The Medium Access Control Sublayer

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The Medium Access Control Sublayer

- Network Links can be divided into:
  1. Point-to-point connections
  2. Broadcast channels
- We have discussed Point-to-Point Connections.
- Broadcast Links and their Protocols will be discussed next.

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The Medium Access Control Sublayer

- In any broadcast network, the key issue is how to determine who gets to use the channel when there is competition.
- Example: teleconferencing.
- Broadcast Channels are also known as Multi-access channels or random access channels.

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The Medium Access Control Sublayer

- The protocols used to determine who goes next on a multi-access channel belong to a sublayer of the data link layer called the MAC (Medium Access Control) sublayer.
- Especially important in LAN's and particularly in wireless communication.
- WANs use point-to-point links with the exception of satellite links.

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Channel Allocation Problem

- Static channel allocation
- Dynamic channel allocation.

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Static Channel Allocation

- Traditionally capacity of the channel is split among multiple competing users (e.g., TDM or FDM).
- Example: FM radio stations.
- However, when the number of senders is large and varying or the traffic is bursty FDM presents some problems.

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Static Channel Allocation

- If the spectrum is cut up into N regions and
  - Fewer than N users are currently interested in communicating, a large piece of valuable spectrum will be wasted.
  - More than N users want to communicate some of them will be denied permission for lack of bandwidth.
- Dividing the channel into constant number of users of static sub channels is inherently inefficient.

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Static Channel Allocation

- A static allocation is poor fit to most computer systems, in which data traffic is extremely bursty:
  - Peak traffic to mean traffic ratios of 1000:1 are common.
  - Consequently most of the channels will be idle most of the time.

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Static Channel Allocation

- Example:
  - Mean Time delay ***T*** seconds,
  - Channel capacity ***C*** bps,
  - Average arrival rate λ frames/sec
  - Frames average length of $1/\mu$ bits.
  - With these parameters, the service rate of the channel is μC frames/sec.

$$T = \frac{1}{\mu C - \lambda}$$

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Static Channel Allocation

- ***C*** = 100 Mbps,
- $1/\mu = 10{,}000$ bits
- $\lambda = 5000$ frames/sec
- ***T*** = 200 μsec
- This result holds only when there is no contention in the channel.

$$T = \frac{1}{\mu C - \lambda}$$

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Static Channel Allocation

- ***Divide a single channel into N independent channels:***
  - $C/N = 100/N$ Mbps,
  - $1/\mu = 10{,}000$ bits
  - $\lambda/N = 5000/N$ frames/sec
  - $T_N = N \times 200$ µsec
  - For N=10 => T_N = 2 msec.

$$T_N = \frac{1}{\mu\left(\frac{C}{N}\right) - \left(\frac{\lambda}{N}\right)}$$

$$= \frac{N}{\mu C - \lambda} = \mathrm{NT}$$

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Assumptions for Dynamic Channel Allocation

- Before we get to the first of the many channel allocation methods, it is worthwhile to carefully formulate the allocation problem.
- Underlying all the work done in this area are the following five key assumptions:
  1. Independent traffic
  2. Single channel
  3. Observable Collisions
  4. Continuous or slotted time
  5. Carrier sense or no carrier sense

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Assumptions for Dynamic Channel Allocation

- Independent Traffic:
  - The model consists of N independent **stations**.
  - The expected number of frames generated in an interval of length Δt is $\lambda \Delta t$. λ – is arrival rate of new frames.
  - Once the frame has been generated, the station is blocked and does nothing until the frame has been successfully transmitted.

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Assumptions for Dynamic Channel Allocation

- Single Channel:
  - The single channel is available for all communication.
  - All stations can transmit on it and all can receive from it.
  - The stations are assumed to be equally capable though protocols may assign them different roles (i.e., priorities)

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Assumptions for Dynamic Channel Allocation

- Observable Collisions:
  - If two frames are transmitted simultaneously, they overlap in time and the resulting signal is garbled.
  - This event is know as **collision**.
  - All stations can detect that a collision has occurred. A collided frame must be retransmitted.
  - No errors other than those generated by collision occur.

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Assumptions for Dynamic Channel Allocation

- Continuous or Slotted Time:
  - Time may be assumed continuous. In which case frame transmission can begin at any instant.
  - Alternatively, time may be slotted or divided into discrete intervals (called slots).
  - Frame transmission must then begin at the start of a slot.
  - A slot may contain 0, 1 or more frames, corresponding to an idle slot, a successful transmission, or collision, respectively.

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Assumptions for Dynamic Channel Allocation

- Carrier Sense or No Carrier Sense:
  - With the carrier sense assumption, stations can tell if the channel is in use before trying to use it.
  - No station will attempt to use the channel while it is sensed as busy.
  - If there is no carrier sense, stations cannot sense the channel before trying to use it.
  - They will transmit then. Only later they can determine whether the transmission was successful.

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Multiple Access Protocols

- ALOHA
- Carrier Sense Multiple Access
- Collision-free protocols
- Limited-contention protocols
- Wireless LAN protocols

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ALOHA

- 1970 Hawaii
- Norman Abramson and colleagues have enabled wireless communication between users in a remote island to the central computer in Honolulu.
- Two versions of the protocol now called ALOHA:
  - Pure ALOHA and
  - Slotted ALOHA

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Pure ALOHA

- Each user is free to transmit whenever they have data to be sent.
  - There will be collisions
  - Senders need some way to fond out if this is the case.
- In ALOHA after the station transmits its message to the central computer, the computer rebroadcasts the frame to all of the stations.
  - Original sending station can listen for the broadcast from the hub to see if its frame has gone through.

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Pure ALOHA

- In other wired systems the sender might be able to listen for collisions while transmitting.
- If the frame is destroyed, the sender just waits a random amount of time and sends it again.
  - Waiting time must be random or the sending frames will collide over and over.
  - Systems in which multiple users share a common channel in a way that can lead to conflicts are known as Contention Systems.

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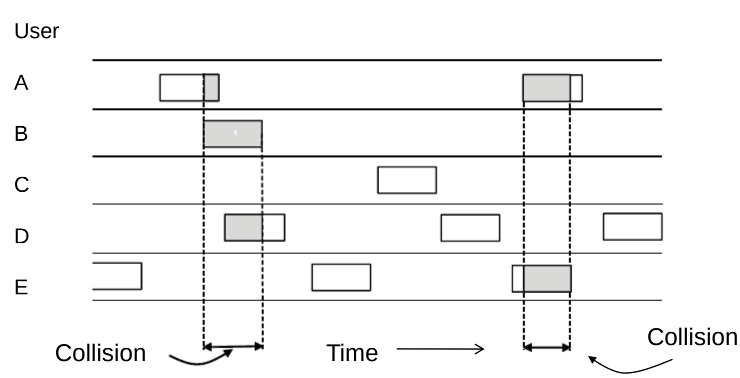
PURE ALOHA (1)



In pure ALOHA, frames are transmitted at completely arbitrary times

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Pure ALOHA

- What is the efficiency of an ALOHA channel?
- What fraction of all transmitted frames escape collisions under these chaotic circumstances?
  - Infinite collection of users typing at their terminals (stations).
  - User states: WAITING or TYPING.
  - When a line is finished, the user stops typing waiting for response.
  - The station then transmits a frame containing the line over the shared channel to the central computer and checks the channel to see if it was successful.
  - If so the users sees the reply and goes back to typing
  - If not, the user continuously to wait while the station retransmits the frame over and over until it has been successfully sent.

