Data Communication Networks Multiple Access Control Sublayer

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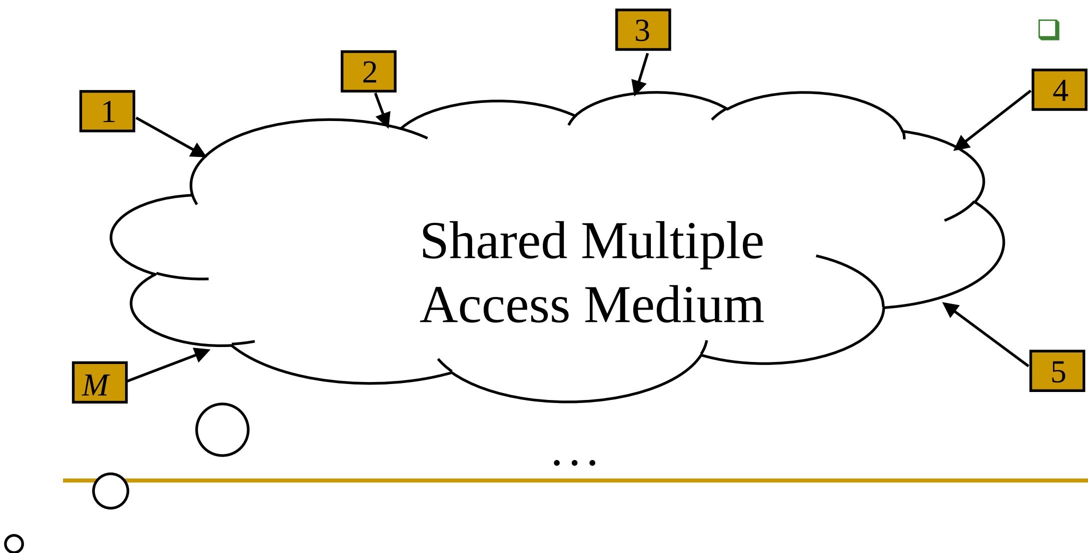
The Medium Access Sublayer

- A number of systems are connected to share the medium: Who gets access?
  - Used for LANs
  - Addressing
  - Broadcast



- Channel Allocation problem:
  - Single channel has to be shared among multiple users
- Solutions:
  - **Static** allocation : user gets a channel for the whole ‘conversation’
  - **Dynamic** allocation: channel capacity allocated for a user is not fixed; depends on usage

Static Channel Allocation

- Using FDM or TDM to divide channel capacity among N users
- Inefficient bandwidth use: some users may be idle
- Users may be denied access even when other users do not use there allocated capacity
- Long time service delay T

Static Channel Allocation

- Delay in a single M/M/1 Queue
  - Channel can transfer C bits/sec
  - Frames arrive randomly with an average rate of λ frames/sec and the inter-arrival times are exponentially distributed
  - Frame length values has an exponential distribution with an average length of $1/\mu$ bits.
  - Mean delay of frames in the queue is given by: $T = \frac{1}{\mu C - \lambda}$
  - Example: C=100 Mbps, $1/\mu$=10000 bits, λ=5000 frames/sec, T=200 μsec
- Delay if we divide the channel into N sections
  - Assume we divide the same stream into N smaller streams and serve each of them in a separate queue
  - There will be N channels with a capacity of C/N bits/sec for each
  - There will be N streams with an average rate of λ/N frames/sec each
  - Mean delay of each queue: $T_N = \frac{1}{\mu\left(\frac{C}{N}\right) - \frac{\lambda}{N}} = \frac{N}{\mu C - \lambda} = NT$
  - Example: If we divide the above queue into 10 sections, $T_N = 2msec$

Dynamic Channel Allocation

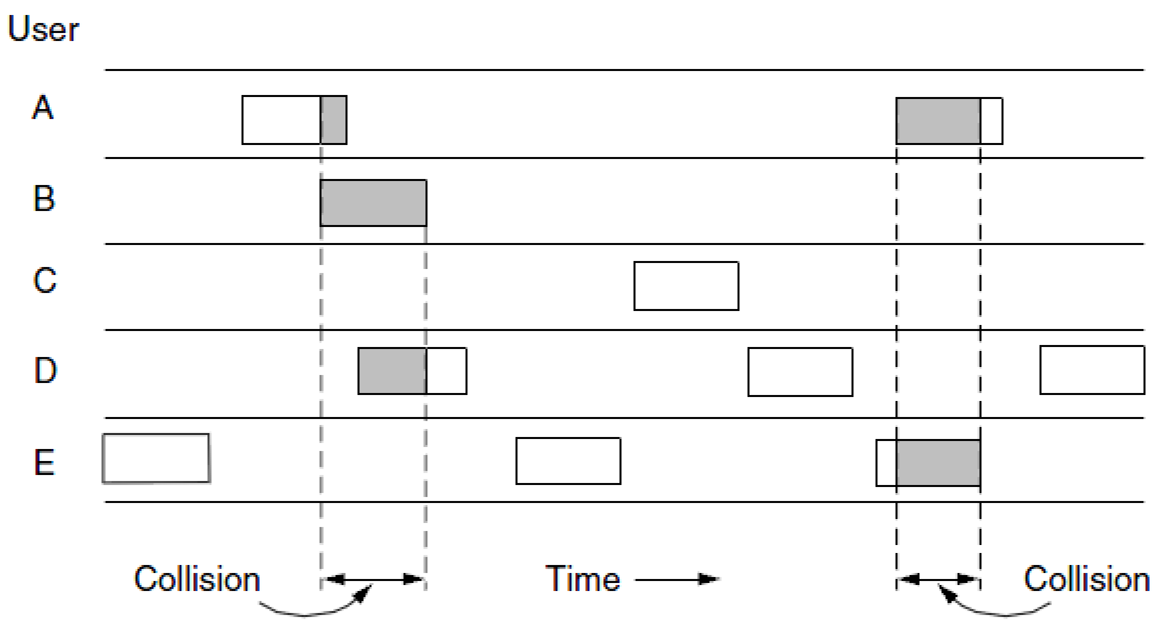
- In data communication, the peak to mean ratio of traffic can be very high.
- In many applications, users require the channel in random times
- Static allocation will be a waste of channel resources
- It is best to assign the channel based on user demand
- Different protocols for coordination:
  - ALOHA : pure and slotted
  - CSMA : carrier sense multiple access protocols
  - Collision free protocols
  - Limited contention protocols
  - Wireless LAN protocols

Dynamic Channel Allocation

- Assumptions for analysis of dynamic channel allocation algorithms:
  - Station model:
    - N independent stations generating frames within interval Δt with probability = $\lambda \Delta t$ where λ is frame rate (frames/second)
  - Single communication channel
  - Collision occurs when 2 frames are transmitted simultaneously
  - Time is
    - a) continuous, or
    - b) slotted (discrete intervals)
  - Stations may have the hardware to notice:
    - Collision of frames
    - The presence of another signal on the channel (carrier sense)

Multiple Access Protocols

- ALOHA:
  - Station transmits as soon as it has a frame
  - If a collision is detected, it waits for a random time interval and then retransmits



ALOHA Efficiency

- Notes and assumptions:
  - Large number of stations
  - Frames of equal length
  - Transmit time for frame on the channel is normalized to unity
  - Stations can sense channel collision and re-try transmission if there is a collision
- Poisson distribution:
  - Poisson distribution is drived from the binomial distribution:
  - If event happens with probability p, the probability that the event happens exactly X times in N trials is:

$$P(X) = \binom{X}{N} p^{X} (1 - p)^{N-X}$$

  - If N is large and p is not close to 0 or 1 we get a Normal distribution
  - If N is large and p is small (rare event) we get a Poisson distribution
  - Probability of *k* events in a given time interval:

$$P_r[k] = \frac{G^k e^{-G}}{k!}$$

ALOHA Efficiency

- ***Analysis:***
  - All stations together, generate an average of S <u>new</u> frames per frame time
    - If S>1, every frame suffers a collision, so for reasonable operation, 0<S<1
    - A station does not send a new frame until the old frame has been transmitted successfully. So, S can be seen as a measure of throughput as well.
  - Probability of k attempts per frame time by all stations, old and new combined is Poisson with mean G per frame time.
  - Low load $\Rightarrow$ rare collision $\Rightarrow$ $S \approx G$
  - Increase the load $\Rightarrow$ More collisions $\Rightarrow$ $G > S$
  - Throughput is then the offered load, G, times the probability of no collision, P_0
    $\Rightarrow S = G \times P_0$

ALOHA Efficiency

- Probability of k frames generated per frame-time (t) is (Poisson distribution)

$$P_r[k] = \frac{G^k e^{-G}}{k!}$$

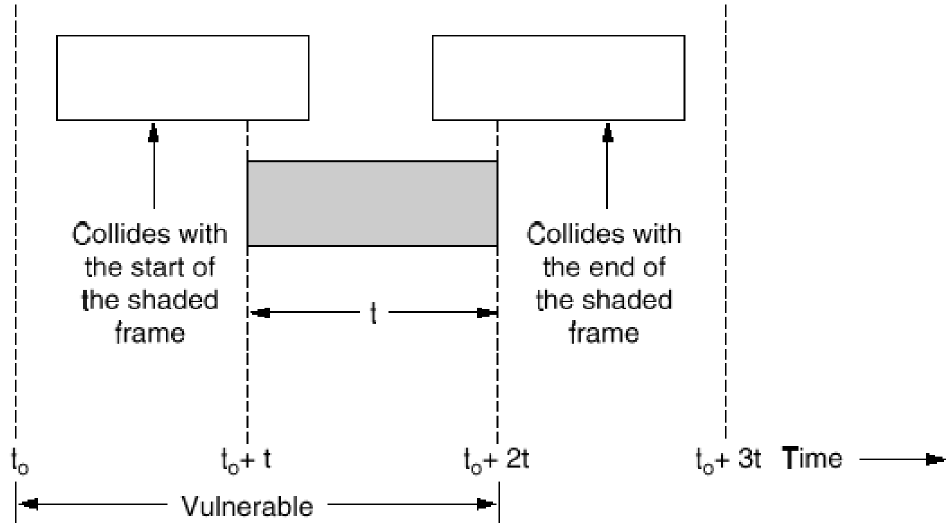
- Probability that there is no frame generated in a given interval t is

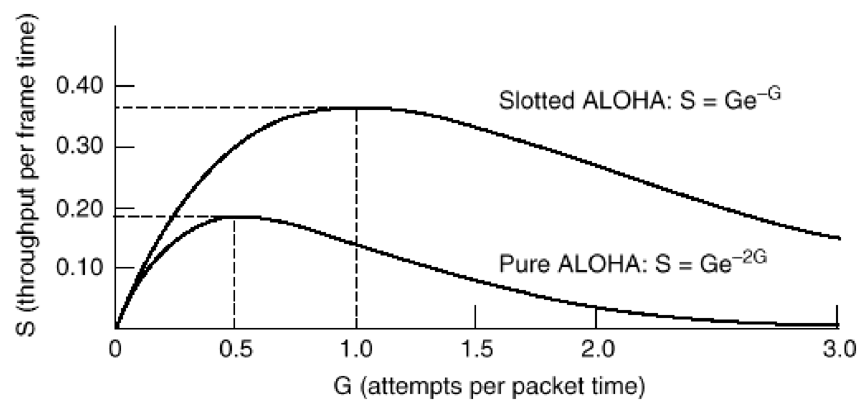
$$P_r[0] = e^{-G}$$

- No collision if no other frame generated in two frame-times.
- Mean number of frames generated during 2t sec is 2G so:

$$\Pr[k] = \frac{(2G)^k e^{-2G}}{k!} \Rightarrow \Pr[0] = e^{-2G}$$

- ALOHA Efficiency: $S = Ge^{-2G}$





Slotted ALOHA Efficiency

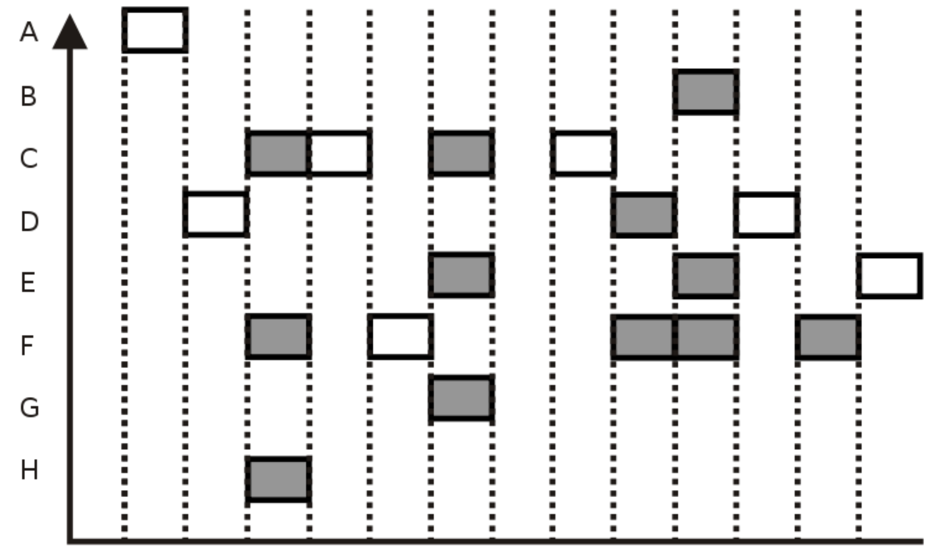
- Divide time in discrete intervals
- Users have to agree on slot boundaries
- In each slot, one or more users send their frames
- Probability of transmission success (no other frame is generated in a given interval) t is

$$\Pr[k] = \frac{(G)^k e^{-G}}{k!} \Rightarrow \Pr[0] = e^{-G}$$

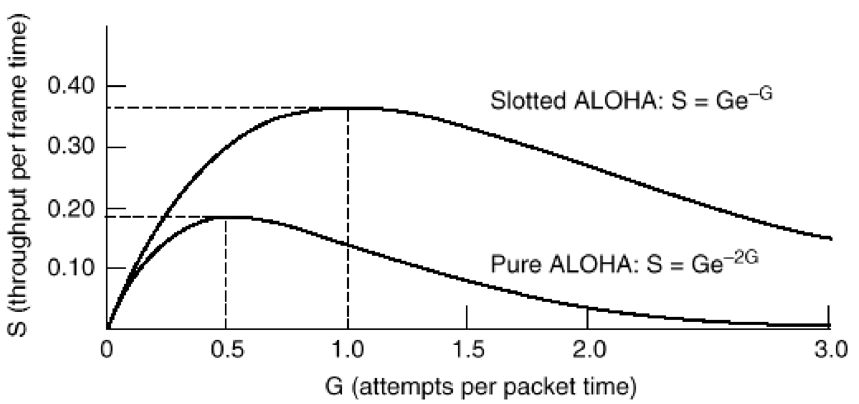
- Slotted ALOHA Efficiency:

$$S = Ge^{-G}$$

- Maximum channel utilization:
  - Pure Aloha : 18.4%
  - Slotted Aloha : 36.8% (37% empty slots, 26% collisions)



Slotted ALOHA protocol (shaded slots indicate collision)



Impact of Load

- Probability of transmission failure for a single frame:

$$P = (1 - e^{-G})$$

- Probability of a transmission requiring exactly k attempts:

$$P_k = e^{-G}(1 - e^{-G})^{k-1}$$

- Expected Number of transmissions per frame is:

$$E = \sum_{k=1}^{\infty} kP_k = \sum_{k=1}^{\infty} ke^{-G}(1 - e^{-G})^{k-1} = e^{G}$$

- A small increase in channel load, G can results in exponentially increase in transmissions (most of which cause collisions) resulting:
  - Reduced system throughput (S)
  - Longer queues in MAC layer for accumulated, waiting frames.
  - Increase in average frame delay

ALOHA Delay Analysis

- Frame transmission duration: X
- Frame propagation time: t_{prop}
- Average back-off time: B
- Average number of transmission attempts per frame: $G/S=e^{2G}$
- Average number of unsuccessful attempts per frame: $\varepsilon=G/S\text{-}1=e^{2G}\text{-}1$
- Successful transmission requires $X+t_{prop}$ seconds and each re-transmission requires $2t_{prop}+X+B$ seconds
- Therefore, average MAC delay in ALOHA is given by: $E[T_{ALOHA}]=X+t_{prop}+(e^{2G}-1)(X+2t_{prop}+B)$
- Normally, backoff time is uniformly distributed between 1 and K packet transmission times and therefore, $B=(K+1)X/2$

MAC Layer trade offs

- **Normalized Transfer Delay** (NTD):

$$\text{NTD} = \frac{E[T] \rightarrow (\text{Average Transfer Delay})}{E[X] \rightarrow (\text{Average Frame Transmission Time})}$$

