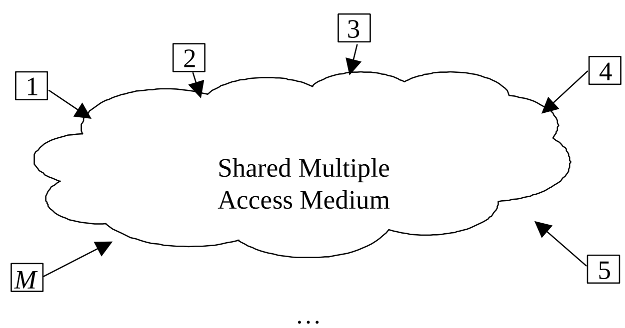
# Local Area Networks and Medium Access Control Protocols

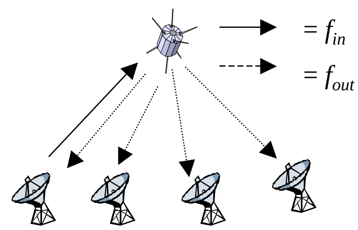
## Multiple Access Networks

- Broadcast and multiple access technologies are very common for LANs and for wireless settings.

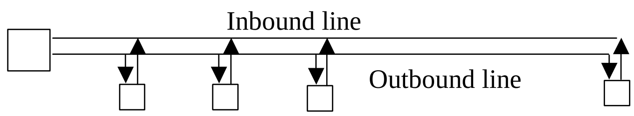


# Multiple Access Communication: Examples

Satellite Channel

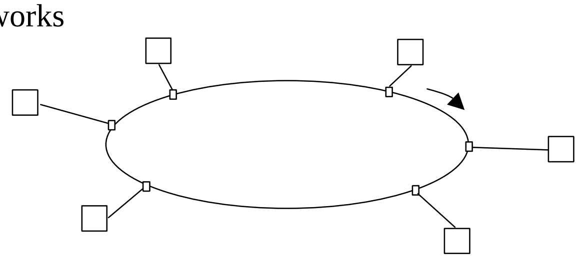



Multidrop telephone lines

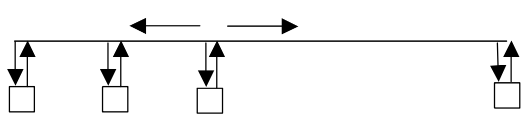



# Examples (2)

Ring networks

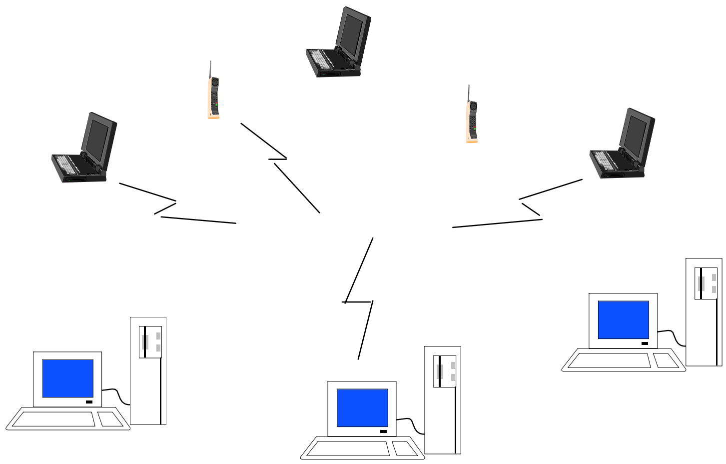


Multitapped Bus



# Examples (3)

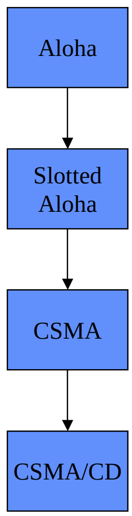
Wireless LAN



# Multi-Access Protocols

- Protocols that resolve the resolution problem dynamically are called Multiple-Access (**Multi-Access**) Protocols
- **Contention Protocols** resolve a collision after it occurs. These Protocols execute a collision resolution protocol after each collision.
- **Collision-free Protocols** ensure that a collision never occurs.

# Evolution of Contention Protocols




Developed for Univ. of Hawaii packet radio network

Start transmission only at fixed times (slots)

CSMA = **C**arrier **S**ense **M**ultiple **A**ccess

Start transmission only if no transmission is ongoing

CD = **C**ollision **D**etection

Stop ongoing transmission if a collision is detected

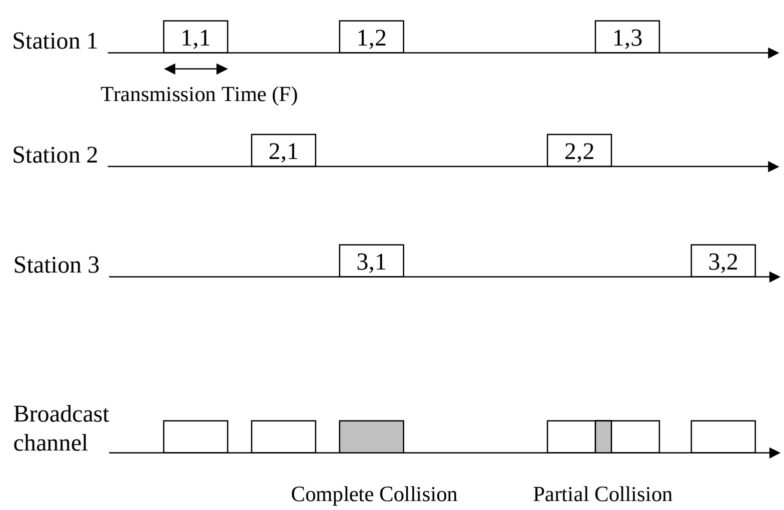
# Contention Protocols

- ALOHA Protocols
  - (Pure) Aloha
  - Slotted Aloha
- CSMA (Carrier Sense Multiple Access)
  - Persistent CSMA
  - Non-persistent CSMA
  - CSMA/CD: Carrier Sense Multiple Access with Collision Detection (used in Ethernet)
- Etc…

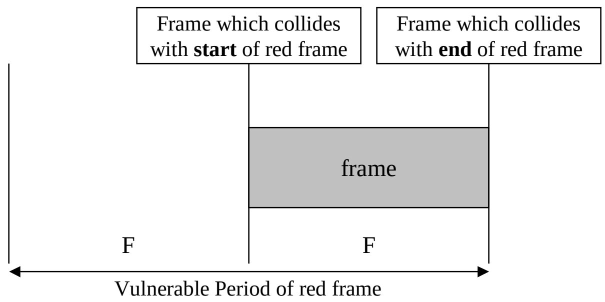
# (Pure) ALOHA

- Topology:
  - Multiple transmitters (stations) share same medium.
- Aloha protocol:
  - Whenever station has data, it transmits immediately
  - Whenever a collision occurs, it is treated as transmission error, and frame is retransmitted.
  - Sender backs off for some random time after collision before it retransmits.

# Collisions in Pure ALOHA



## Collisions and Vulnerable Period

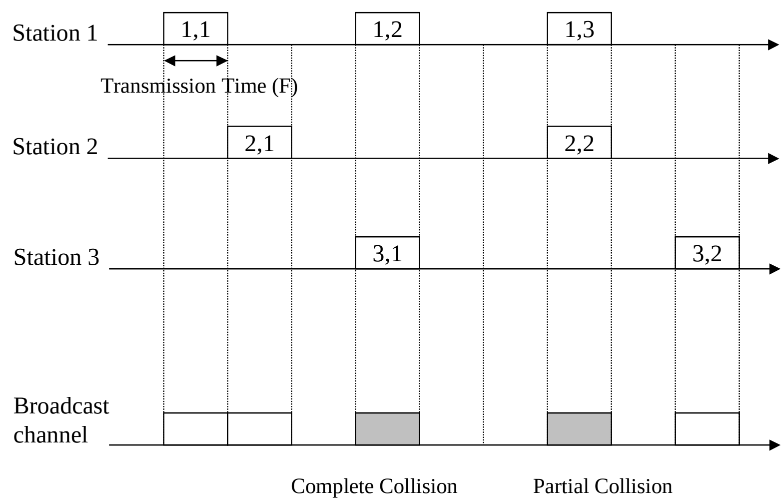



- A frame (dark frame) collides whenever another transmission begins in the vulnerable period of the frame.
- Vulnerable period has length of 2 frame times.

