Channel Allocation Protocols

Dynamic Channel Allocation Parameters

- Station Model.
  - probability of frame being generated in interval of Δt is $\lambda \Delta t$.
  - Station is blocked after sending the pkt, till successful trans.
  - *N* independent stations, each acting as a Poisson Process for the purpose protocol analysis
- Single Channel Assumption.
  - A single channel is available for all communication.
- Collision Assumption.
  - If transmitted frames overlap in time, the resulting signal is garbled. → collision.
- Transmission Discipline:
  - Continuous time → Frames can be transmitted at any time
  - Slotted time → Frames can be transmitted at particular time points
- Sensing capability:
  - Station cannot sense the channel before trying to use it.
  - Stations can tell if the channel is in use before trying to use it

Poisson Process

- The Poisson Process is a celebrated model used in Queuing Theory for "random arrivals". Assumptions leading to this model include:
  – The probability of an arrival during a short time interval Δt is proportional to the length of the interval, and does not depend on the origin of the time interval (memory-less property)
  – The probability of having multiple arrivals during a short time interval Δt approaches zero.

Poisson Distribution

The probability of having k arrivals during a time interval of length t is given by:

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

where λ is the arrival rate. Note that this is a single-parameter model; all we have to know is λ.

ALOHA

- It is very simple.
- Norman Abramson was devised at university of Hawaii in 1970.
- it used ground based radio station broadcasting.
- applicable to any application which contains uncoordinated users, competing for use of single shared channel.
- two types :
  - **1. Pure Aloha**
  - **2. Slotted Aloha.**

Pure ALOHA Protocol

While there is a new frame A to send DO

1. Send frame A and wait for ACK
2. If after “some” time ACK is not received (timer times out), wait a random amount of time and go to 1.

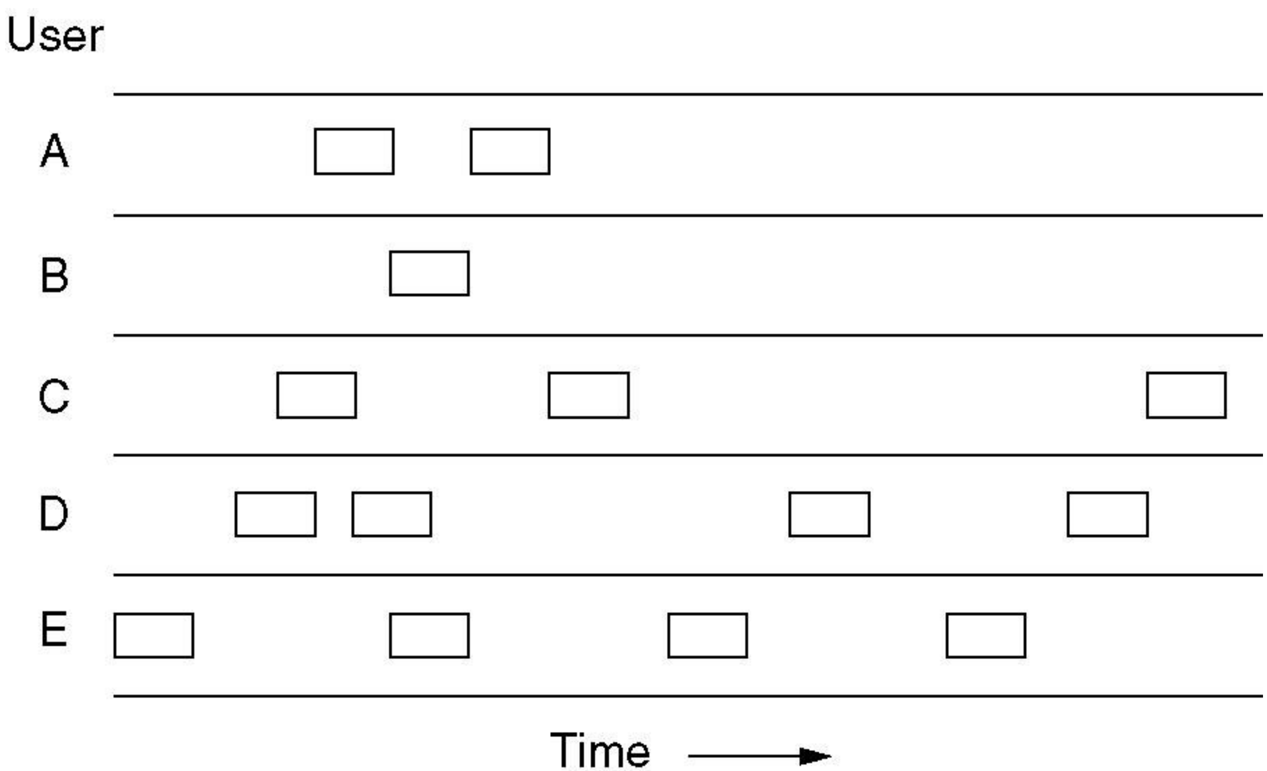
End

* random --> 0 to 2 power (N) -1

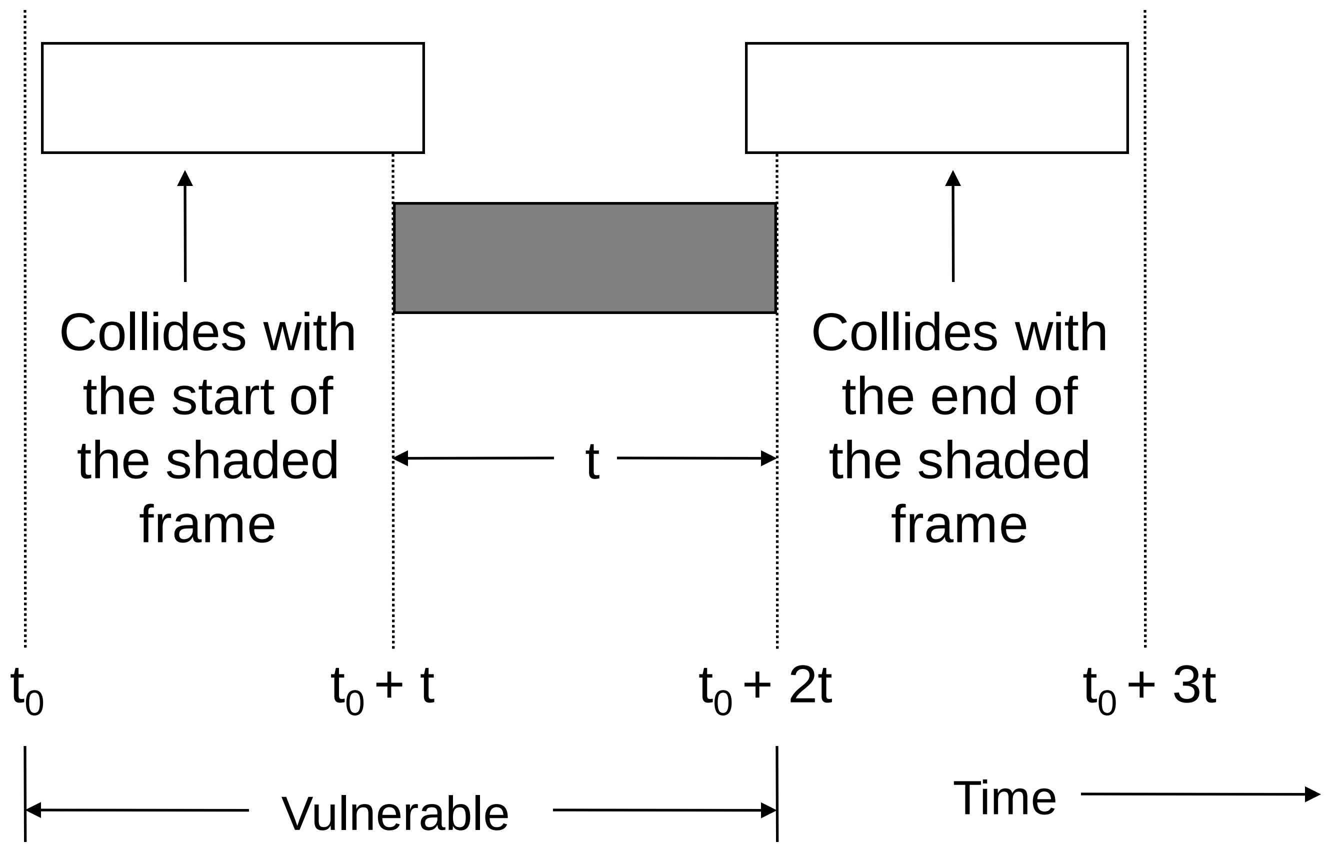
* Explicitly need ack.