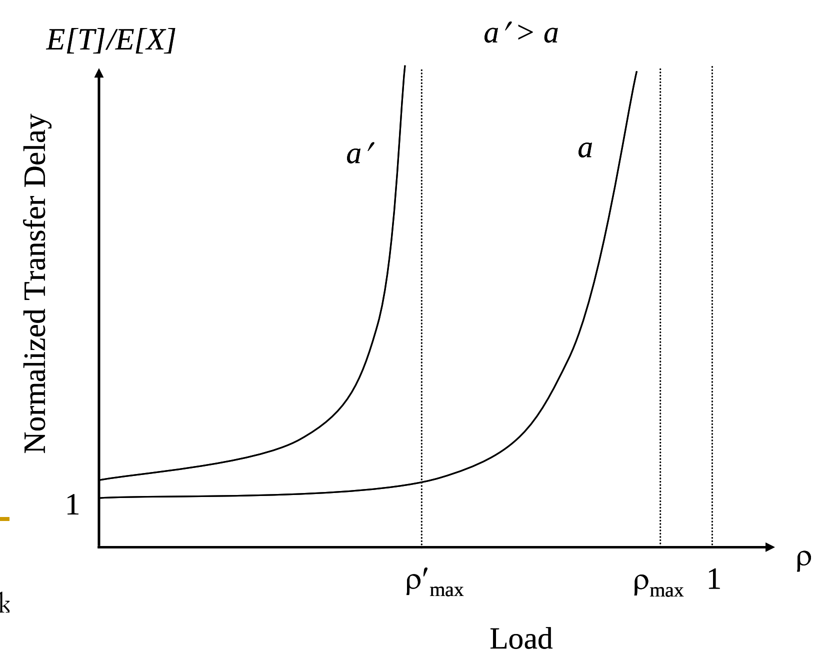
  - A measure of delay caused by access control algorithm (Collisions, reservations, etc).
- **Normalized Delay Bandwidth** (a):

$$a = \frac{\text{One way delay} \times \text{Bandwidth}}{\text{Average Frame Size}}$$

  - Number of lost frames due to a collision is proportional to *a*
  - Example: 1000 bit frames, 2 Mbps channel, 40 msec. one-way delay $\Rightarrow$

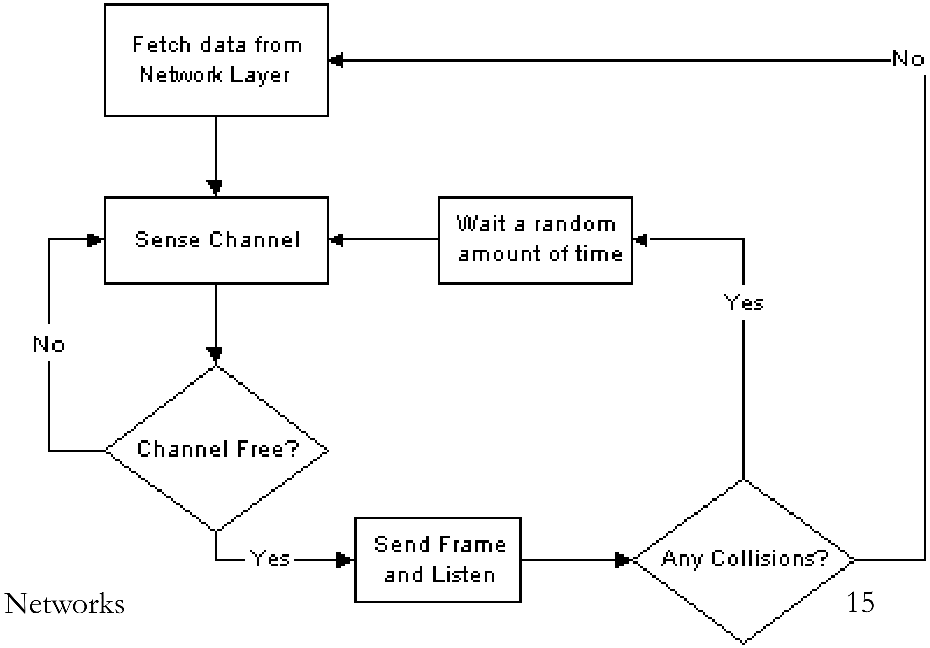
$$a = \frac{2 \times 10^6 \times 40 \times 10^{-3}}{1000} = 80$$

- For ALOHA type MACs, the trend is:
  - When Load is low, NTD is near 1. NTD increases steadily as load is increased.
  - Maximum achievable load is usually much less than 1.
  - Maximum achievable load decreases when *a* is increased ($\Rightarrow$ Cost of MAC is higher for long distance or high speed links)



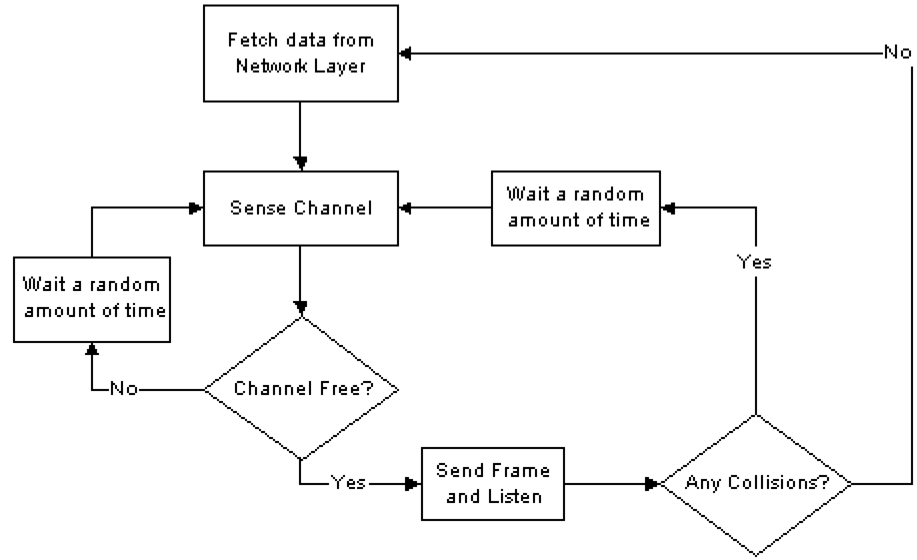
Carrier Sense Multiple Access Protocols (CSMA)

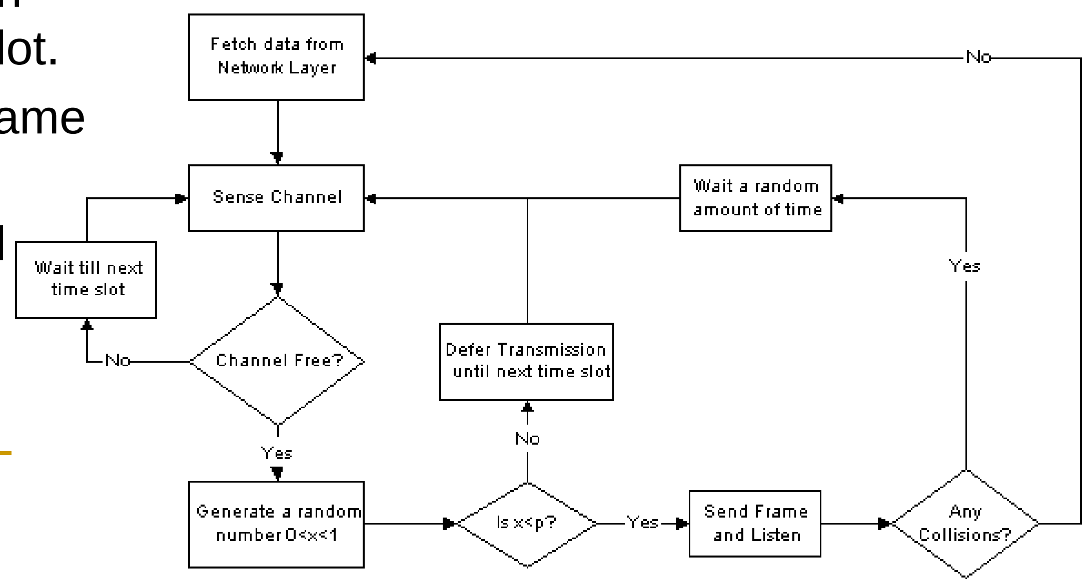
- Idea: The number of collisions can be reduced by sensing the carrier before transmission
- *1-persistent*
  - Listen to channel and transmit as soon as channel becomes idle
  - If collision, wait random time, and try again
  - This approach is too greedy (*name 1-persistent: if idle transmit with p=1*)
  - Note: Long propagation delays must be avoided (if not, a greater chance exist that, even after one station starts transmission, another one senses idle, and starts as well)



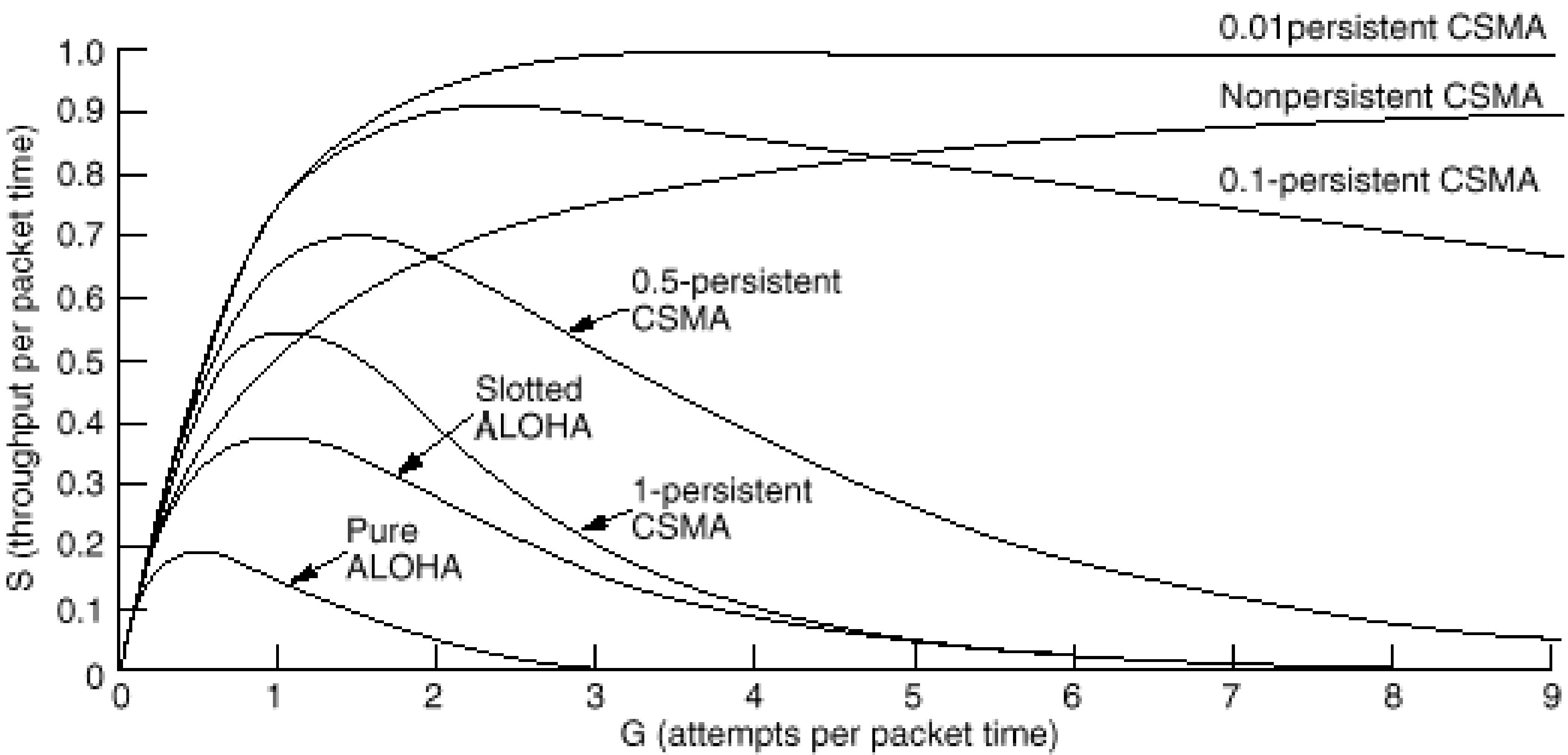
Carrier Sense Multiple Access Protocols

- *Non-persistent*:
  - Sense channel; if idle, transmit If not idle, wait a random period before sensing the channel
  - Better utilisation, however, longer delays
- *P-persistent:*
  - Sense channel, if idle, transmit with probability p, defer With probability 1-p to the next slot.
  - If next slot idle repeat the same algorithm
  - If busy the first time, wait till next time slot and try again



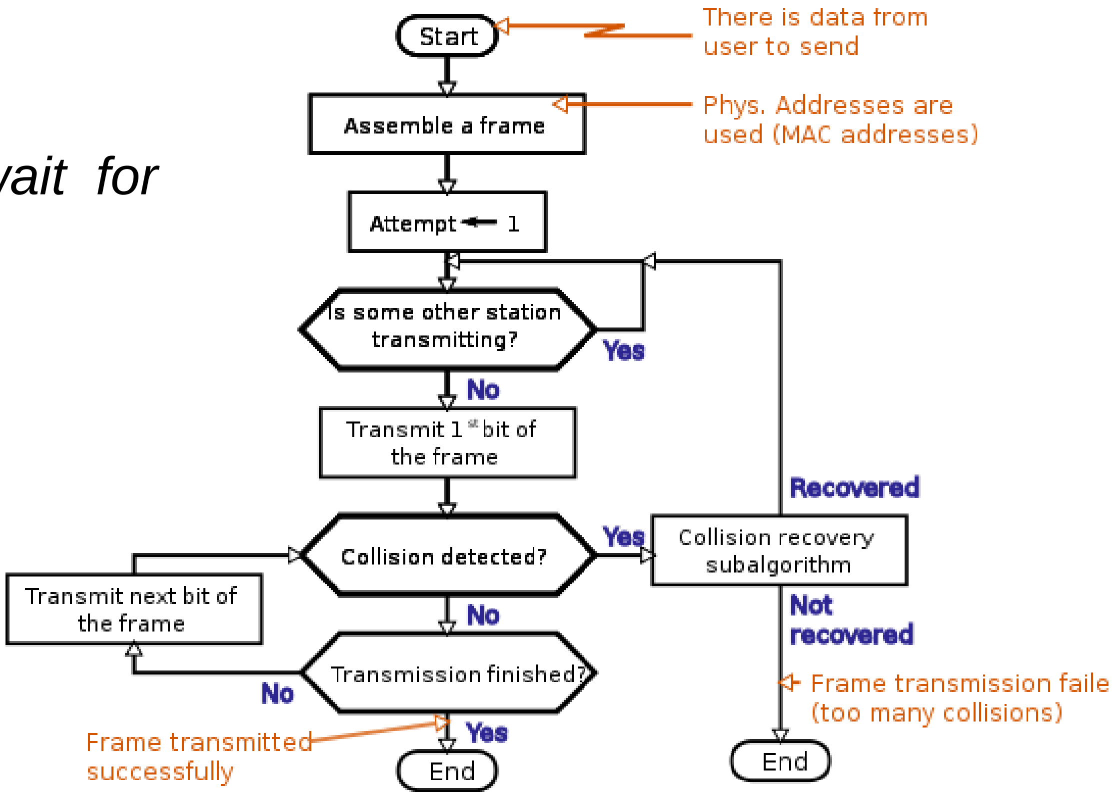


Throughput of ALOHA and CSMA



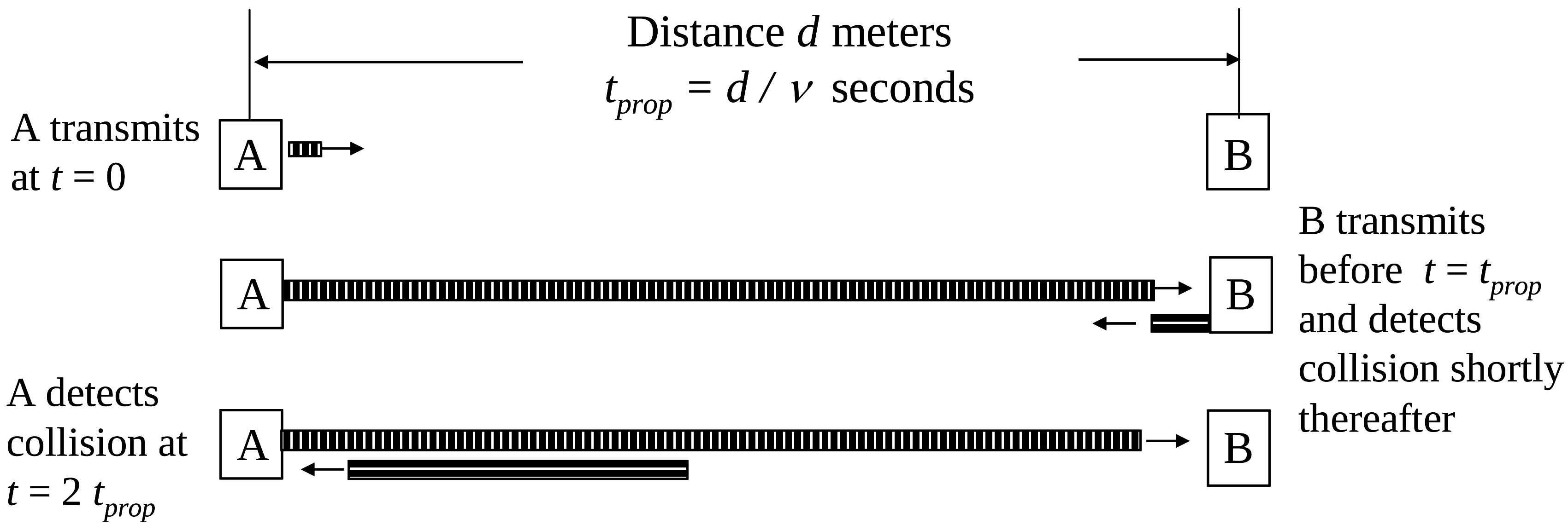
CSMA with Collision Detection

- Widely used on LANs in MAC sublayer (IEEE 802.3; Ethernet)
- Idea: *stop directly after detecting collision and wait for a random period*



