Chapter 3: The Data Link Layer

Our goals:

- understand principles behind data link layer services:
  - framing
  - error detection, correction
  - reliable data transfer
  - sharing a broadcast channel: multiple access

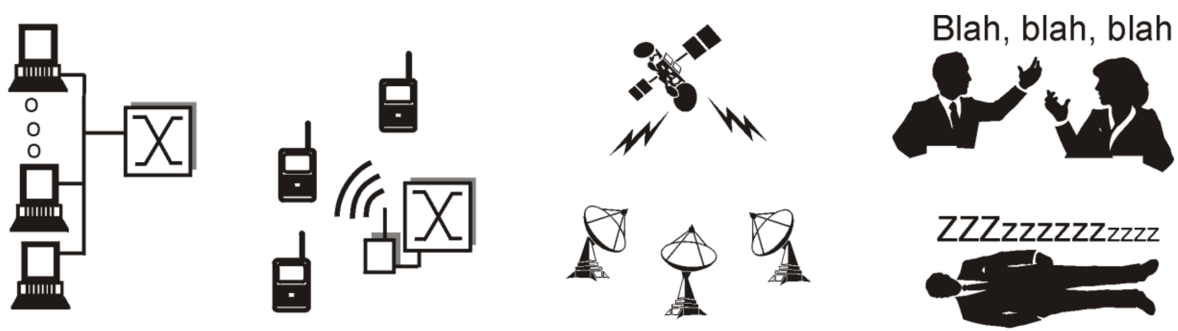
Overview:

- link layer services
- framing
- error detection, correction
- reliable data transfer
- multiple access protocols

Multiple Access Links and Protocols

Three types of "links":

- point-to-point (single wire, e.g. PPP, SLIP)
- broadcast (shared wire or medium; e.g, Ethernet, Wavelan, etc.)



shared wire (e.g. Ethernet) | shared wireless (e.g. Wavelan) | satellite | cocktail party

- switched (e.g., switched Ethernet, ATM etc)

Multiple Access protocols

- single shared communication channel
- two or more simultaneous transmissions by nodes: interference
  - only one node can send successfully at a time
- *multiple access protocol:*
  - distributed algorithm that determines how stations share channel, i.e., determine when station can transmit
  - communication about channel sharing must use channel itself!
  - what to look for in multiple access protocols:
    - synchronous or asynchronous
    - information needed about other stations
    - robustness (e.g., to channel errors)
    - performance

Multiple Access protocols

- claim: humans use multiple access protocols all the time
- class can "guess" multiple access protocols
  - multiaccess protocol 1:
  - multiaccess protocol 2:
  - multiaccess protocol 3:
  - multiaccess protocol 4:

MAC Protocols: a taxonomy

Three broad classes:

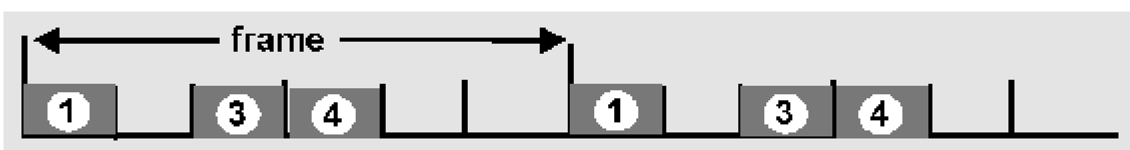
- Channel Partitioning
  - divide channel into smaller "pieces" (time slots, frequency)
  - allocate piece to node for exclusive use
- Random Access
  - allow collisions
  - "recover" from collisions
- **"Taking turns"**
  - tightly coordinate shared access to avoid collisions