Pure ALOHA

In pure ALOHA, frames are transmitted at completely arbitrary times.



Analysis of Pure ALOHA (4)



Vulnerable period for the shaded frame

Analysis of Pure ALOHA

- Notation:
  - T_f = frame time (processing, transmission, propagation)
  - *S*: Average number of successful transmissions per T_f; that is, the *throughput* or *efficiency*.
  - *G*: Average number of total frames transmitted per T_f
  - *D*: Average delay between the time a packet is ready for transmission and the completion of successful transmission.
- We will make the following assumptions
  - All frames are of constant length
  - The channel is noise-free; the errors are only due to collisions.
  - Frames do not queue at individual stations
  - The channel acts as a Poisson process.

Analysis of Pure ALOHA…

- Since S represents the number of "good" transmissions per *frame time*, and G represents the total number of attempted transmissions per *frame time*, then we have:

  $S = G \times$ (Probability of good transmission)

- The vulnerable time for a successful transmission is $2T_f$
- So, the probability of good transmission is not to have an "arrival" during the vulnerable time .

Analysis of Pure ALOHA…

Using:

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

And setting $t = 2T_f$ and $k = 0$, we get

$$P_0(2T_f) = \frac{(\lambda 2T_f)^0 e^{-\lambda 2T_f}}{0!} = e^{-2G}$$

because $\lambda = \dfrac{G}{T_f}$. Thus, $S = Ge^{-2G}$

Analysis of Pure ALOHA…

- If we differentiate $S = Ge^{-2G}$ with respect to G and set the result to 0 and solve for G, we find that the maximum occurs when

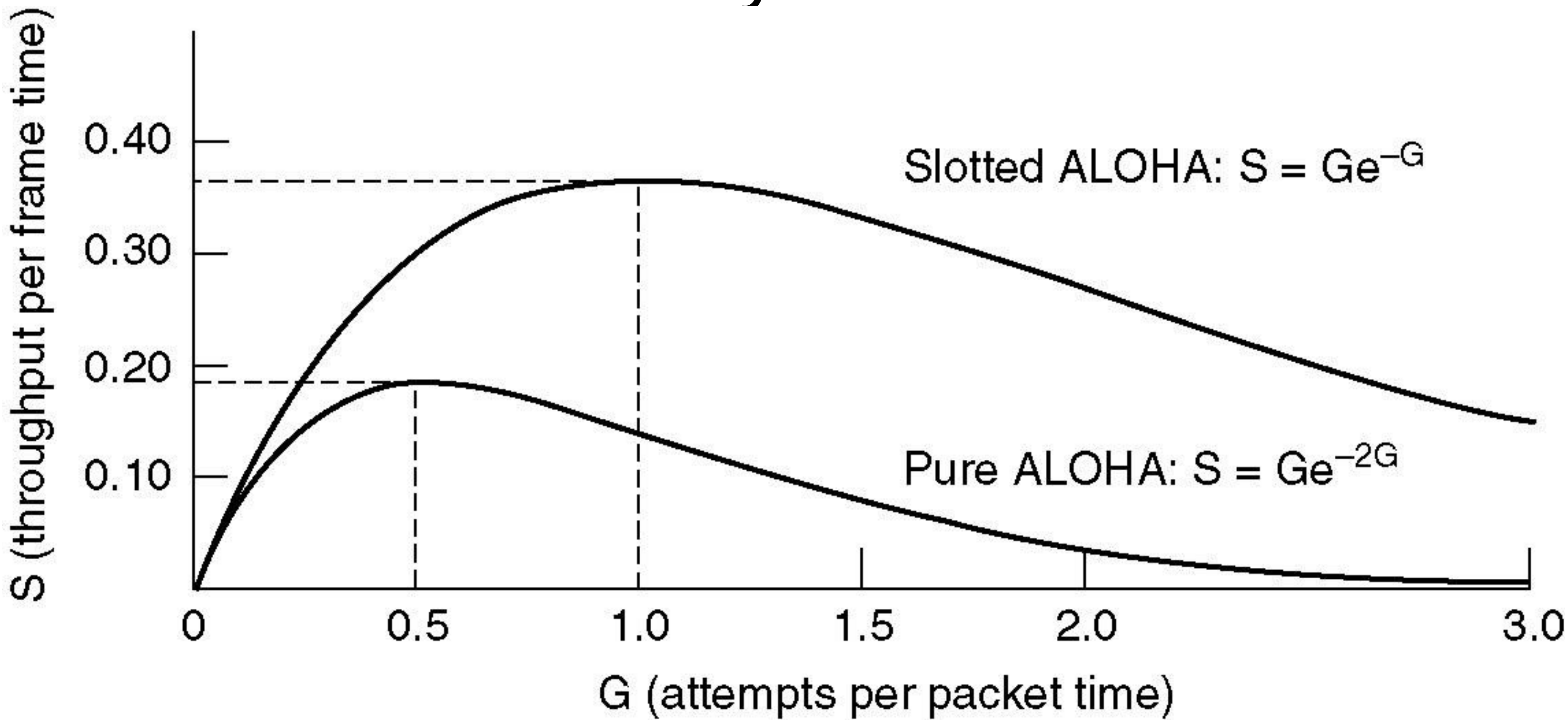
$$G = 0.5,$$

  and for that $S = 1/2e = 0.18$. So, the maximum throughput is only 18% of capacity.

- ALOHANET uses a data rate of 9600bps. This means the maximum total throughput (sum of data arriving from all user nodes) is only $0.18 \times 9600 = 1728$bps.

Pure ALOHA …

Throughput versus offered traffic for ALOHA systems.