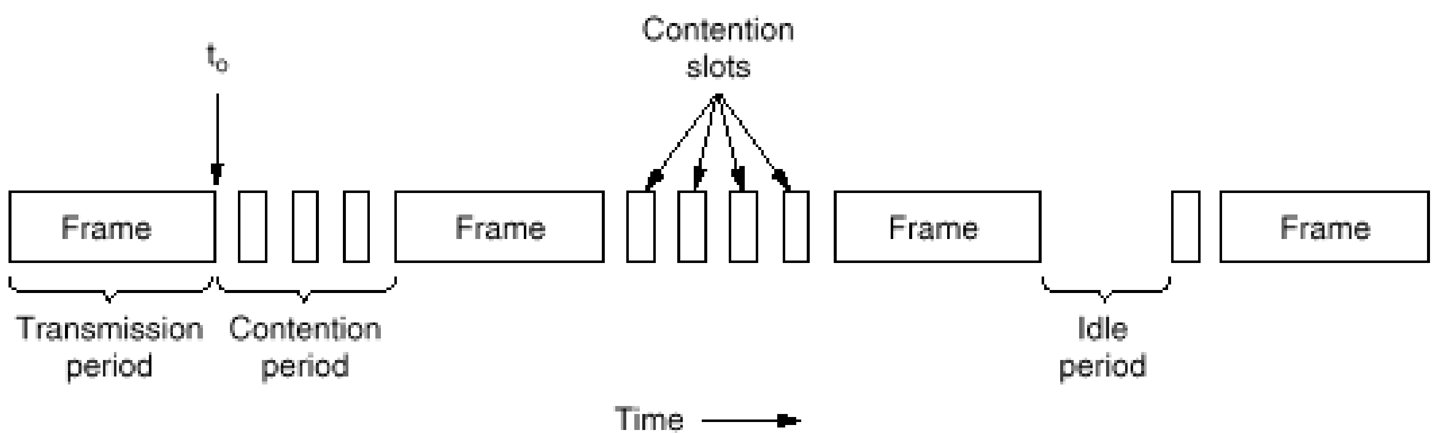
CSMA with Collision Detection

- How long does it take to detect collision?
  - Assuming a max travel time of t_{prop}, it takes $2t_{prop}$ to be sure (contention period) (10 μsec on 1 km cable)



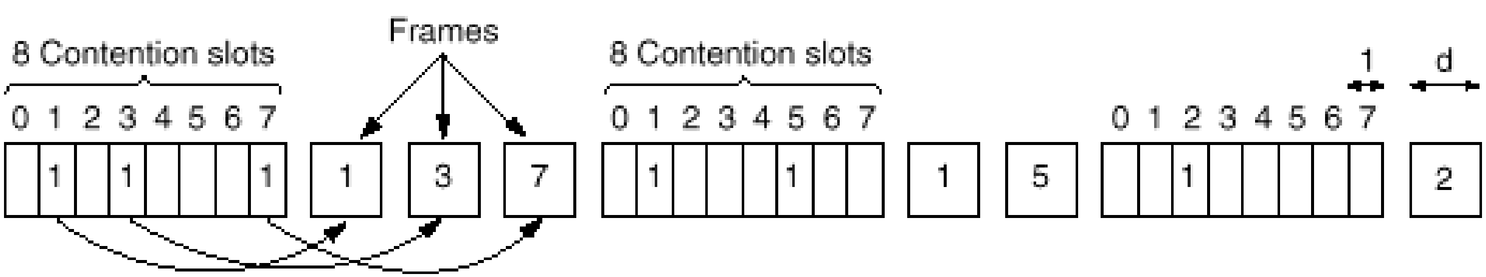
CSMA with Collision Detection

- Although CSMA/CD avoids collisions once a station has seized the channel; collisions still occurs during the contention period
- Contention period may become large for long (fibre) cables
- Solution: Try avoiding all collisions !



Collision Free Protocols

- Bit-Map protocol (reserve bandwidth)
  - In contention period each station broadcasts if it has a frame to send
  - Efficiency of d/(d+N) for low load and d/(d+1) for high load
  - Can be further optimized by allowing reservation for multiple slots. Efficiency approaches 1.

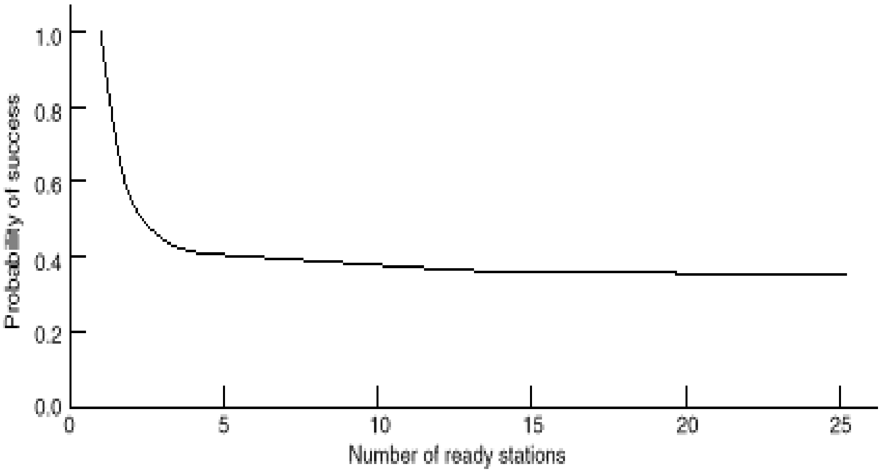


Limited Contention Protocols

- So far:
  - Contention protocols: low delay at low load
  - Collision-free protocols: high channel utilization at high load
  - Let's combine good properties of both using adaptive algorithms
- Consider k stations; each has probability *p* of transmitting a frame in a certain slot.
- Probability that some station acquires the channel and its optimal value:

$$P_r = kp(1-p)^{k-1} \Rightarrow p_{optimal} = \frac{1}{k} \Rightarrow P_{r,optimal} = \left(1 - \frac{1}{k}\right)^{k-1}$$

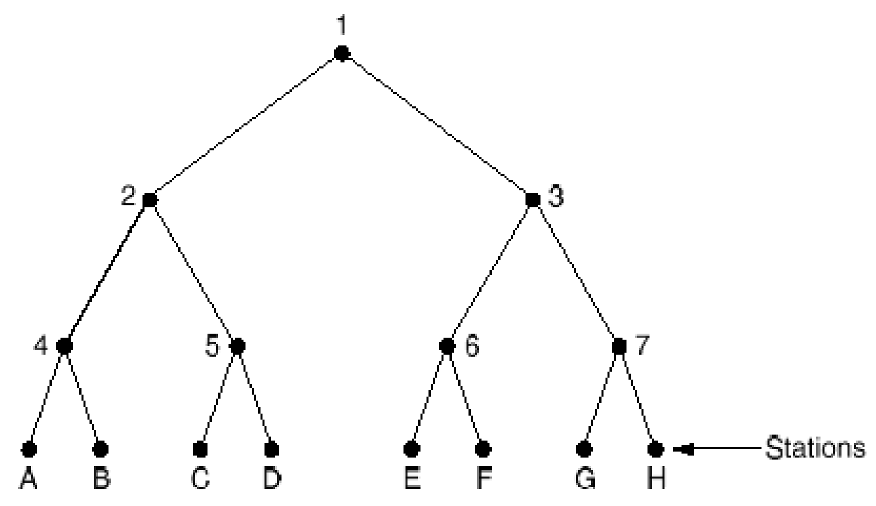
- Lesson: Reduce the number of competing stations, k



Adaptive Tree Walk Protocol

- How to assign stations to slots?
- Dynamic assignment:
  - Many stations may try per slot if load low
  - Few stations may try per slot if load is high
- Adaptive tree walk protocol: a depth-first traversal of a tree:
  - In slot 0 all stations may try
  - If collision, all stations under node 2 may try in slot 1
  - Three cases
    - one station succeeds: give next frame slot to node 3 stations
    - collision: continue with node 4 during slot 2
    - no one sends: continue with node 6 !!

- Example
  - Assume only G & H have a load
  - Collision in slot 0 at node 1
  - Node 2 is tried at slot 1 and discovered idle
  - No point in trying Node 3. Try Node 6 instead
  - If Node 6 is idle, again, no point in trying 7. Try G and H.

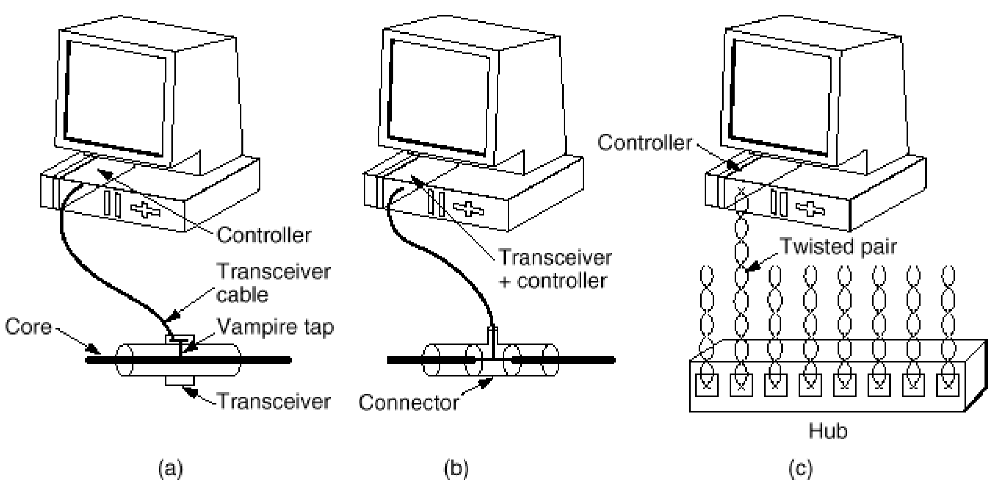


IEEE 802 standards

- IEEE 802 refers to a family of IEEE standards dealing with local area networks and metropolitan area networks:
  - IEEE 802: Overview & Architecture
  - IEEE 802.1 Bridging & Management
  - IEEE 802.2: Logical Link Control
  - IEEE 802.3: CSMA/CD Access Method (Ethernet)
  - IEEE 802.5: Token Ring Access Method
  - IEEE 802.11: Wireless Local Area Networks (LAN)
  - IEEE 802.15: Wireless Personal Area Networks (PAN)
  - IEEE 802.16: Broadband Wireless Metropolitan Area Networks (MAN)
  - IEEE 802.17: Resilient Packet Rings (RPR)
  - IEEE 802.20: Mobile Broadband Wireless Access
  - IEEE 802.21: Media Independent Handoff
  - IEEE 802.22: Wireless Regional Area Network
  - IEEE 802.23: Emergency Services Working Group

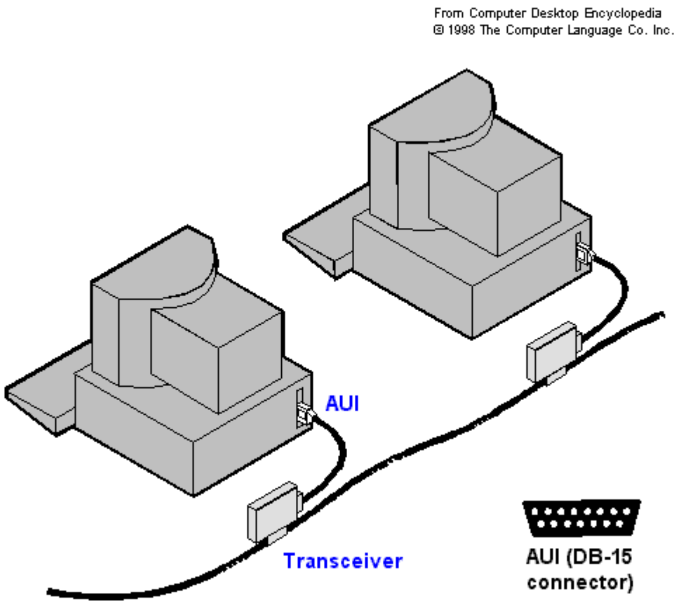
IEEE standard 802 for LANs

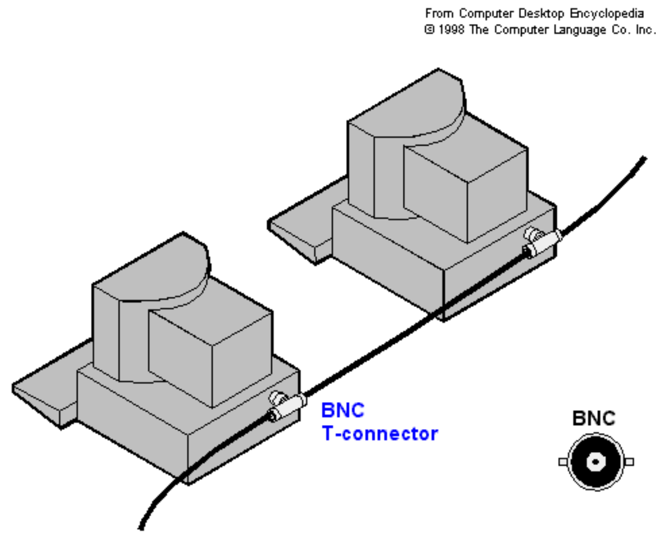
- 802.3 Ethernet
  - Whole family of 1-persistent CSMA/CD protocols
  - Original design for 1-10 Mbps
  - Various media, first used on 50 ohm coaxial cable
  - Started as ALOHA system on Hawaiian Islands
  - Carrier sensing was added by Xerox

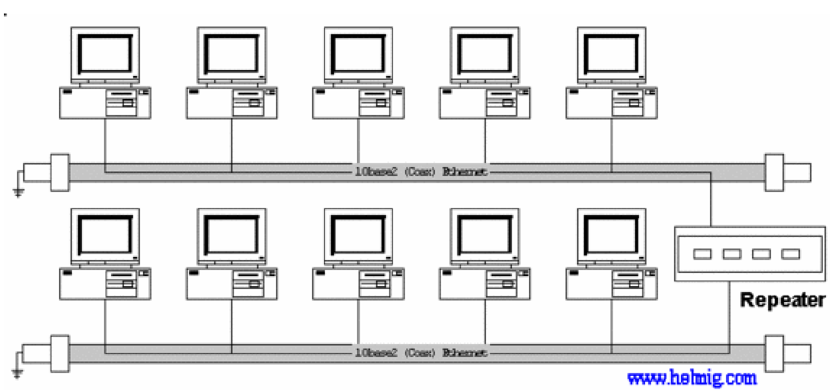


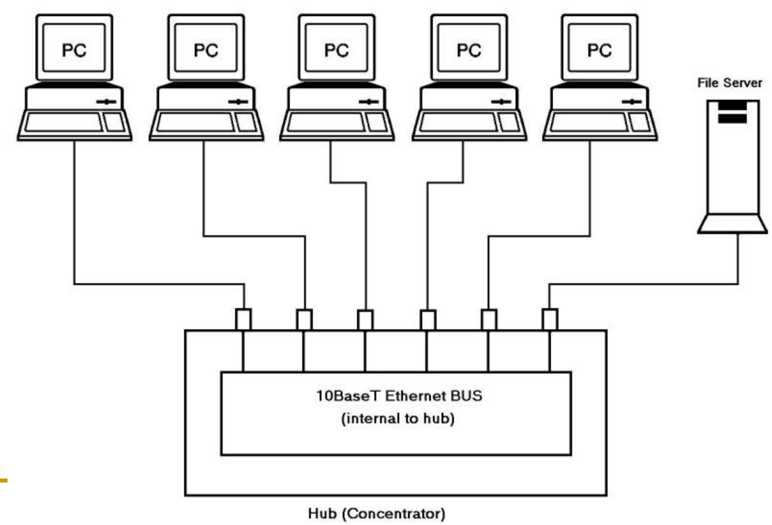
Name	Cable	Max. segment	Nodes/seg.	Advantages
10Base5	Thick coax	500 m	100	Good for backbones
10Base2	Thin coax	200 m	30	Cheapest system
10Base-T	Twisted pair	100 m	1024	Easy maintenance
10Base-F	Fiber optics	2000 m	1024	Best between buildings