Pure ALOHA

- Frame Time – denotes the amount of time needed to transmit the standard, fixed-length frame.
- Each new frame is assumed to be generated by Poisson distribution with a mean of N frames per frame time.
  - If $N>1$ the user community is generating frames at a higher rate than the channel can handle, and nearly every frame will suffer a collision.
  - For reasonable throughput we expect $0 < N < 1$.

Pure ALOHA

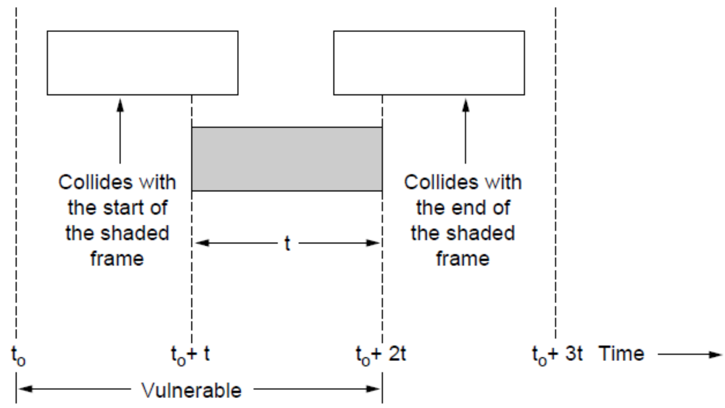
- In addition to the new frames, the stations also generate retransmissions of frames that previously suffered collisions.
- Assume that the new and the old frames combined are well modeled by a Poisson distribution with mean G frames per frame time. $G \geq N$.
  - Low load: $N \approx 0$ there will be few collisions, hence few retransmissions, $G \approx N$
  - High load: there will be many collisions, $G > N$.

Pure ALOHA

- Under all loads the throughput S is just the offered load, G, times the probability P_0 of a transmission succeeding:

$$S = GP_0$$

ALOHA (2)



Vulnerable period for the shaded frame.

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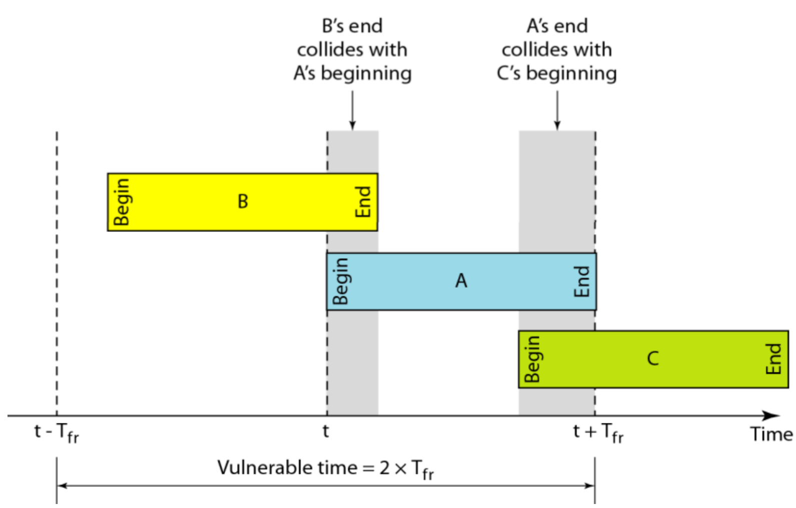
Vulnerable time for pure ALOHA protocol



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Pure ALOHA

- The probability that k frames are generated during a given frame time, in which G frames are expected, is given by the Poison distribution:

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

  - Probability of zero frames: e^{-G}
  - In an interval two frame times long, the mean number of frames generated is $2G$.
  - Probability of no frames being initiated during the entire vulnerable period is given by $P_0 = e^{-2G}$.
  - Using $S = GP_0$

$$S = Ge^{-2G}.$$

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Pure ALOHA

- The relation between the offered traffic and the throughput is given in the next slide.
- The maximum throughput occurs at G=0.5 with S=1/2e which is about 0.184.
  - The maximum utilization of the channel thus is 18%.

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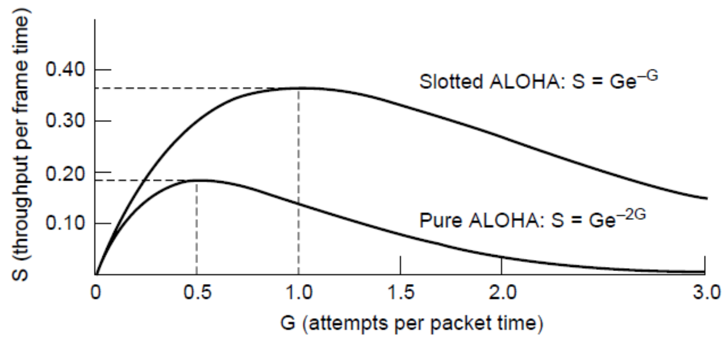
ALOHA (3)



Throughput versus offered traffic for ALOHA systems.

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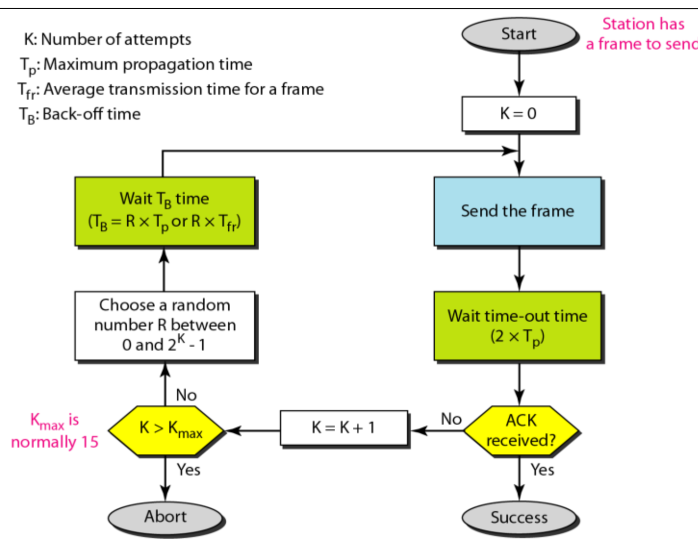
Procedure for pure ALOHA protocol



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Pure ALOHA Example

Example 1 : A pure ALOHA network transmits 200-bit frames on a shared channel of 200 kbps. What is the requirement to make this frame collision-free?

Solution

Average frame transmission time T_{fr} is 200 bits/200 kbps or 1 ms.