Analysis of Pure ALOHA; another approach

- There are N stations
- Each station transmits with probability p
- For a typical node i to have a successful transmission means that there was no prior overlapping transmissions before or after, each with probability $(1-p)^{N-1}$
- Thus the probability of node i having a successful transmission is $p\,(1-p)^{2(N-1)}$
- Therefore, the probability of a successful transmission is $Np\,(1 - p)^{2(N-1)}$
- The maximum value for the above term when N is large is $1/2e$

Analysis of Pure ALOHA; another approach…

$$f = Np(1-p)^{2(N-1)}$$

$$\frac{df}{dp} = N(1-p)^{2(N-1)} + 2(N-1)(1-p)^{2(N-1)-1}(-1)Np$$

$$\frac{df}{dp} = N(1-p)^{2(N-1)-1}\big[(1-p) - 2(N-1)p\big] = N(1-p)^{2(N-1)-1}[1+p-2Np]$$

$$\frac{df}{dp} = 0 \Rightarrow p^* = \frac{1}{2N-1}$$

$$f^* = N\frac{1}{2N-1}\left(1 - \frac{1}{2N-1}\right)^{2(N-1)}$$

Expected number of transmissions

- In Pure ALOHA, what is the expected number of transmissions per frame?
  - Let x be the random variable representing the number of transmissions. Thus, x will take on values 1, 2, 3, …, etc
  - The probability P_k that x takes value k is when we have (k-1) unsuccessful transmissions followed by a successful transmission.
  - For PURE ALOHA, the probability of a successful transmission is e^{-2G}

Expected number of transmissions

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

$$E[x] = \sum_{k=1}^{\infty} k P_k = \sum_{k=1}^{\infty} k e^{-G}(1-e^{-G})^{k-1} = e^{G}$$

Thus $E[x]$ grows exponentially with G, which means that a small increase in the channel load, that is G, can drastically reduce its performance. The ALOHA protocol is an example of an *unstable* protocol.

Slotted ALOHA

- Channel is organized into uniform slots whose size equals the frame transmission time.
- Transmission is permitted only to begin at a slot boundary.
- Here is the procedure:

While there is a new frame A to send do

1. Send frame A at a slot boundary and wait for ACK
2. If after “some” time ACK is not received, wait a random amount of time and go to 1.

End

Analysis of Slotted ALOHA

- Note that the vulnerable period is now reduced in half. Using:

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

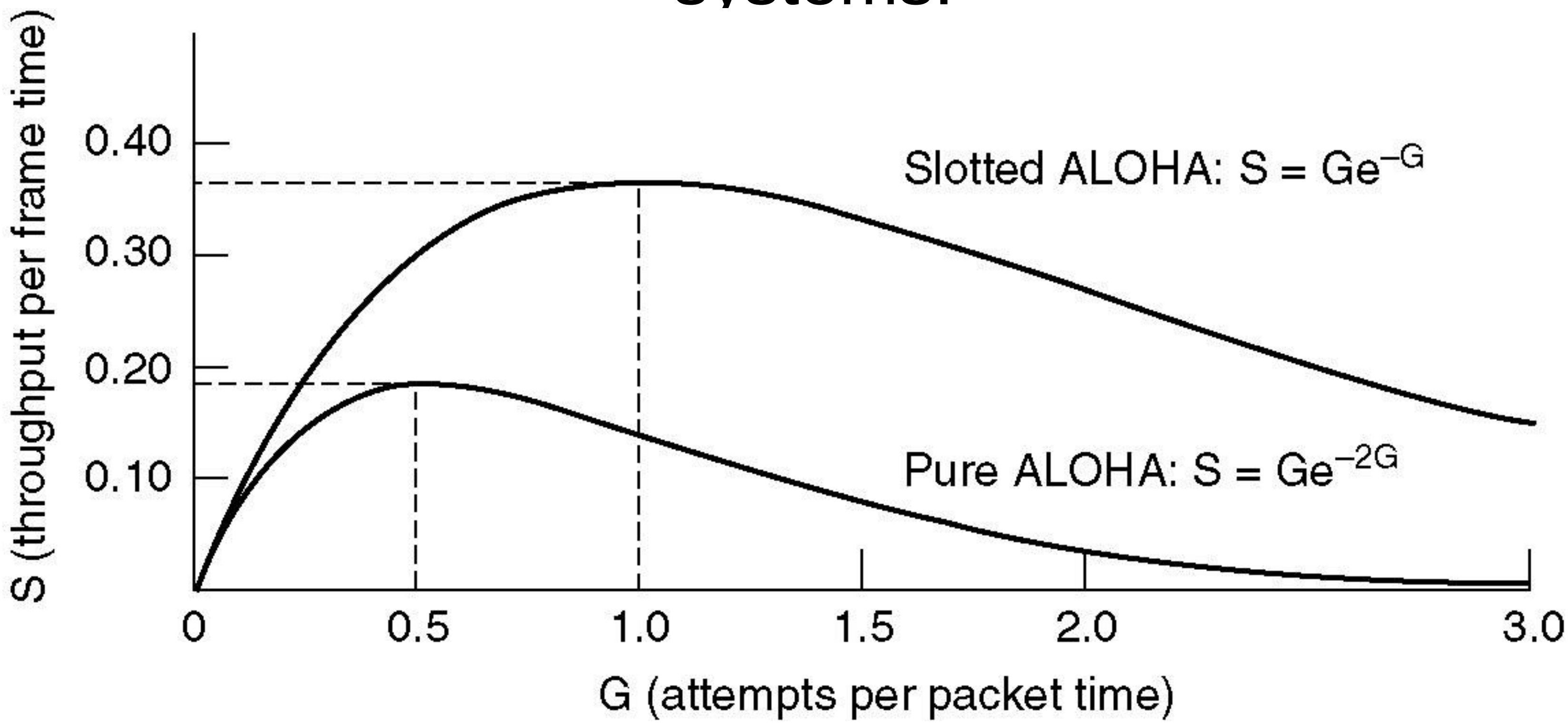
And setting t = T_f and k = 0, we get

$$P_0(T_f) = \frac{(\lambda T_f)^0 e^{-\lambda T_f}}{0!} = e^{-G}$$

$$\text{because } \lambda = \frac{G}{T_f}. \quad \text{Thus, } S = Ge^{-G}$$

Slotted ALOHA

Throughput versus offered traffic for ALOHA systems.



Analysis for Slotted Aloha

- If System is using G=1, then the probability of empty slot is 0.368.
- Analysis : @ G = 1
- 37 percentage of empty slots
- 37 percentage of success
- 26 percentage of failure

Carrier Sense Multiple Access (CSMA)

- In LAN, the systems are known other systems tasks. → achieve more utilization.
- Slotted ALLOHA, channel utilization→ 1/e.
- Protocols are listen for carrier and act accordingly is called carrier sense protocols.
- Additional assumption:
  - Each station is capable of sensing the medium to determine if another transmission is underway

1-persistent CSMA

While there is a new frame A to send do

1. Check the medium
2. If the medium is busy, go to 1.
3. (medium idle) Send frame A and wait for ACK
4. If after some time ACK is not received (timer times out), wait a random amount of time and go to 1.

End.

1-persistent CSMA

Problems :

collisions may occurs?

How?

if propagation delay is more.

even propagation delay is zero, still collisions.

Example : 2 stations → trans simulations after completion of current frame.

Still better than aloha protocols.

Non-persistent CSMA

While there is a new frame A to send DO

1. Check the medium
2. If the medium is busy, wait some time, and go to 1.
3. (medium idle) Send frame A and wait for ACK
4. If after some time ACK is not received (timer times out), wait a random amount of time and go to 1.