## Slotted ALOHA

- Slotted Aloha Protocol
  - Time is divided into discrete time intervals (=slots)
  - A station can transmit only at the beginning of a frame
- As a consequence:
  - Frame either completely or do not collide at all
  - Vulnerable period = 1 frame time

## Collisions in Pure ALOHA




## Performance of ALOHA

- What is the maximum throughput of the ALOHA protocol?

- Notation:
  - ***S*** **Throughput**:
    Expected number of successful transmission
    per time unit
  - ***G*** **Offered Load:**
    Expected number of transmission <u>and retransmission</u>
    attempts (from all users) per time unit.

- Normalization:
  - Frame transmission time is 1 => maximum throughput is 1

# Modeling Assumptions

- Normalization: All frames have a fixed length of one time unit.
- Infinite user population
- Offered load is modeled as a **Poisson process** with rate G:

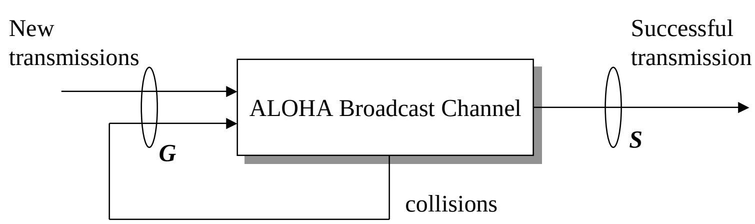
Prob[$k$ packets are generated in $t$ frame times] =

$$\frac{(Gt)^k}{k!} \times e^{-tG}$$

# Throughput of ALOHA

- Relation between throughput and offered load:

*S = G * Prob[frame suffers no collision]*



## Performance of (pure) ALOHA

- Prob[frame suffers no collision]

  = Prob[no other frame is generated during the vulnerable period of this frame]

  = Prob[no frame is generated during a **2-frame a period**]

  =

$$\frac{(2G)^0}{0!} \times e^{-2G} = e^{-2G}$$

- **Throughput in ALOHA:** $S = G \times e^{-2G}$

## Results: Maximum Achievable Throughput

- Take derivative and set $\frac{\partial S}{\partial G} = 0$
- Maximum is attained at $G = 0.5$
- We obtain: $s_{\max} = 0.5 \times e^{-1} = \frac{1}{2e} = 0.184$
- Note: That is 18% of channel capacity!

## Performance of Slotted ALOHA

- Derivation is analogous to (pure) ALOHA:

  *S = G * Prob[frame suffers no collision]*

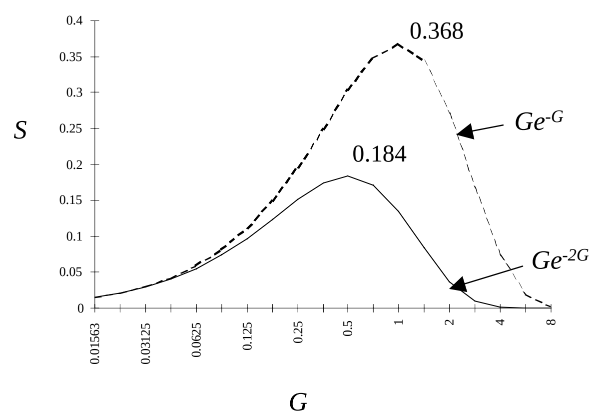
- Prob[frame suffers no collision]

  = Prob[no other frame is generated during a vulnerable period]

  = Prob[no frame is generated during **1 frame period**] = $\frac{(1G)^0}{0!} \times e^{-1G} = e^{-1G}$

- **Total throughput in Slotted ALOHA:** $S = G \times e^{-G}$
- **Achievable Throughput:** $s_{\max} = e^{-1} = \frac{1}{e} = 0.37$

## Comparison of ALOHA and Slotted ALOHA



## CSMA – Carrier Sense Multiple Access

- Improvement over ALOHA protocol:
  - If stations have **carrier sense capability** (stations can test the broadcast medium for ongoing transmission), and
  - If stations only transmit if the channel is idle,
  - Then many collisions can be avoided

- **Note**: This improves ALOHA only in cases with small delay bandwidth products. Why?

## CSMA – Carrier Sense Multiple Access

- CSMA protocol
  - A station that wishes to transmit listens to the medium for an ongoing transmission
  - Is the medium busy?
    - Yes: Station backs off for a specified period
    - No: Station transmits
  - If a sender does not receive an acknowledgement after some period, it assumes that a collision has occurred.
  - After a collision a station backs off for a certain (random) time and retransmits.

## CSMA - Variations

- Variations of CSMA protocol

- Each variant specifies what to do if the medium is found busy:

  - Non-persistent CSMA
  - 1-persistent CSMA
  - *p*-persistent CSMA

## Non-Persistent CSMA

1. If the medium is idle, transmit immediately
2. If the medium is busy, wait a random amount of time and Repeat Step 1.

- Random back-off reduces probability of collisions.
- Wasted idle time if the back-off time is too long.
- May result in long access delays.

## 1-Persistent CSMA

1. If the medium is idle, transmit immediately
2. If the medium is busy, continue to listen until medium becomes idle, and then transmit immediately.

- What if two stations want to transmit when channel is busy?

## *p*-Persistent CSMA

1. If the medium is idle, transmit with probability *p*, and delay for one time unit with probability (1-*p*) (time unit = length of propagation delay)
2. If the medium is busy, continue to listen until medium becomes idle, and then go to Step 1.
3. If transmission is delayed by one time unit, continue with Step 1.

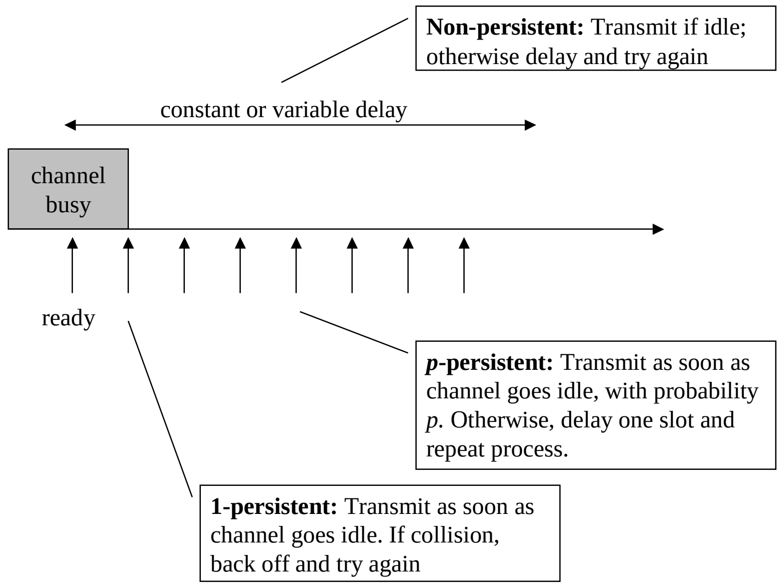
- Good trade-off between non-persistent and 1-persistent CSMA.

## How to Select Probability *p* ?

- Assume that *N* stations have a packet to send and the medium is busy.
- Expected number of stations that will attempt to transmit once the medium becomes idle: $N * p$
- If $N * p > 1$, then a collision is expected to occur (with retransmission, and so more collisions)

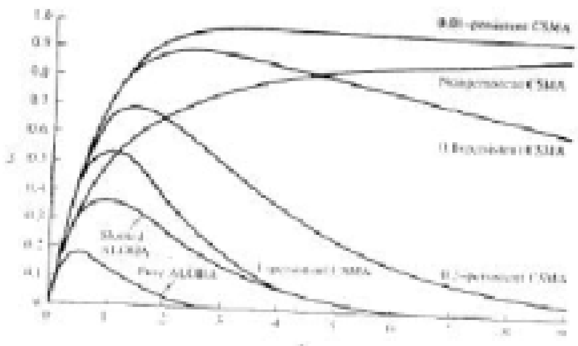
- **Therefore**: Network must make sure that $N * p < 1$, where *N* is the maximum number of stations that can be active at a time.