The vulnerable time is 2×1 ms = 2 ms. This means no station should send later than 1 ms before this station starts transmission and no station should start sending during the one 1-ms period that this station is sending.

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Pure ALOHA Example

Example 2 : A pure ALOHA network transmits 200-bit frames on a shared channel of 200 kbps. What is the throughput if the system (all stations together) produces

a. 1000 frames per second. b. 500 frames per second c. 250 frames per second

Solution

The frame transmission time is 200/200 kbps or 1 ms.

a. If the system creates 1000 frames per second, this is 1 frame per millisecond. The load is 1. In this case $S = G \times e^{-2G}$ or S = 0.135 (13.5 percent). This means that the throughput is 1000 × 0.135 = 135 frames. Only 135 frames out of 1000 will probably survive.

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Pure ALOHA Example

Example 2: Solution

b. If the system creates 500 frames per second, this is 1/2 frame per millisecond. The load is (1/2). In this case $S = G \times e^{-2G}$ or S = 0.184 (18.4 percent). This means that the throughput is 500 × 0.184 = 92 frames and that only 92 frames out of 500 will probably survive. Note that this is the maximum throughput case, percentagewise.

c. If the system creates 250 frames per second, this is 1/4 frame per millisecond. The load is (1/4). In this case $S = G \times e^{-2G}$ or S = 0.152 (15.2 percent). This means that the throughput is 250 × 0.152 = 38 frames and that only 38 frames out of 250 will probably survive.

Slotted ALOHA

- Roberts in 1972 doubled the capacity of an ALOHA system.
  - Divide time into discrete intervals called **slots**.
  - Each interval corresponds to one frame.
  - Users will have to agree on slot boundaries.
- Synchronization is required:
  - One special station emit a pip at the start of each interval, like clock.

Slotted ALOHA

- A station is not permitted to send whenever the user types a line.
- User waits for the beginning of the next slot.
- Continuous time ALOHA is turned into a discrete time one.
- The probability of no other traffic during the same slot as our test frame is then e^{-G}, which leads to:

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

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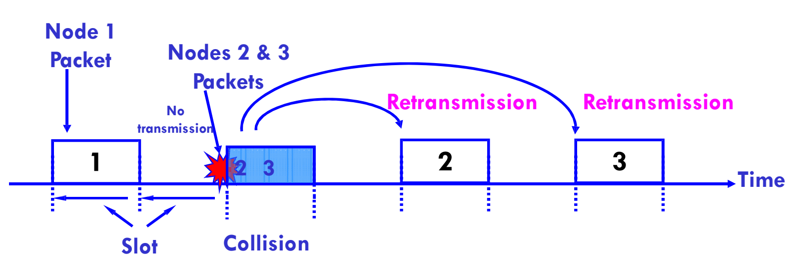
Slotted ALOHA



Collision mechanism in slotted ALOHA

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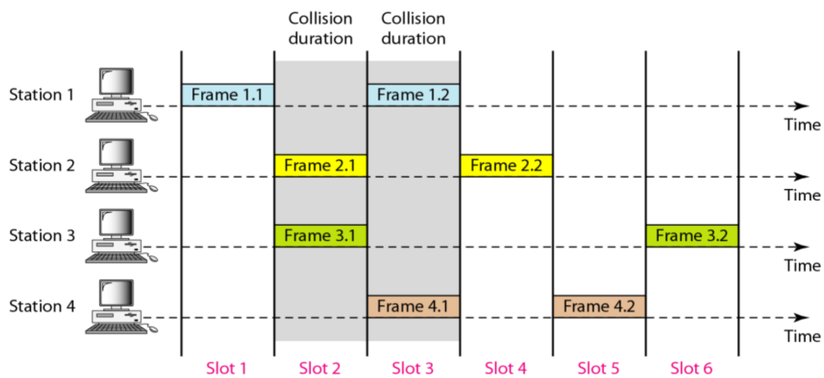
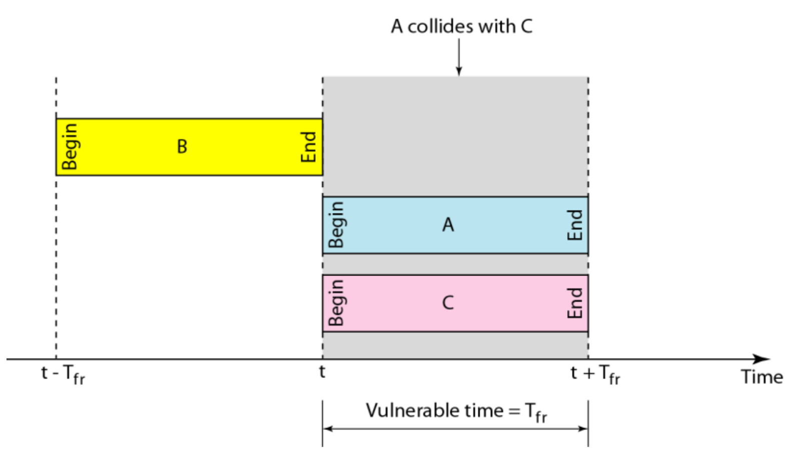
Frames in a slotted ALOHA network



Vulnerable time for slotted ALOHA protocol



Slotted ALOHA

- Slotted ALOHA
  - peaks at the G = 1
  - Throughput S = 1/e = 0.367 or 37%.
- The best case scenario:
  - 37% of slots are empty
  - 37% of successes, and
  - 26% collisions.

Slotted ALOHA Example

Example 2 : A slotted ALOHA network transmits 200-bit frames on a shared channel of 200 kbps. What is the throughput if the system (all stations together) produces
a. 1000 frames per second. b. 500 frames per second c. 250 frames per second

Solution

The frame transmission time is 200/200 kbps or 1 ms.

a. If the system creates 1000 frames per second, this is 1 frame per millisecond. The load (G) is 1. In this case $S = G \times e^{-G}$ or S = 0.368 (36.8 percent).
This means that the throughput is $1000 \times 0.368 = 368$ frames. Only 368 frames out of 1000 will probably survive.

Slotted ALOHA Example

Example 2: Solution

b. If the system creates 500 frames per second, this is 1/2 frame per millisecond. The load is (1/2). In this case S = G× e^{-G} or S = 0. (18.4 percent). This means that the throughput is 500 × 0.184 = 92 frames and that only 92 frames out of 500 will probably survive. Note that this is the maximum throughput case, percentagewise.

c. If the system creates 250 frames per second, this is 1/4 frame per millisecond. The load is (1/4). In this case S = G× e^{-G} or S = 0.195 (19.5 percent). This means that the throughput is 250 × 0.195 = 49 frames and that only 49 frames out of 250 will probably survive.