End

p-persistent CSMA

While there is a new frame A to send do

1. Check the medium
2. If the medium is busy, go to 1.
3. (medium idle) With probability p send frame A and the go to 4, and probability (1- p) delay one time slot and go to 1.
4. If after some time ACK is not received (timer times out), wait a random amount of time and go to 1.

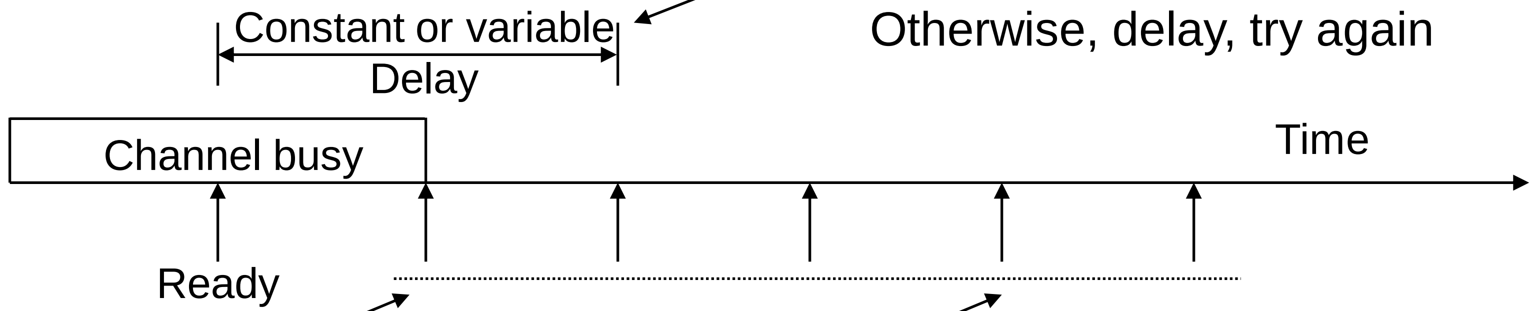
End.

CSMA Summary

- Nonpersistent
- 1-persistent
- *p*-persistent

<u>CSMA persistence and backoff</u>

***Non-persistent*:**
Transmit if idle
Otherwise, delay, try again

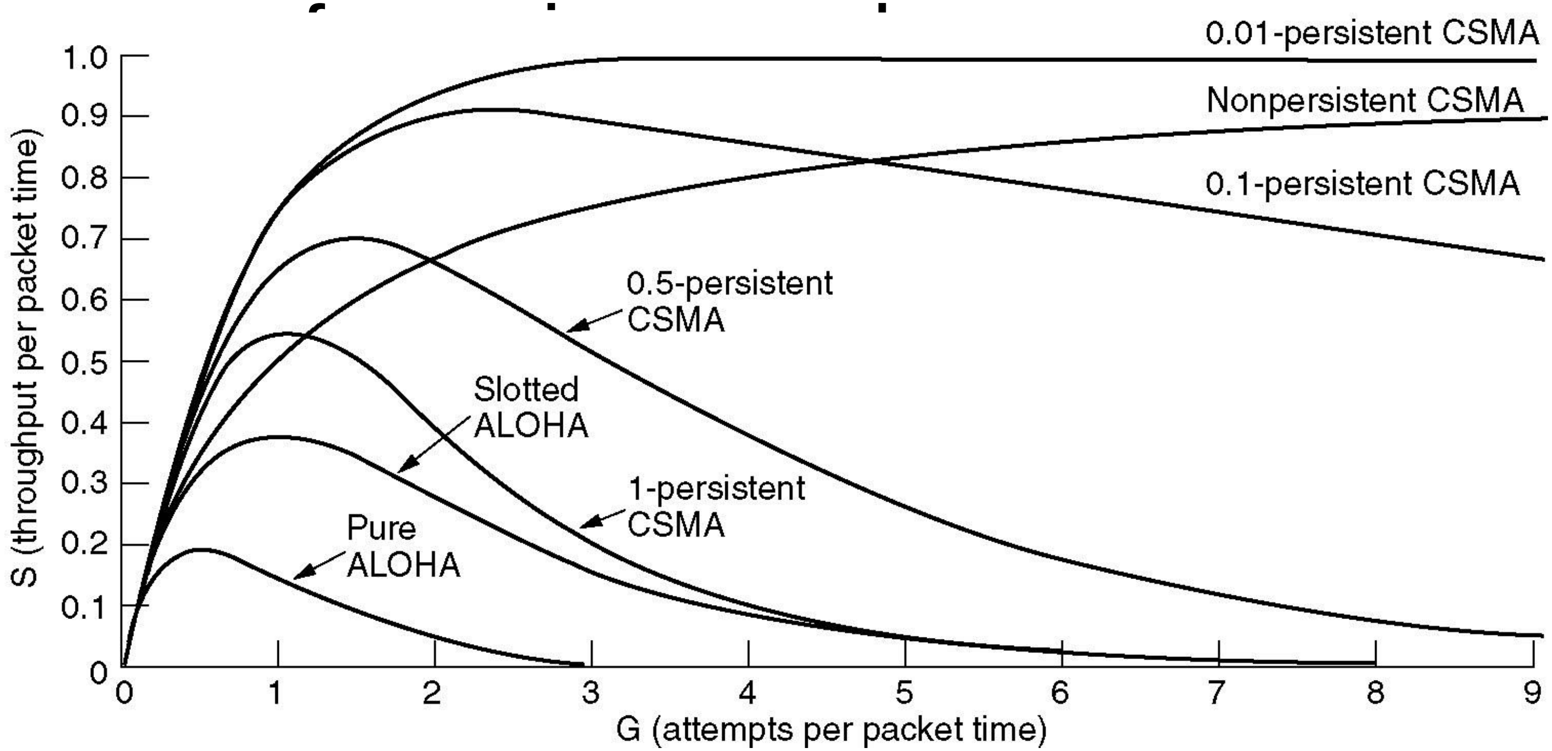


***1-persistent*:**
Transmit as soon as channel goes idle
If collision, back off and try again

p-persistent:
Transmit as soon as channel goes idle with probability *p*
Otherwise, delay one slot, repeat process

Persistent and Non-persistent CSMA

Comparison of throughput versus load



CSMA with Collision Detection

- Stations can sense the medium while transmitting
- A station aborts its transmission if it senses another transmission is also happening (that is, it detects collision)
- Quickly terminating damaged frames saves time and bandwidth.
- collisions can be declared by looking the power of received signal and compare with transmitting signals.

CSMA with Collision Detection

- Question : How long it will take them to realize that there has been a collision?