Goal: efficient, fair, simple, decentralized

Channel Partitioning MAC protocols: TDMA

TDMA: time division multiple access

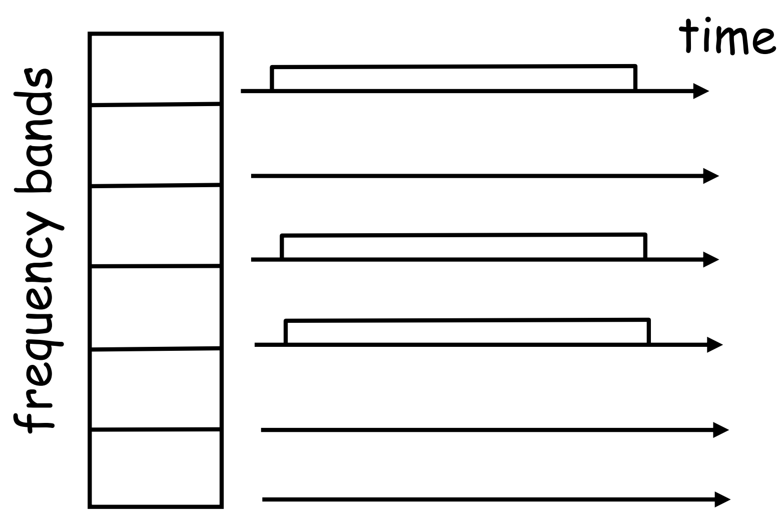
- access to channel in "rounds"
- each station gets fixed length slot (length = pkt trans time) in each round
- unused slots go idle
- example: 6-station LAN, 1,3,4 have pkt, slots 2,5,6 idle



Channel Partitioning MAC protocols: FDMA

FDMA: frequency division multiple access

- channel spectrum divided into frequency bands
- each station assigned fixed frequency band
- unused transmission time in frequency bands go idle
- example: 6-station LAN, 1,3,4 have pkt, frequency bands 2,5,6 idle



Channel Partitioning (CDMA)

CDMA (Code Division Multiple Access)

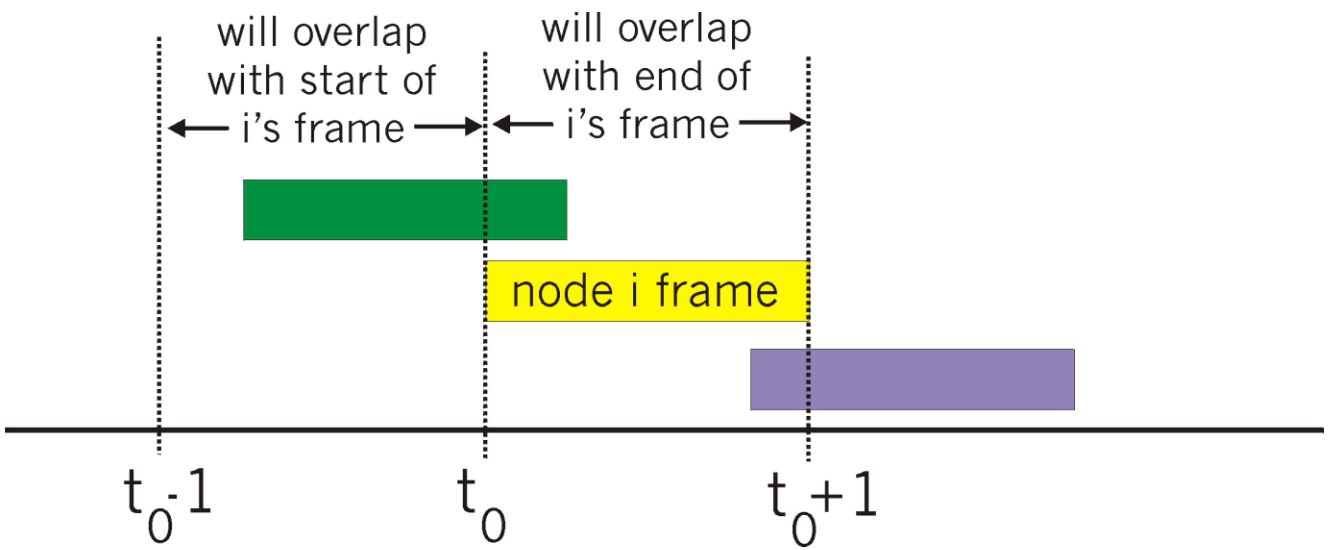
- unique "code" assigned to each user; ie, code set partitioning
- used mostly in wireless broadcast channels (cellular, satellite,etc)
- all users share same frequency, but each user has own "chipping" sequence (ie, code) to encode data
- *encoded signal* = (original data) X (chipping sequence)
- *decoding:* inner-product of encoded signal and chipping sequence
- allows multiple users to "coexist" and transmit simultaneously with minimal interference (if codes are "orthogonal")

