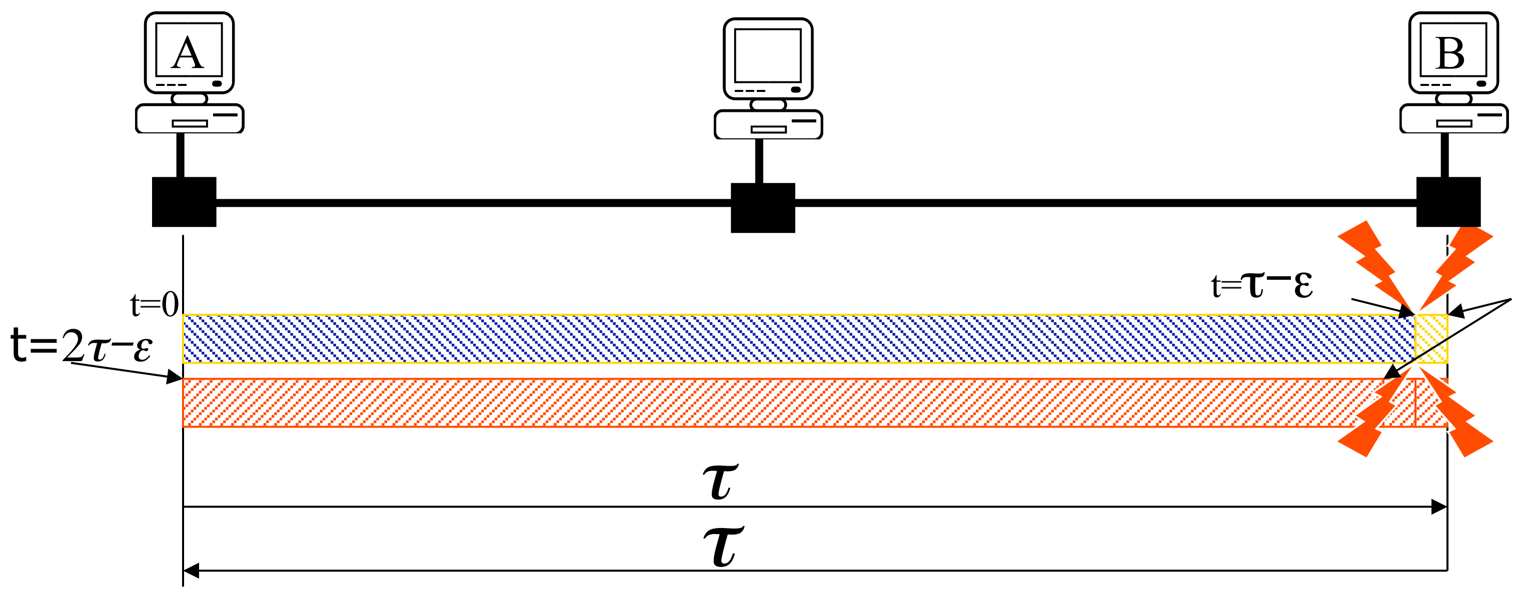
CSMA/CD: carrier sensing, deferral as in CSMA

- collisions *detected* within short time
- colliding transmissions aborted, reducing channel wastage
- persistent or non-persistent retransmission

- Collision detection:
  - easy in wired LANs: measure signal strengths (power or pulse width), compare transmitted, received signals
  - difficult in wireless LANs: receiver shut off while transmitting

CSMA/CD
Time to Detect Collision

- Let the time for a signal to propagate between two farthest stations be τ
- It takes 2τ seconds for two stations to realize that there has been a collision after starting the transmission



Events:

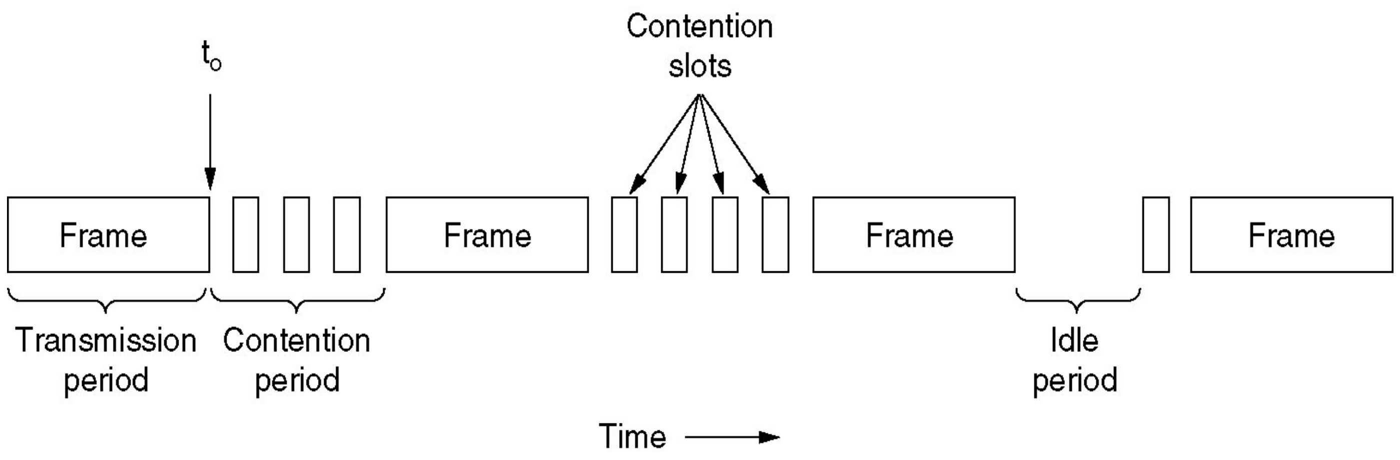
t=0: Host A starts transmitting a packet.

t=$\tau-\varepsilon$ Just before the first bit reaches Host B, Host B senses the line to be idle and starts to transmit a packet. A collision takes place near Host B.

t=$2\tau-\varepsilon$: Host A receives the noise burst caused by the collision

CSMA/CD

CSMA/CD can be in one of three states: contention, transmission, or idle.