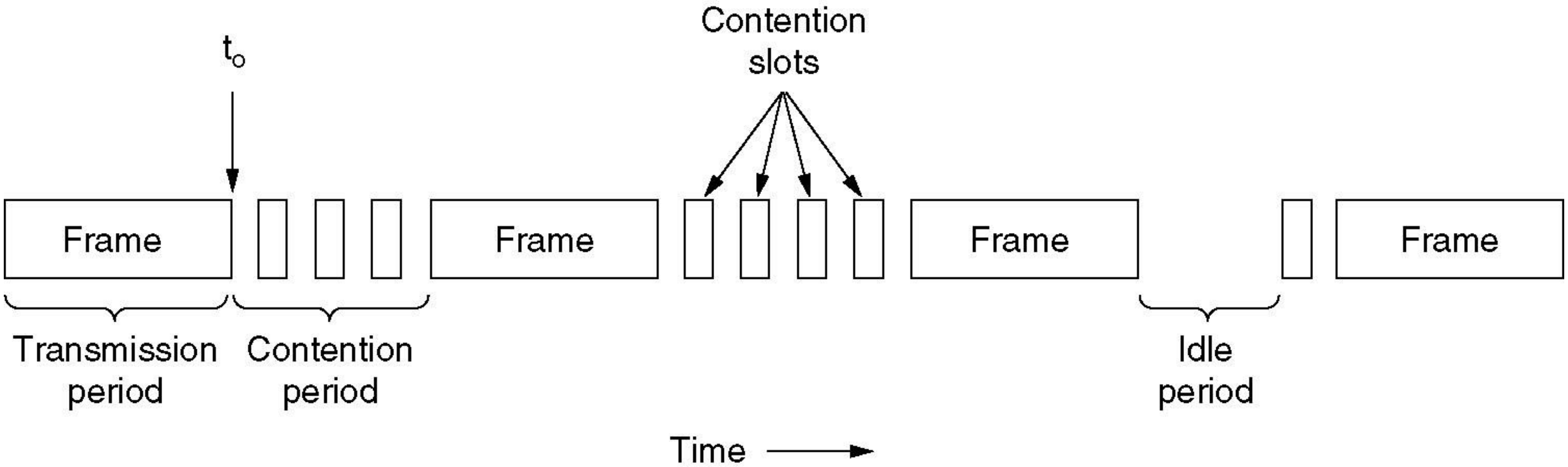
✓ Length of Contention Period, delay and Throughput .

✓ Time to detect the collision is just the time it takes the signal to propagate from one station to another station.

- Strategy

- Try to detect collisions as soon as possible.
  - Listen while transmitting.
  - If collision is detected, abort transmission.

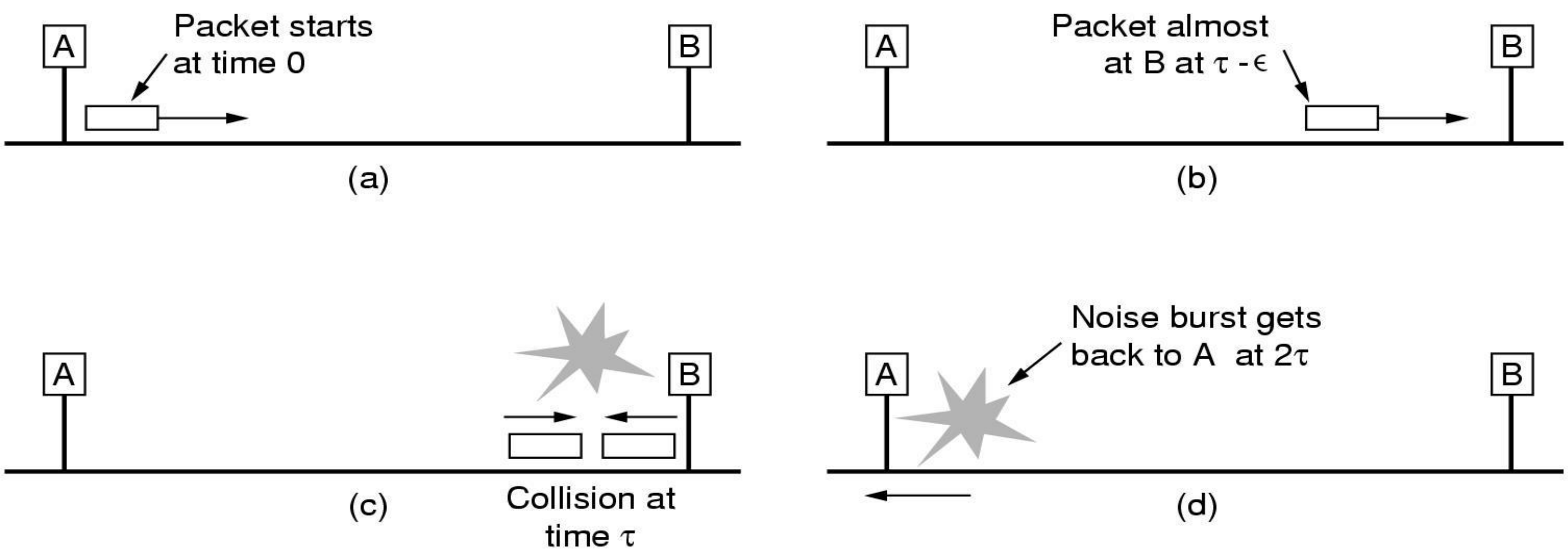
CSMA with Collision Detection



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

CSMA/CD

- A station is said to *seize* the channel if all the other stations become aware of its transmission.
- There has to be a lower bound on the length of each frame for the *collision detection* feature to work out.
- it used in Ethernet and uses half duplex.



CSMA-CD Model

- Assumptions
  - Collisions can be detected and resolved in $2t_{prop}$
  - Time slotted in $2t_{prop}$ slots during contention periods
  - Assume n busy stations, and each may transmit with probability p in each contention time slot
  - Once the contention period is over (a station successfully occupies the channel), it takes X seconds for a frame to be transmitted
  - It takes t_{prop} before the next contention period starts.

Contention Resolution

- How long does it take to resolve contention?
- Contention is resolved (“success’) if exactly 1 station transmits in a slot:

$$P_{success} = np(1 - p)^{n-1}$$

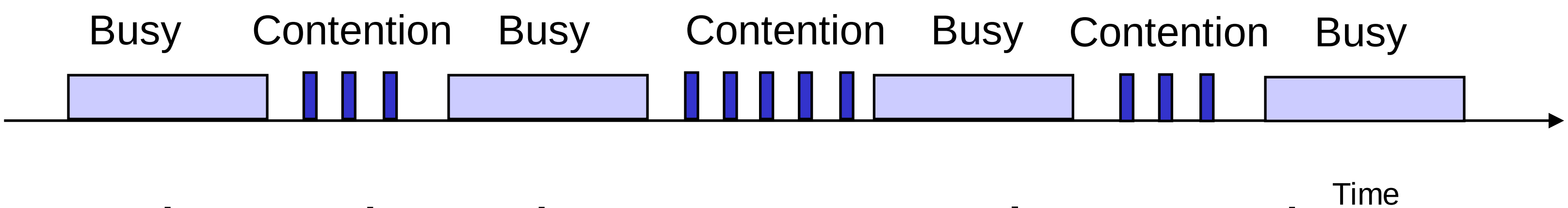
- By taking derivative of $P_{success}$ we find max occurs at p=1/n

$$P_{success}^{max} = n\frac{1}{n}(1 - \frac{1}{n})^{n-1} = (1 - \frac{1}{n})^{n-1} \rightarrow \frac{1}{e}$$

- On average, $1/P^{max} = e = 2.718$ time slots to resolve contention

$$\textbf{Average Contention Period} = 2t_{prop}e\ \textbf{seconds}$$

CSMA/CD Throughput



- At maximum throughput, systems alternates between contention periods and frame transmission times

$$\rho_{\max} = \frac{X}{X + t_{prop} + 2et_{prop}} = \frac{1}{1 + (2e+1)a}$$

- where:

  R bits/sec, L bits/frame, $X = L/R$ seconds/frame

  $a = t_{prop}/X$

  $2e+1 = 6.44$

CSMA/CA

- Identical to CSMA/CD but used when listening is not possible while transmitting
- Idle channel reservation is done by sending a short request message asking other nodes to defer transmission
- If collison is detected then, then random wait is used
- Wireless IEEE 802.11 uses CSMA/CA with an RTS/CTS mechanism

Collision Free Protocols

- Collisions will occurs in contention period in CSMA/CD.
- These collision will effect the system performance if the frames are short and large propagation.
- so we need a protocols, which are not supports the collision even in contention period. So those protocols are called collision free protocols.
- Assumptions :
- 1. There are exactly N- stations with unique address (0 – N-1) in networks.
- 2. Propagation Time is negligible.