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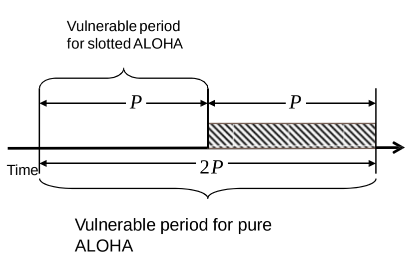
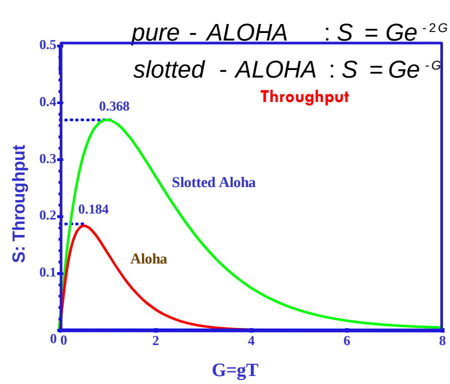
Pure ALOHA versus Sloted ALOHA

- **ALOHA**
  - (p)ure-ALOHA : users transmit any time they desire.
  - (s)lotted-ALOHA : users begin their transmission only at the beginning of a slot



P= frame transmission time



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Carrier Sense Multiple Access Protocols

- We have seen that maximum throughputs of pure and slotted ALOHA protocols, are equal to 0.184 and 0.368, respectively.
- We need to find another way of improving throughputs and supporting high-speed communication networks.
- We could achieve better throughput if we can prevent potential collision in a shared channel by simply listening to the channel before transmitting a packet.

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Carrier Sense Multiple Access Protocols

- Protocols in which stations listen for a carrier (i.e., transmission) and act accordingly are called carrier sense protocols.
- Several Versions of those protocols will be discussed.
  1. Persistent and Non-persistent CSMA
  2. CSMA with Collision Detections

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Carrier Sense Multiple Access(CSMA) Protocols

- CSMA gives improved throughput compared to Aloha protocols
- CSMA protocols are based on the fact that each terminal on the network is able to monitor the status of the channel before transmitting information.
  - Listens to the channel before transmitting a packet (avoid avoidable collisions)
- In CSMA, **detection** delay and **propagation** delay are two important parameters.
  - Detection delay is the time required for a terminal to sense whether or not the channel is idle.
  - Propagation delay is a relative measure of how fast it takes for a packet to travel from a source station to a destination station.

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Persistent and Non-persistent CSMA

- 1-Persistent Carrier Sense Multiple Access (CSMA) protocol.
  - When a station has data to be send it first listens to the channel to see if anyone else is transmitting at that moment.
  - If the channel is idle the station sends the data,
  - Otherwise, the station just waits until it becomes idle.

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Persistent and Non-persistent CSMA

- 1-Persistent Carrier Sense Multiple Access (CSMA) protocol.
  - If a collision occurs, the station waits a random amount of time and starts all over again.
  - This protocol has problems with collisions:
    - Two patiently waiting stations will start transmitting at the same time when the channel becomes idle.
    - Propagation delay can make even more subtle the collision.

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Persistent and Non-persistent CSMA

- 1-persistent refers to the probability of 1 of transmission when the channel found to be idle.

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Persistent and Non-persistent CSMA

- **Non-persistent CSMA -** In this protocol the transmitting stations are less greedy.
  - The transmitting station will send the packet if the channel is found to be idle.
  - However, if the channel is already in use the station does not continuously sense it for transmission. Instead it waits a random amount of time and then repeats the algorithm.

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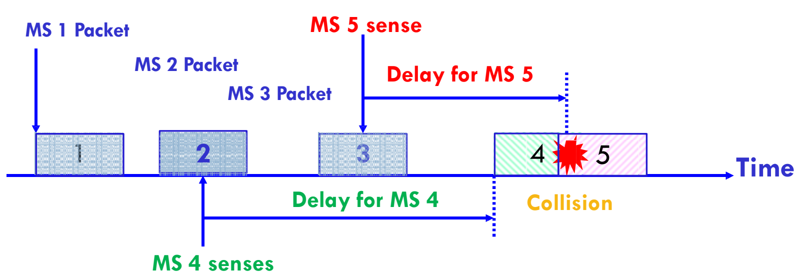
Collision Mechanism in Non-persistent CSMA

- Each MS can sense the transmission of all other MSs, and the propagation delay is small as compared with the transmission time.
- Following figure shows the collision process in the Non-persistent CSMA protocol.



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Persistent and Non-persistent CSMA

- **P-persistent CSMA**.
  - The transmitting station will send the packet if the channel is found to be idle with a probability of p ($q = 1\text{-}p$; it defers that action until the next slot).
  - If the slot is still empty it does or not transmit with the probability of p and q respectively.
  - If the channel in use the station will treat this as being a collision (waits random amount of time)

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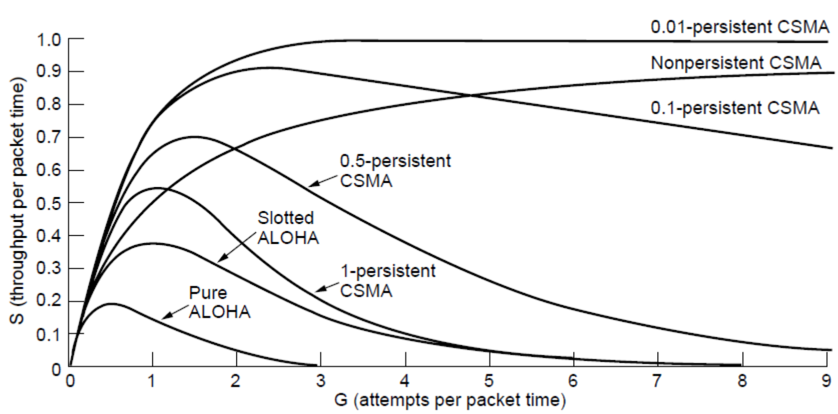
Persistent and Non-persistent CSMA



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

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CSMA/CD (CSMA with Collision Detection)

- Persistent and non-persistent CSMA protocols are definitely an improvement over ALOHA because they ensure that no station begins to transmit while the channel is busy.
- However, if two stations sense the channel to be idle and begin transmitting simultaneously, their signals will still collide.
- Another improvement is for the stations to quickly detect the collision and abruptly stop transmitting, (rather than finishing them) since they are irretrievably garbled anyway.
- This strategy saves time and bandwidth.

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CSMA with Collision Detection

- Protocols that sense Collisions are known as **CSMA with Collision Detection** (CSMA/CD)
- This protocol is a basis of classical Ethernet LAN.
  - The transmitting station hardware must listen to the channel while it is transmitting.
  - If it is garbled up then it will know that collision has occurred.