- The minimum time it takes to detect a collision is just the time it takes for the signal to propagate from any computer to any other computer and back again → 2τ Slot Time
  - E.g., for a 1km long cable: τ=(1000 m)/ (2x10^8 m/sec)=5 μsec

Contention Period: modeled as a Slotted ALOHA System with Slot Time of 2τ

CSMA/CD

Propagation delay and collision detection

- Define parameter α=D/T

  D: max propagation delay between any 2 stations

  T: time takes to transmit an average size packet

- α: is the # of packets (or a fraction of a single packet) that a transmitting station can place in the medium before the station farthest away receives the first bit

- when α is small (<<1)
  - prop. delay is a small fraction of packet transmission time
  - every station in the network receives some part before the transmission is finished
  - when α small collision detection is fast

CSMA/CD
Binary Exponential Backoff

- After a collision occurs, if the stations transmit as soon the channel becomes idle again, another collision will occur
  - To avoid multiple collisions, CSMA/CD requires each computer to delay after a collision before attempting to retransmit.
- The algorithm that CSMA uses to delay retransmission of frames, after collisions, is called the Binary Exponential Backoff Algorithm.
- *Backoff:* Idle for random time chosen from

  [0, 2*maxpropdelay],

  if collision [0, 4*maxpropdelay], …

Successful transmission → interval is reset

MAC sub-layer does not guarantee reliable delivery!

CSMA/CD Performance

- If the mean frame takes P seconds to transmit →

Time to transmit

$$\text{Channel Efficiency} = \frac{P}{P + 2\tau / A}$$

Time to capture and then transmit

- Assume (for optimal p)
  F: frame length (bits)
  B: bandwidth (bps)
  L: cable length (m)
  c: speed of signal propagation (m/s)

$$\text{Channel Efficiency} : \eta = \frac{1}{1 + 2BLe / cF}$$

Example

- Find the maximum user data rate for a 2.5km long coax. cable with a 10Mbps transmission rate and 620-bit packets with 30B header.

$$\tau = \frac{2500m}{2.3x10^{8} m/\sec} = 1.09x10^{-5} \sec$$

Signal propagation speed in coax.

$$P = \frac{620bits}{10x10^{6} bps} = 6.2x10^{-5} \sec \longrightarrow \text{Channel Efficiency}: \eta \cong 53\%$$

If the network transmits packets with 30B header:

$$10\ Mbps\ x\ \ 0.53\ x\ \frac{620 - 30x8}{620} = 3.2\ Mbps$$

Max. user data rate

Example

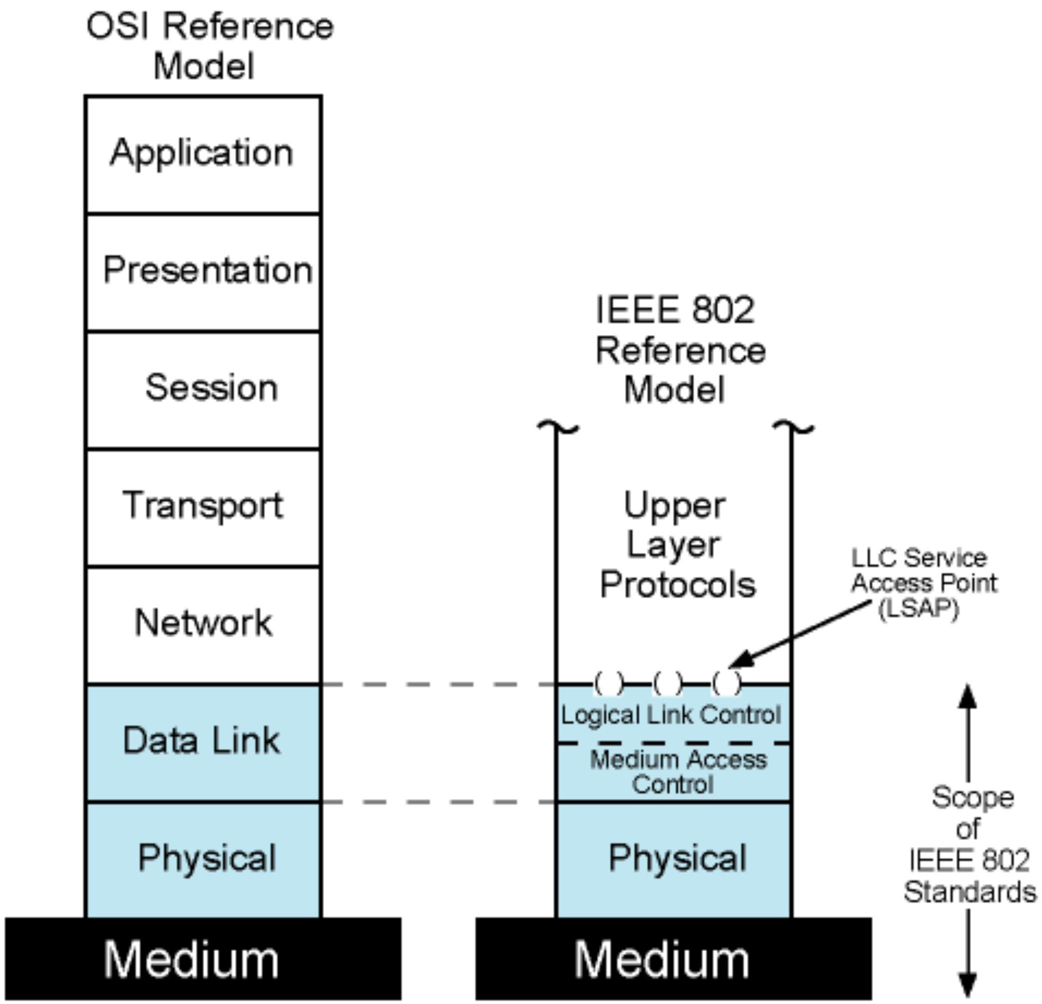
In an experimental 1Mbps CSMA/CD network with 10 stations, each station is independently generating Poisson traffic of 1024B frames at an average rate of 10 frames/sec.

a) Find the probability of collision occurring in a 1/128 sec slot.
b) Find the average length of a contention interval.
c) What is the average time taken to successfully deliver a frame?
d) What is the average data rate observed by MAC users if the CSMA/CD protocol header inside the 1024B frame is 32B long?

