Medium Access Sublayer

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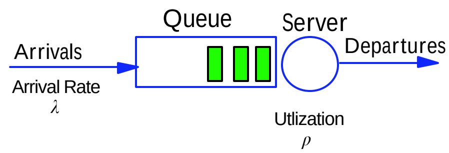
Broadcast Channels (vs pt-to-pt)

- Shared channel where (many) users compete for its use.
  - Random Access...Multiaccess Channels
- Examples: (LANs, Wireless, Satellite)
- Note: In a LAN, DLC runs **on top** of the MAC sublayer.
- Major problem of MAC layer is how to allocate a single broadcast channel among competing users.
  - Static (time or frequency division)
  - Dynamic

Simple Queue Model



- There are n terminals (or stations) each modeled as above.
- Unit time is Δt and prob of frame arriving at the queue is $\lambda\Delta t$.
- Once a frame is generated the terminal is blocked until the frame has been successfully transmitted.
- A single channel is available for all communication.
- If two frames are transmitted and overlap to any extent, the resulting signal is garbled and we have a *collision.*
- Collisions are the only errrors.
- In *continuous time* model frame transmissions can begin at any instant in time.
- In *slotted time* model frame transmissions can only begin at the start of a slot. Slots are provided by a master clock.
- In *carrier sense* transmission, station first senses channel and waits if in use. If no carrier sense, station simply transmits when ready.

Poisson Distribution

Probability of k arrivals during time t is:

$$P_k(t) = \frac{(\lambda t)^k e^{-\lambda t}}{k!}$$

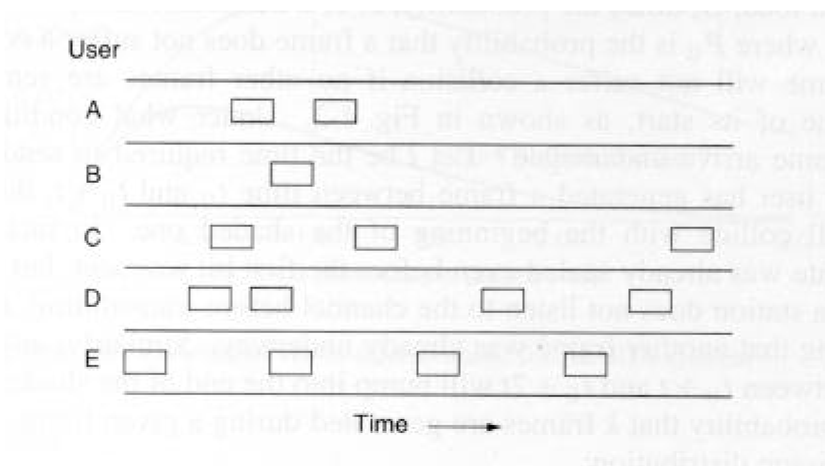
Sometimes we assume "unit time" and write the above without t.

If X is a random variable with a Poisson distribution, then the mean of X or $E(X) = \lambda$.

Pure Aloha System

- Many radio transmitters near Hawaii in early 1970s.
- Each transmits by relaying signal through satellite.
- Each station simply sends when it has something.
- There is a delay for satellite relay and sender then knows if collision or not.
  - Collision if the first bit of a new frame overlaps even with one bit of the previous frame.
- If collision, sender waits a **random** amount of time and retransmits.

Pure Aloha Frame Transmissions



Pure Aloha Throughput

- Assume all frames have a common length.
- Let "unit time" be the time needed to transmit one frame.
- We seek throughput in frames per unit time (a fraction because no more than 1 frame may be transmitted per unit time.)

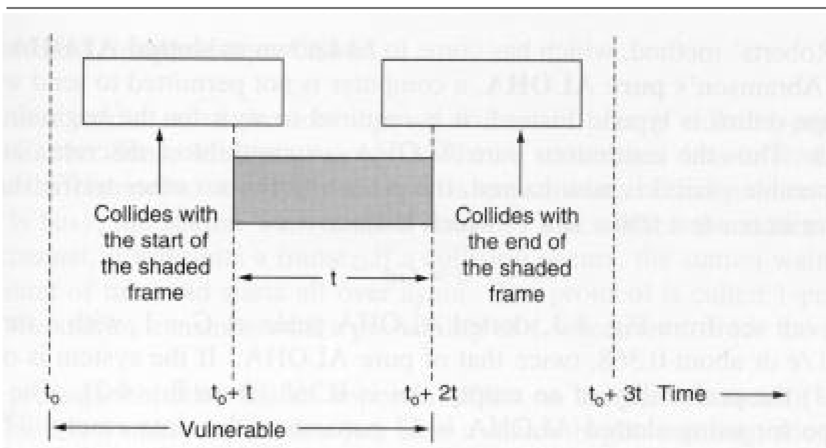
Pure Aloha Throughput (continued)

- Assume infinitely many radio statons (terminals).
- Assume population of stations generates frames according to Poisson distribution with mean number of frames N (note: NOT λ.)
- If $N>1$, population is generating too many frames per unit time and "nothing" gets through.
- Thus, $0<N<1$.