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CSMA/CD (CSMA with Collision Detection)

- In CSMA, if two terminals begin sending packet at the same time, each will transmit its complete packet (although collision is taking place).
- Wasting medium for an entire packet time.
- CSMA/CD

  Step 1: If the medium is idle, transmit

  Step 2: If the medium is busy, continue to listen until the channel is idle then transmit

  Step 3: If a collision is detected during transmission, cease transmitting

  Step 4: Wait a random amount of time and repeats the same algorithm

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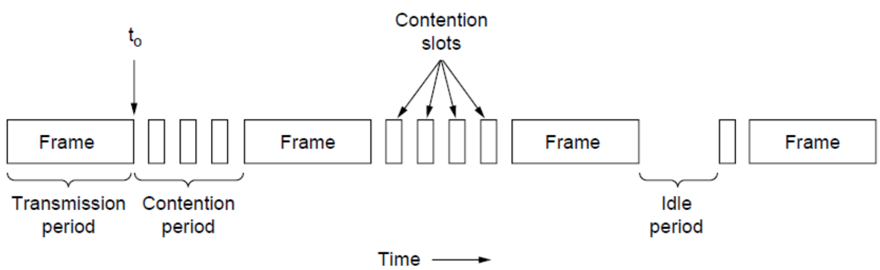
CSMA with Collision Detection



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

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CSMA/CD (CSMA with Collision Detection)

- Suppose that two stations both begin transmitting at exactly time t_0.
- How long will it take them to realize that they have collided?
- The minimum time to detect the collision is just the time it takes the signal to propagate from one station to the other.
- Based on this information, you might think that a station that has not heard a collision for a time equal to the full cable propagation time after starting its transmission can be sure it has seized the cable.
- By "seized," we mean that all other stations know it is transmitting and will not interfere.
- This conclusion is wrong.

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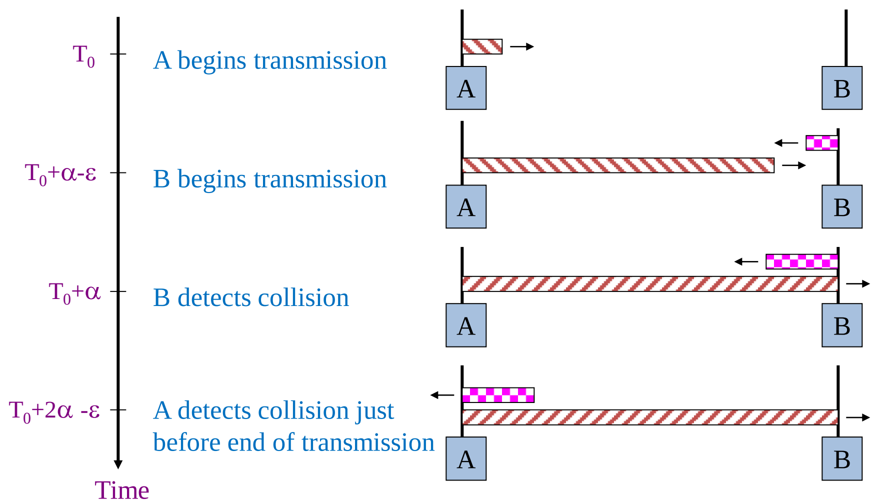
CSMA/CD (Cont'd)



(α is the propagation time)

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CSMA/CD (CSMA with Collision Detection)

- In the worst case a station cannot be sure that it has seized the channel until it has transmitted for 2α without hearing a collision.
- With this understanding, we can think of CSMA/CD contention as a slotted ALOHA system with a slot width of 2α.
- The difference for CSMA/CD compared to slotted ALOHA is that slots in which only one station transmits (i.e., in which the channel is seized) are followed by the rest of a frame.
- This difference will greatly improve performance if the frame time is much longer than the propagation time.

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Collision-Free Protocols

- In CSMA/CD collisions do not occur once the station has unambiguously captured the channel, but they still occur during the contention period.
- These collisions adversely affect the system performance (e.g., bandwidth-delay product is large – long cable that has a large propagation delay α and frames are short).

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Collision-Free Protocols

- Collisions reduce the bandwidth
- This make the time to send a frame variable.
- Bad fit for real-time traffic:
  - VoIP
  - Video,
  - Teleconferencing, etc.

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Collision-Free Protocols

- In the protocols to be described, we assume that there are exactly *N* stations
- Each programmed with a unique address: *0-(N-1).*
- We also assume Propagation delay is negligible.
- Question: Which station gets the channel (e.g., the right to transmit) after a successful transmission.

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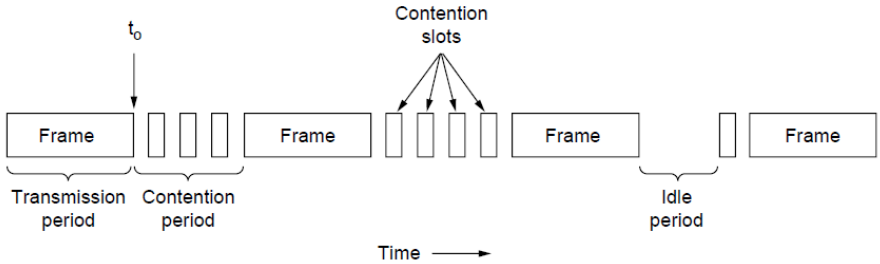
Basic Bit-Map Protocol



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

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Basic Bit-Map Protocol

- Each contention period consists of exactly N slots.
- If station 0 has a frame to send, it transmits a 1 bit during the slot 0.
- No other station is allowed transmit during this slot.
- Regardless what station 0 does, station 1 gets to opportunity to transmit a 1 bit during slot 1, but only if it has a frame queued.
- In general, station j may announce that it has a frame to send by inserting a 1 bit into slot j.
- After all N slots have passed by, each station has complete knowledge of which stations wish to transmit. At which point they begin transmitting frames in numerical order.

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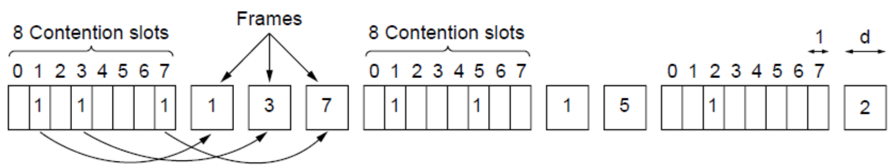
Collision-Free Protocols (1)



The basic bit-map protocol.

Bit-Map Protocol

- Protocols that broadcast their intention before that actually transmission are called **reservation protocols**.
- Low-load conditions:
  - Average wait conditions for low-numbered stations:
    - N/2 slots for current scan to finish, and
    - N slots for the following scan to run to completion before it may begin transmitting.
    - 1.5N slots wait time.
  - Average wait conditions for high-numbered stations:
    - 0.5N slots wait time.
  - Mean of all stations is N times.

Bit-Map Protocol

- Efficiency:
  - Overhead bits N
  - Data bits d

$$\frac{d}{(d+N)}$$

- High-load
  - N bit contention period is prorated over N frames, yielding an overhead of only 1 bit per frame:
- Efficiency:

$$\frac{d}{(d+1)}$$

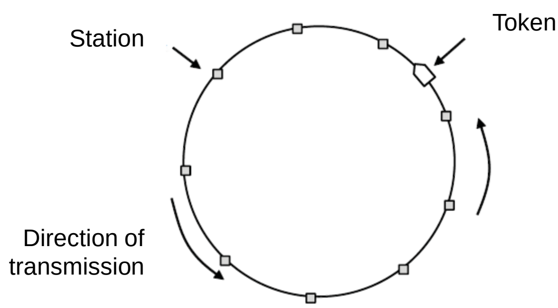
- Mean delay for a frame:
  - Sum of the time it queues inside the station +
  - $(N\text{-}1) \times d + N$ once it gets to the head of its internal queue.