Ethernet Topology





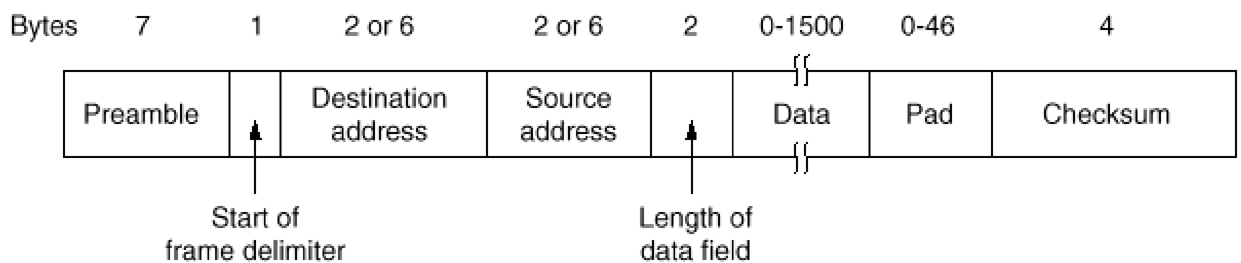


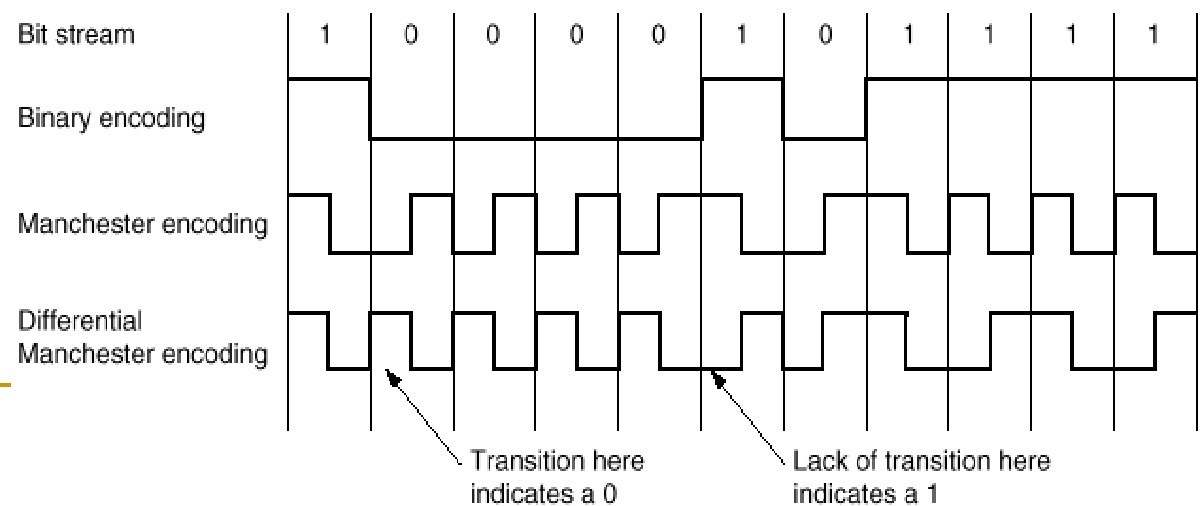


802.3 LAN Standard

- 802.3 Encoding
  - Needed: unambiguously determine start, end and middle of each bit without reference to external clock
- Two encoding techniques
- Manchester encoding
  - 1: 1-0 transition
  - 0: 0-1 transition
  - Every bit has transition in the middle. However, twice the bandwidth capacity needed !
- Differential encoding
- 802.3 uses Manchester, +/- 0.85 volt signalling

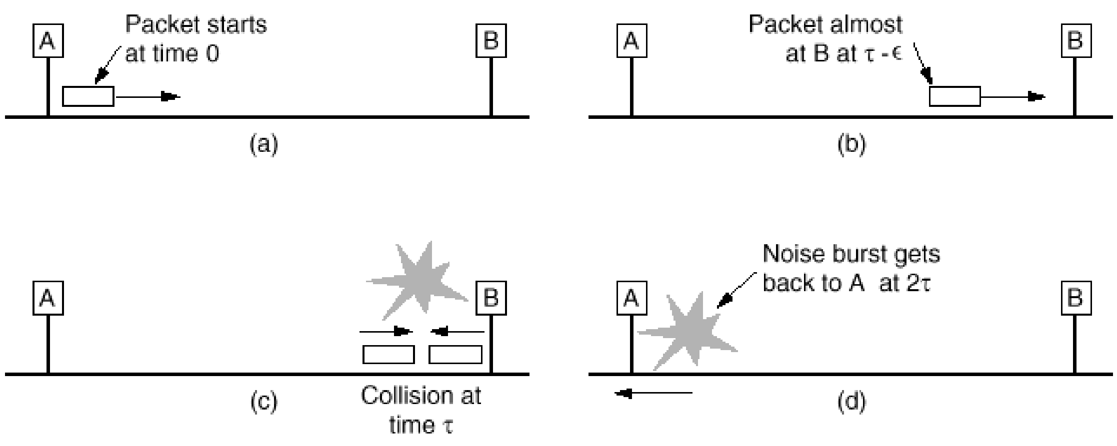
- 802.3 Framing
  - Preamble: 7 x 1010.1010 pattern
  - creates 10 MHz square wave of 5.6 microsecond for synchronization
  - Start field: 1010.1011 denotes start of frame





802.3 Framing

- Length field: 0-1500 bytes
- Data: payload
- Pad: ensure minimum frame length = 64 bytes. needed for collision detection (LAN, 2500 meter, 10 Mbps, 4 repeaters: 51.2 microseconds minimum frame length => 64 bytes)
- Jam Signal: When a collision is detected during a frame transmission, the transmission is not terminated immediately. A station noting a collision has occurred sends a 4 to 6 byte long pattern composed of 16 1-0 bit combinations.
- The purpose of this is to ensure that any other nodes which may currently be receiving a frame will receive the jam signal in place of the correct 32-bit MAC CRC, this causes the other receivers to discard the frame due to a CRC error



802.3 LAN Standard

- 802.3 Addressing
  - Addressing: 6 bytes addresses that are assigned by IEEE
  - Bit 47 46 45…0 type of address
    - 0 0 ordinary local
    - 0 1 ordinary global
    - 1 0 group local
    - 1 1 group global
    - 1 1 1…..1 broadcast
- Binary Exponential Back off
  - After collision wait 0 or more slots (of 51.2 msec)
  - First collision: wait 0 or 1 slot (choose randomly)
  - Second collision: wait 0, 1, 2 or 3 slots
  - N-th collision: wait 0 - 2^{N-1} slots
  - N max = 10 => wait between 0 - 1023 slots
  - Give up after 16 trials and leave recovery to higher layers
- Algorithm ensures low latency at low load and fairly resolves collisions when the load is high.

802.3 Performance Analysis

- Assume constant transmission probability p (no exp back off)
- Probability A of acquiring a slot (by one of k stations):

$$A = kp(1-p)^{k-1}$$

- Probability that contention interval, W, has precisely j slots:

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

- Therefore, the average #slots per contention is given by

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

- Each slot has a duration interval 2τ
- Mean contention interval is $W = 2\tau/A$
- p optimal (= 1/k) $\Rightarrow$ A = $(1\text{-}1/k)^{k\text{-}1}$ =1/e (for k $\rightarrow\infty$ heavy load) $\Rightarrow$ $W=2\tau e=5.4\tau$

802.3 Standard

- Channel Utilization
  - Assume each frame takes T seconds to be transmitted.
  - When many stations have frames to send

$$U = \frac{T}{T + 2\tau / A} = \frac{1}{1 + 2BLe / cF}$$

  - F=frame length,
  - L =cable length,
  - B=network rate,
  - c= propagation speed,
  - e=contention slots per frame
  - (Note: τ=L/c and T=F/B)

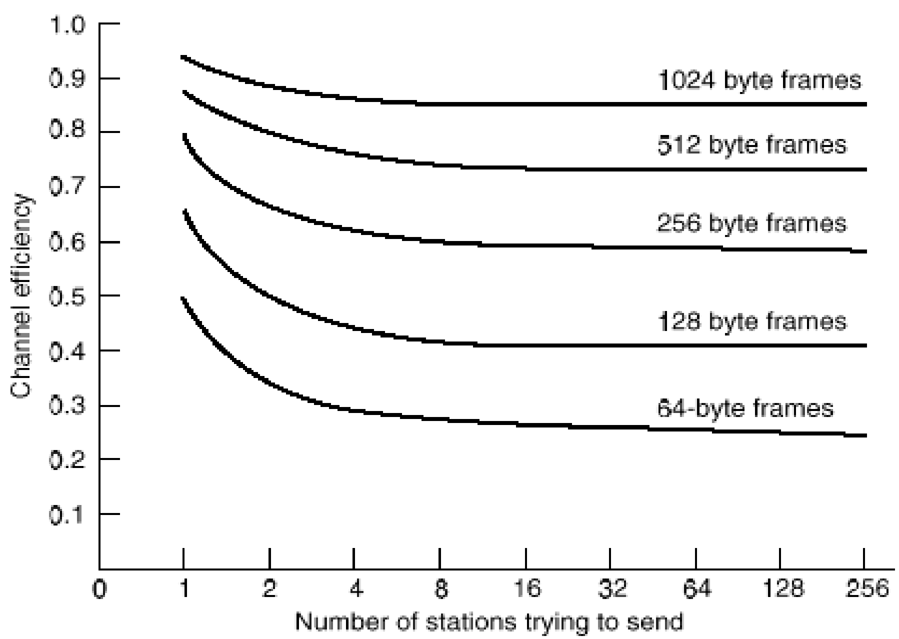
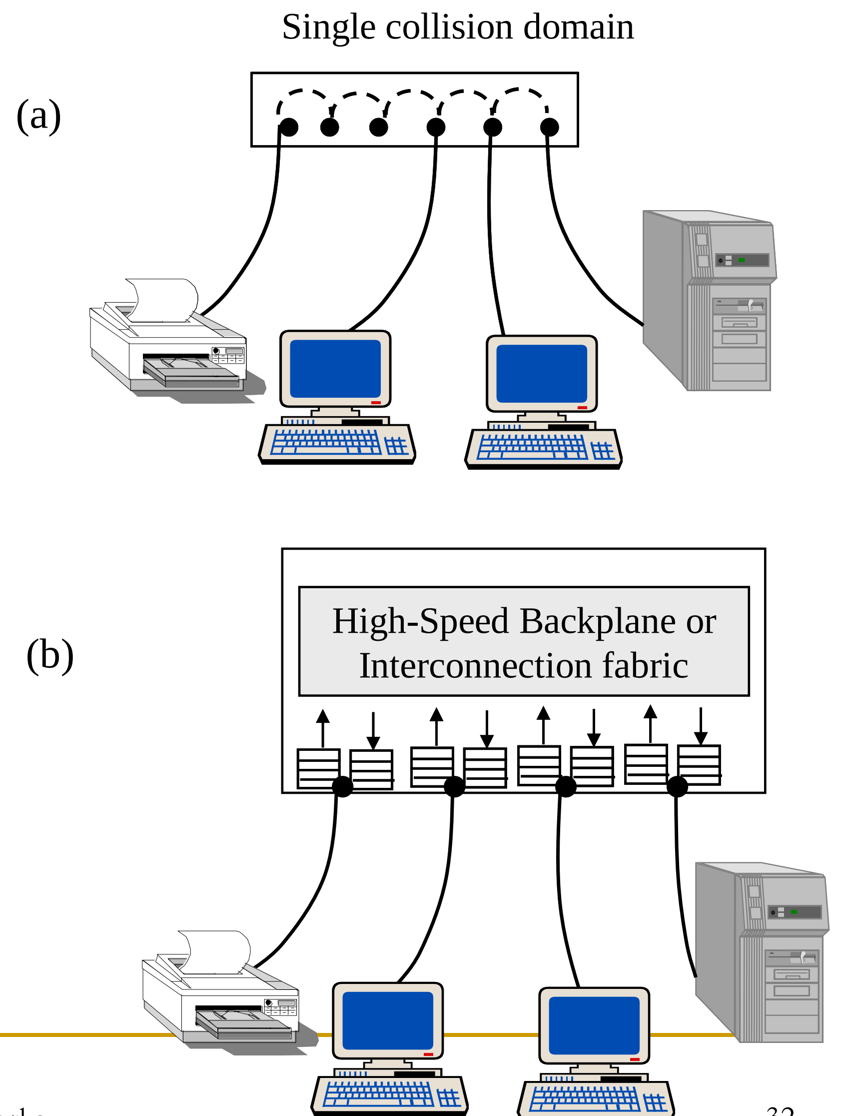


Fig. 4-23. Efficiency of 802.3 at 10 Mbps with 512-bit slot times.

Switched Ethernet

- To improve the performance of the system, a switch can be used
- Each port of the system receives the frame of only one sender.
- Therefore, it can buffer them and send them to the destination port while minimizing the probability of a collision.
- Appropriate buffer management, high speed packet processing and high speed backplane design are key to the successful design of a switch
- Switch improves the performance because:
  - There are no collisions and capacity is used more efficiently
  - Multiple frames can be sent through a switch simultaneously.

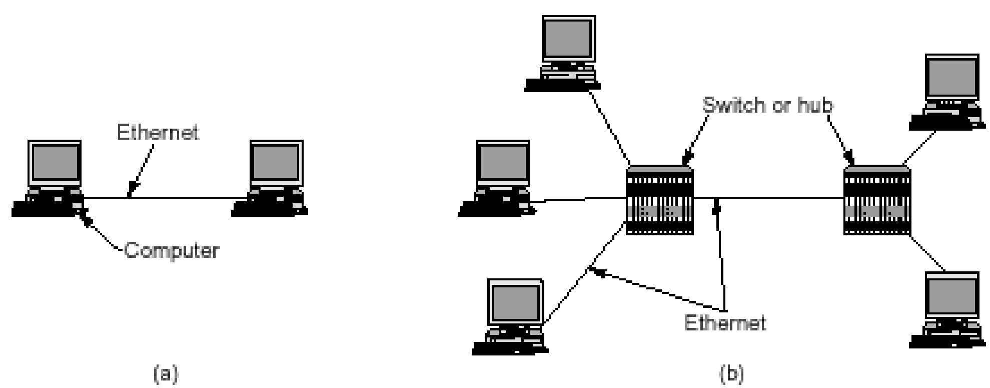


Fast Ethernet

- IEEE adopted the 802.3u standard for Fast Ethernet in 2005
- Transmission speed increased from 10 Mbps to 100 Mbps
- Maintained the same principles of operation with modified physical layer cabling system (No multi-drop cables)
  - 100 BaseT4: Operates in half duplex mode. Uses four pairs of UTP3 wires. One from hub, one to hub and the other two are switchable depending on current transmission direction.
  - 100 BaseTX: Operates in full duplex mode. Uses two UTP5 wires, one for transmission and one for reception. 4B/5B encoding at 125 MHz clock to send 100 Mbps.
  - 100BaseFX: Operates in full duplex mode. Uses two strands of multimode fibers to transmit and receive 100 Mbps in each directions up to 2km.
- Two modes of operation
  - HUB Mode: a hub is a single collision domain. CSMA/CD is used
  - Switched Mode: frames are buffered and switched in the hub/switch. No CSMA/CD. (100BaseFx works only in this mode)

Gigabit Ethernet

- Faster version of Ethernet supporting a gigabit per second transfer rate, named IEEE 802.3z.
- Designed to be frame-compatible with Classic Ethernet.
- Supports two modes of operation:
  - Full duplex: Send and receive independently. No contention
  - Half duplex: A Hub is used to connect the nodes. Collision is possible and CSMA/CD is used.
- To increase the supported cable length in half duplex mode while allowing proper collision detection:
  - Minimum frame size should be at least 512 bytes. Use padding for small frames to meet this requirement (carrier extension)
  - Allow a sender to transmit multiple frames in a single transmission to activate the channel for the duration of 512 bytes. (frame bursting)



Gigabit Ethernet

- Physical interfaces
  - Fiber based:
    - Uses 8B/10B coding instead of Manchester to help carrier recovery at receiver
    - 0.85 μ lasers on multimode fibers (Short range)
    - 1.3 μ lasers on single mode fibers (Long range)
  - Copper based
    - 2 pairs of STP (Not popular)
    - Four CAT5 cables together
- Flow control is required due to large speed variation between a Gigabit Ethernet and a normal Ethernet receiver
- Pause frames generated by Rx can pause Tx for a period specified in the frame.
- 8B/10B coding