Pure Aloha Throughput (continued)

- Stations are generating new frames at rate N (collectively).
- In addition stations are generating retransmissions - depending on collisions.
- Assume that total transmissions of new plus old frames has a Poisson distribution with parameter G (per unit time).
  - Clearly $G \geq N$. When N is low, few retransmissions so G approx equal to N. When N is high, many retransmissions so G>N.
- Note that (rate of frames getting through) = (total rate of frames submitted)*(probability that a frame is successful).
  - We write this as $S = GP_0$

Collisions in Pure Aloha: Frame Transmission Time is t.



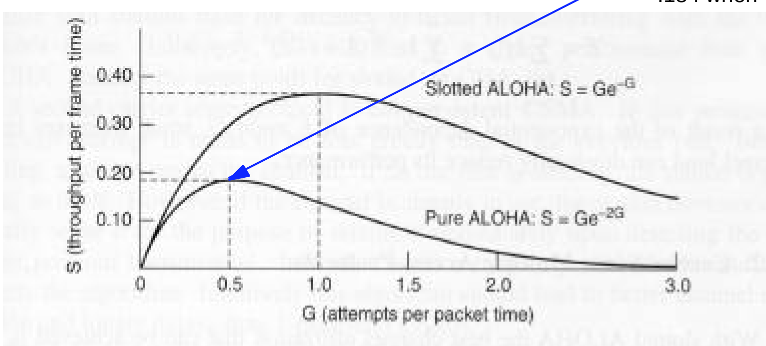
Arbitrarily label the transmission time of "shaded frame" as (t_0+t). Any other frame that begins in (t_0,t_0+2t) will overlap part of "shaded frame." Two such frames are shown.

Max Throuput in Pure Aloha

In $S=GP_0$ we need P_0 = probability of no frames transmitted during an interval of length 2t which is 2(unit time).

Thus, $P_0 = \frac{(2G)^0 e^{-2G}}{0!} = e^{-2G}$, and $S=Ge^{-2G}$.

Note S has a max of .184 when G = 0.5.



Max Throughput for Slotted Aloha

- Slotted Aloha invented to improve on throughput of 18.4% of channel (max) with 50%-18.4%= 31.6% of channel used for retransmission.
- Time divided into "slots." When message is ready, station waits for beginning of next slot.
- Collision will only occur if two or more stations become ready during the same1slot time that precedes when they begin.
- Throughput equation now: $S=Ge^{-G}$.
- Max throughput for slotted Aloha is 0.368 for total offered load of 1 frame per unit time.

Carrier Sense Multiple Access

- Slotted Aloha limited to .368
- Protocols which listen first and then transmit if clear can do much better.
  - Called carrier sense protcols
- 1-persistent CSMA
  - station has frame to transmit
  - station listens until channel is idle
  - transmits when idle
  - backoff a random time if collision
  - then listens and transmits when idle.
  - station transmits with prob 1 when idle: 1-persistent

Non-persistent and p-persistent CSMA

- Non-persistent
  - station senses the channel and transmits if idle.
  - if NOT idle, then waits a random time before sensing again.
- p-persistent
  - assumes slotted channel
  - station senses the channel and, if idle, transmits with prob p. With prob 1-p waits to next slot, senses again and makes same decision.
  - if NOT idle, then senses the next slot until idle and repeats the p & 1-p decision above.
  - if transmits and collision occurs, backs off random time
  - if, after senses idle, another station begins transmitting behaves as though collision had occurred.

Channel Utilization versus Load for Random Access Protocols

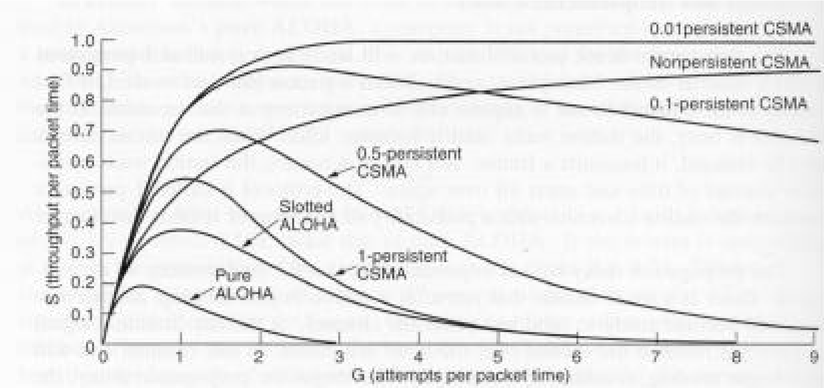


Fig. 4-4. Comparison of the channel utilization versus load for various random access protocols.

CSMA (CD) Collision Detection

- Station senses channel and transmits if idle
- Continues to listen and aborts immediately if collision is detected
- Backs off random amount of time before repeating this process
- If the propagation time between the two furthest stations is τ, then station must listen for almost 2τ before being sure no collision occurs.
- Analysis of throughput is complex.