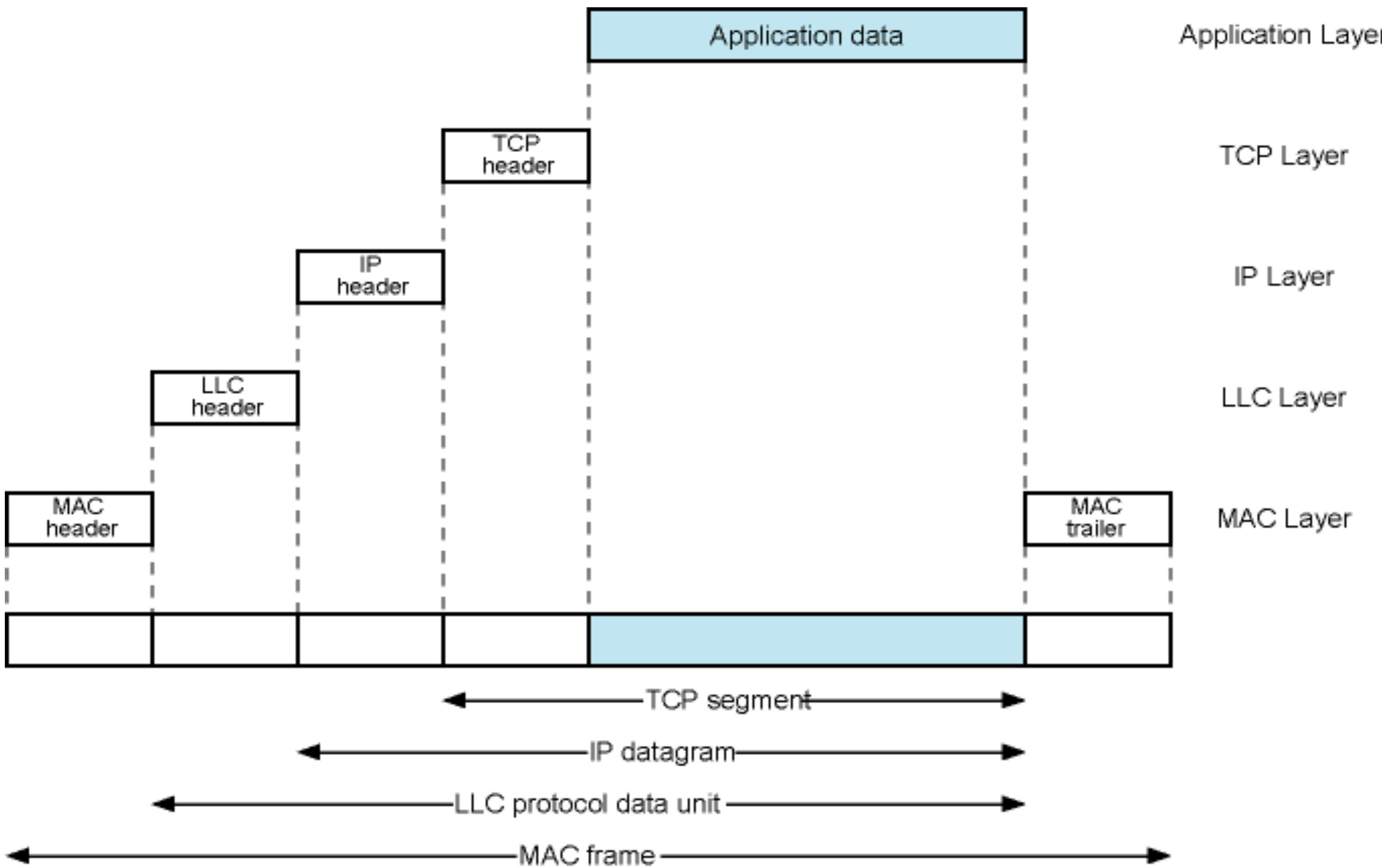
d) t_f is the time period with which the network delivers frames. Each individual station experiences 10 times this delay due to each station capturing the medium with equal probability. Therefore,

$$\text{Data rate achieved} = \frac{(1024-32)x8}{10t_f} = 27.4\ bits/m\sec$$

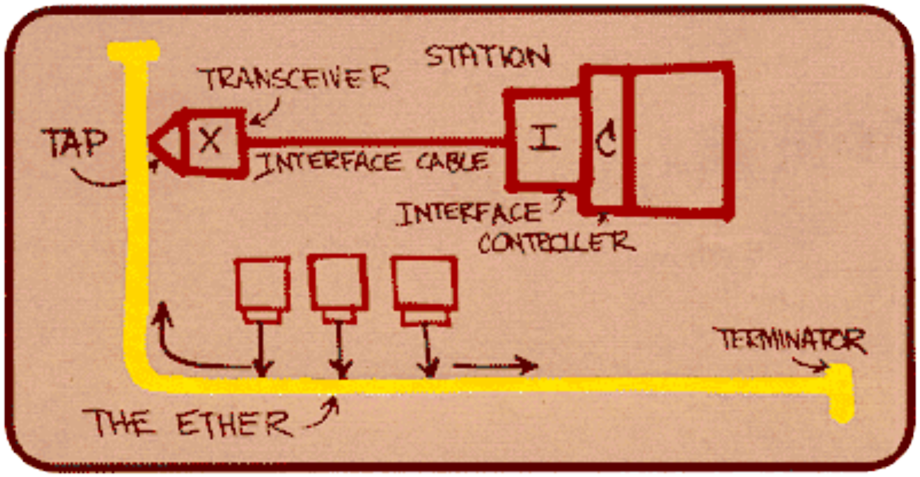
IEEE 802 Protocol Layers Compared to OSI Model