Name	Cable	Max. segment	Advantages
1000Base-SX	Fiber optics	550 m	Multimode fiber (50, 62.5 microns)
1000Base-LX	Fiber optics	5000 m	Single (10 μ) or multimode (50, 62.5 μ)
1000Base-CX	2 Pairs of STP	25 m	Shielded twisted pair
1000Base-T	4 Pairs of UTP	100 m	Standard category 5 UTP

10-Gigabit Ethernet

- 10-Gigabit Ethernet is developed to support the requirements of high speed data transmission both in data centers as well as transmission backbone of wide area networks
- All versions of 10-Gigabit Ethernet support only full duplex operation and CSMA/CD is no longer used.
- Supports Fiber optic as well as copper media
- Can extend the transmission range to 40 km using single mode fiber optic

Name	Cable	Max. segment	Advantages
10GBase-SR	Fiber optics	Up to 300 m	Multimode fiber (0.85μ)
10GBase-LR	Fiber optics	10 km	Single-mode fiber (1.3μ)
10GBase-ER	Fiber optics	40 km	Single-mode fiber (1.5μ)
10GBase-CX4	4 Pairs of twinax	15 m	Twinaxial copper
10GBase-T	4 Pairs of UTP	100 m	Category 6a UTP

802.5 LAN Standard (Token Ring)

- Based on physical ring connecting participating nodes
- A rotating "Token" specifies the transmitting node.
- Protocol steps:
  - Sender takes token and puts interface in ***'transmit mode'***
  - After sending final bit, token is regenerated (1 bit flip in header)
  - Sender removes incoming bits from ring; may check if they are not corrupted
  - One of the next stations can pick up the token
- Ring must be long enough (in bit times) to contain at least a complete token!
- Therefore, artificial delays may be inserted (specially when some stations are not connected)
- If one cable or system breaks down ring becomes unusable
- Solution: use wire center
- IEEE 802.5 Rate: 16 Mb/s, later extended to 100 Mbps

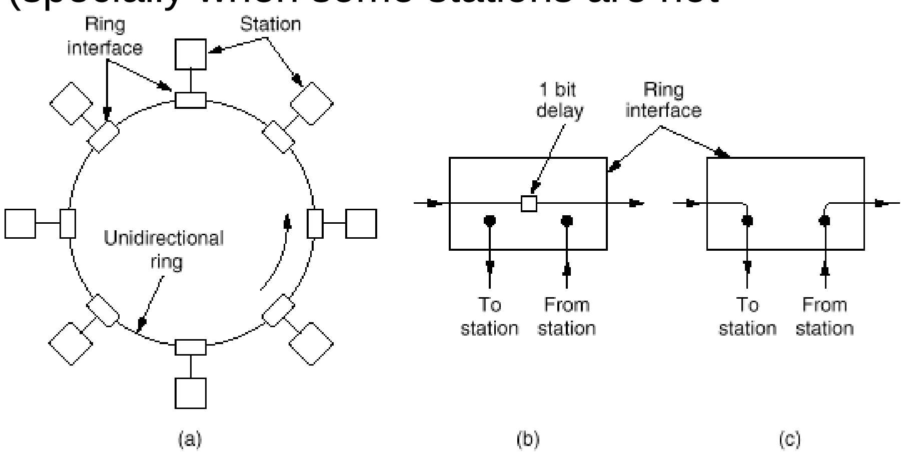
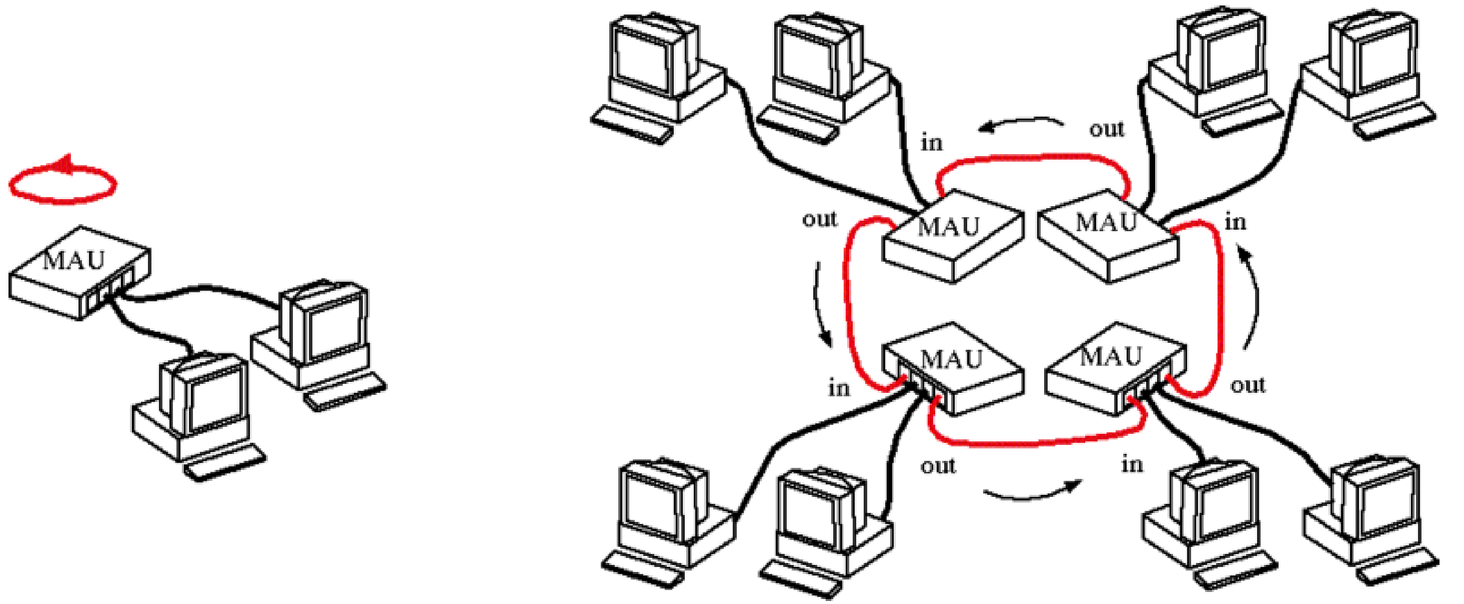


Fig. 4-28. (a) A ring network. (b) Listen mode. (c) Transmit mode.

802.5 LAN Standard (Token Ring)



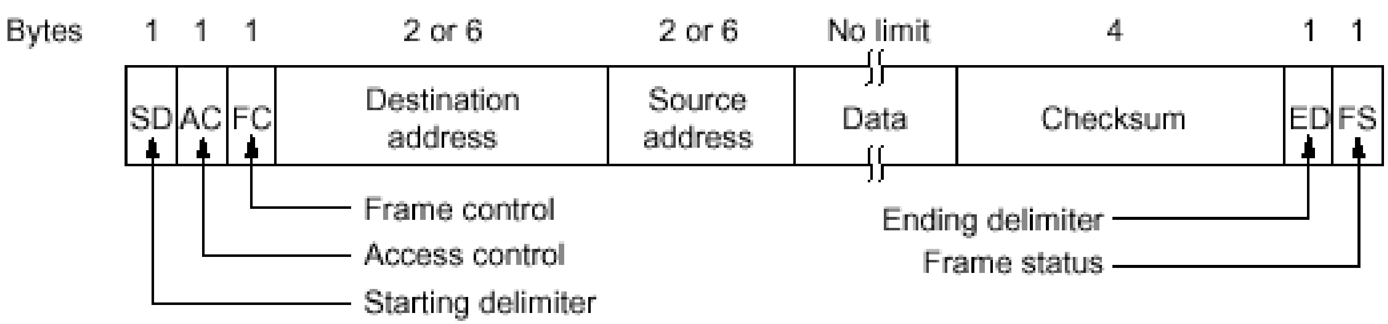
a) b)

MAU: Media Access Unit

Source: http://en.wikipedia.org/wiki/File:Token_ring.png

Token ring frame format

- Token is the first three bytes
- AC byte:
  - Token is reserved by reversing a bit in AC byte (Includes priority bit)
  - To send a frame with priority n, a free token with priority less than n should be seen
  - Priority can be reserved by using Reservation bit of this byte in a frame
  - Each station should reduce the priority to its original value after sending its frame
- Start and End delimiters contain invalid Manchester codes to mark start/end of the frames
- FC byte specifies frame type (Data or Control)
- Frame Status byte (FS):
  - Contains A and C bits for ACK
  - Sending station sets A=0, C=0
  - When the Tx drains the frame
    - If A=0, C=0 : destination not alive
    - If A=1, C=0 : destination present, but frame not accepted
    - If A=1, C=1 : destination present and frame was accepted



Logical Link Control: 802.2

- For some applications, an error-controlled, flow controlled connection is desired
- Data link layer for 802 protocols consists of two parts:
  - LLC logical link control
  - MAC multiple access control
- LLC implements the functionality as discussed in the data link layer section like:
  - Error control
  - Flow control
- LLC offers three services:
  - Unreliable datagram service
  - Acknowledged datagram service
  - Reliable connection-oriented service
- LLC header is based on the HDLC protocol

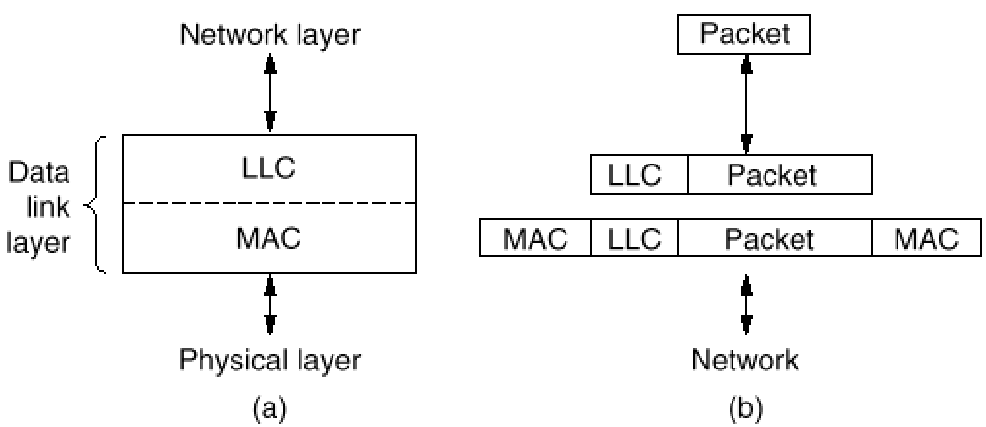
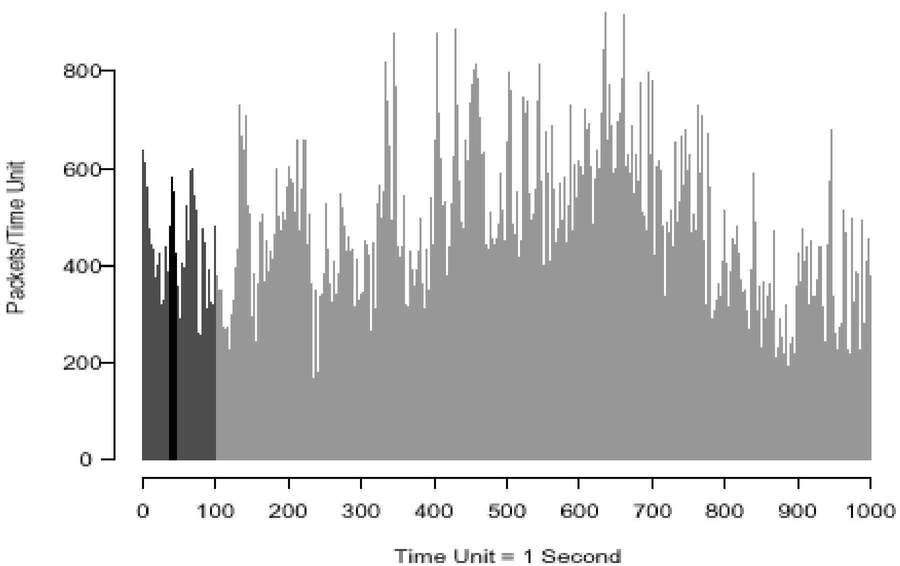


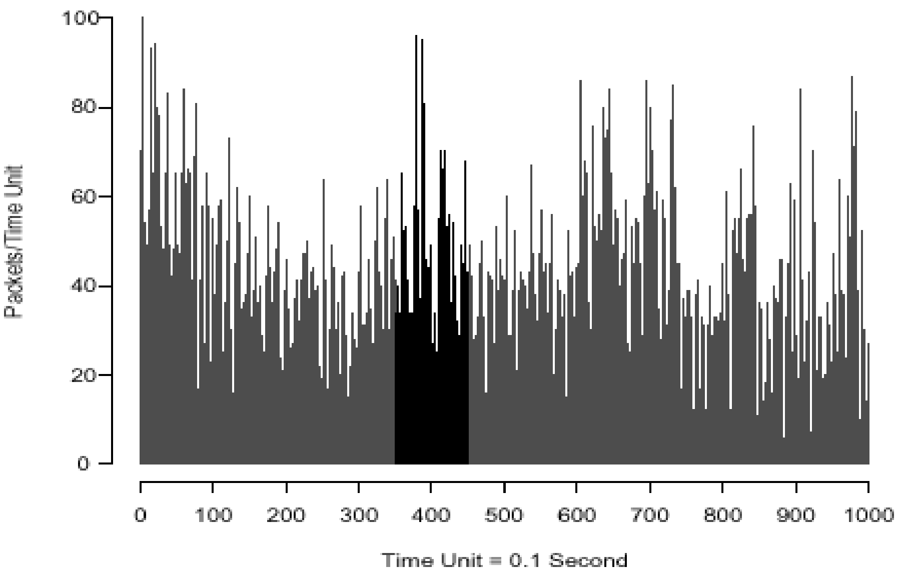
Fig. 4-33. (a) Position of LLC. (b) Protocol formats.

Self Similar Traffic

- Most traffic analysis studies of 802.3 have assumed a Poisson distribution for the load
- Real network traffic is self-similar, i.e. averaging over long time periods does not smooth out the traffic
- The average number of packets in each minute of an hour has as much variance as the average number of packets in each second of a minute

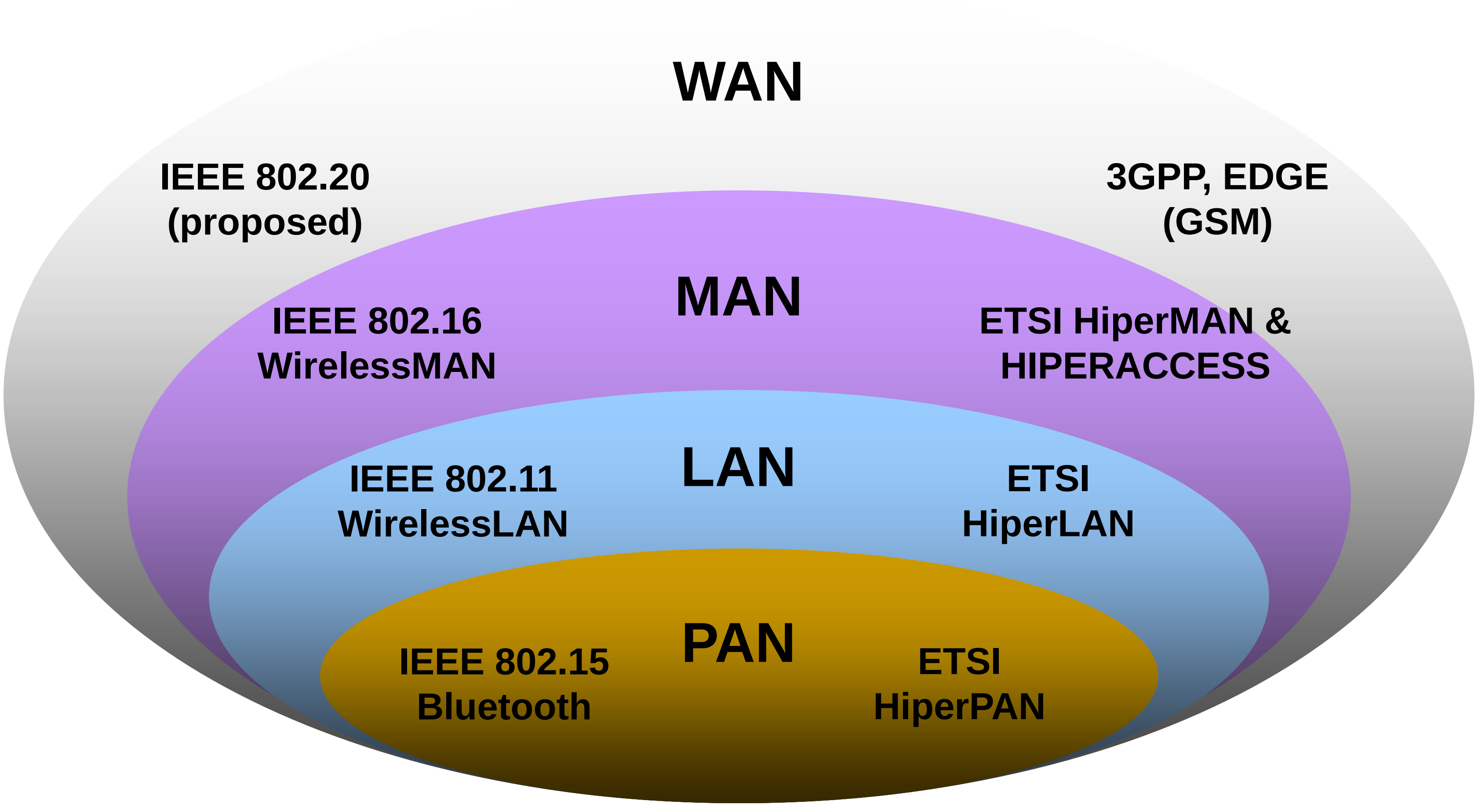


(c)