Reservation Protocols

- Protocols in which a "reservation" is made during the contention period (just after a frame has been transmitted).
- Assume N stations with address 0, ... , N-1
- Bit-Map Protocol
  - Contention period of N 1-bit slots.
  - Station j inserts bit into slot j if has something to send.
  - After stations have seen reservations, transmit in order.
  - No collisions
  - Bitmap repeats...if no one has traffic to send.
- Analysis: low-load (assume no traffic)
  - low-number station gets ready to transmit and finds bit map about half way through on average. Must wait N/2 slots until his slot shows up. Sets bit. Must wait for remainder of N slots to go by. Then transmits. So waits 1.5N slots on the average.
  - High-number stations gets ready to transmit and waits only N/2 slots before transmitting.
  - Conclusion: considering both cases a station waits an average of N slots to begin transmitting. This is delay. If frame contains d bits, then efficiency is d/(N+d).

Bit-Map Protocol (continued)

- For high load assume all statons have traffic to send.
- N-bit slot goes by and everyone sets their 1-bit.
- Then everyone sends one frame.
- Efficiency is d/(d+1) because 1 additional bit sent per frame.
- Delay is N(d+1)/2 once it reaches the head of any queue at the station.

IEEE 802 Standards

- CSMA/CD, Token Bus, Token Ring
- Adopted by ANSI, NIST, ISO
- 802.1 is Introduction and Interface Primitives
- 802.2 is upper data link layer: LLC protocol
- Mac Sublayer and Physical Layer:
  - 802.3 is CSMA/CD LAN
  - 802.4 is token bus LAN
  - 802.5 is token ring LAN

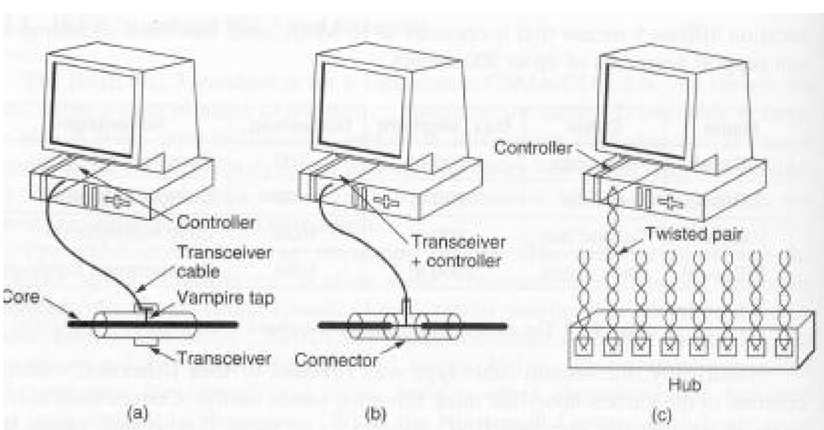
Ethernet and CSMA/CD (802.3)

- Beginning was Aloha System
- In 1976 Xerox Parc built LAN on 1km cable to interconnect about 100 w/s
  - 2.94 Mbps using CSMA/CD
  - sense channel, 1-persistent, abort on collision
  - called Ethernet
- Xerox, Dec, Intel created standard for 10Mbps Ethernet.
- Led to the 802.3 standard which differs:
  - Includes additional media
  - Has a different header from Ethernet

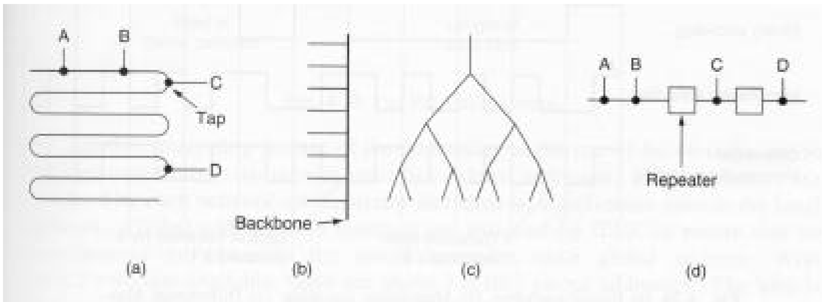
802.3 Cabling

- 10Base5 cabling (thick Ethernet)
  - 10Mbps, baseband signaling, 500 meter segments
  - Like yellow garden hose
  - Uses "vampire" taps at least 2.5 meters apart
- 10Base2 cabling (thin Ethernet)
  - 10Mbps, baseband, 200 meter segments
  - only 30 connections per segment
  - industry standard BNC connections (T junctions) much easier and more reliable
  - difficult to find and fix breaks
- 10BaseT
  - each station connected to central hub
  - twisted pair (max run to station 100m-150m)
- 10BaseF uses fiber optics for long runs (between bldgs)

10Base5, 10Base2, 10BaseT



Topologies: Linear, Spine, Tree, Segmented



With repeaters:

No two stations more than 2.5 km apart
No path between two stations may contain more than 4 repeaters.