## Comparison of CSMA Strategies



## Comparison of ALOHA and CSMA

- Load *vs.* Throughput (very small delay-bandwidth product)



## CSMA/CD

- CSMA has an inefficiency:
  - If a collision occurred, the channel is unstable until colliding packets have been fully transmitted
- CSMA/CD overcomes this as follows:
  - While transmitting, the sender is listening to medium for collision. Sender stops if collision has occurred.

- Note:
  - CSMA: Listen Before Talking
  - CSMA/CD: Listen While Talking

# Operation CSMA/CD

- Generic CSMA/CD Protocol:
  - Use one of the CDMA persistence algorithms (non-persistent, 1-persistent, p-persistent) for transmission.
  - If a collision is detected during transmission, cease transmission and transmit a jam signal to notify other stations of collision.
  - After sending the jam signal, back off for a random amount of time, then start to transmit again.

# Collision Detection in CSMA/CD

To detect a collision, in the worst case, it takes twice the maximum propagation delay of the medium.

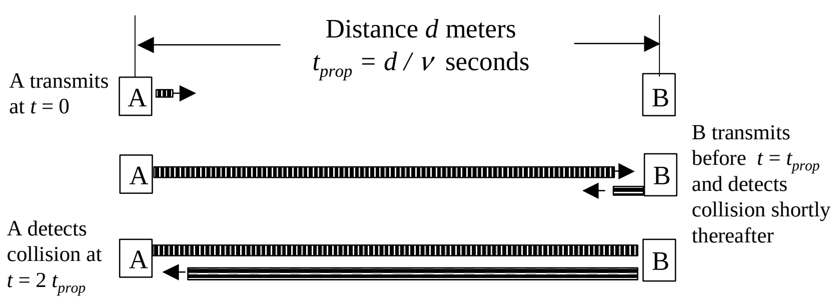



Figure 6.7

## CSMA/CD: Restrictions

- Packet should be twice as long as time to detect a collision (2 * max. propagation delay)
- Otherwise, CSMA/CD does not have an advantage over CSMA

- Example: Ethernet
  - Ethernet requires a minimum packet size and restricts the maximum length of the medium.
  - **Question**: What is the minimum packet size in a 10Mbit/sec network with a maximum length of 500 meters?

## Exponential Backoff Algorithm

- Ethernet uses an exponential backoff algorithm to determine when a station can retransmit after a collision.

Algorithm:

Set “slot time” equal to $2a$

After first collision, wait 0 or 1 slot times.

After *i*-th collision, wait random number between 0 and $2i$-1 time slots.

Do not increase random number range if $i$=10.

Give up after 16 collisions

# Performance of CSMA/CD

- Parameters and assumptions:

  *a* : end-to-end propagation delay

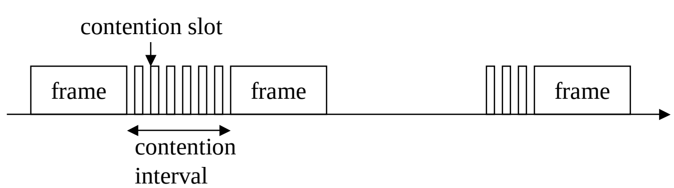
  1 : packet transmission time (normalized)

  *N*: Number of stations

- Time can be thought of as being divided in contention intervals and transmission intervals.

- Contention intervals can be thought of as being slotted with slot length of 2*a* (roundtrip propagation delay).

# Performance of CSMA/CD




- Contention slots end in a collision
- Contention interval is a sequence of contention slots
- Length of a slot in contention interval is 2*a*
- Probability that a station attempts to transmit in a slot is *P*

# Performance of CSMA/CD

- Derivation of maximum throughput of CSMA/CD
  - Let A be the probability that some station can successfully transmit in a slot. We get:

$$A = \binom{N}{1} \times P^1 \times (1-P)^{N-1} = N \times P \times (1-P)^{N-1}$$

  - In the above formula, *A* is maximized when *P=1/N*. Thus:

$$A = (1 - \frac{1}{N})^{N-1}$$

# Performance of CSMA/CD

Prob[contention interval has a length of *j* slots] =
Prob[1 successful attempt] * Prob[*j-1* unsuccessful attempts] =

$$A \times (1-A)^{j-1}$$

- The expected number of slots in a contention interval is then calculated as:

$$\sum_{j=0}^{\infty} j \times A \times (1-A)^{j-1} = \frac{1}{A}$$

## Performance of CSMA/CD

- Calculate the maximum efficiency of CSMA/CD with usual formula:

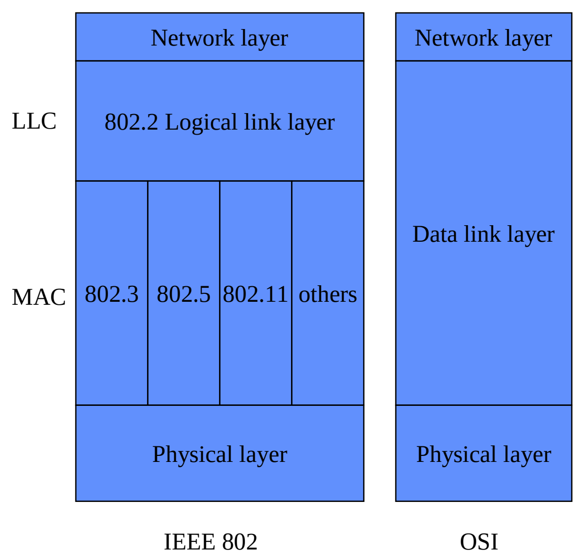
$$\frac{\text{Frame Time}}{\text{Frame Time} + \text{Overhead}} =$$

$$\frac{\text{Frame Time}}{\text{Frame Time} + \text{Average Contention Interval}} =$$

$$\frac{1}{1+\frac{2a}{A}}$$

## LAN -- Overview

- Almost all local area networks use a multiple access channel.
- Lan technologies differ in the control protocol for the access to the channel (MAC)
- MAC protocols are implemented as a sublayer of the Data Link Layer.



## Logical Link Layer

- Similar to HDLC
- Provides SAP to higher layers
- Provides different services
  - Acknowledged connectionless service
  - Unacknowledged connectionless service
  - Connection-oriented service
- Framing
- Error Control
- Addressing

## Standards for MAC Protocols

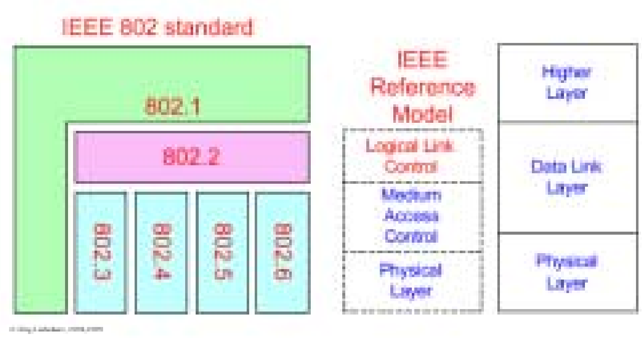
- Bus Networks:
  - IEEE 802.3 CSMA/CD (=Ethernet)
  - IEEE 802.4 Token Bus
- Ring Networks:
  - IEEE 802.5 Token Ring
  - ANSI FDDI
- Dual Bus Networks
  - IEEE 802.6 DQDB
- Tree Networks
  - IEEE 802.14 HFC (Cable Modems)

# IEEE 802 Architecture

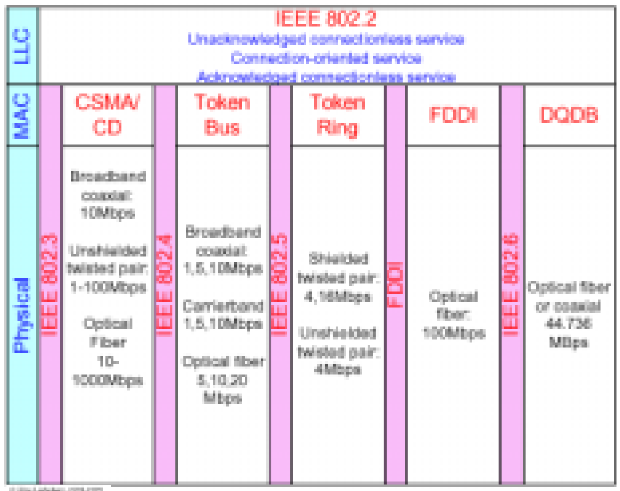
- The IEEE 802 Architecture is a family of standards for LANs (local area networks) and MANs (metropolitan area networks)

- Organization of IEEE 802 Protocol Architecture
  - Higher Layers: 802.1 Higher Layer Interfaces
  - Logical Link Control: 802.2 LLC
  - MAC Layers: 802.3 CSMA/CD
    802.4 Token Bus
    802.5 Token Ring
    Etc.