Random Access protocols

- When node has packet to send
  - transmit at full channel data rate R.
  - no *a priori* coordination among nodes
- two or more trasnmitting nodes -> "collision",
- random access MAC protocol specifies:
  - how to detect collisions
  - how to recover from collisions (e.g., via delayed retransmissions)
- Examples of random access MAC protocols:
  - ALOHA
  - slotted ALOHA
  - CSMA and CSMA/CD

Pure ALOHA

- unslotted Aloha: simpler, no synchronization
- pkt needs transmission:
  - send without awaiting for beginning of slot
- collision probability increases:
  - pkt sent at t_0 collide with other pkts sent in $[t_0-1, t_0+1]$



Pure Aloha (cont.)

P(success by given node) = P(node transmits) $\cdot$

P(no other node transmits in $[p_0-1, p_0]$ $\cdot$

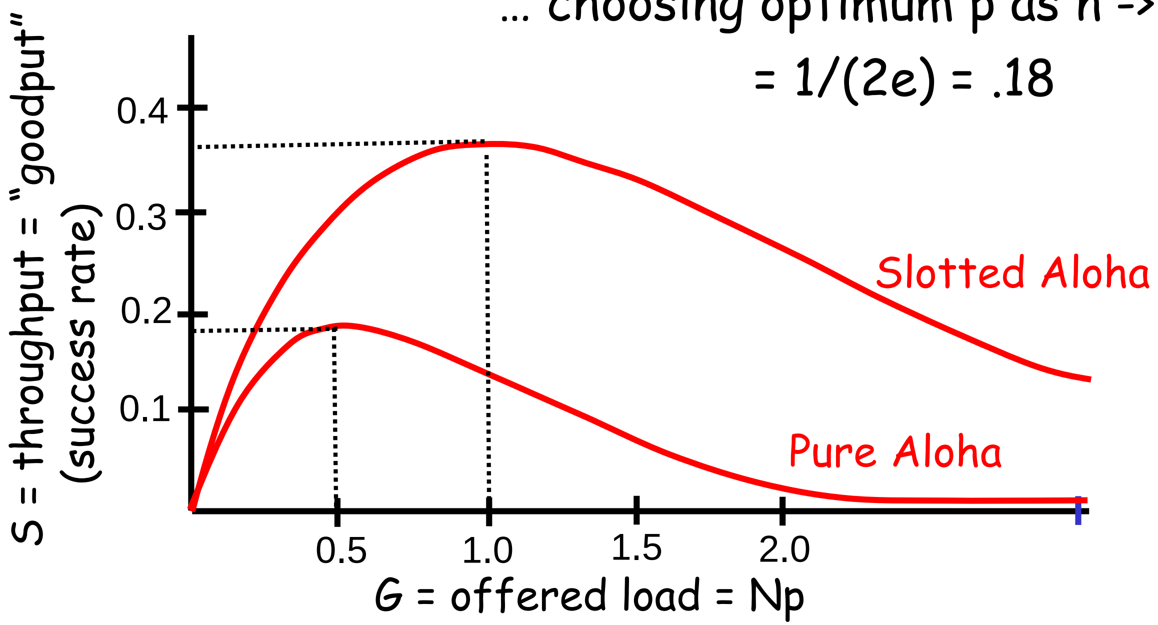
P(no other node transmits in $[p_0, p_0+1]$