Manchester Encoding

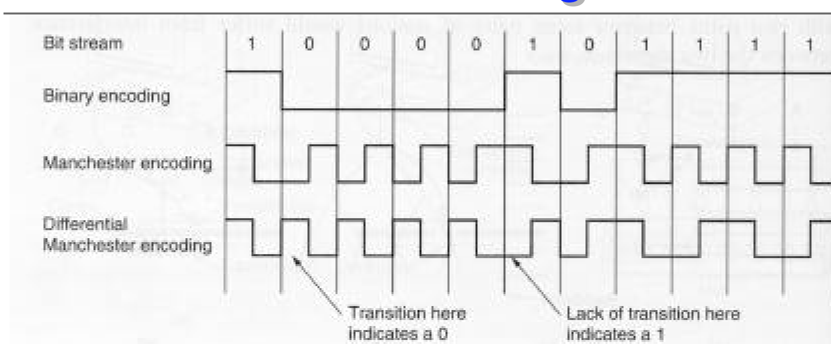
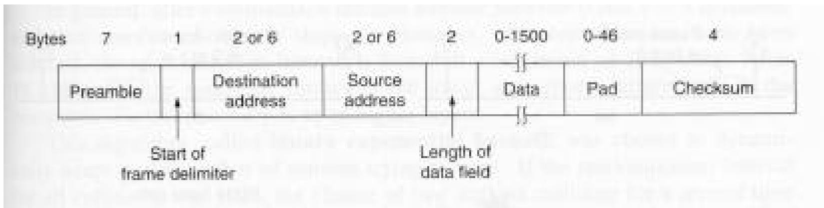


Fig. 4-20. (a) Binary encoding. (b) Manchester encoding. (c) Differential Manchester encoding.

802.3 Frame Format



- Preamble: 7 byes 10101010 (clock synch)
- Start of frame: 10101011
- Dest Addr: 6 (2) bytes, supports multicast or broadcast
  - global addresses assigned by IEEE (in blocks to corps)
- Source addr: 6 (2) bytes
- Length (of data) from 0 to 1500 bytes
  - min length is 64 bytes including dest address thru checksum
- Pad: bytes added in insure 64 byte length
- Checksum: CRC

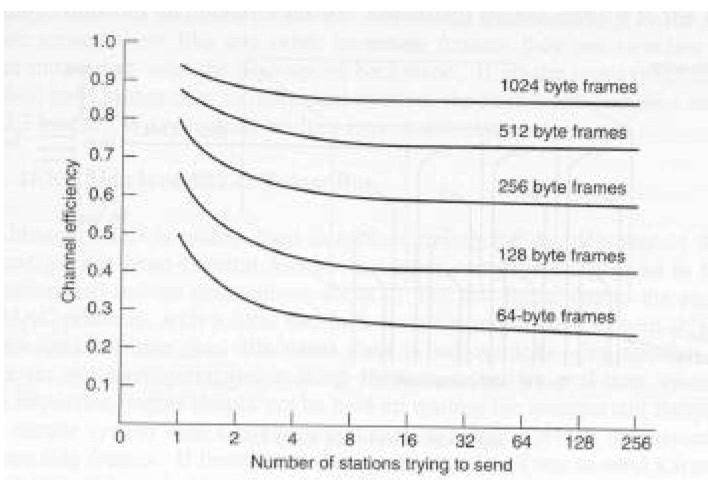
Binary Exponential Backoff

- After collision time is slotted (length of 2500m roundtrip propagation) to 512 bit-times or 51.2 microsecs.
- After collision i, each station picks a random number 0,1,2,...,2^{i-1} and skips that many slots (for i=1...11).
  - For larger i, number of slots frozen at 1023.
  - Random interval grows exponentially with number of collisions.
  - Tradeoff between prob of re-collission and delay.

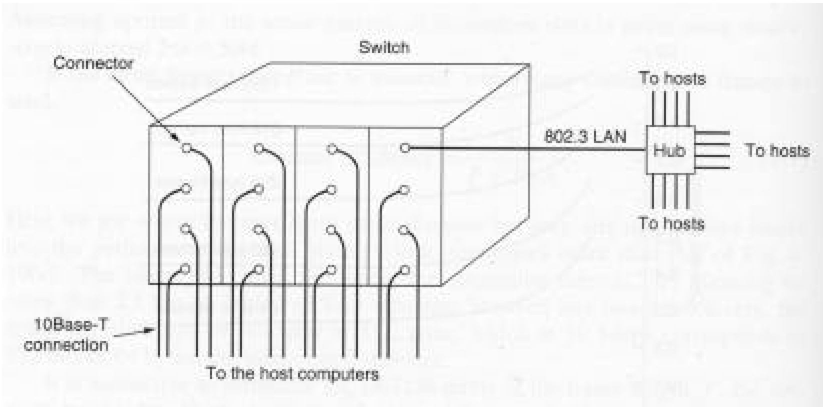
802.3 Performance: Heavy Load

- Assume each of k stations always has something to transmit
- Approximate binary exponential backoff plus arrivals by saying each station transmits with probability p in each slot.
- The probability that exactly one station gets the channel in a given slot is binomial: $A=kp(1-p)^{k-1}$
- Can show that A is maximized when p=1/k.
- In this case $A=(1-1/k)^{k-1}$
- As k gets large A goes to 1/e for p=1/k.
- Mean slots per backoff period is $\Sigma jA(1-A)^{j-1}=1/A$
  - sum from j=0 to infinity
- Each slot of duration 2τ so mean contention interval $2\tau/A$
- If mean frame takes P secs to transmit, then channel efficiency is $P/(P+2\tau/A)$ or $P/(P+2\tau e)=P/(P+5.4\tau)$ for optimal p.
- Author also gives channel efficiency = 1/(1+2BLe/cF)
  - Indicates efficiency decreases with BL so Ethernet not suited for very high bandwidth and large frames.