(d)

Global Wireless Standards



Wireless Platforms

Fixed

Licensed and Unlicensed
E1/ T1 & DSL level service

- **Enterprise / Backhaul** → **802.16 HiperMAN**
- **Residential access** → **802.16 HiperMAN**

Portable

Licensed and Unlicensed
Consumer DSL level service

- **Destination based** → **802.11 Hot Spots**
- **Nomadic** → **802.16e**

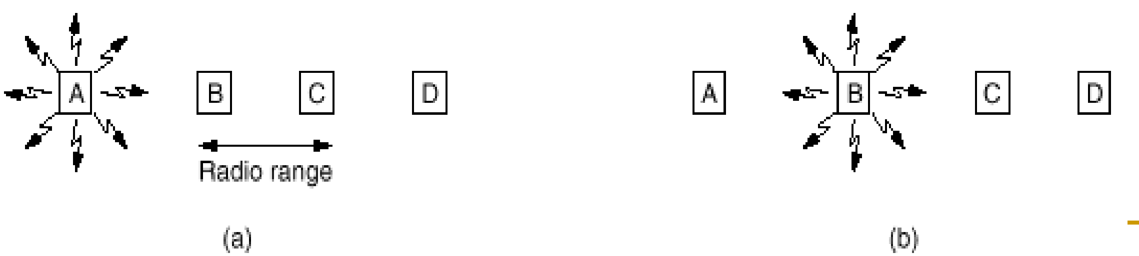
Mobile

Licensed
Wideband Data Rates

- **Cellular Wideband** → **2.5G, 3G**

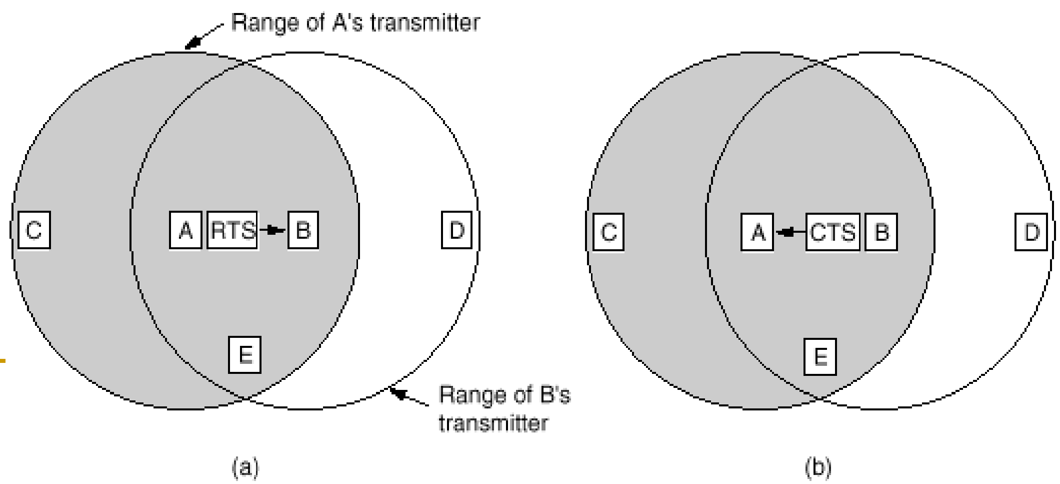
Wireless LAN Protocols

- Wireless protocols are *inherently multiple access* !
- Can we use ***sensing*** ?
  - What matters is collision at Rx
- Hidden station problem:
  - C can not sense A. If both target B, there will be a collision
- Exposed station problem:
  - B sends to A. C senses the medium and concludes that there is activity. So, it does not send to D. The link between C and D is not susceptible to the conversation of A and B.



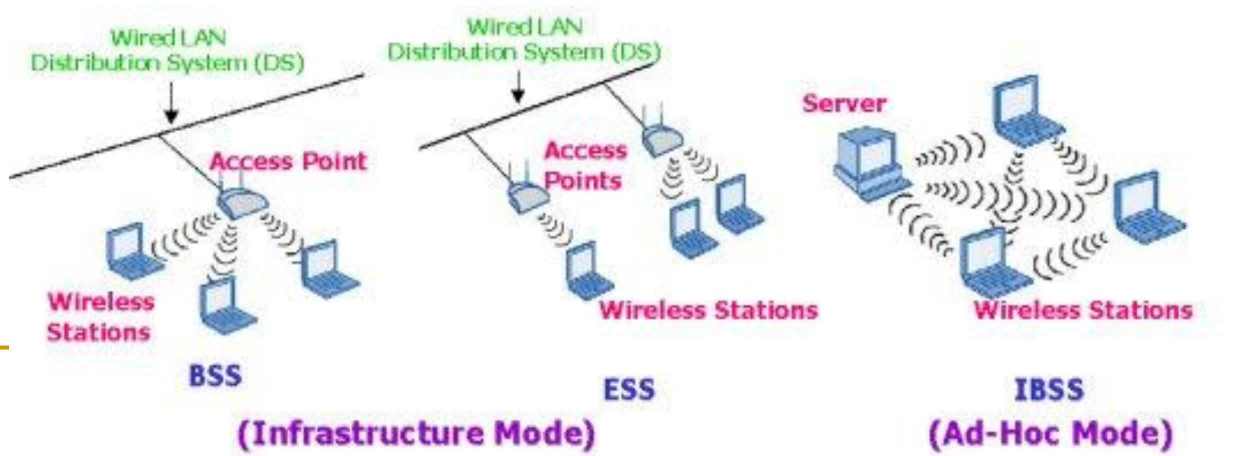
Wireless LAN Protocols

- MACA: ***Multiple Access with Collision Avoidance***
  - Sender: sends RTS (request to send)
  - Receiver: sends CTS (clear to send)
  - RTS and CTS contain length of message to be sent
- Key observations:
  - Any station hearing RTS must keep silent during the next phase of data transmission
  - Any station hearing CTS must keep silent during next message



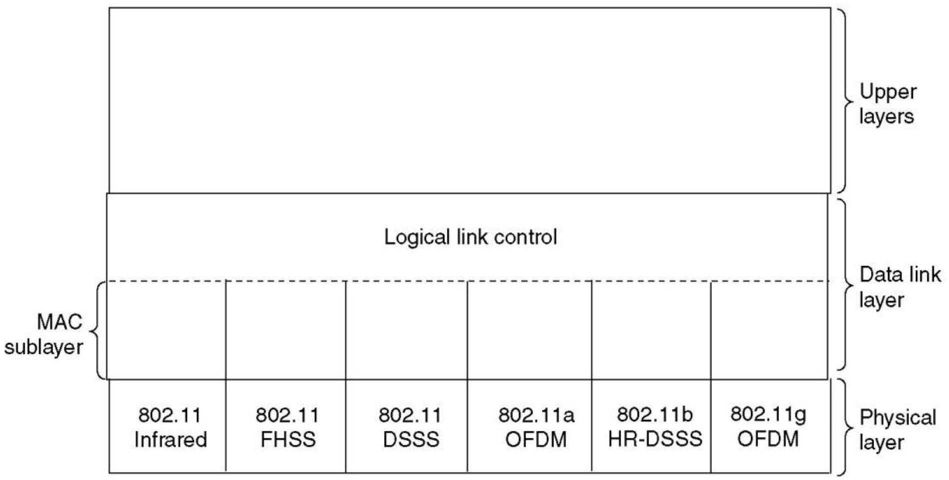
Wireless LANs

- Wireless LANs are becoming increasingly popular due to:
  - Ease of installation
  - Support of mobility
  - Easy connection to back-bone networks in places like airports, shopping centers, conference rooms, etc
- Key Architectures
  - Infrastructure Mode: Require Access Point/Base Station
  - Ad-Hoc Mode: On demand networking without infrastructure



Wireless LANs

- Several standards have been developed in the last decade
  - Legacy WLAN:
    - 802.11 Infrared
    - 802.11 FHSS
    - 802.11 DSSS
  - New Currently used WLAN:
    - 802.11a OFDM
    - 802.11b HR-DSSS
    - 802.11g OFDM



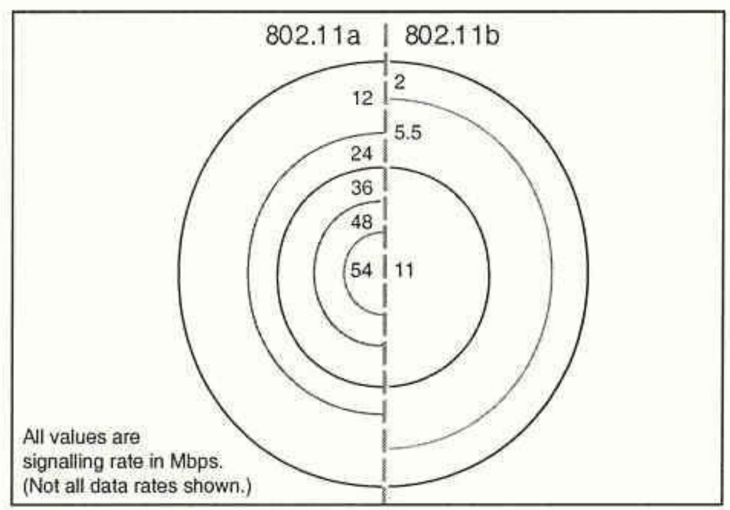
- One of the hottest areas of telecommunication
- The list of standards keeps growing every year!

IEEE 802.11 PHY Review

- 802.11 Infrared
  - Diffused infrared with rate of 1 or 2Mbps
  - Use pulse position modulation (PPM)
- 802.11 Frequency Hopping Spread Spectrum
  - 1 Mbps or 2 Mbps at 2.4 GHz ISM band
  - 79 channels of 1 MHz each
  - Pseudorandom code to determine hopping patterns (Initial seed determines the pattern)
- 802.11 Direct Sequence Spread Spectrum
  - 1 Mbps or 2 Mbps at 2.4 GHz ISM band
  - Uses Barker sequence with a spreading factor of 11

IEEE 802.11 PHY Review

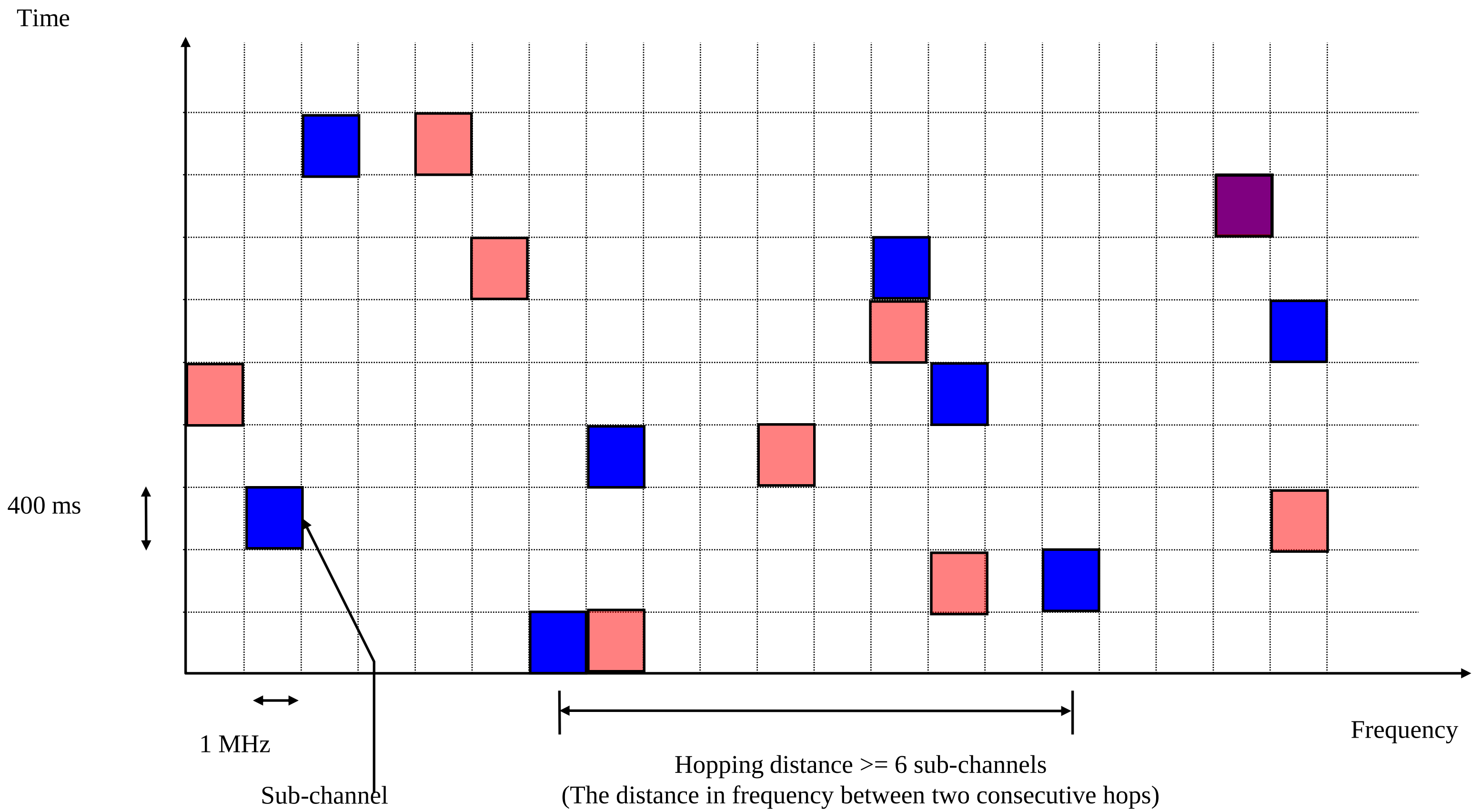
- 802.11a Orthogonal Frequency Division Multiplexing (OFDM)
  - Variable bit rates up to 54 Mbps
  - Uses 5 GHz ISM band
  - Much more immune to channel variations
  - Short range, mostly used for indoor LANs
- 802.11b High Rate Direct Sequence Spread Spectrum (HR-DSSS)
  - Variable bit rate up to 11 Mbps (1,2,5.5,11)
  - Uses 2.4 GHz ISM band
  - Longer range than 802.11a (Can be used for inter-office LAN connection)
- 802.11g (OFDM)
  - Variable bit rate up to 54 Mbps
  - Uses 2.4 GHz band
  - Higher speed



IEEE 802.11 Overview

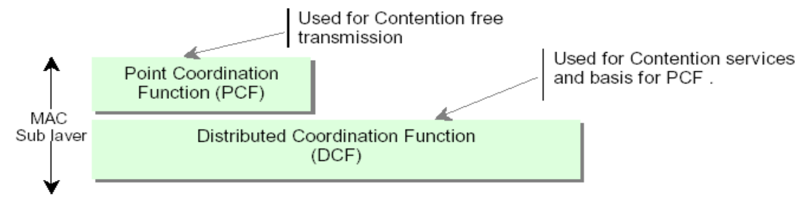
Protocol	Release Date	Op. Frequency	Data Rate (Typ)	Data Rate (Max)	Range (Indoor)
Legacy	1997	2.4 -2.5 GHz	1 Mbit/s	2 Mbit/s	~50 meters
802.11a	1999	5.15-5.35/5.47-5.725/5.725-5.875 GHz	25 Mbit/s	54 Mbit/s	~50 meters
802.11b	1999	2.4-2.5 GHz	6.5 Mbit/s	11 Mbit/s	~100 meters
802.11g	2003	2.4-2.5 GHz	25 Mbit/s	54 Mbit/s	~100 meters
802.11n	2007	2.4 GHz or 5 GHz bands	200 Mbit/s	540 Mbit/s	~250 meters