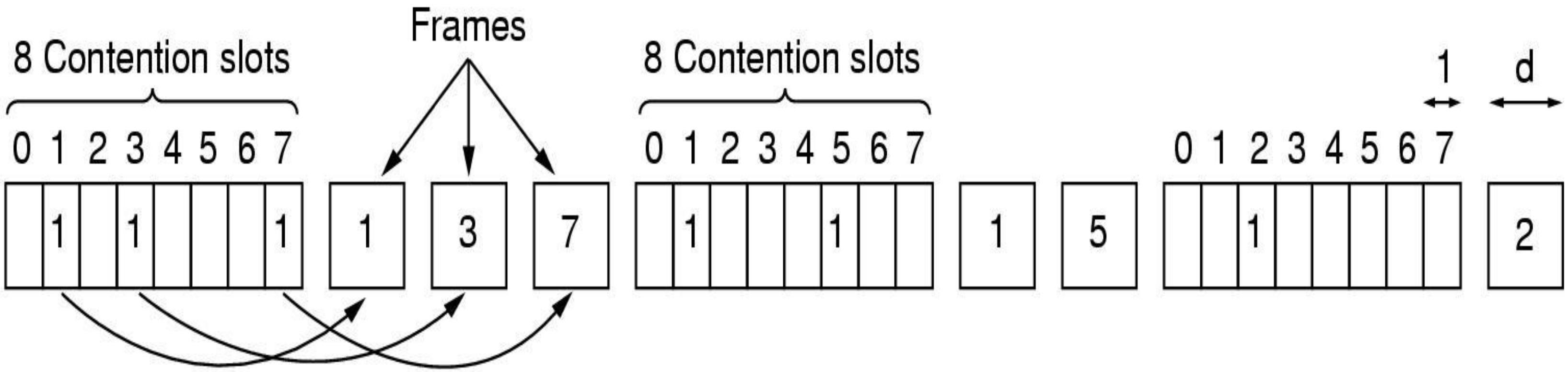
Bit Map Protocol

Basic Bit Map Protocol :

- Each Contention period consists of N slots exactly.
- If station - 0 has frame to send, it transmits a 1 bit during the zeroth slot. No other station allowed to transmit during this slot.
- so, generally , the stations has announced it willingness to transmission of frames by just inserting 1 bit in their corresponding slots of contention period.
- after the contention slots are over → all stations monitors → every one agrees on who goes next.
- Luck factor → station ready with frame, just after its slot in contention period.

Bit Map Protocol

- Problem : How would be second station come to know about its transmission turn. Transmission time may vary for each station.
- Example :



Bit Map Protocol - performance

- Low Numbered Stations : averagely it has to wait N/2 slots for current scan and N slots for the transmission of current slot.
- High numbered stations : it only 0.5N slots.
- so total mean is (1.5N + 0.5N) /2 = N
- Efficiency at low load → d/(N+d) d → data bits
- efficiency at high load → d/(d+1)

Bit Map Protocol - Problem

- No scalability
- Inefficiency at low load
- 1 bit overhead

Binary Countdown

- Each station is addressed by using binary format.
- If any station want to transmits data, it has to broadcast the bit string with higher order bits of address.
- The arbitration mechanism using BOOLEAN OR ing method to identify the next to acquire the channel.
- It assumed the transmission delays are negligible
- This approach used in DATAKIT network.

- The channel efficiency is d/(d+log N).
- Example --> 256 stations --> 8 bits --> 8 bit slots time

Limited Contention Protocol

- Contention protocols
    - @ low load → performance is good
    - @ high load → poor performance
- Collision Free Protocols
    - @ low load → high delay
    - @ high load → efficient channel utilization.
- combine best properties of these protocols → New protocol → Limited Contention Protocols.
-

Limited Contention Protocol

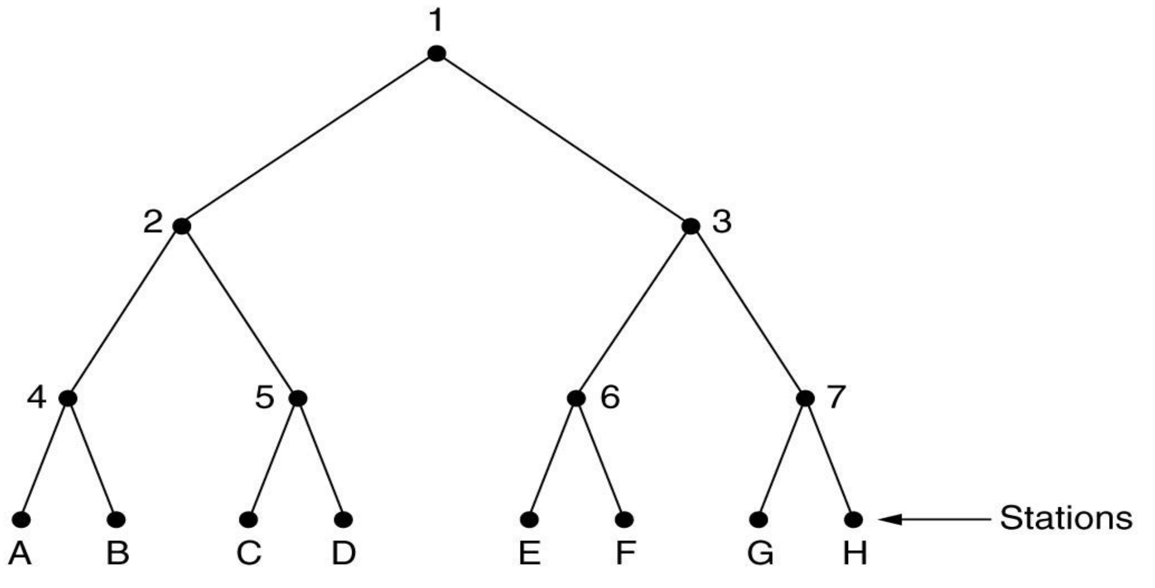
- Contention protocols may asymmetric → more channel utilizations.
- symmetric contention → every user has equal probability of access the channel.
- asymmetric → stations has different probabilities of access the channel.
- in symmetric → if # channel increased to five, its performance decreases.
- to avoid this situation → decrease the competation.