Efficiency of 802.3 at 10Mbps with 512-bit slot times



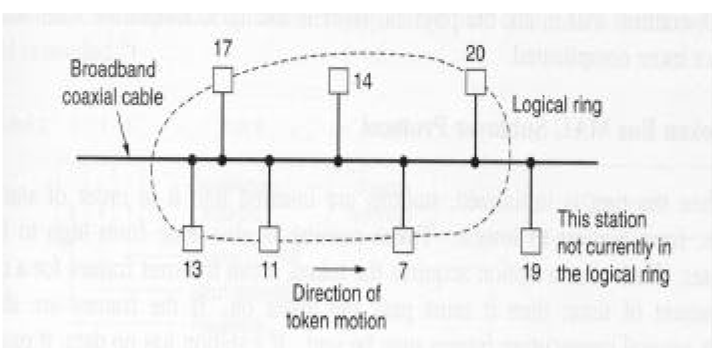
Switched 802.3 LAN



- Interconnects hubs at highspeed without changing adapter cards at workstations
- Hubs may interconnect at 100Mbps or higher (backplane usually 1Gbps)
- Collision domain restricted to single port on switch.

802.4: Token Bus

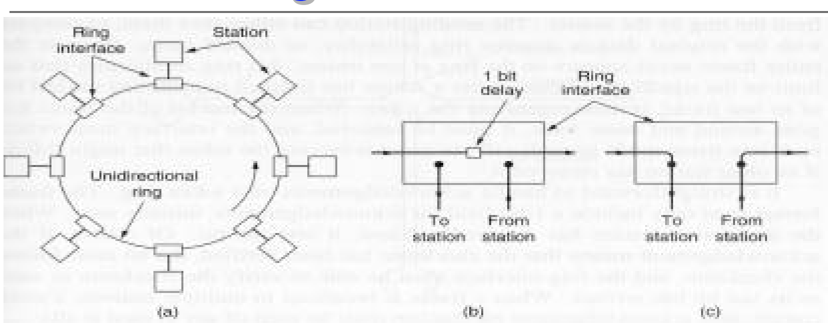
- 802.3 most widely used office LAN
- Many businesses concerned about potential for unbounded delay on Ethernet.
- General Motors drove new standard based on passing a "token"
- Token bus supporters concerned about reliability of token ring so supported token bus: an arbitrary linear or tree topology.



Token Bus (continued)

- Stations uniquely numbered highest to lowest and token passes accordingly.
  - Physical location not important
- Broadcast domain so everyone "hears."
- 75 Ohm cable with speeds of 1, 5, 10 Mbps possible.
- Modulation relatively complex vs CSMA CD.
- Four priority classes for traffic: 6, 4, 3, 0 (hi->low)
  - Significant advantage over Ethernet
- Example: 50 stations on 10Mbps network with 3.333Mbps dedicated to priority 6 traffic. Implies each station gets $3.333 \text{x} 10^6/50$ = 67kbps (approx) guaranteed for priority 6. Enough to support voice.
- Examine frame format and logical ring maintenance text pages 289-290.

Token Ring: 802.5

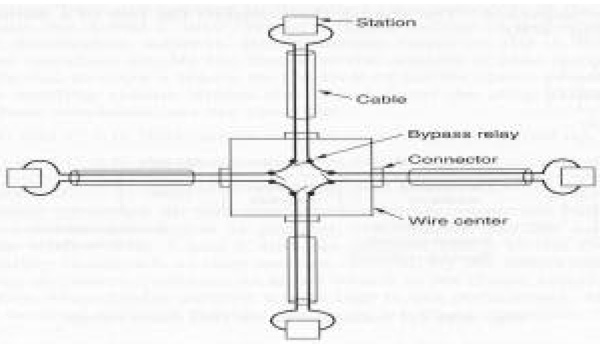


Topology — Listen Mode — Transmit Mode

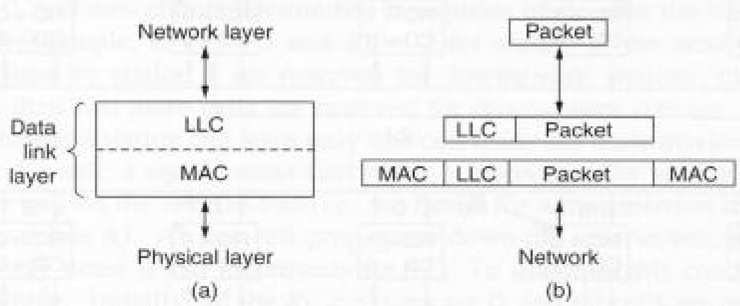
- Also passes token (like token bus)
  - Station removes token (by flipping bit) before transmitting.
  - Note 1-bit delay.
- 4 or 16Mbps
- One Bit-distance is either
  - $200 \text{x} 10^6$mps/$4 \text{x} 10^6$bps (approx 25m) or 200/16 (6.25m)
  - 1000m ring can hold 40 or 160 bits