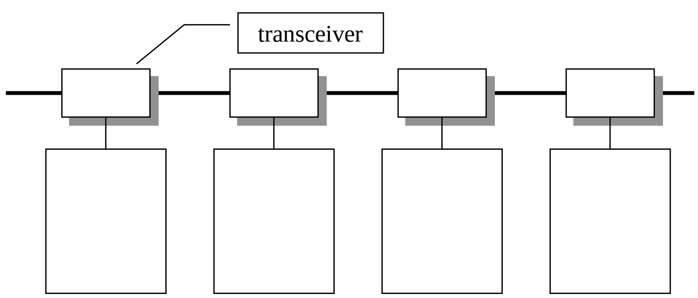
# IEEE 802 LAN Standard



# IEEE 802 LAN Standard

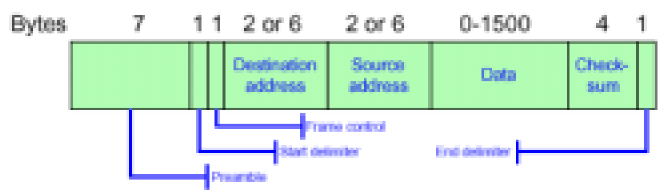



# IEEE 802.3 (CSMA/CD)




- Bus Topology
- Generally referred to as “Ethernet”
- Based on CSMA/CD
- Exponential back-off after collisions
- Data rate: 2Mbps – 1Gbps
- Maximum cable length dependent on the data rate

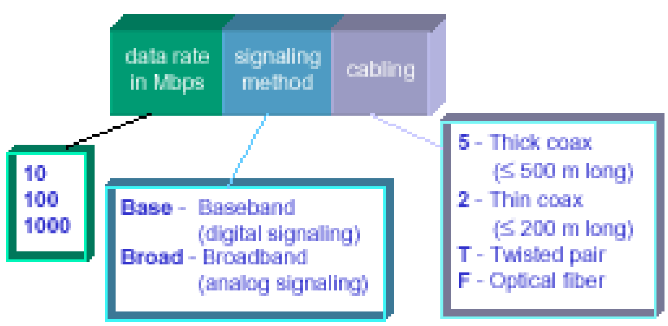
# 802.3 Frame Format




- Preamble is sequence of 7 bytes (“10101010” for each byte). Helps receiver synchronize with bit pattern before frame is received.
- At 10 Mbps, a frame must be at least 46 byte long. Otherwise, station may not detect collision with its own transmission.
- Maximum frame size is set to 1500 byte of data, minimum frame size is set to 512 bits.

# Ethernet

- Several physical layer configurations are possible for 802.3 LANs.
- The following notation is used to denote the configuration



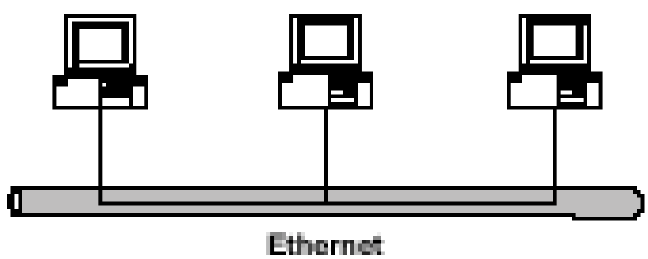
# Ethernet

- Speed: 10 Mbps
- Standard: 802.3

- Physical layers:
  - Used today:
    - **10Base-T** 10Mbps Twisted Pair
    - **10Base2** (Thin Ethernet) 10Mbps thin coax cable
  - Used in the past
    - **10Base5** (Thick Ethernet) 10Mbps thick coax cable
  - Analog version
    - **10Broad36** 10Mpbs on coax cable using analog signaling

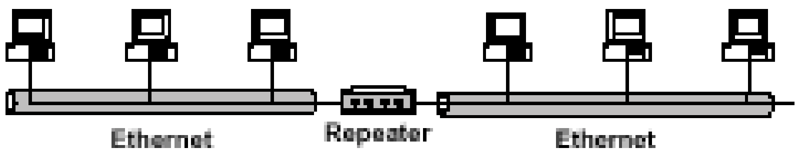
# Bus Topology

- 10Base5 and 10Base2 Ethernets have a bus topology



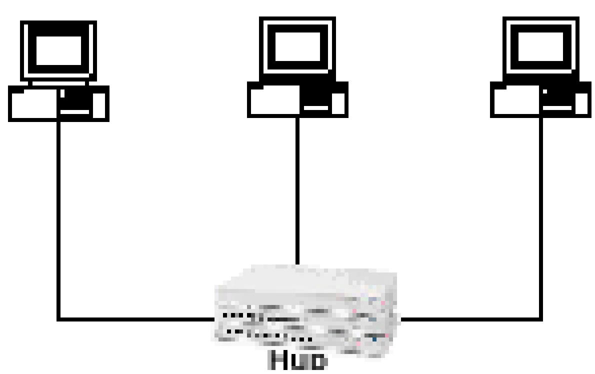
## Repeaters

- Maximum length of a segment is 500m (10Base5) and 200m (10Base2)
- The maximum span can be extended by connecting segments via repeaters
- Repeaters do not isolate collisions




## Star Topology

- With 10Base-T, stations are connected to a hub in a star configuration.
- Distance of a node to the hub must be <= 100m.



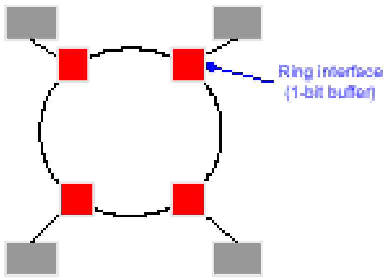
# Fast Ethernet

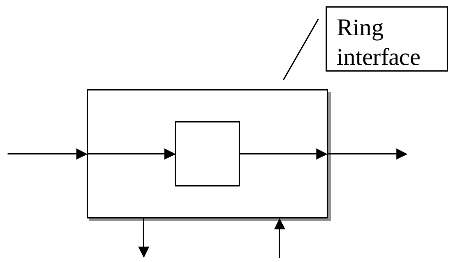
- “Fast Ethernet” = Ethernet at 100Mpbs rates
- Standard: IEEE 802.3u
  - 100Base-T4 (100 Mbps over telephone-grade twisted pair)
  - 100Base-TX (100 Mbps over Category 5 twisted pair)
  - 100Base-FX (100 Mbps over Fiber Optic)
- 100Base-X schemes have two physical links, one for receiving and one for transmitting, each at 10o Mpbs. A station can send an transmit at the same time (full-duplex)
- 100 Base-T4 operates in half-duplex mode

# Gigabit Ethernet

- Data rate is 1 Gbps = 1000 Mbps
- Standard: IEEE 802.3z
- Physical layers:
  - 1000Base-SX (short wave laser over multimode fiber)
  - 1000Base-LX (long-wave laser over single mode fiber and multimode fiber)
  - 1000Base-?? (twisted pair)

# Ring-Based LANs



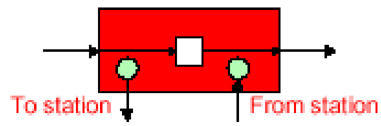




# Ring-Based LANs

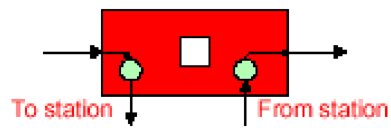
- The ring can be thought of as a series of bit-wise repeaters, each connected via a unidirectional transmission link.
- All arriving data is copied into a 1-bit buffer and then copied out again (1-bit delay)
- Data in the buffer can be modified before transmission
- The ring interface can be in one of the following states:
  - Listen State
  - Transmit State
  - Bypass State

## States of the Ring Interface

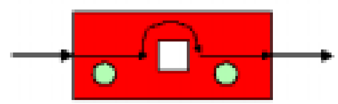
- **Listen State**: Incoming bits are copied to output with 1-bit delay




- **Transmit State**: write data to the ring




- **Bypass State**: Idle station does not incur bit-delay



## Ring-Based LANs

- If a frame has traveled once around the ring, it is retired by the sender.