Limited Contention Protocol

- So Limited Contention Protocol → divide stations into groups.
- only corresponding members of the group are compete for channel during their slots.
- By making appropriate division of stations into groups→ contention in each slots can be reduced.
- Problem → how to assign stations to slots → grouping.
- Possibility → one station in a group (Binary Countdown)
- → 2 stations in a group → collisions affordable
- → more stations in group → collisions (ALOHA)

Limited Contention Protocol

- Adaptive Tree walk Protocol:
- algorithm devised by U.S Army.
- Assume stations are leaves of binary tree.



Limited Contention Protocol

- If collision occurred during slot -0 → entire tree is searched in depth first manner to locate all ready stations.
- each bit slot associated with particular node in tree.
- if collisions, search continues recursively with left and right children.
- it bit slot is idle or only one station transmits in it, search stops.

Limited Contention Protocol

- Where should we do search process at higher load in network → search starts at lower levels of the tree.
- let us take q # stations are ready. This information know by all station by monitoring the traffic.
- let us assume the level-0 at node -1
- each node at level – i has a fraction 2^{-l}
- expected # ready station under that level is $2^{-1}q$
- So search will be started at level $i = \log_2 q$
- improvements → skip the test @ node-3, (diagram)
-

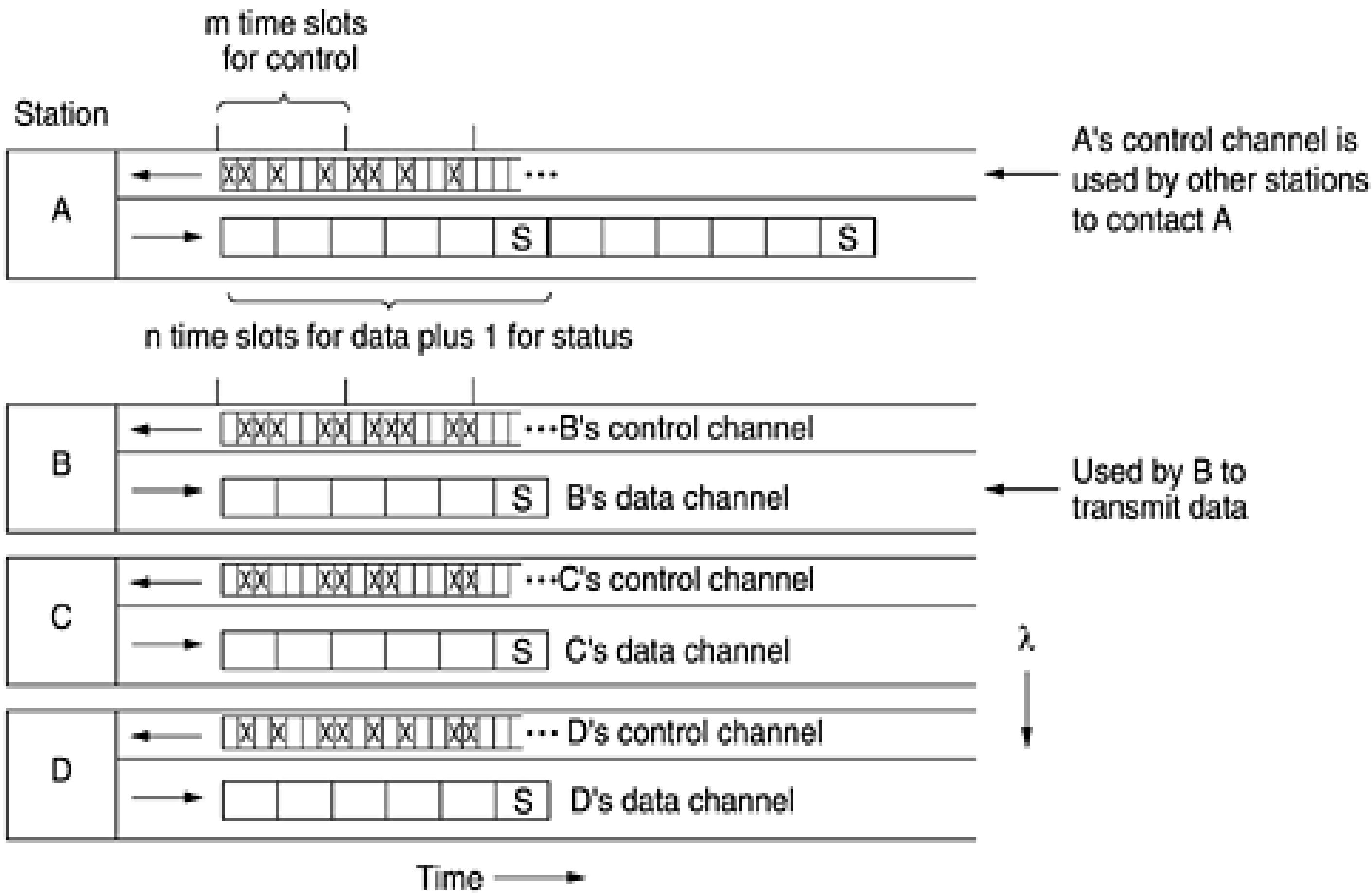
Wavelength Division Multi Access Protocols

- channel allocation → divide the channel into sub channels using FDM, TDM or both and dynamically allocate them as needed.
- used in optical LAN’s
- it uses a passive stat coupler.
- Two fibers from each station are fused into cylinder.
- one is for output to the cylinder and another input from cylinder.
- It can handle multiple stations as well.

Wavelength Division Multi Access Protocols

- Spectrum is divided into channels using WDMA
- each station is assigned two channels
- narrow channel → control signal
- wide channel → data frames
- each channel is divided in to groups of slots.
- control channel → m slots
- Data channel → n+1 slots → 1 specifies the status.
- All channels are synchronized by single global clock

Wavelength Division Multi Access Protocols



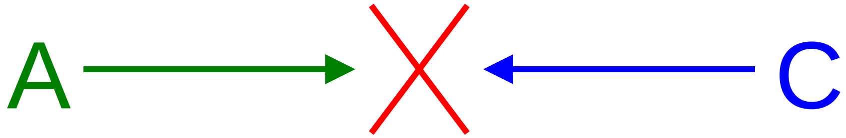
Wavelength Division Multi Access Protocols

- it supports three traffics
- 1. constant data rate connection oriented traffic
- 2. Variable data rate connection oriented traffic
- 3. datagram traffic
- Stations has 2 transmitters and 2 receivers
- Fixed wavelength receiver → listing own control msg
- tunable transmitter → transmitting control msg to other
- fixed wavelength transmitter → outputting data frames
- tunable receiver → selecting data transmitter to listen

Wireless LAN Protocols

- Assume radio Transmitters has fixed range.
- User (receiver) in two ranges of active transmitters → problem → signal garbled and useless
- Problem → all stations are not in one range.
- so it is not useful to use CDMA.
- another approach → CAMA..
- Problems → Hidden Terminal and Exposed Terminal

Hidden Terminal Problem



Nodes placed a little less than one radio range apart

CSMA: nodes listen to determine channel idle before transmitting

C can’t hear A, so will transmit while A transmits; result: collision at B

Carrier Sense insufficient to detect all transmissions on wireless networks!

Key insight: collisions are spatially located at receiver

Exposed Terminal Problem

Two flows, this time B sends to A; C sends to a node other than B

If C transmits, does it cause a collision at A?