Token Ring (continued)

- Station gets token, sends frame, removes frame from ring (as bits propagate around the ring and return), then regenerates token and goes to listen mode.
- Max frame size in practice is 2000 bytes
- If no traffic to send, station simply passes token along.
- Under heavy load channel utilization can approach 100%.
- Virtually all installations use star-wired hubs as below.



802.2 LLC Layer

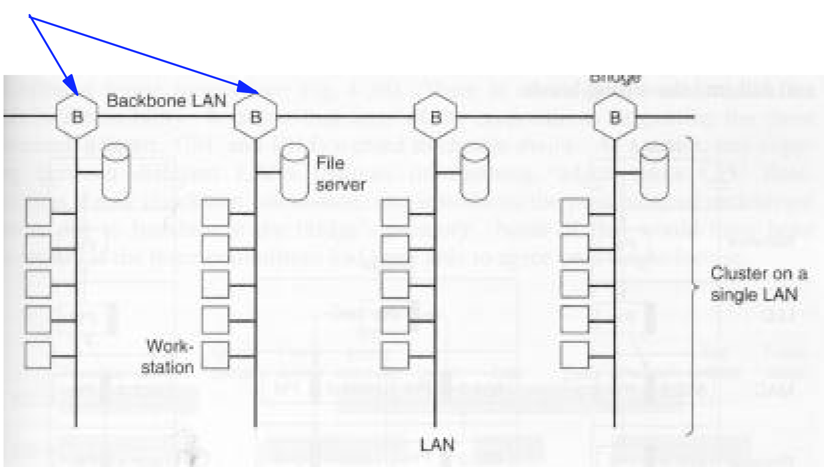


- Runs on top of CSMA/CD, Token Bus, Token Ring
- Single format and interface to network layer
- Three service options:
  - Unreliable datagram service
  - acknowledged datagram service
  - reliable connection-oriented service

Problems (for March 19)

- Chapter 4:
- 1 thru 6
- 17, 19, 20, 21, 22, 24, 25, 27, 28, 30, 32, 35, 37, 38, 39

Bridges



Interconnect differing LAN technologies (802.3, 802.4, 802.5)
Forward multiple Network Layer protocols (IP, IPX, Appletalk...)
Segment bandwidth according to requirements.
Span greater distance than single LAN segment.
Intelligent forwarding (filtering).

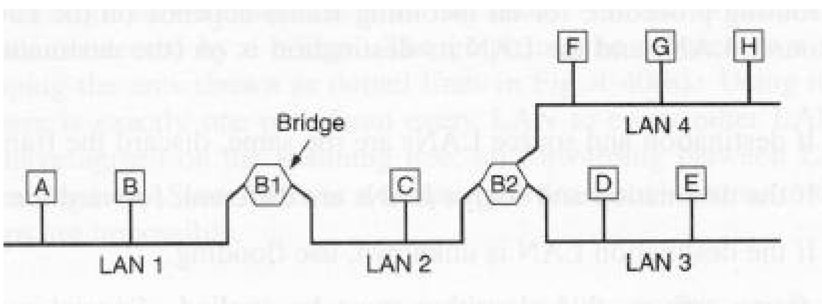
Bridge Challenges

- Each LAN type has unique frame format
- Two LANs may have different effective speeds
  - destination may be overloaded
- Two/more input LANs may feed one output LAN
- Compatibilty with higher-layer timers (acks, etc.)
- Max frame lengths are different
  - Not possible to segment in this layer.
  - Frames larger than max are discarded.
- Priorities in one LAN no priorities in another...

Transparent Bridges

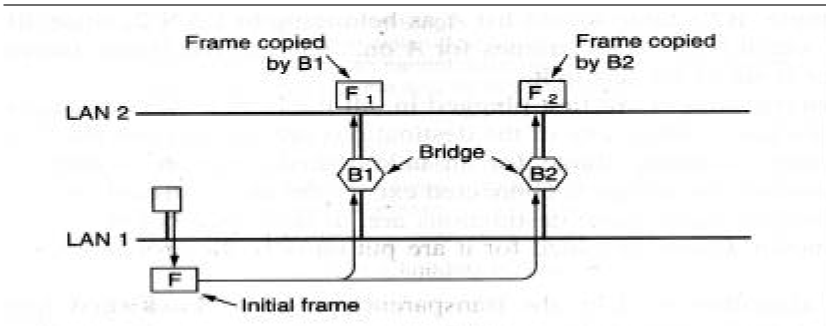
- Goal: plug and play...no hardware changes, no software changes, no tables downloaded, etc.
  - Operation of existing LANs unaffected
- In steady-state transparent bridge will forward frames only through the port that leads to the destination LAN.
  - Lookup in table that gives correct port for destination.
- Table must be initialized.
  - First flood all unknown frames (destinations) onto all ports except the one on which it arrives.
  - Use "backward learning" algorithm to learn destinations.