- Ring-based LANs have a simple acknowledgement scheme:
- Each frame has one bit for acknowledgement.
- If the destination receives the frame it sets the bit to 1.
- Since the sender will see the returning frame, it can tell if the frame was received correctly.

# “Length” of a Ring

- The length of a ring LAN, measured in bits, gives the total number of bits that can be in transmission on the ring at a time.

- Note: Frame size is not limited to the “length” of the ring since entire frame may not appear on the ring at one time. (Why?)

- Bit length = propagation delay * length of ring * data rate + No. of stations * bit delay at repeater

# “Length” of Ring: Example

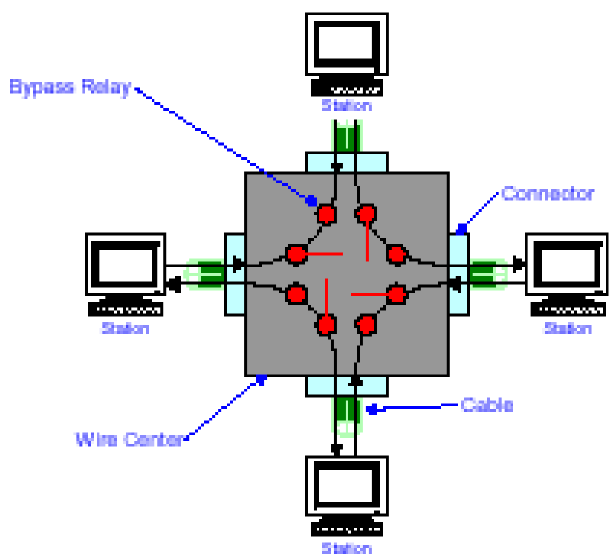
- Calculate the length of the following ring LAN:
  - 3 km ring
  - 1 Mbps data rate
  - 5 usec/km propagation speed
  - 20 stations with 1 bit delay each

- Bit length =

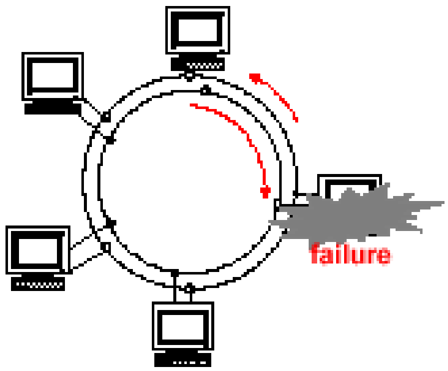
## Ring-Based LANs

- Advantages:
  - Can achieve 100% utilization
  - No collisions
  - Can achieve deterministic delay bounds
  - Can be made efficient at high speeds
- Disadvantages:
  - Long delays due to bit-delays
    - **Solution**: Bypass state eliminates bit-delay at idle station
  - Reliability problems
    - **Solution 1**: Use a wire center
    - **Solution 2**: Use a second ring (in opposite direction)

## Ring-Based LANs: Wire Center (802.5)



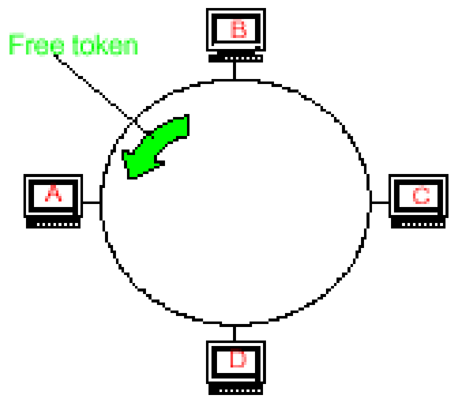
## Ring-Based LANs: Use a Second Ring




## Token Ring MAC Protocol (802.5)

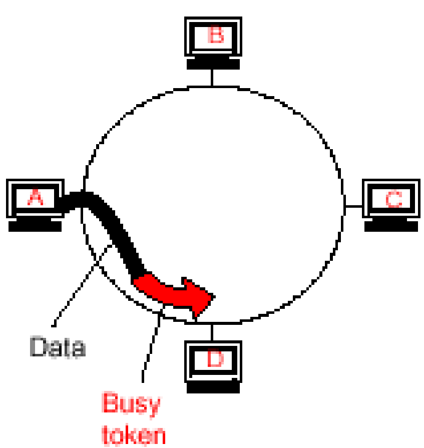
- In order to transmit a station must catch a free token.
- The station changes the token from free to busy.
- The station transmits its frame immediately followig the busy token.
- After a complete transmission of a frame, the sender station inserts a new free token after the busy token has returned to the station.
- Only one station can transmit at a time. If a station releases a free token, the next station downstream can capture the token

## Transmission in a Token Ring



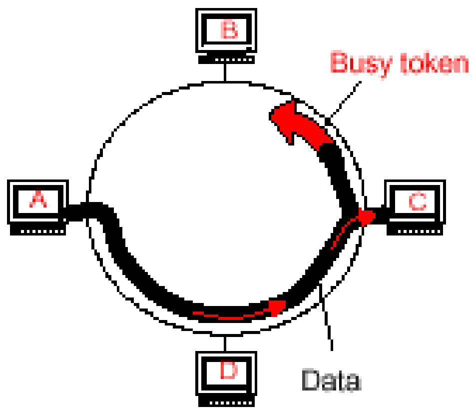

- Sender looks for free token.

## Transmission in a Token Ring



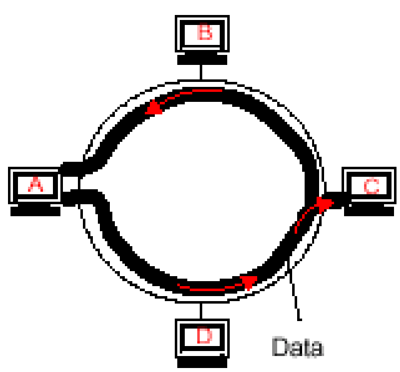

- Sender changes free token to busy token and appends data to the token.

## Transmission in a Token Ring



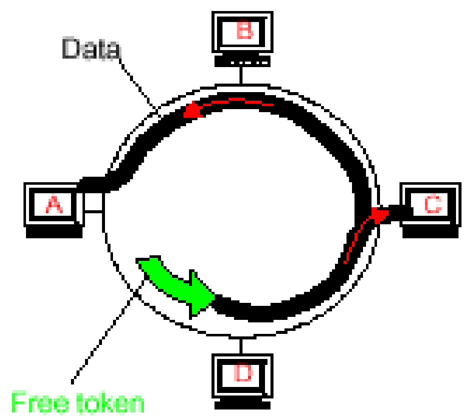

- Receiver recognizes that it is the destination of the frame
- Receiver copies frame to station
- Note: Frame also returns to sender

## Transmission in a Token Ring




- Receiver recognizes that it is the destination of the frame
- Receiver copies frame to station
- Note: **Frame also returns to sender**

## Transmission in a Token Ring

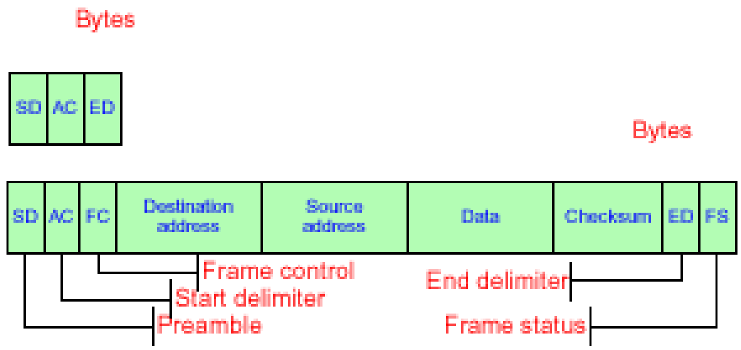



- Sender generates free token when it is done transmitting (Note: the busy token has returned).