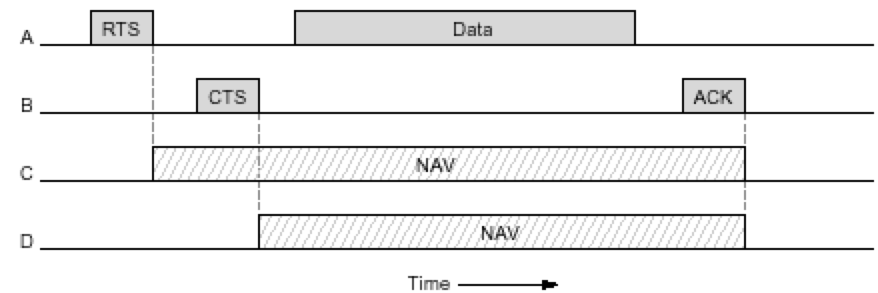
Frequency Hopping Spread Spectrum

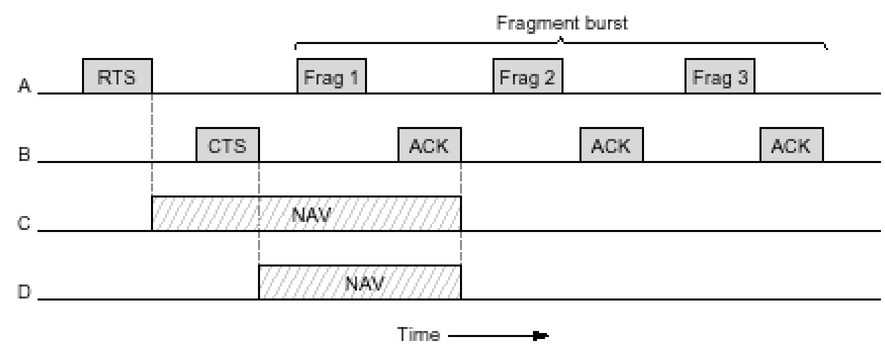


Overview of 802.11 MAC

- All 802.11 (a,b,g) networks use the same MAC
- MAC supports two modes of operation
  - Distributed Coordination Function: Used for Ad-Hoc connections
  - Point Coordination Function: Used for base station oriented networks
- DCF employs CSMA/Ca that has two access methods
  - Start transmitting as soon as channel is idle. If a collision, wait a random time (exponential back off) and try again
  - Use MACAW using RTC/CTS
    - Note: RTS and CTS contain data length thereby setting the waiting time (Not Available Vector) in other stations.
- A long frame has a much higher chance of error than a short frame
  - For BER=1e-4, Probability of frame error is more than 70% for a frame of length 12kbit.
- Once channel is acquired, a burst of short frames can also be sent to increase system throughput
- Uses Stop and Wait for each fragment





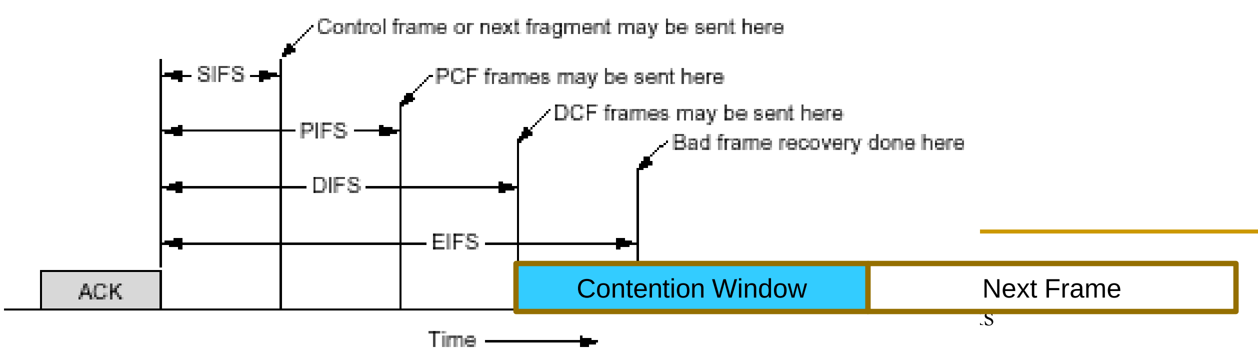


Overview of 802.11 MAC

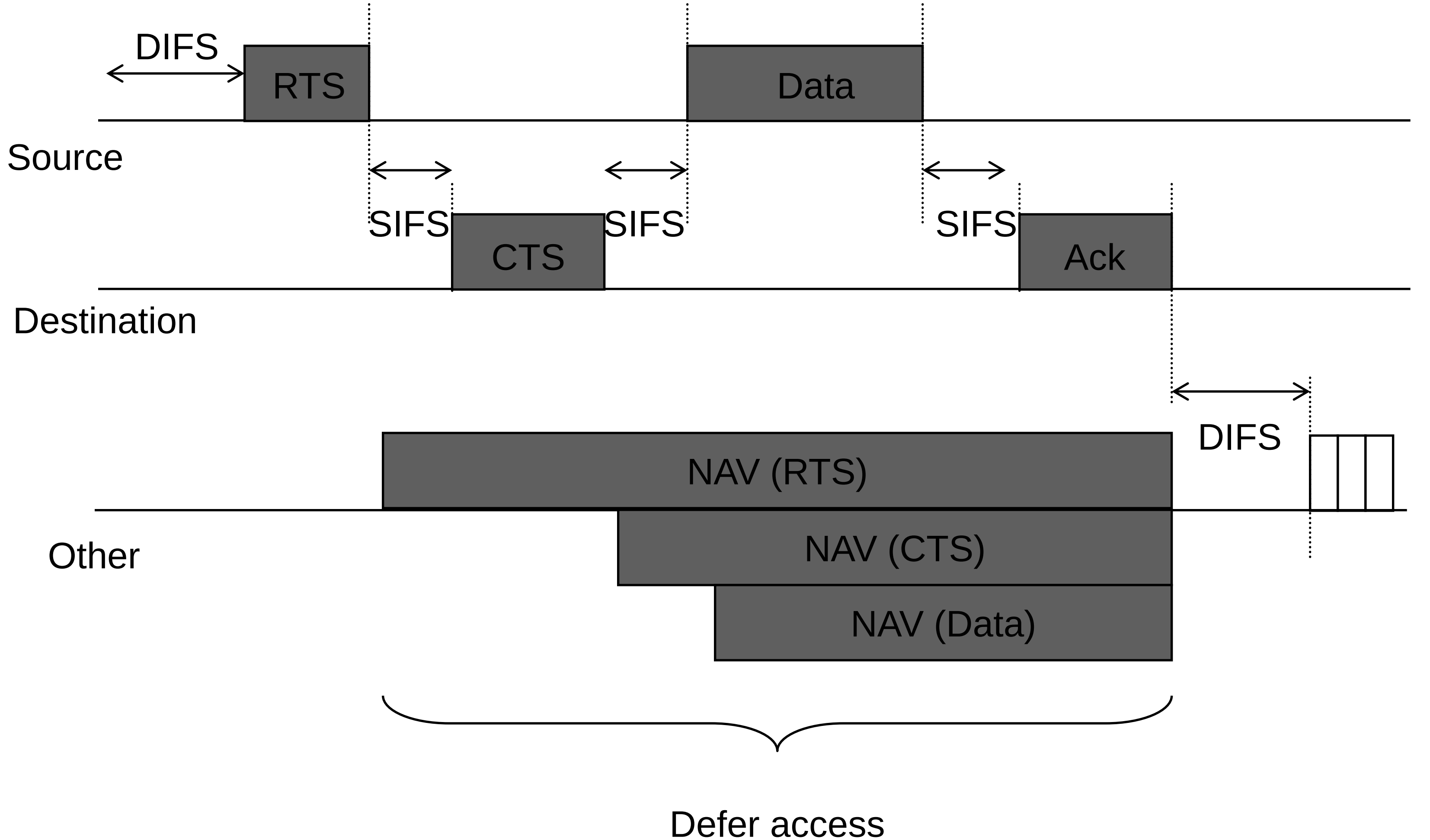
- PCF Mode:
  - Base station broadcasts a beacon frame that contains frequency hopping, synch and some other information periodically
  - Stations can sign up to the base for receiving services
  - Once base station registers a user, it will assign the necessary resources.
  - Base station can manage the activity of users by putting them in sleep mode to save battery power. It wakes them up when needed.

Overview of 802.11 MAC

- DCF and PCF modes can coexist in the same area.
- All stations should remain quiet for a certain period after a transmission has been completed (Inter Frame Space (IFS)) .
  - Short Interframe Spacing (SIFS):
    - High priority frames (ACK, CTS or fragment burst) only wait for SIFS duration
  - PCF Interframe Spacing (PIFS)
    - Base station can send beacon during this time
  - DCF Interframe spacing (DIFS)
    - If Base does not acquire the channel, any user can compete to get the channel at this time
  - Extended Interframe spacing
    - A station can report a bad frame during this time



Overview of 802.11 MAC



Overview of 802.11 MAC

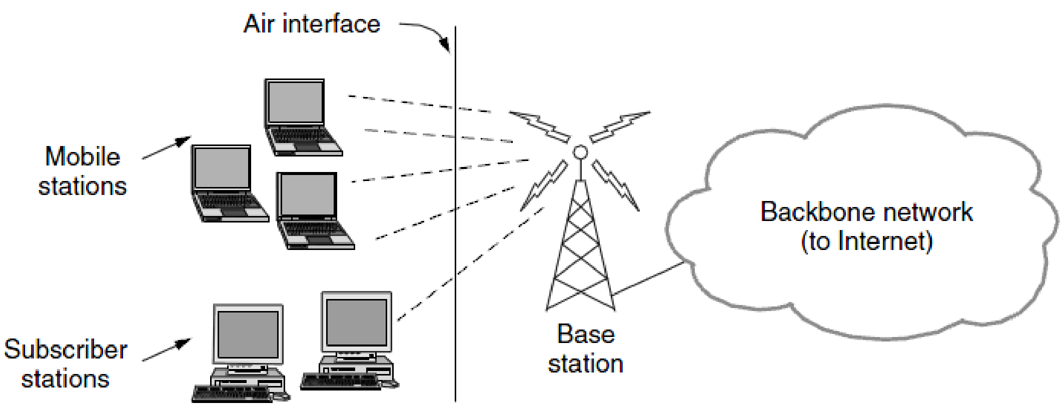
- A station can send if channel is idle for a period of DIFS or longer
- If medium is busy, node starts a random backoff timer
- Station is allowed to transmit when its backoff timer expires during a contention period
- If another station starts transmission during the contention period, the backoff timer is <u>suspended</u> and resumed next time a contention period takes place
- When a station has successfully completed a frame transmission and has another frame to send, the station must first execute the backoff procedure
- Waiting stations tend to have smaller remaining backoff time and can access channel sooner. Therefore, a degree of fairness is provided in the channel access process.

IEEE 802.11 services

- A wireless LAN can provide these services:
  - Distribution Services
    - Association: A mobile can connect to base station using this service.
    - Disassociation: Breaking the relationship between the base and mobile
    - Re-association: Change the preferred base station by moving from one cell to another cell
    - Distribution: A Service that determines how to route frames sent to a base
    - Integration: A service that handles the required translation of frame format for sending a packet to a non-802.11 format
  - Station services
    - Authentication: prove the identity of the mobile
    - De-authentication: cancel the approved identification of a user
    - Privacy: Encryption of messages sent over PHY
    - Data Delivery: Transmission of data from one node to another

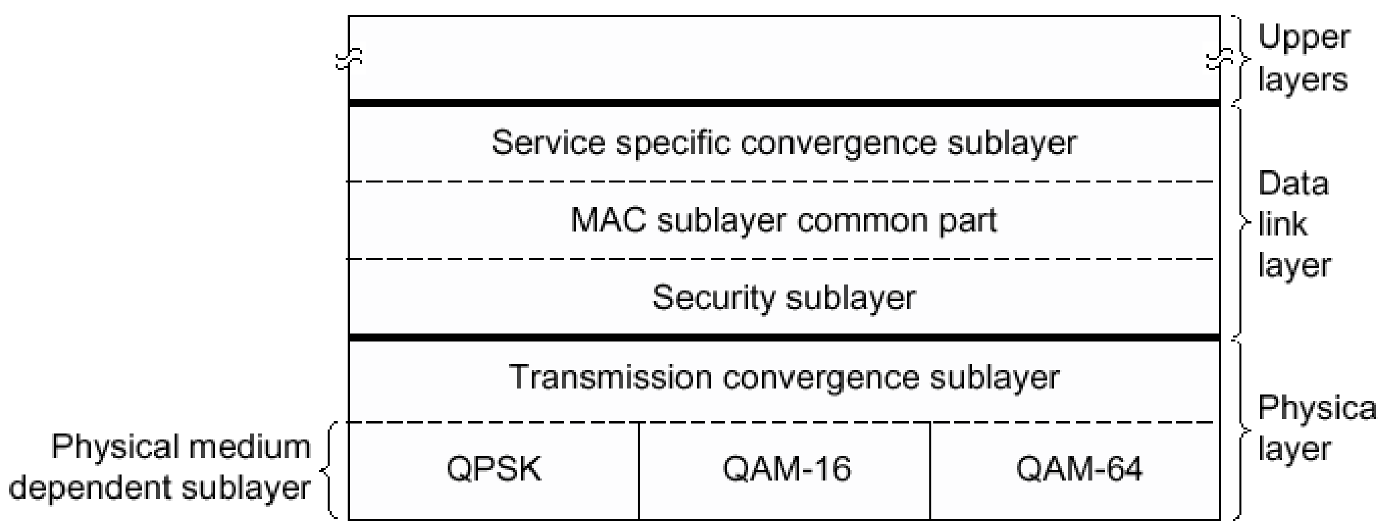
WiMax and IEEE 802.16

- A point to multi-point radio (P2MP) system designed for high speed metropolitan area connectivity
- Key current standards:
  - IEEE 802.16-2009: Air Interface for Fixed and Mobile Broadband Wireless Access System
  - IEEE 802.16j-2009 Multi-hop relay
- Key Applications:
  - Wireless backhaul of:
    - Data centric services (hotspot backhaul)
    - Mobile services (2G/3G BTS backhaul)
    - Therefore, it should support voice and multimedia traffic (QoS needed)
  - Broadband last mile access for home users (data/voice/video)



802.16 Protocol Stack

- Several different options for physical layer modulation and coding
- Transmission convergence (TC) to adapt frames to PHY
- Three sub-layers in MAC
  - Security layer : Security and Privacy of the link
  - MAC Common parts: The base station controls the system by scheduling downstream channels and manage upstream channels. Connection oriented and provides QoS
  - Service specific sub-layer: Allow seamless integration with different network layers such as IP and ATM

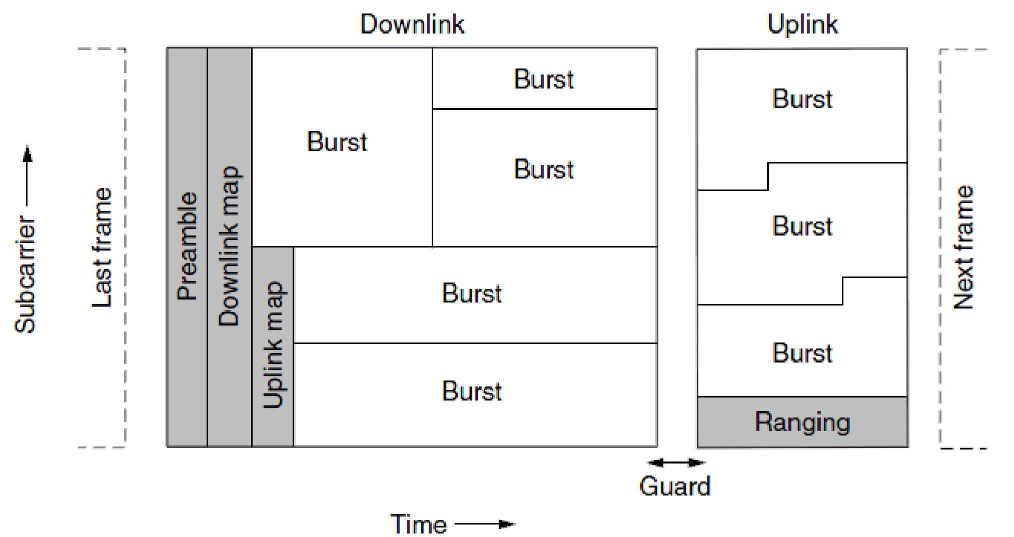


IEEE 802.16 PHY

- Designed to support up to 70 Mbps and a range of up to 100km
- Rate and range depends on number of users and channel conditions.
- 802.16e uses Scalable OFDMA to carry data, supporting channel bandwidths of between 1.25 MHz and 20 MHz, with up to 2048 sub-carriers.
- It supports adaptive modulation and coding, so that in conditions of good signal, a highly efficient 64 QAM coding scheme is used, whereas where the signal is poorer, a more robust BPSK coding mechanism is used.
- In intermediate conditions, 16 QAM and QPSK can also be employed.
- Support for Multiple-in Multiple-out (MIMO) antennas in order to provide good NLOS (Non-line-of-sight) characteristics (or higher bandwidth)
- Hybrid automatic repeat request (HARQ) for good error correction performance

IEEE 802.16 MAC

- 802.16 uses OFDMA: Frequency subcarriers can be dynamically assigned to users depending on their traffic.
- Standard allows both TDD and FDD mode of operation. TDD is more popular
  - Time Division Duplex (TDD): stations alternate between sending and receiving traffic
  - Frequency Division Duplexing (FDD): Stations can send and receive at the same time on different frequency subcarriers
- Base Station sends the map of downlink and uplink at the start of downlink frames.