Flooding and learning...



- Transparent bridge first forwards all frames on ports other than where received.
- Sees all traffic on attached LANs and records source LANs.
  - NOTE B1 will record that D can be reached on LAN2.
- Time of entry into hash table is also stored.
  - updated with each new arrival
  - discarded after a few minutes
- If A is quiet for 15 mins and D sends a frame to A, what happens?

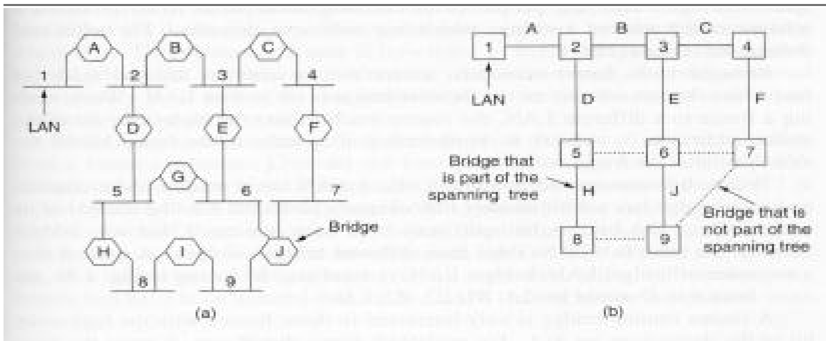
Transparent Bridge Susceptible to Looping



If destination of Frame F unknown:

- Frame F arrives at B1 and B2 from LAN1.
- B1 forwards to B2 and B2 forwards to B1.
- Each bridge sees Frame arriving from LAN2 and forwards to other bridge on LAN1.
- Process continues...

Spanning Tree Bridges

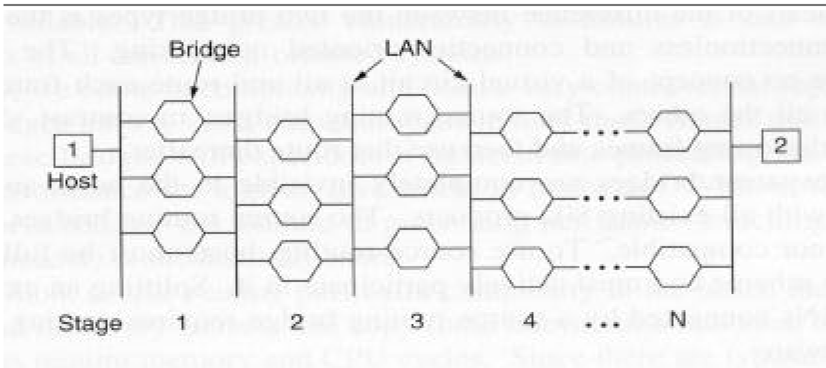


- With spanning tree exactly one path between every two LANs.
  - Note loss of bandwidth and potential redundancy.
- Spanning tree algorithm:
  - choose bridge with lowest serial number as root
  - Uses distributed algorithm to build spanning tree

Source Routing Bridges

- In standards CSMA/CD and Token Bus supporters like transparent bridge. Token Ring people liked source routing bridges.
  - Connectionless vs connection-oriented in the LAN
  - Concern about waste of bandwidth from TR people.
- Source routing:
  - Set high order bit of source addr to 1 if destination off-LAN.
  - Insert into the frame (Routing Information Field) the entire route from source to destination...L1,B1,L2,B2,L3
  - SR bridge scans the list until it finds LAN on which frame arrived.
  - If next field is its own bridge number, then forwards to next LAN...otherwise discards frame.
  - NOTE depends on every terminal being able to find a good path to every other terminal in the interconnected LAN network.
  - To get routes, source broadcasts a discovery frame that is forwarded by every bridge in the network. Every destination terminal responds and bridges insert their numbers into the response. Source generally picks the route contained in the quickest response.