## Properties of the 802.5 Token Ring

- No collision of frames
- Full utilization of bandwidth is feasible
- Transmission can be regulated by controlling access to token
- Recovery protocols are needed if token is not handled properly, e.g. token is corrupted, station does not change to “free”, etc.

## Token Format / Data Format




## IEEE 802.5 Frame Format

- One 3-byte token circulates if all stations are idle
  AC = "PPPTMRRR" where
  "PPP" Priority fields
  "RRR" Reservation fields
  "T" Indicates "Token" or "Data frame"

- SD,ED: Start/End delimiter of a frame
- FC: Identifier type of a control frame
- FS: Contains address recognized bit (A bit) and frame copied bit (C bit)
  - Receiver sets A=1 when frame arrives
  - Receiver sets C=1 when frame has been copied

## Priority of Transmission in 802.5

- Eight levels of priorities
- Priorities handled by 3-bit priority field and 3-bit reservation field

- Define:
  - $P_m$ = priority of the message to be transmitted
  - $P_r$ = token priority of received token
  - $R_r$ = reservation priority of received token

## Priority Transmission in 802.5

1. A station wishing to transmit a frame with priority $P_m$ must wait for a free token if $P_r <= P_m$

2. The station can reserve a future priority-$P_m$ token as follows:
   - If busy token comes by, the set $R_r = P_m$ (if $R_r < P_m$)
   - If free token comes by, then set $R_r = P_m$ (if $R_r < P_m$ and $P_m < P_r$)

## Priority Transmission in 802.5

3. If a station gets a free token, it sets the reservation field to "0", and leaves the priority field unchanged and transmits

4. After transmission send a free token with
   1. Priority = max($P_r$, $R_r$, $P_m$)
   2. Reservation = max($R_r$, $P_m$)

5. Station that upgraded the priority level of a token must also downgrade the priority (if no one used the token)

## Ring Maintenance

- Token ring selects one station as the monitor station

- Duties of the monitor:
  - Check that there is a token
  - Recover ring if it is broken
  - Detect garbled frames
  - Make sure the token (24-bit) is shorter than the ring length

## Terms in IEEE 802.5

- IEEE 802.5 requires to maintain a large number of counters
- **THT**: Token Holding Timer (one per station)
  - Limits the time that a station can transmit (Default 10 ms)
- **TRR**: Time-to-Repeat Timer (one per station)
  - Limits that a station waits for return of own message (Default 2.5 ms)
- **TVX**: Valid Transmission Timer (in monitor station)
  - Verifies that station which accessed the token actually used it (Default: THT + TRR = 12.5 ms)
- **TNT**: No-Token Timer (one per station)
  - If expire, a new token is generated (Default: N*(THT+TRR))

## Performance of Token Rings

- Parameters and Assumptions

- End-to-end propagation delay $a$
- Packet transmission time 1
- Number of stations $N$

- Assume that each station always has a packet waiting for transmission
- Note: The ring is used either for data transmission or for passing the token

## Performance of Token Rings

- Define:
- $T_1$ = Average time to transmit a frame. Per assumption, $T_1 = 1$
- $T_2$ = Average time to pass token

$$\text{Maximum Throughput} = \frac{\text{Frame Time}}{\text{Frame Time} + \text{Overhead}} = \frac{T_1}{T_1 + T_2}$$

## Effect of Propagation Delay

- Effect of propagation delay on throughput
- Case 1: a < 1 (Packet longer than ring)
  - T2 = time to pass token to next station = a/N

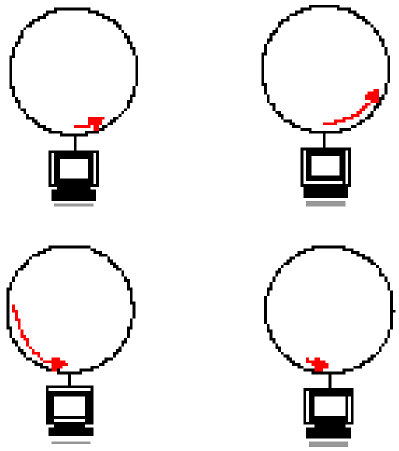
$$S = \frac{1}{1 + a/N}$$

- Case 2: a > 1 (Packet shorter than ring)
  - Note: Sender finishes transmission after T1=1, but cannot release the token until the token returns
  - T1+T2 = min(1,a) + a/N

$$S = \frac{1}{a + a/N}$$

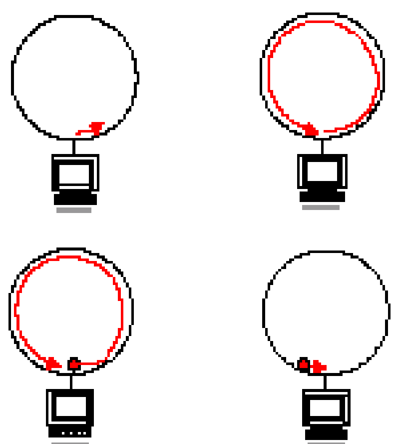
## Performance of Token Rings

Illustration of Analysis (a > 1)



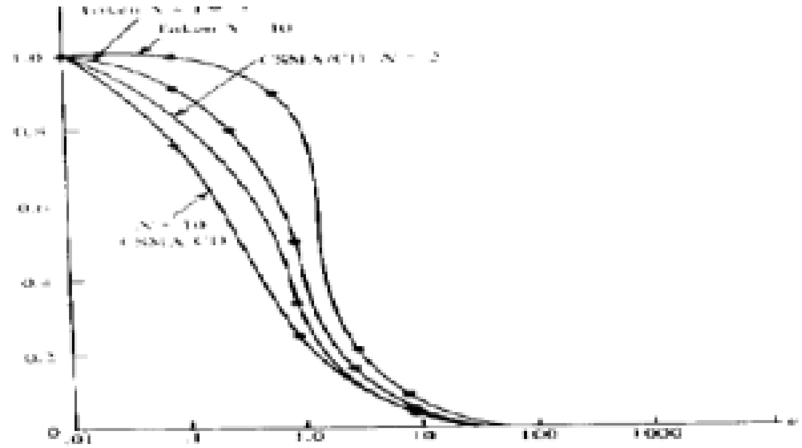
## Performance of Token Rings

Illustration of Analysis (a < 1)