LAN Protocols in Context



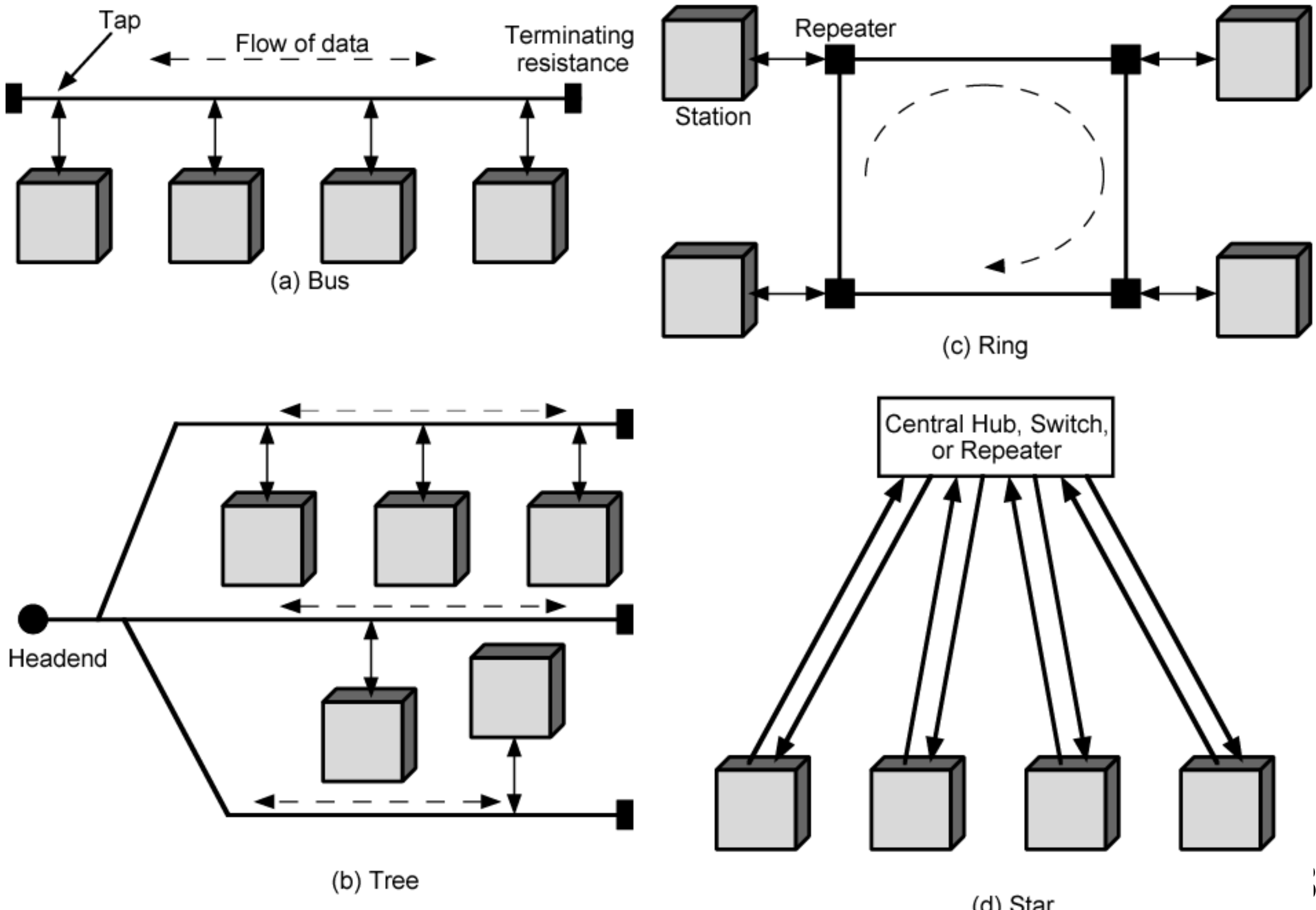
Ethernet



Original picture drawn by Bob Metcalfe, inventor of Ethernet (1972 – Xerox PARC)

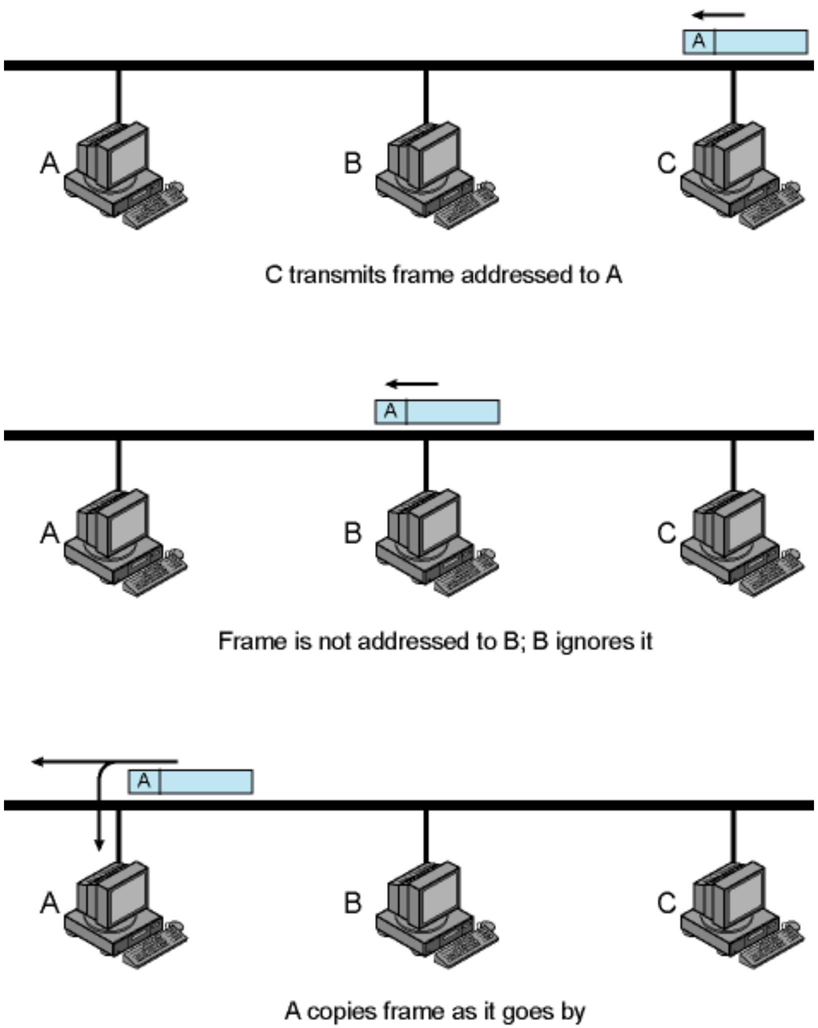
- Developed by Bob Metcalfe and others at Xerox PARC in mid-1970s
  - Roots in Aloha packet-radio network
  - Standardized by Xerox, DEC, and Intel in 1978
  - LAN standards define MAC and physical layer connectivity
    - IEEE 802.3 (CSMA/CD - Ethernet) standard – originally 2Mbps
    - IEEE 802.3u standard for 100Mbps Ethernet
    - IEEE 802.3z standard for 1,000Mbps Ethernet
- CSMA/CD: Ethernet's Media Access Control (MAC) policy (1-persistent CSMA/CD with binary exponential backoff)
- Bandwidths: 10Mbps, 100Mbps, 1Gbps
- Max bus length: 2500m: 500m segments with 4 repeaters
- Bus and Star topologies are used to connect hosts
- Manchester Encoding