Yet C will refuse to transmit while B transmits to A!

Same insight: collisions are spatially located at receiver

Thinking ahead: implications for multi-hop forwarding?

One possibility: directional antennas

Simpler solution: use *receiver's* medium state to determine transmitter behavior

Contention-based protocols

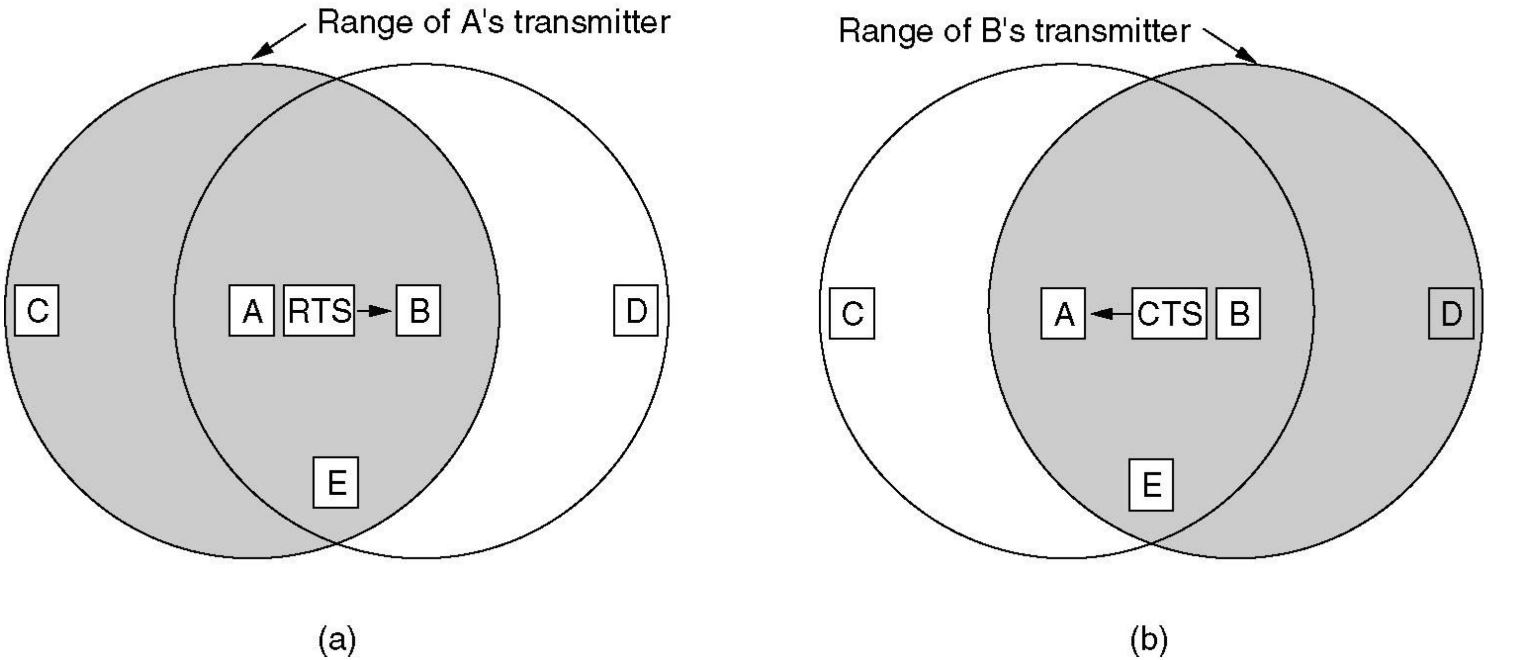
MACAW: A Media Access Protocol for Wireless LANs is based on MACA (Multiple Access Collision Avoidance) Protocol

MACA

- When a node wants to transmit a data packet, it first transmit a **RTS** (**Request To Send)** frame.
- The receiver node, on receiving the RTS packet, if it is ready to receive the data packet, transmits a **CTS (Clear to Send)** packet.
- Once the sender receives the CTS packet without any error, it starts transmitting the data packet.
- If a packet transmitted by a node is lost, the node uses the binary exponential back-off (BEB) algorithm to back off a random interval of time before retrying.

The binary exponential back-off mechanism used in MACA might starves flows sometimes. The problem is solved by MACAW.

MACA Protocol



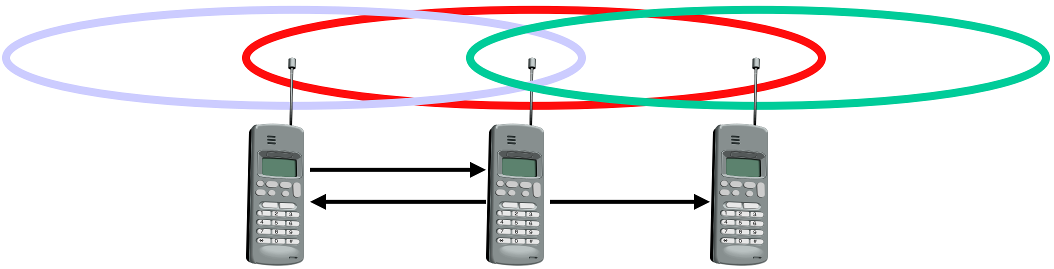
The MACA protocol. (a) A sending an RTS to B.

(b) B responding with a CTS to A.

MACA examples

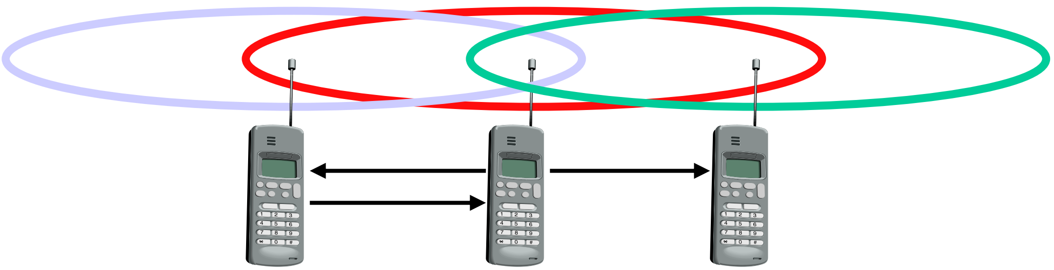
MACA avoids the problem of hidden terminals

- A and C want to send to B
- A sends RTS first
- C waits after receiving CTS from B



MACA avoids the problem of exposed terminals

- B wants to send to A, C to another terminal
- now C does not have to wait for it cannot receive CTS from A



MACAW

Variants of this method can be found in IEEE 802.11 as DFWMAC (Distributed Foundation Wireless MAC),

MACAW (MACA for Wireless) is a revision of MACA.

- The sender senses the carrier to see and transmits a **RTS** (**Request To Send)** frame if no nearby station transmits a RTS.
- The receiver replies with a **CTS** (**Clear To Send**) frame.
- Neighbors
  - see CTS, then keep quiet.
  - see RTS but not CTS, then keep quiet until the CTS is back to the sender.
- The receiver sends an ACK when receiving an frame.
  - Neighbors keep silent until see ACK.
- Collisions
  - There is no collision detection.
  - The senders know collision when they don’t receive CTS.
  - They each wait for the exponential backoff time.