$= p \cdot (1-p)^{N-1} \cdot (1-p)^{N-1} = p \cdot (1-p)^{2(N-1)}$

P(success by any node) $= Np(1-p)^{2(N-1)}$

… choosing optimum p as n -> infinity

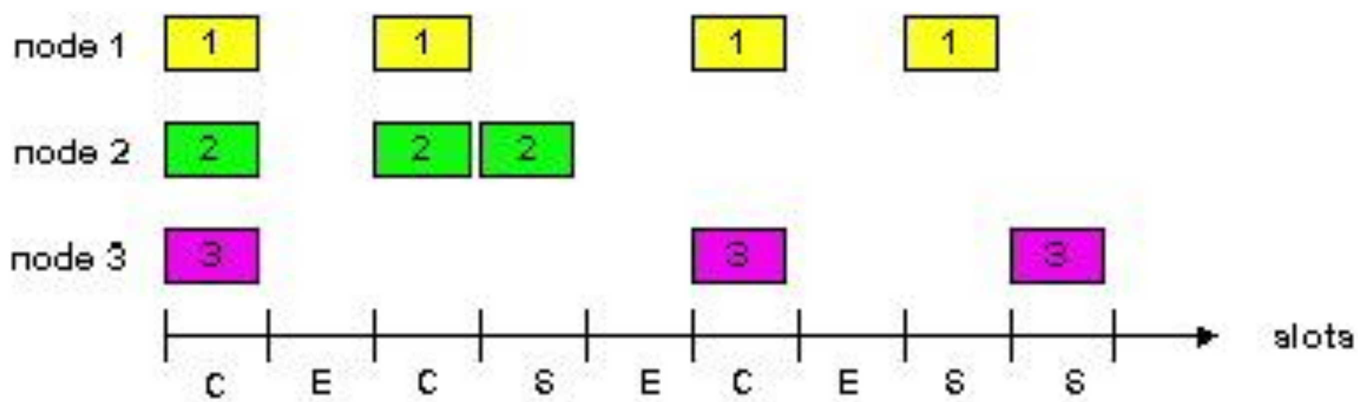
= 1/(2e) = .18



protocol constrains effective channel throughput!

Slotted Aloha

- time is divided into equal size slots (= pkt trans. time)
- node with new arriving pkt: transmit at beginning of next slot
- if collision: retransmit pkt in future slots with probability p, until successful.



Success (S), Collision (C), Empty (E) slots

Slotted Aloha efficiency

Q: what is max fraction slots successful?

A: Suppose N stations have packets to send

- each transmits in slot with probability *p*
- prob. successful transmission *S* is:

by single node: $S = p\,(1-p)^{(N-1)}$

by any of N nodes

S = Prob (only one transmits)

$= N\,p\,(1-p)^{(N-1)}$

… choosing optimum p as n -> infty …

$= 1/e = .37$ *as N -> infty*

At best: channel use for useful transmissions 37% of time!