LAN Topologies

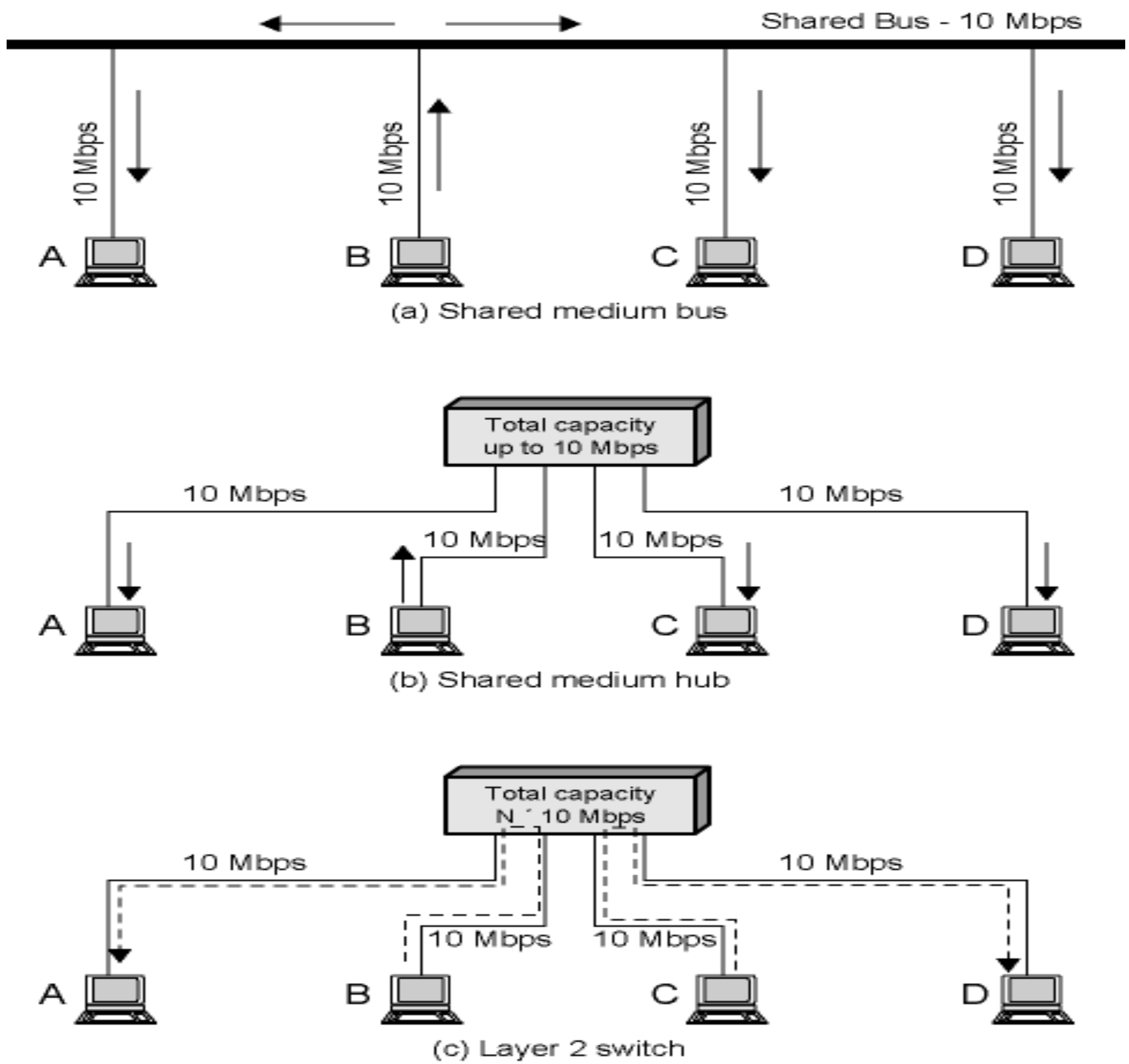


Bus Topology

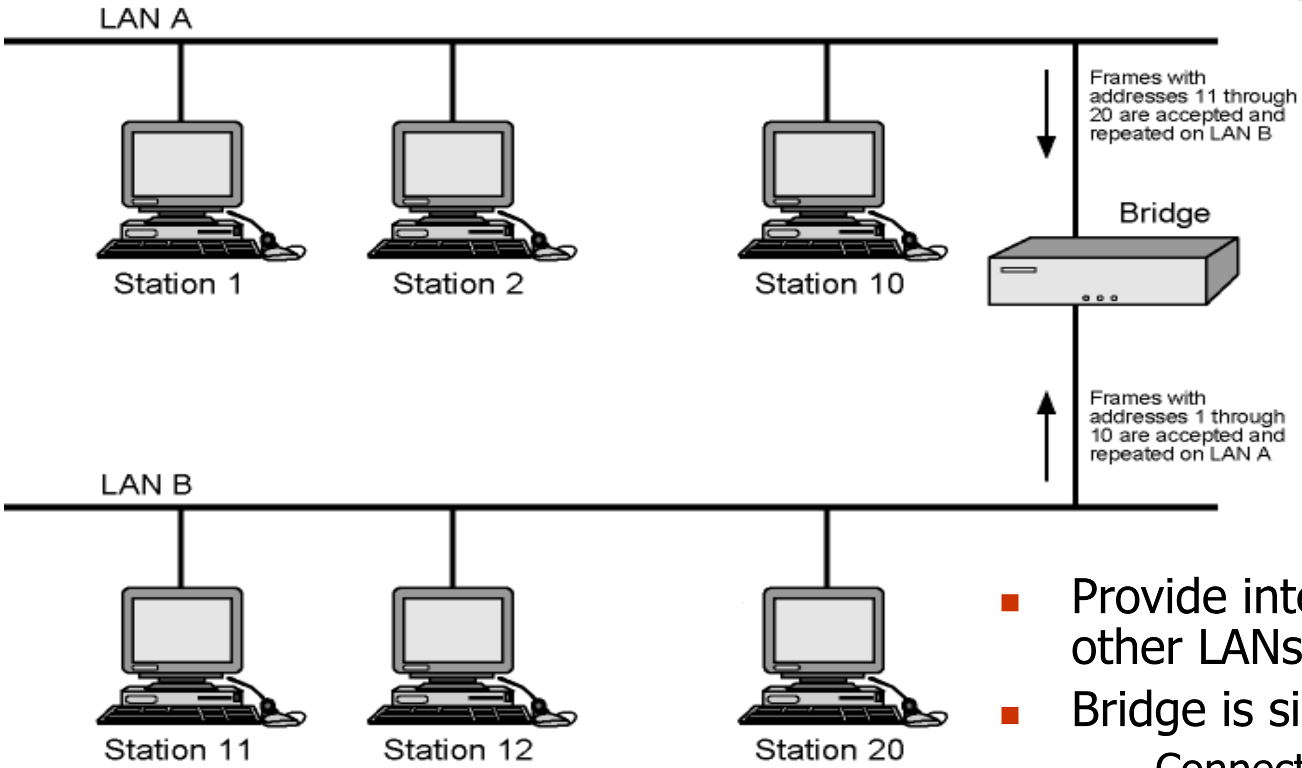
- Stations attach to linear transmission medium (bus)
  - Via a tap
- Full-duplex between station and tap
- Transmission propagates length of medium in both directions
- Received by all other stations
- Ends of bus terminated
  - Absorbs signal
- Transmit data in small blocks (frames)
- Each station assigned unique address
  - Destination address included in frame header