Token Passing

- The essence of the bit-map protocol is that it lets every station transmit a frame in turn in a predefined order.
- Another way to accomplish the same thing is to pass a small message called **token** form one station to the next in the same predefined order.
- The token represents permission to send.
- If a station has a frame queued for transmission when it receives the token, it can send that frame before it passes the token to the next station.
- If it has no queued frame, it simply passes the token.
- In a token ring protocol, the topology of the network is used to define the order in which stations send.

Collision-Free Protocols (2)

- The stations are connected one to the next in a single ring.
- Each station is receiving the token in from one direction and transmitting it out in the other direction.
- Frames are also transmitted in the direction of the token. .



Token ring.

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Token Passing

- To stop the frame circulating indefinitely (like the token), one has to pay attention to remove the frame from the ring.
- Typically it will be removed by the receiving station and/or sending station.
- We do not need a physical ring to implement token passing.
- The channel connecting the stations might instead be a single long bus.
- Token Ring or Token Bus protocols work the same way.

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Token Passing

- The performance of token passing is similar to that of the bit-map protocol, though the contention slots and frames of one cycle are now intermingled.
- After sending a frame, each station must wait for all N stations (including itself) to send the token to their neighbors and the other N − 1 stations to send a frame, if they have one.
- A subtle difference is that, since all positions in the cycle are equivalent, there is no bias for low- or high-numbered stations.

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Binary Countdown

- A problem with the basic bit-map and token passing protocols is the overhead of 1 bit per station.
  - Large overhead for the network with large number of stations.
- A better solution is to use binary station addresses with a channel that combines transmissions.
- A station wanting to use the channel now broadcasts its address as a binary bit string, starting with the high-order bit. The addresses are assumed to be the same length.
- The bits in each address position from different stations are.
  - BOOLEAN OR-ed together by the channel when they are send at the same time.
  - **Binary Countdown** protocol
- It implicitly assumes that the transmission delays are negligible so that all stations see asserted bits essentially instantaneously.

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Binary Countdown

- Arbitration rule: As soon as a station sees that a high-ordered bit position that is 0 in its address has been overwritten with 1 it gives up.
- Example:
  - If stations 0010, 0100, 1001, and 1010 are all trying to get the channel, in the first bit time the stations transmit 0, 0, 1, and 1, respectively.
  - They are OR-ed together to get 1.
  - Stations 0010 and 0100 see the 1 and know that higher-numbered stations is competing for the channel and they give up for the current round.
  - Stations 1001 and 1010 continue.

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Binary Countdown

- The next bit is 0 so both stations continue.
- The next bit is 1 so the station 1001 gives up and station 1010 wins the bidding.
- This gives it a right to transmit the frame, after which a new cycle starts.

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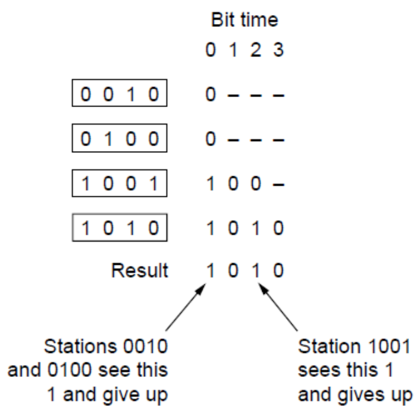
Binary Countdown

The binary countdown protocol. A dash indicates silence.



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Limited-Contention Protocols

- So far we have considered two basic strategies for channel acquisition in a broadcast network:
  - Contention (e.g., CSMA), and
  - Collision free protocols.
- Each strategy can be rated as to how well it does with respect to the two important performance measures:
  - Delay at low-loads, and
  - Channel efficiency at high-loads.

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Limited-Contention Protocols

- Contention (Pure or Slotted ALOHA) protocols are preferred under
  - The low load conditions:
    - Low delay and
    - practically collision free.
  - But, the high load conditions:
    - High Delay due to High number of collisions or contentions

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Limited-Contention Protocols

- Reverse is true for collision-free protocols
  - The low load conditions:
    - High delay and
  - The high load conditions:
    - Relatively low Delay due to which, Channel efficiency improves (fixed overheads).
- Obviously, it would be nice if we could combine the best properties of the contention and collision-free protocols, arriving at a new protocol that used contention at low load to provide low delay, but uses a collision-free technique at high load to provide good channel efficiency.
- Such protocols, which we will call Limited-Contention Protocols.

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Limited-Contention Protocols

- Up to now, the only contention protocols we have studied have been symmetric i.e., each station attempts to acquire the channel with some probability, p, with all stations using the same p.
- k – stations are contending for channel access.
- Each station has p – probability of transmission during each slot.
- Probability that some station acquires a channel is its probability p multiplied with all the remaining (k-1) stations deferring with probability of (1-p):

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

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Limited-Contention Protocols

- Probability that any station acquires a channel is its probability p multiplied with all the remaining (k-1) stations deferring with probability of (1-p):

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

- To find the optimal value of p, we differentiate with respect to p, set the result to zero, and solve for p.
- Doing so, we find that the best value of p is 1/k. Substituting p = 1/k, we get
- $Pr\ [success\ with\ optimal\ p]\ = \left[\frac{k-1}{k}\right]^{k-1}$
- This probability is displayed in the next slide.

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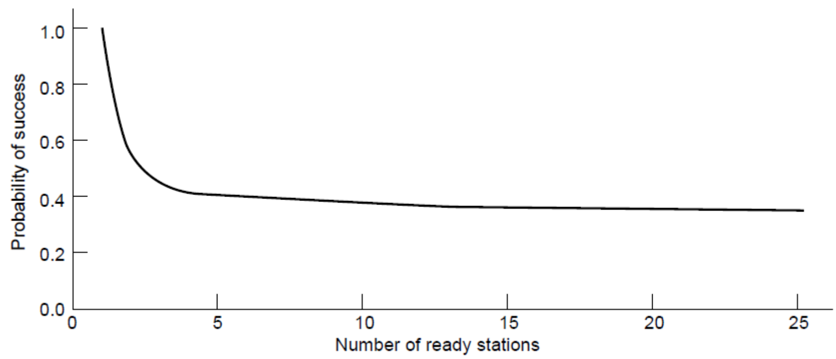
Limited-Contention Protocols



Acquisition probability for a symmetric contention channel.

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Limited-Contention Protocols

- From the figure in previous slide it is fairly obvious that probability that some stations will acquire the channel can be increased only by decreasing the amount of competition.
- The limited contention protocols do just that by:
  1. Dividing the stations into (not necessarily disjoint) groups.
  2. Only the members of group 0 are permitted to compete for slot 0.
  3. If one of them succeeds, it acquires the channel and transmits its frame.
  4. If there is a collision the members of the group 1 contend for slot 1. etc.