IEEE 802.16 QoS

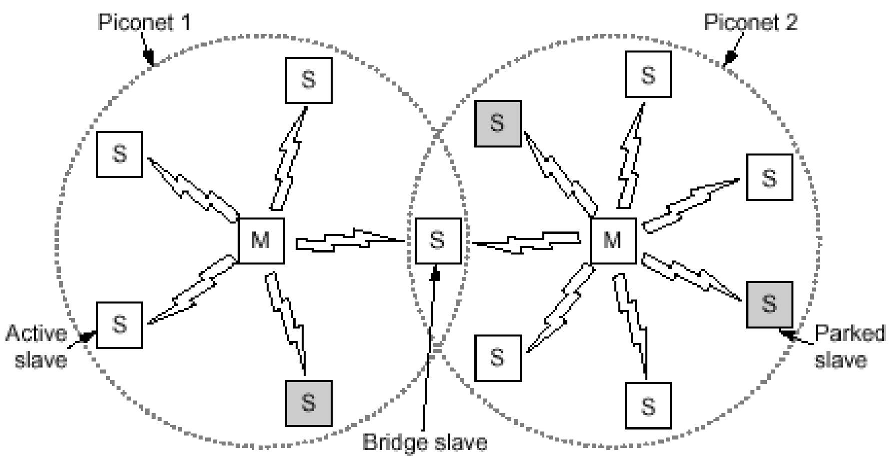
- The BS and the SS use a service flow with an appropriate QoS class (plus other parameters, such as bandwidth and delay) to ensure that application data receives QoS treatment appropriate to the application.
- All services in 802.16 are connection oriented

802.16e-2005 QoS classes

Service	Abbrev	Definition	Typical Applications
Unsolicited Grant Service	UGS	Real-time data streams comprising fixed-size data packets issued at periodic intervals	T1/E1 transport
Extended Real-time Polling Service	ertPS	Real-time service flows that generate variable-sized data packets on a periodic basis	VoIP
Real-time Polling Service	rtPS	Real-time data streams comprising variable-sized data packets that are issued at periodic intervals	MPEG Video
Non-real-time Polling Service	nrtPS	Delay-tolerant data streams comprising variable-sized data packets for which minimum data rate is required	FTP with guaranteed minimum throughput
Best Effort	BE	Data streams for which no minimum service level is required and therefore may be handled on a space-available basis	HTTP

Bluetooth (IEEE 802.15)

- A standard for Inexpensive, compact , short range wireless communication.
- Started by Ericsson, IBM, Nokia, Intel and Toshiba in 1994, Version 1.0 finalized in 1999.
- Based on pico-nets connected together by slave bridges
- Each piconet has one master node and seven slaves and up to 255 parked nodes (nodes in power stand-by)
- Each piconet is a centralized TDM system managed by Master. All communications between slaves are done through the master. (No direct slave to slave comm.)



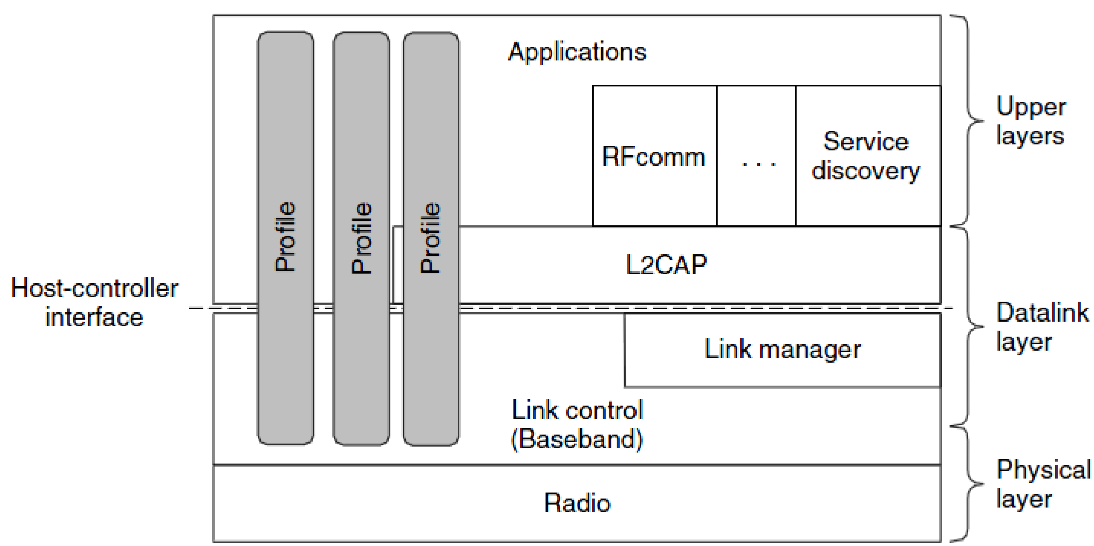
Bluetooth Applications

- Standard specifies the entire protocol stack for various applications.
- Important defined profiles (Important applications which are standardized by the standard):
  - Serial port emulator
  - LAN Access
  - Dial up networking
  - Cordless telephony
  - Intercomm
  - Headset

Name	Description
Generic access	Procedures for link management
Service discovery	Protocol for discovering offered services
Serial port	Replacement for a serial port cable
Generic object exchange	Defines client-server relationship for object movement
LAN access	Protocol between a mobile computer and a fixed LAN
Dial-up networking	Allows a notebook computer to call via a mobile phone
Fax	Allows a mobile fax machine to talk to a mobile phone
Cordless telephony	Connects a handset and its local base station
Intercom	Digital walkie-talkie
Headset	Allows hands-free voice communication
Object push	Provides a way to exchange simple objects
File transfer	Provides a more general file transfer facility
Synchronization	Permits a PDA to synchronize with another computer

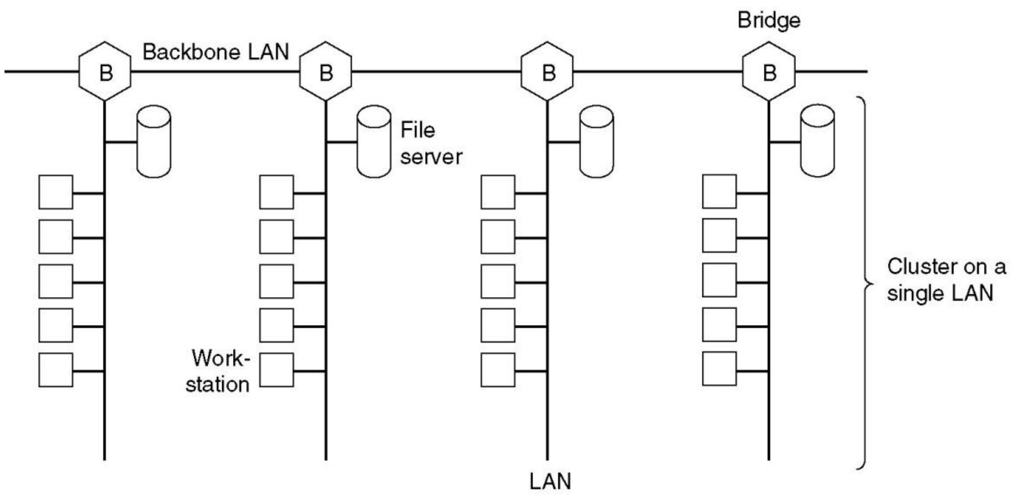
Bluetooth Protocol Stack

- Physical Radio:
  - Frequency Hopping, 79 channels of 1 MHz each in 2.4 GHz ISM Band.
- Baseband Layer (MAC)
  - Turns raw bits to frames and defines key formats
  - Each frame is transmitted over a “Link”.
  - Two types of links:
    - Asynchronous Connectionless (ACL) used for packet data
    - Synchronous Connection Oriented (SCO) used for real time data such as voice
- L2CAP:
  - Frame segmentation and re-assembly
  - Mux/Demux of multiple data sources
  - Handles QoS requirements during link establishment and normal operation



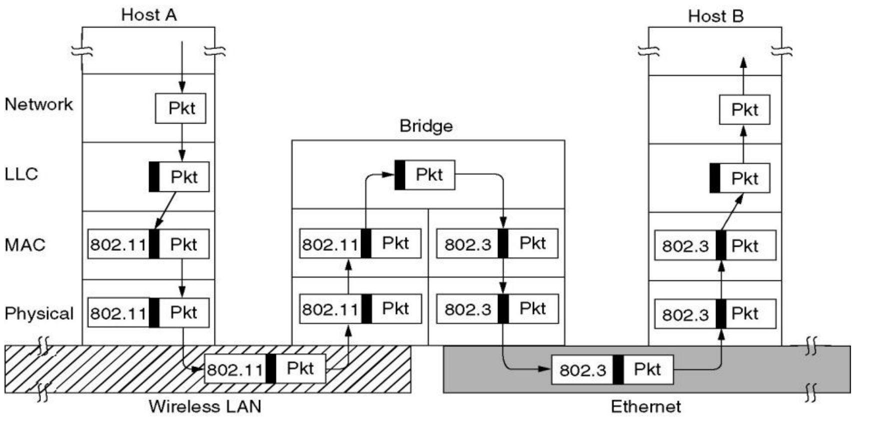
Data Link Layer Switching

- LANs need to be connected together:
  - Different departments of a corporation have their own LAN
  - Separate LANs in different locations need to be connected together
  - Split the LAN to accommodate the load
  - Separate LANs for reliability (prevent LAN failure due to mis-behaviour of one machine)
  - Increase security of the organization
- Bridges are used to connect two or more LANs together
- Operate in Data Link Layer => no knowledge of network layer header => can copy IP, IPX or OSI



Bridging from 802.x to 802.y

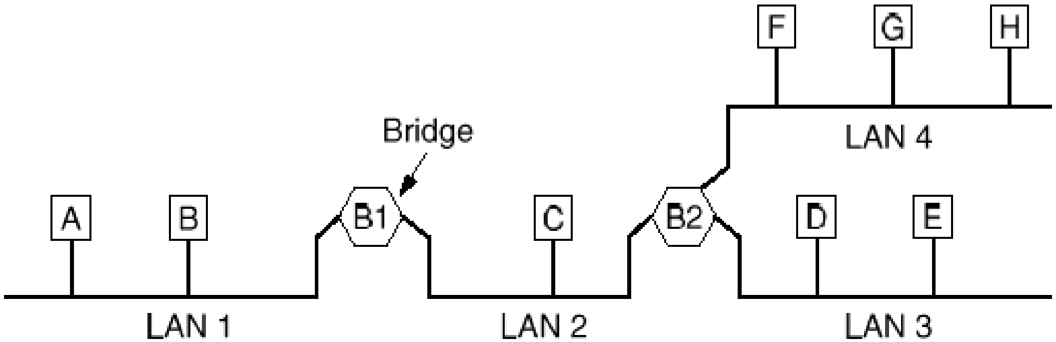
- Bridges need to route packets at layer 2 and also do some frame conversions
- Bridging problems
  - Different frame formats (e.g. 802.3 and 802.11)
  - Different data rates (Gigabit Ethernet to 802.11 traffic)
  - Different maximum frame sizes
  - Handling of Encryption (e.g. 802.11 with security to 802.3 with no security)
  - Handling of Qos (e.g. 802.16 has QoS and 802.3 does not)

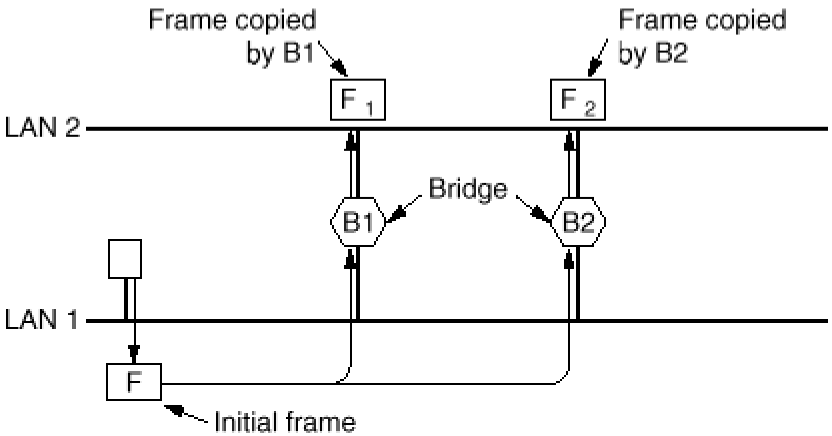


Transparent Bridging

- Design Objective: Can be inserted anywhere (no hardware/software changes required for LAN nodes)
- Forwards packets if needed
- **Backward learning**:
  - keep table of (destination address + outgoing LAN-link) entries
  - update table every time a packet comes in (using the source address)

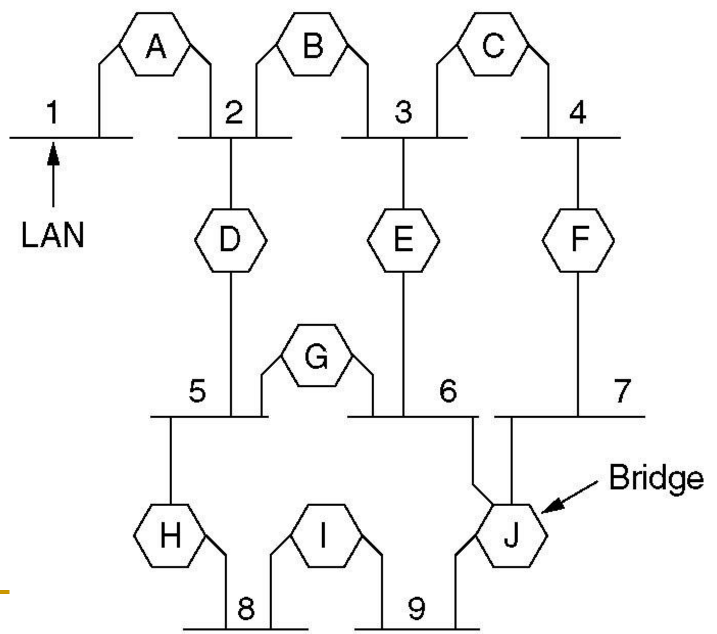
- Routing procedure of a bridge:
  - discard frame if source and destination LAN are equal forward if they are different
  - use flooding otherwise (also for broadcast frames)
  - Redundancy: use multiple bridges between LANs => ***loop problem***
  - Solution to loop problem: spanning tree bridges build spanning tree using shortest path from root algorithm.





Spanning Tree

- Spanning Tree
  - First assign a root (Bridge with the lowest serial number)
  - Build a tree with the shortest path from the root to every bridge and LAN (Perlman algorithm)
  - If a bridge or LAN fails, re-calculate the tree



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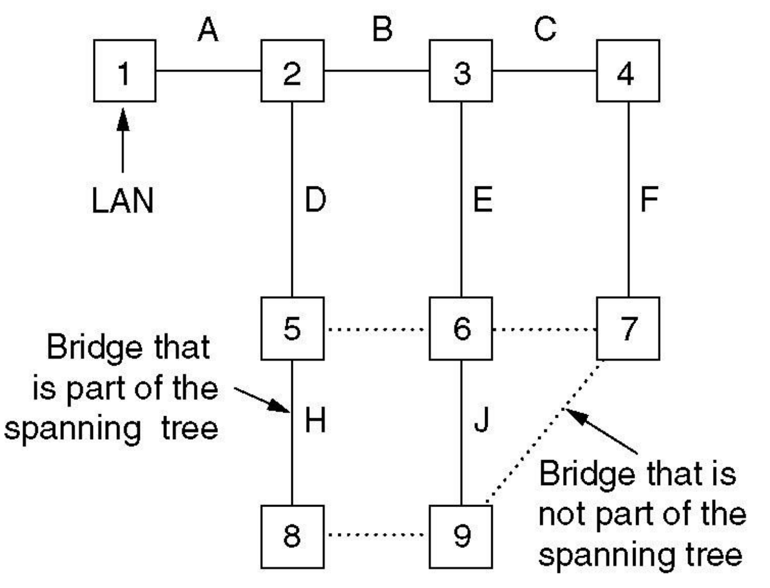

(b)