LAN Bus, Hubs and Switches



Bridge Operation



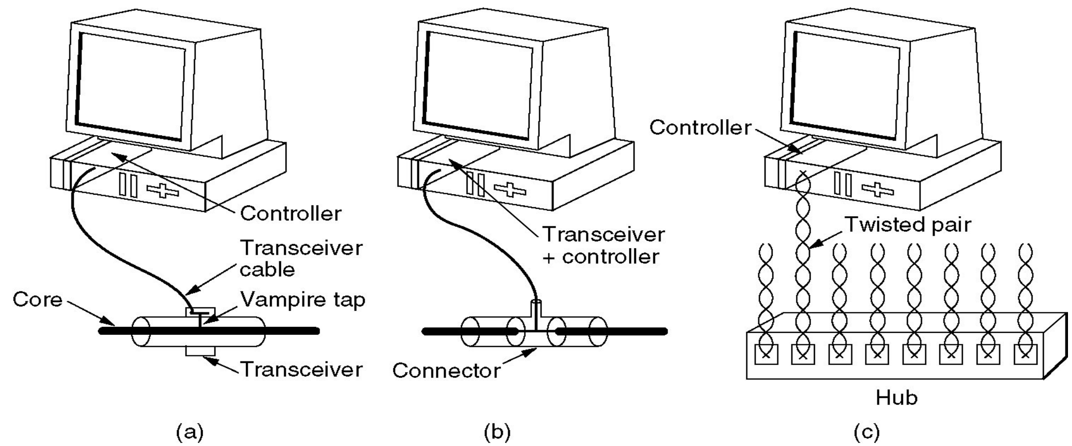
- Provide interconnection to other LANs/WANs
- Bridge is simpler
  - Connects similar LANs
  - Identical protocols for physical and link layers
  - Minimal processing
- Router more general purpose
  - Interconnect various LANs and WANs

Ethernet Cabling

10Base-T:

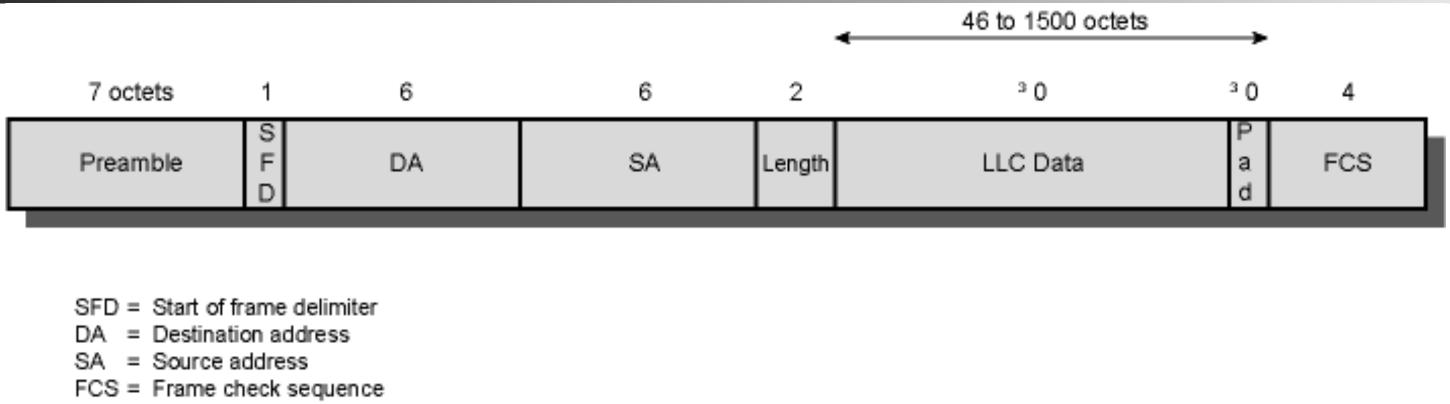
- Unshielded twisted pair (UTP) medium
- Star-shaped topology
  - Stations connected to central point (hub), (multiport repeater)
  - Two twisted pairs (transmit and receive)
  - Repeater accepts input on any one line and repeats it on all other lines
- Link limited to 100 m on UTP
- Multiple levels of hubs can be cascaded

(a) 10Base5, (b) 10Base2, (c) 10Base-T.