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Limited-Contention Protocols

- By making an appropriate division of stations into groups the amount of contention for each slot can be reduced, thus operating each slot near the left of the figure presented in previous slide.
- The trick is how to assign stations to slots? Before Looking at the general case, let us consider some special case:
  - At one extreme, suppose each group has utmost one member. Such assignment guarantees that there will never be collisions because at most one station is contending for any given slots (binary countdown protocol)
  - The next case is to assign two stations per group. The probability that both will try to transmit during a slot is $p,^2$ which for a small p is negligible.

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Limited-Contention Protocols

- If more stations are assigned to the same slot, the probability of a collision grows, but the length of the bit-map needed to give everyone a chance shrinks.
- The limiting case is a single group containing all stations (i.e., slotted ALOHA).
- We need a way to assign station slots dynamically:
  - Many stations per slot when the load is low, and
  - Few (or just one) station per slot when the load is high.

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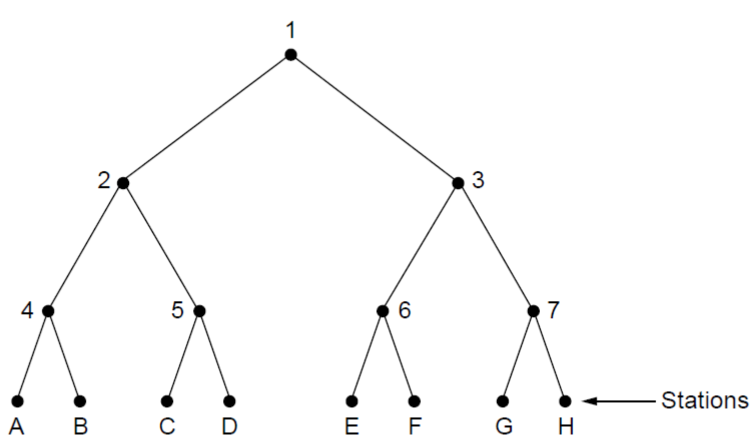
The Adaptive Tree Walk Protocol

- One particularly simple way of performing the necessary assignment is to use the algorithm devised by the U.S. Army for testing soldiers for syphilis during World War II (Dorfman, 1943) :
  - Blood samples from N soldiers
  - A portion of each sample was poured into a single test tube.
  - This mixed sample was testing:
    - If none of antibodies were found all the soldiers in the group were declared healthy.
    - Binary search was performed to pick which soldier was infected.

The Adaptive Tree Walk Protocol



The tree for eight stations

The Adaptive Tree Walk Protocol

- In the first contention slot following the successful transmission, slot 0, all stations were permitted to try to acquire the channel.
- If there is a collision then during slot 1 only those stations falling under node 2 in the tree (previous slide) may compete.
- If one of them acquires the channel the slot following the frame (i.e., slot 2) is reserved for those stations under node 3.
- If on the other hand two or more stations under node 2 want to transmit, there will be a collision during slot 1, in which case it is node 4's turn during slot 2.

The Adaptive Tree Walk Protocol

- Depth first search of the tree to locate all ready stations if the collision occurs during slot 0.
- Each bit slot is associated with some particular node in the tree.
- If collision occurs the search continues recursively with the node's left and right children.
- If a bit slot is idle or if only one station transmits in it. The searching of its node can stop because all ready stations have been located.

The Adaptive Tree Walk Protocol

- When a load on the system is high it is not worth to dedicate slot 0 to node 1.
- Similarly one would argue that nodes 2 and 3 should be skipped.
- In general the question is at what level in the tree should we began the search?
  - Heavier load the farther down the tree the search should begin.

The Adaptive Tree Walk Protocol

- We will assume that each station has a pretty good idea of the number of ready stations q, (from monitoring traffic).
- Numbering the levels:
  - Level 0: Node 1
  - Level 1: Nodes 2, 3
  - Level 2: Nodes 4,5,6 and 7. etc.

The Adaptive Tree Walk Protocol

- If the q ready stations are uniformly distributed.
- Expected number of the stations below a specific node at level i is just $2^{-i}q$
- Optimal number of contending station per slot should be 1 and hence $2^{-i}q = 1$.
- Solving this equation, we find:

$$i = log_2(q)$$

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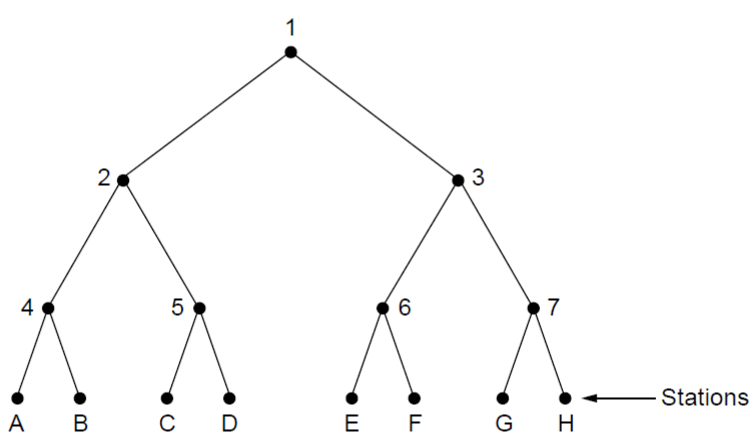
The Adaptive Tree Walk Protocol



The tree for eight stations

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The Adaptive Tree Walk Protocol

- Numerous improvements to the basic algorithm have been discovered by Bertsekas and Gallager (1992).
- For example, consider the case of stations G and H being the only ones wanting to transmit.
- At node 1 a collision will occur, so 2 will be tried and discovered idle.
- It is pointless to probe node 3 since it is guaranteed to have a collision (we know that two or more stations under 1 are ready and none of them are under 2, so they must all be under 3).
- The probe of 3 can be skipped and 6 tried next. When this probe also turns up nothing, 7 can be skipped and node G tried next.

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Wireless LAN Protocols

- A system of laptop computers that communicate by radio – wireless LAN.
- It also has somewhat different properties than a wired LAN.
- Leads to different MAC protocols.

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Wireless LAN Protocols

- Common configuration of wireless LAN:
  - Office Building with Access Points (APs)
  - APs Strategically placed
  - APs are wired together (copper or fiber)
  - APs provide connectivity

Wireless LAN Protocols

- Transmission power of APs and laptops is adjusted to have a range of tens of meters, nearby rooms become like a single cell and the entire building becomes like the cellular telephony system.
- But, each cell has only one channel.
- This channel is shared by all the stations in the cell, including APs.
- Bandwidth provided – up to 600 Mbps.

Wireless LAN Protocols

- Wireless system can not normally detect a collision while it is occurring.
- The received signal is weak (millions times fainter than the signal that is being transmitted)
- Difficulty in finding collision.
- Instead ACK are used to discover collisions and other errors after the fact.

Wireless LAN Protocols

- Additional, and even more important, difference between wireless LAN and wired LAN:
  - Wireless LAN: A station may not be able to transmit or receive frames to or from all other stations due to limited radio range.
  - Wired LAN: Once the one station sends a frame, all other stations receive it.