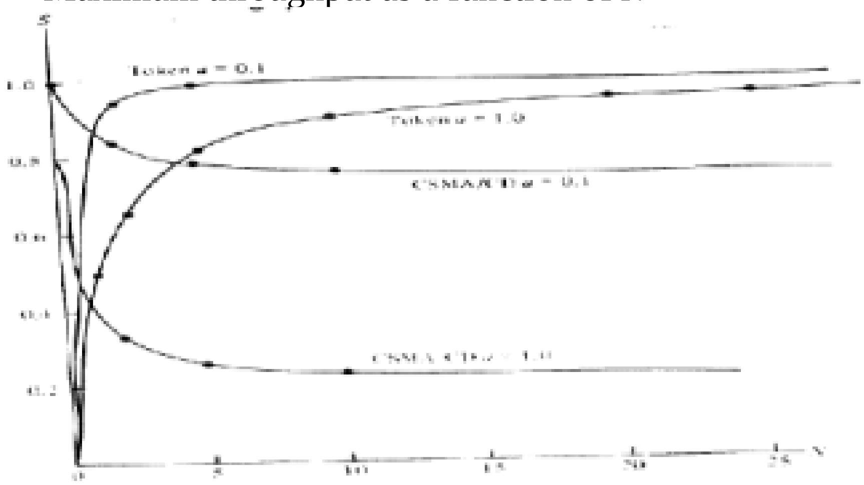
# Ethernet vs. Token Ring

- Maximum throughput as a function of *a*




# Ethernet vs. Token Ring

- Maximum throughput as a function of *N*



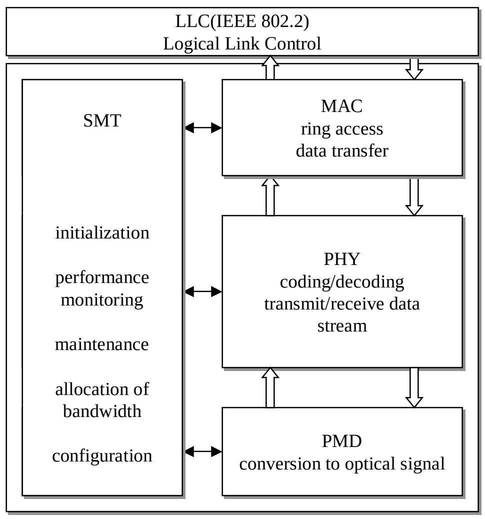
## FDDI

- Some Facts
- FDDI = Fiber Distributed Data Interface
- FDDI is high-speed token ring
- Fiber-optic (dual redundant counter rotating) ring LAN
- Multimode fiber
- Standardized by ANSI and ISO X3T9.5 committee
- 100Mbps data rate
- Maximum frame size is 4500 bytes
- Allows up to 1000 connected stations
- Maximum ring circumference is 200 km

## FDDI

- FDDI distinguishes 4 Service Classes
  - Asynchronous
  - Synchronous
  - Immediate (monitoring and control)
  - Isochronous (only in FDDI-II)

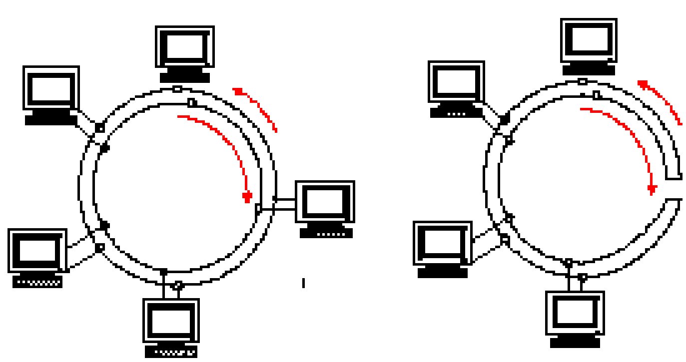
# FDDI-Protocol Architecture




| | |
|---|---|
| SMT | Station Management |
| MAC | Medium Access Control |
| PHY | Physical Layer Protocol |
| PMD | Physical Layer Medium Dependend |

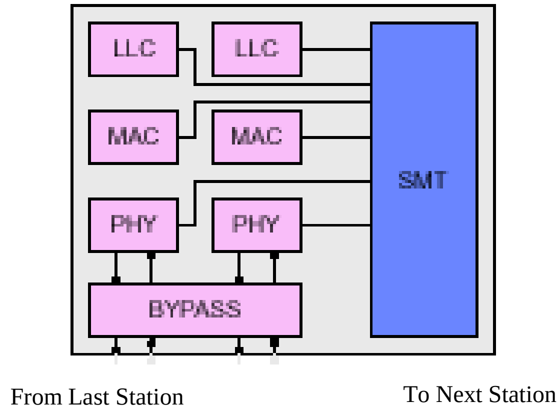
# Dual Redundant Counter Rotating Ring

- Second ring adds fault tolerance:



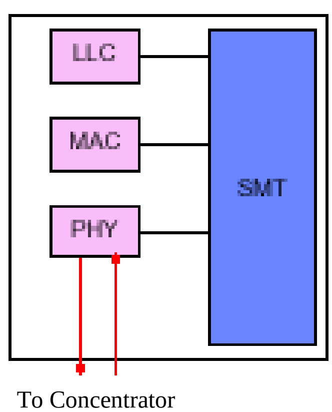
# Station Types: Class A Station

- Two PHY (and onr or two MAC) entities
- Connects to another Class A station or to a concentrator



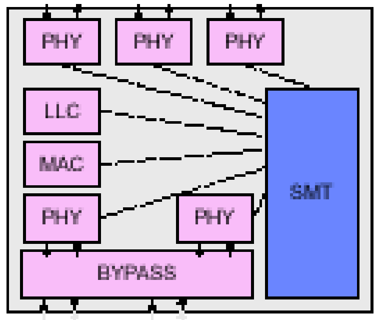

# Station Types: Class B Station

- Class B station has one PHY (and one MAC) entity
- Connects to a concentrator

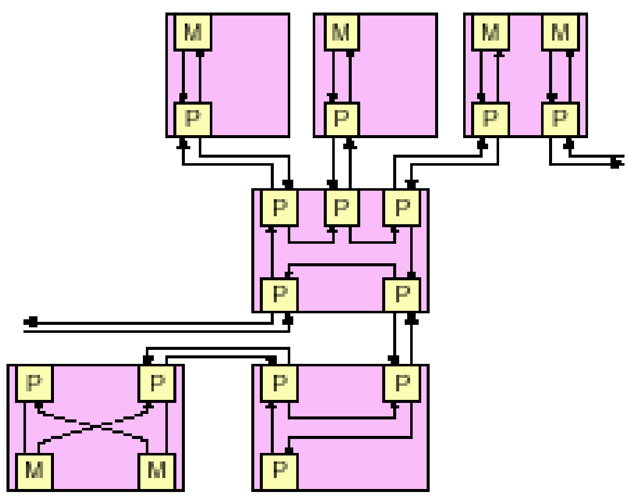


## Station Types: Concentrator

- Connects Class A and Class B stations into one of the counter rotating rings.
- Concentrator can bypass failing stations.



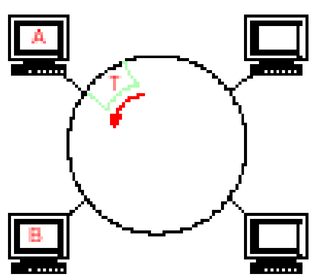

## Topology Example



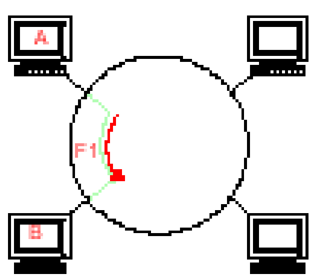
## FDDI Medium Access Control

- FDDI uses a Token Ring Protocol, similar to 802.5
- Differences of FDDI and 802.5:
  - To release a token, a station does not need to wait until the token comes back after a transmission. The token is released right after the end of transmission.
  - In FDDI, multiple frames can be attached to the token.
  - FDDI has a different priority scheme.