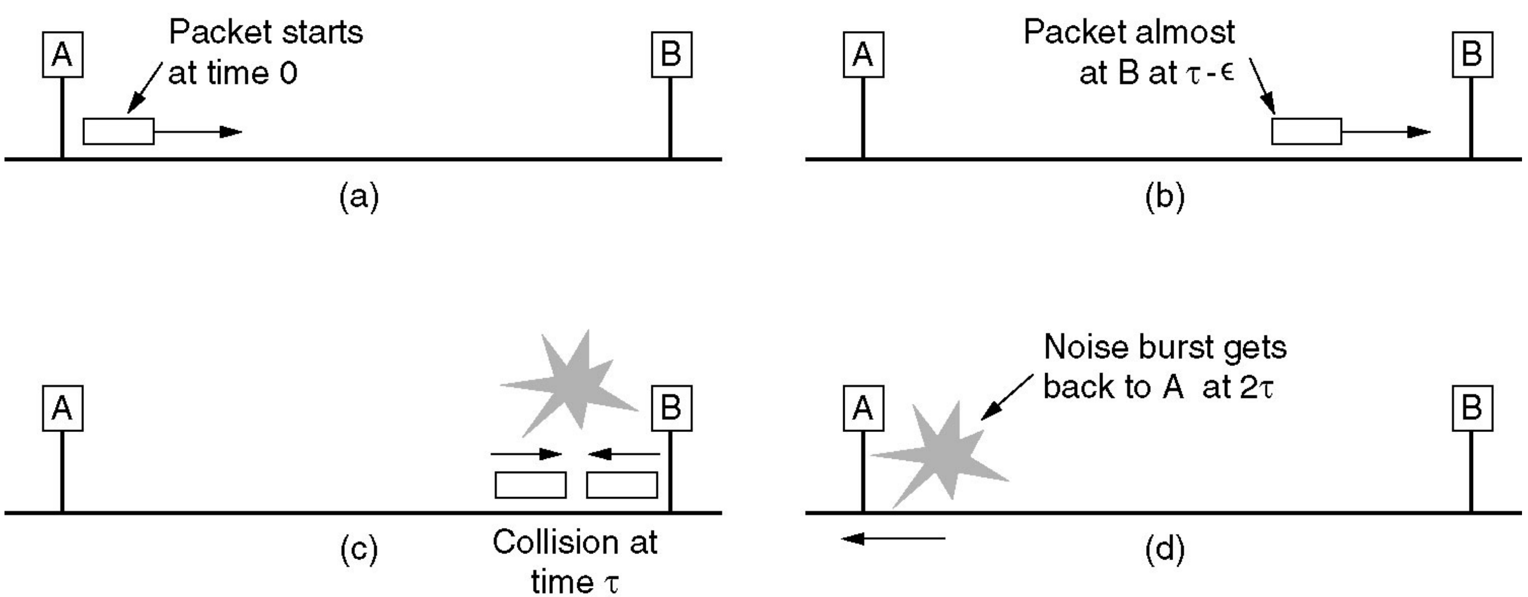
Name	Cable	Max. seg.	Nodes/seg.	Advantages
10Base5	Thick coax	500 m	100	Original cable; now obsolete
10Base2	Thin coax	185 m	30	No hub needed
10Base-T	Twisted pair	100 m	1024	Cheapest system
10Base-F	Fiber optics	2000 m	1024	Best between buildings

802.3 Ethernet Frame Format



- Sending adapter encapsulates IP datagram (or other network layer protocol packet) in Ethernet frame
  - Preamble (+SFD): 7 bytes with pattern 10101010 followed by 1 byte with pattern 10101011 used to synchronize receiver
  - Start of Frame Delimiter (SFD): indicates start of frame (1 byte with pattern 10101011)
  - Addresses: 6 bytes, frame is received by all adapters on a LAN and dropped if address does not match, globally unique address assigned by manufacturer, e.g. 8:0:e4:b1:2
  - Length: frame size
  - Pad: Zeroes used to ensure ***minimum frame length of 64 Bytes (WHY??)***
  - FCS (CRC) Cyclic Redundancy Check: check sequence to detect bit errors, if error is detected, the frame is simply dropped
  - Body can contain up to 1500 bytes of data

CSMA/CD Recap.



Send jamming signal after collision is detected to ensure all hosts see collision → 48-bit signal (noise burst)

$$\text{Collision detection can take as long as } 2\tau.$$

How can we be sure A knows about the collision?

Collision Detection

- How can A know that a collision has taken place?
  - There must be a mechanism to ensure retransmission on collision
  - A's message reaches B at time τ
  - B's message reaches A at time 2τ
  - **So, A must still be transmitting at 2τ**
- IEEE 802.3 specifies max value of 2τ to be 51.2μs
  - This relates to maximum distance of 2500m between hosts
  - At 10Mbps it takes 0.1μs to transmit one bit so 512 bits (64B) take 51.2μs to send
- Therefore, **Ethernet frames must be at least 64B long**
    - 14B header, 46B data, 4B CRC
    - Padding is used if data is less than 46B

To ensure that a packet is transmitted without a collision, a host must be able to detect a collision before it finishes transmitting a packet !!

Binary Exponential Backoff Algorithm

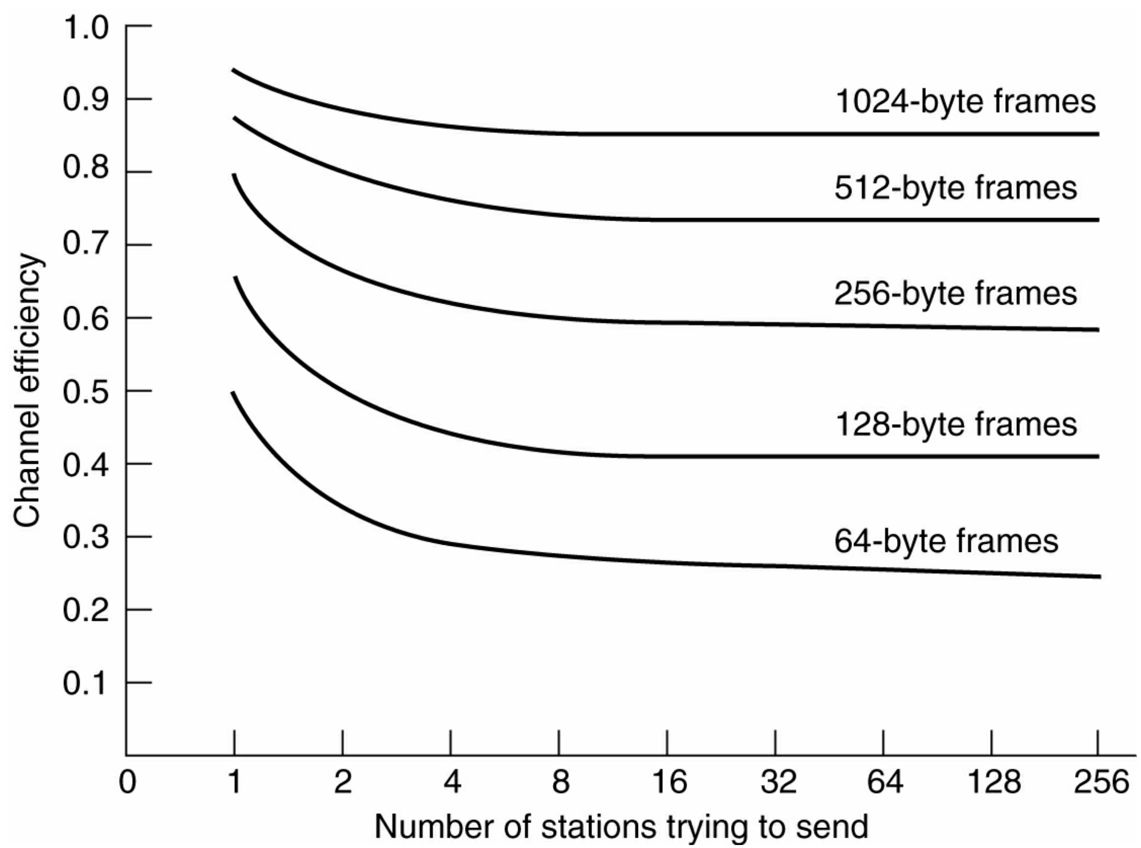
- Truncated Binary Exponential Backoff

```
Attempts := 0;
Attempt Limit is 16 and Backoff Limit 10.
While {(Frame NOT Transmitted Successfully) && (Attempts < Attempt Limit) }
    K : =    Min (Attempts, Backoff Limit)
    R : =    Random (0, 2^k-1)
    delay  : = R * SlotTime;
    Wait (delay)
    Increment Attempts;
End While
```

- Fully freeze backoff interval at 1023 slot times after 10 attempts, and give up altogether after 16 attempts
- Keep delays low at low load but avoid collisions under heavy (high) load
- This algorithm yields a "statistical fairness" in the sharing of bandwidth

Ethernet Performance

Efficiency of Ethernet at 10 Mbps with 512-bit slot times.