Wireless LAN Protocols

- Simplifying assumptions:
  - Each radio transmitter has some fixed range.
  - Its range is represented by an ideal circular coverage region
  - within that region station can sense and receive the station's transmission.

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Wireless LAN Protocols

- Naïve approach:
  - Use CSMA:
    - Just listen for other transmissions.
    - If none is doing it then transmit.
  - Problem:
    - What matters for reception is interference at the receiver and not at the sender.
- Consider the figure in next slide:

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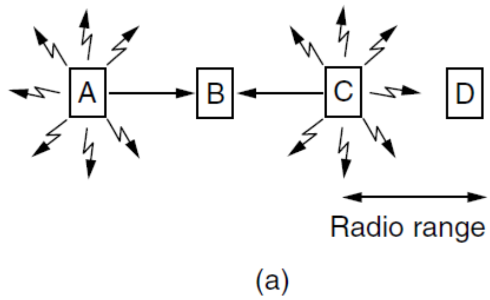
Wireless LAN Protocols (1)



A wireless LAN. (a) A and C are **hidden terminals** when transmitting to B.

- The problem of a station not being able to detect a potential competitor for the medium because the competitor is too far away is called the hidden terminal problem.

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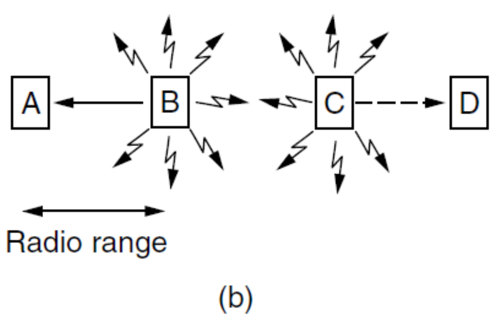
Wireless LAN Protocols (2)



A wireless LAN. (b) B and C are **exposed terminals** when transmitting to A and D.

- The problem of a station to falsely conclude that it may not send and deferred the transmission is called the **exposed terminals problem**.

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Wireless LAN Protocols

- Before starting the transmission a station must know whether there is radio activity around the receiver.
- CSMA merely tells it whether there is activity near the transmitter by sensing the carrier.
  - With wired communication all signals propagate to all stations so this distinction does not exist.
  - However only one transmission can take place at one time.

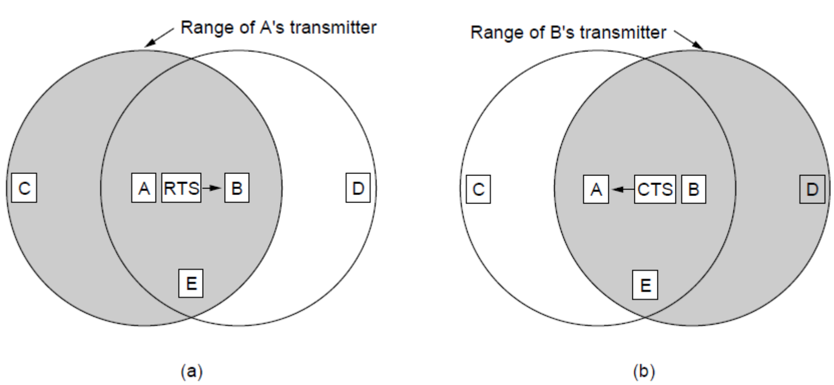
Wireless LAN Protocols

- In a system based on short-range radio waves multiple transmissions can occur simultaneously:
  - If they all have different destinations, and
  - These destinations are out of range of one another.
- **Multiple Access with Collision Avoidance (MACA)** - Early protocol that tackles these problems for wireless LAN's.
  - The basic idea behind it is for the sender to stimulate the receiver into outputting a short frame
  - Nearby stations can detect this transmission and avoid transmitting for the duration of the upcoming (larger) data frame.

Wireless LAN Protocols

- MACA is illustrated in the next slide.
  - A sends a frame to B – A initiates the request by sending an **Request To Send (RTS)** to station B.
    - Short frame (30 bytes) that contains the length of data frame that will eventually follow.
  - B replies with a **Clear To Send (CTS)** frame.
    - This frame contains the data length (copied from RTS).
  - After reception of the CTS frame the station A begins transmission.

Wireless LAN Protocols (3)



The MACA protocol. (a) *A sending an RTS to B. (b) B responding* with a CTS to *A.*

Wireless LAN Protocols

- Any station hearing the RTS is clearly close to A and must remain silent long enough for the CTS to be transmitted back to A without conflict.
- Any stations hearing CTS are clearly close to B and must remain silent during the upcoming data transmission, whole length it can tell by examining the CTS frame.
- Still collisions are possible.

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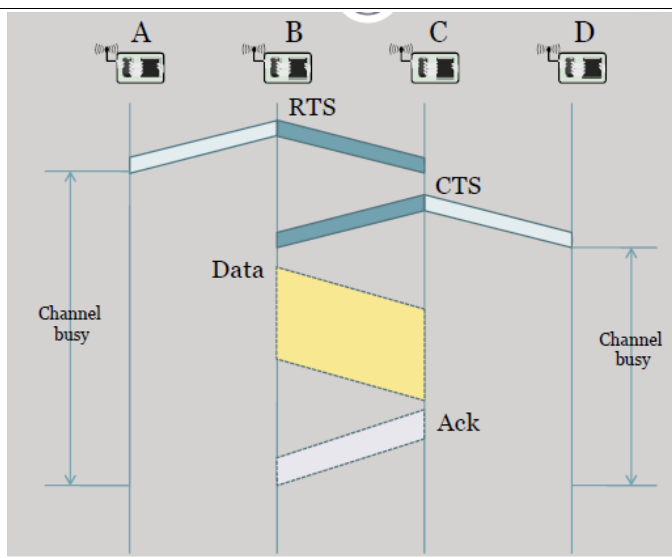
RTS/CTS handshake...



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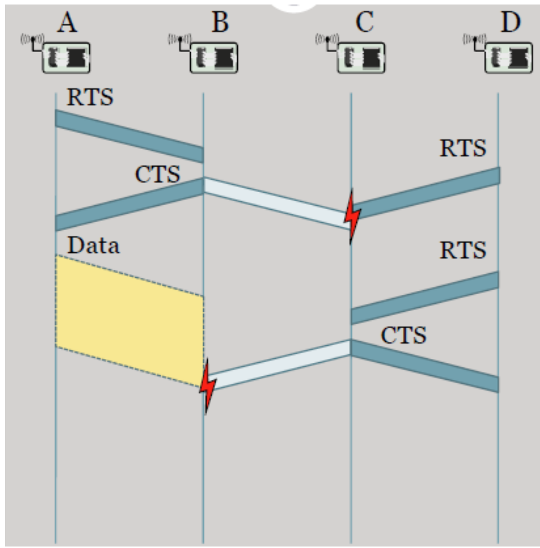
RTS/CTS failure...



RTS/CTS failure...2