## FDDI Token Ring Protocol

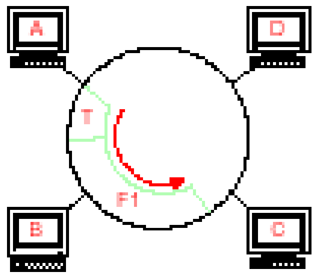



1. A awaits token

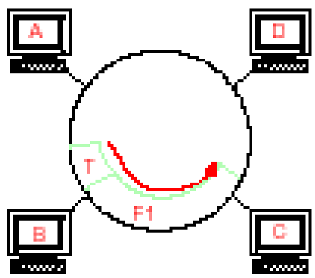



2. A seizes token, begins transmitting frame F1 addressed to C

## FDDI Token Ring Protocol

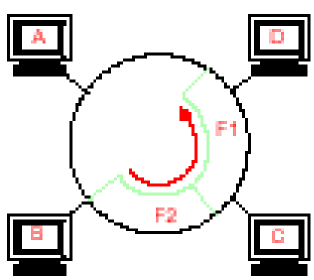



3. A appends token to end of transmission.

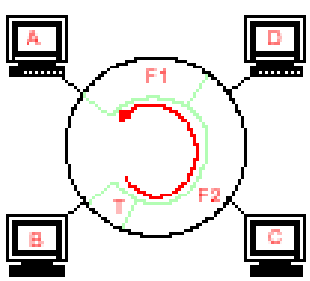



4. C copies frame F1 as it goes by.

## FDDI Token Ring Protocol

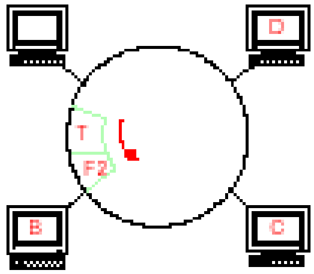



5. C continues to copy F1; B seizes token and transmits frame F2 addressed to D.

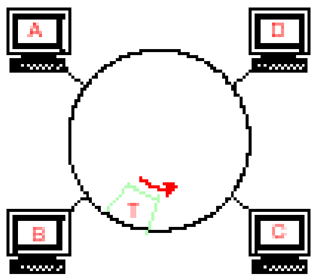



6. B emits token; D copies F2; A absorbs F1

# FDDI Token Ring Protocol




7. A lets F2 and token pass; B absorbs F2




8. B lets token pass

# Frame and Token Format

| Preamble | SD | FC | DA | SA | Info | FCS | ED | FS |
|---|---|---|---|---|---|---|---|---|

*General Frame Format*

| Preamble | SD | FC |
|---|---|---|

*Token Frame Format*

- SD Starting Delimiter
- FC Frame Control (type of frame)
- DA Destination Address
- SA Source Address
- FCS Frame Check Sequence (CRC)
- ED End Delimiter
- FS Frame Status
- Totel Frame length <= 4500 byte

## Timed Token Protocol

- FDDI has a timed token protocol which determines how long a station can transmit
- Each station has timers to measure the time elapsed since a token was last received
- Target Token Rotation Time (TTRT)
  - Value of TTRT is negotiated during initialization (default is 8ms)
  - Set to the maximum desired rotation time

## Parameters of Timed Token Protocol

- Station Parameters
- TRT : **Token Rotation Time**
  - Time of last rotation of the token
  - If TRT < TTRT, then token is “early”, asynchronous traffic can be transmitted
  - If TRT > TTRT, then token is late, asynchronous traffic cannot be transmitted
- THT : **Token Holding Time**
  - Controls the time that a station may transmit asynchronous traffic.
- $f_i$ : Percentage of tht TTRT that is allocated for synchronous traffic at Station *i*

## Timed Token Protocol

- If a station received the token, it sets
  - THT := TRT
  - TRT := TTRT
  - Start TRT timer
- If the station has waiting synchronous frames, then transmit up to the time TTRT + $f_i$ (with $\Sigma_i f_i <= 1$)
- If the station has asynchronous traffic
  - Start THT timer
  - Until timer expires, transmit asynchronous traffic.

## Timed Token Protocol

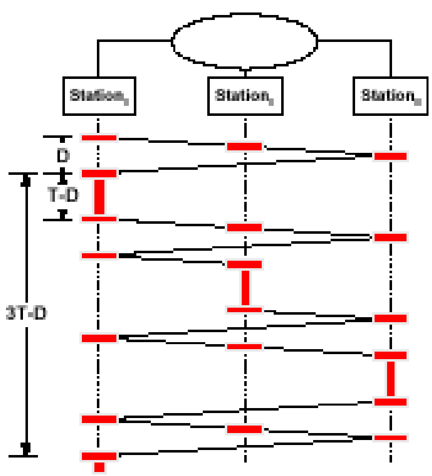
- Transmission is not interrupted if THT expires during a transmission.
- If a station does not utilize its maximum transmission time (that is, THT), the next station can use it.

## Analysis of FDDI: Synchronous Traffic

- Each transmission can transmit synchronous traffic for up to time TTRT + $f_i$ (with $\Sigma_i f_i$ <= 1)
- If $\Sigma_i f_i = 1$, the maximum throughput of synchronous traffic is 100%.
- One can show that the maximum delay unti la frame is completely transmitted is

  Maximum Access Delay <= 2 * TTRT

## Analysis of FDDI: Asynchronous Traffic




- Parameters

  D Ring Latency

  N Number of active sessions (all heavily loaded)

  T Value of TTRT

- Assumption: No synchronous traffic

## Analysis of FDDI: Asynchronous Case

- From the example we see:
  - Cycle in a system has a length of: $nT + D$
  - Time in a cycle used for transmission: $n(T-D)$
- We obtain for the maximum throughput for asynchronous traffic :

$$Max.\ Throughput = \frac{n(T - D)}{nT + D}$$

- … and for the maximum access delay for asynchronous traffic:

$$Max.\ Access\ Delay = T(n - 1) + 2D$$

## Analysis of FDDI: Example

- Number of stations: 16
- Length of fiber: 200km
- Speed of signal: 5ms/km
- Delay per station: 1ms/station
- TTRT: 5msec

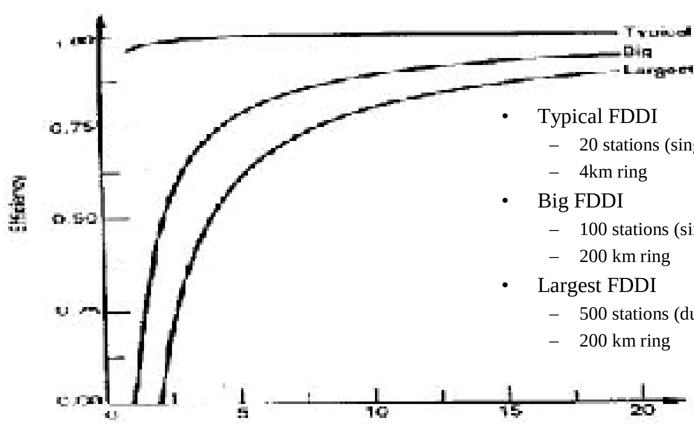
- Ring Latency D = (20km)*(5msec/km) +
  + (16 stations) * 1 msec/station =
  = 0.12msec

# Analysis of FDDI: Comparison

- Synchronous traffic:
  - Max. Throughput = 100%
  - Max. Access Delay = 2*5ms = 10ms

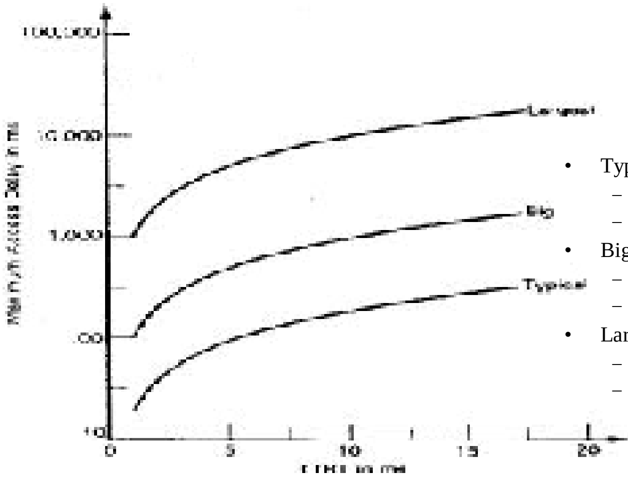
- Asynchronous traffic:
  - Max. Throughput = 16(5-0.12)/(16*5+0.12)=97.5%
  - Max. Access Delay = 5(16-1)+2*0.12=75.24ms

# FDDI: Throughput vs. TTRT




- Typical FDDI
  - 20 stations (single MAC)
  - 4km ring
- Big FDDI
  - 100 stations (single MAC)
  - 200 km ring
- Largest FDDI
  - 500 stations (dual MAC)
  - 200 km ring

# FDDI: Maximum Access Delay vs. TTRT

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