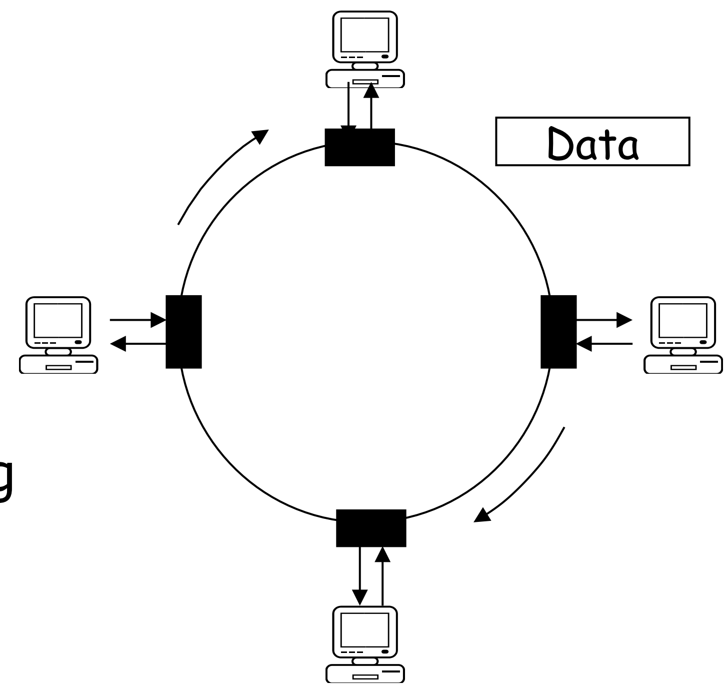


Fast and Gigabit Ethernet

- Fast Ethernet (100Mbps) has technology very similar to 10Mbps Ethernet
  - Uses different physical layer encoding (4B5B)
  - Many NIC's are 10/100 capable
    - Can be used at either speed
- Gigabit Ethernet (1,000Mbps)
  - Compatible with lower speeds
  - Uses standard framing and CSMA/CD algorithm
  - Distances are severely limited
  - Typically used for backbones and inter-router connectivity
  - Becoming cost competitive

A Quick Word about Token Ring

- Developed by IBM in early 80's as a new LAN architecture
  - Consists of nodes connected into a ring (typically via concentrators)
  - Special message called a token is passed around the ring
    - When nodes gets the token it can transmit for a limited time
    - Every node gets an equal opportunity to send
  - IEEE 802.5 standard for Token Ring
- Designed for predictability, fairness and reliability
  - Originally designed to run at either 4Mbps and 16Mbps
- Still used and sold but beaten out by Ethernet

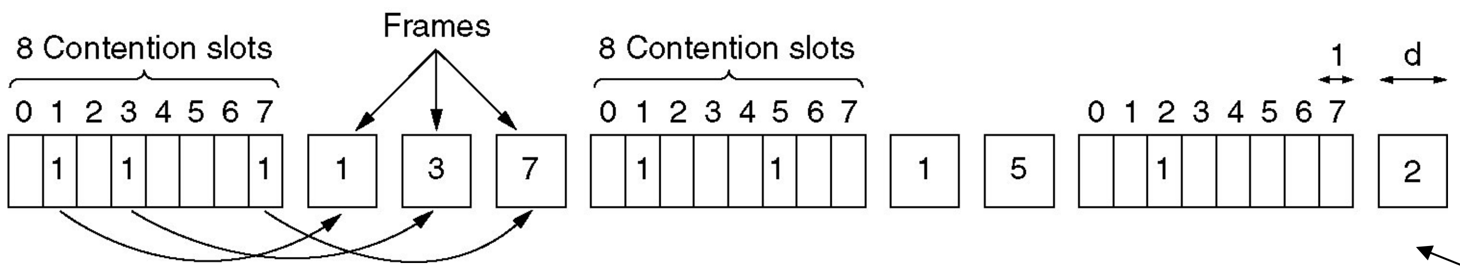


Collision-Free Protocols

- Collisions can still occur with CSMA/CD
- Collisions adversely affect the system performance
- Effect is greater when the cable is long (large τ)
- Resolve contention without any collision!
  - Collision-free protocols: Bit-Map Protocol, Binary Countdown Protocol etc.

Bit-Map Protocol

- Assume that there are N stations each with unique address from 0 to N-1
- Each contention period consists of exactly N slots
  - If station 0 has a frame to send, it transmits a 1 bit during 0^{th} slot
  - No other station is allowed to transmit during this slot
  - Station j may announce that it has a frame to send (only if so) by sending 1 bit in j^{th} slot
  - After all N slots have passed by, each station knows which station will transmit
  - They begin transmitting in the numerical order as agreed before→ NO COLLISION!



If a station is ready just after its bit slot has passed by, it must wait until the bitmap has come around again!!

Reservation protocol !

Performance of Bit-Map Protocol

- Data frames: d time units
- <u>Low load:</u> Bit map will be repeated over and over for lack of data frames
  - *Low-numbered station (e.g., 0, 1):*
    - When it becomes ready to send, the current slot will be somewhere in the middle of the bit map
      - On average, the station will wait for N/2 slots for the current scan to finish + N slots for the next scan to complete before it can begin transmitting→1.5N
  - *High-numbered station:*
    - On average, station will wait for N/2 slots and transmit
  - AVERAGE=(1.5N+0.5N)/2=N slots to wait before transmit
  - OVERHEAD per frame=N bits→ EFFICIENCY=d/d+N
- <u>High load:</u>
  - All stations have something to send all the time → EFFICIENCY=Nd/(Nd+N)=d/d+1