Discovery Frame Explosion

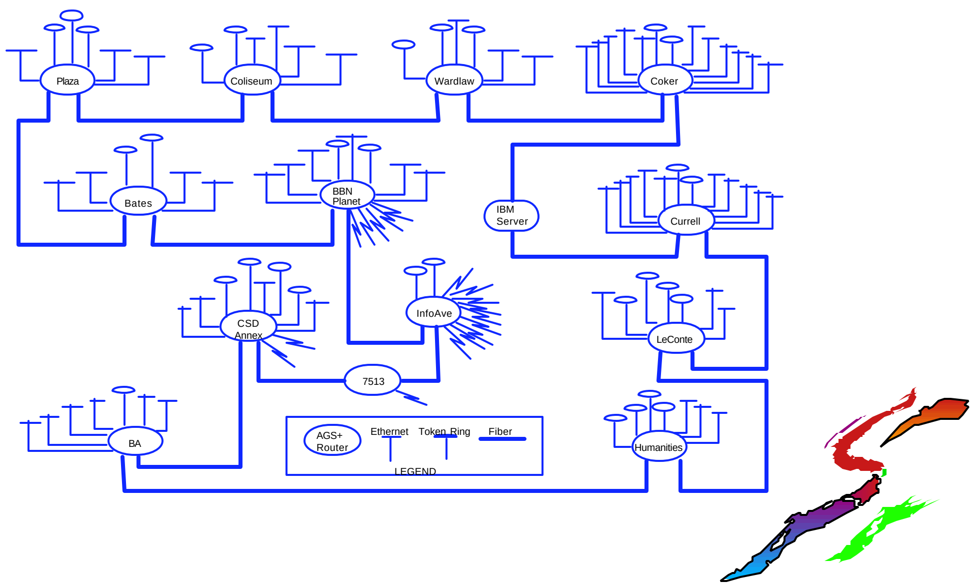


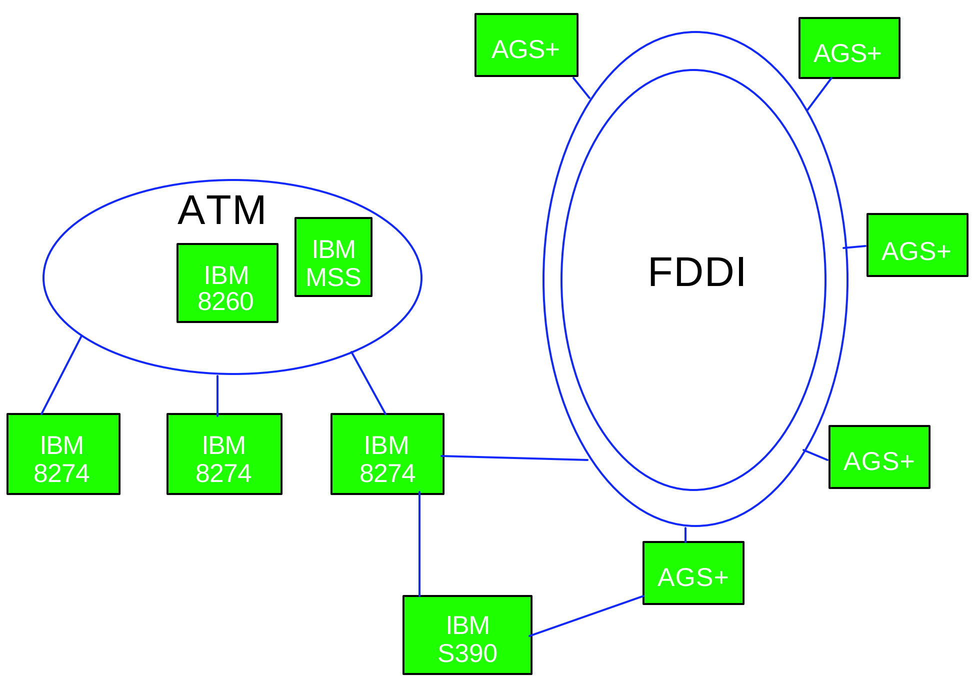
- Terminal 1 tries to "discover" routes to terminal 2.
- Sends "discover" on LAN1 forwarded by 3 bridges to LAN2
- Each forwarded by 3 bridges on LAN2 so 3^2 frames forwarded
- Bridges on LAN3 forward 3^3 frames
- Bridges on LANn forward 3^n frames...
- Last LAN may get thousands (millions) of frames.

Fiber Distributed Data Interface (FDDI)

- Fiber Optic token ring at 100Mbps up to 200km with up to 1000 stations connected.
- Commonly used as backbone to interconnect lower-speed LANs.
- Multimode fiber with LEDs...1 error in 2.5×10^{10} bits.
- Two counter-rotating rings, reconfigure to single ring on break.
- Mac protocol similar to 802.5 (token ring)
  - Also permits synchronous frames for voice circuits (up to 4T1 channels supported per frame).
  - Synch frames have priority over asynch

USC FDDI Backbone





Fast Ethernet

- Expense of FDDI limited use to large campus/business backbones.
- Standard committee produced "fast ethernet" standard in 1992: 100 Mbps, nearly identical to Ethernet formats, interfaces, protocols.

Name	Cable	Max. segment	Advantages
100Base-T4	Twisted pair	100 m	Uses category 3 UTP
100Base-TX	Twisted pair	100 m	Full duplex at 100 Mbps
100Base-FX	Fiber optics	2000 m	Full duplex at 100 Mbps; long runs

Others...

- HIPPI - High-Performance Parallel Interface
  - Designed by Los Alamos as supercomputer interface
  - 800Mbps (later 1600 Mbps option)
  - Interface is 50 bits wide and requires 50 twisted pairs!
  - Max cable length is 25 meters.
- Fiber Channel
  - Basic structure is a crossbar switch from inputs to outputs.
  - Connections for single-packet or longer.
  - Supports up to 800 Mbps...generally used in data centers.