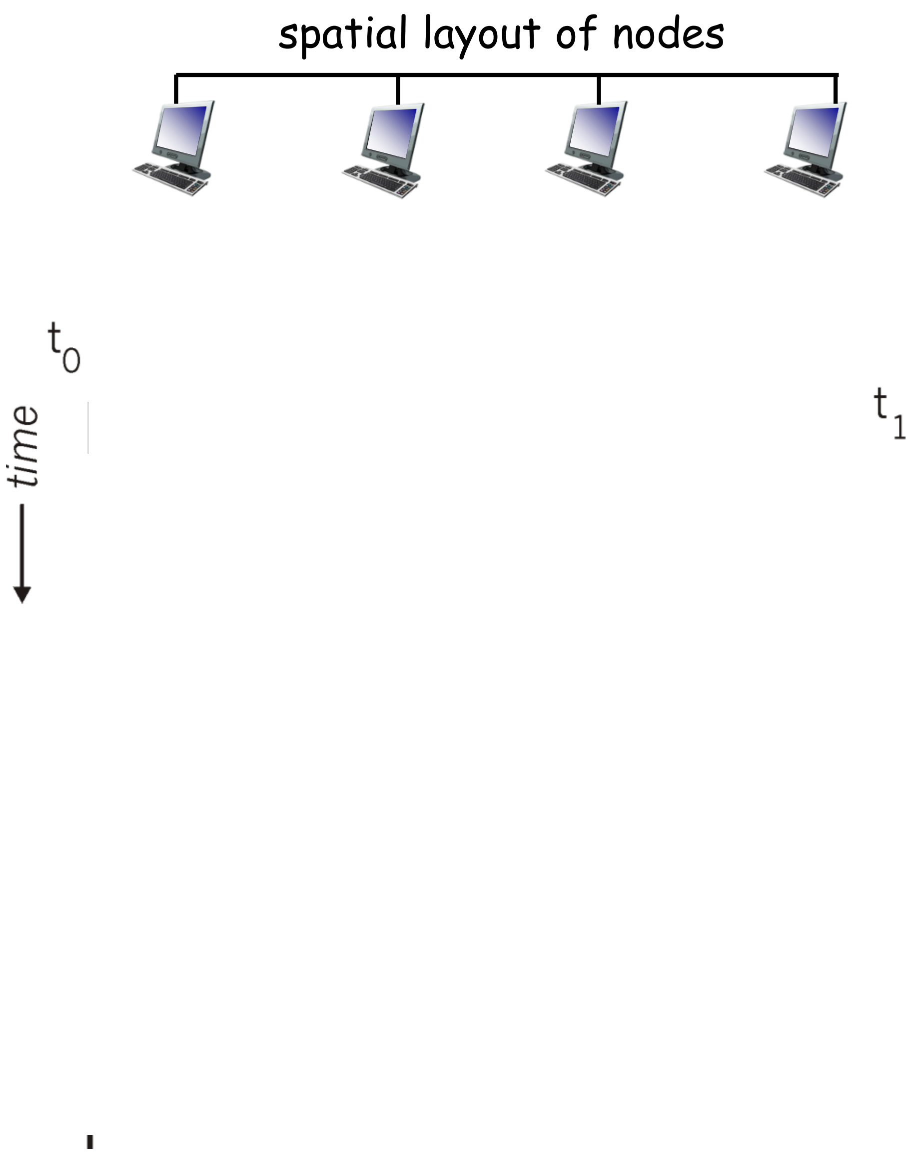
CSMA: Carrier Sense Multiple Access

CSMA: listen before transmit:

- If channel sensed idle: transmit entire pkt
- If channel sensed busy: defer transmission
  - Persistent CSMA: retry immediately with probability p when channel becomes idle (may cause instability)
  - Non-persistent CSMA: retry after random interval
- human analogy: don't interrupt others!

CSMA collisions

- collisions can still occur: propagation delay means two nodes may not hear each other's transmission
- collision: entire packet transmission time wasted
  - distance & propagation delay play role in in determining collision probability

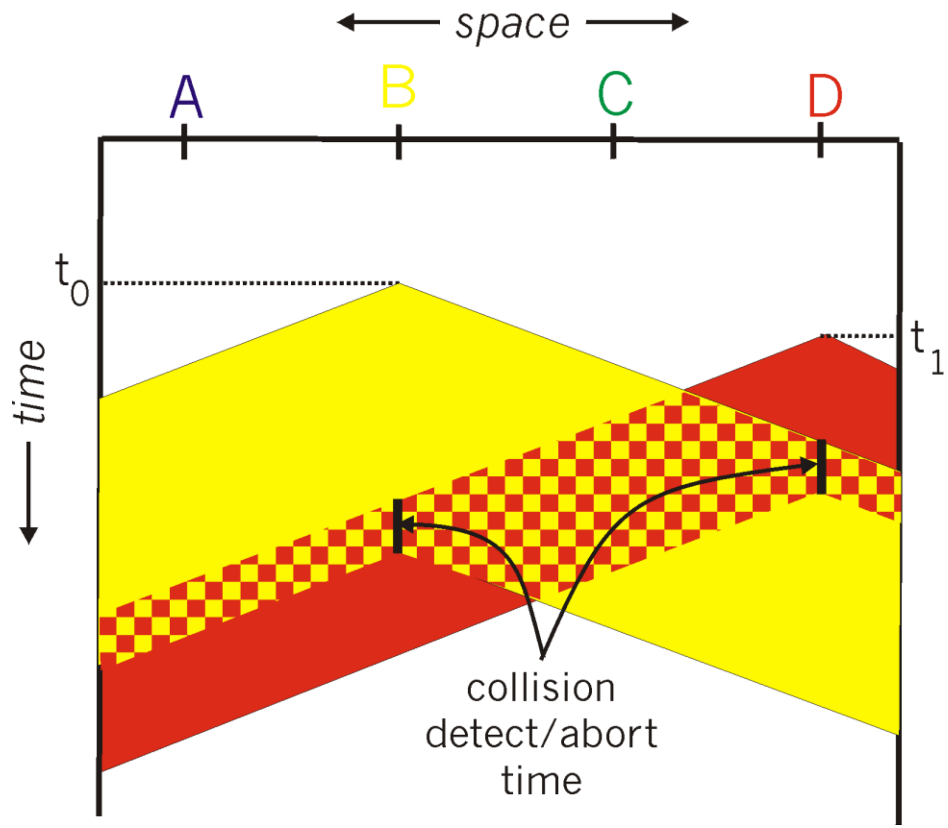


CSMA/CD (Collision Detection)

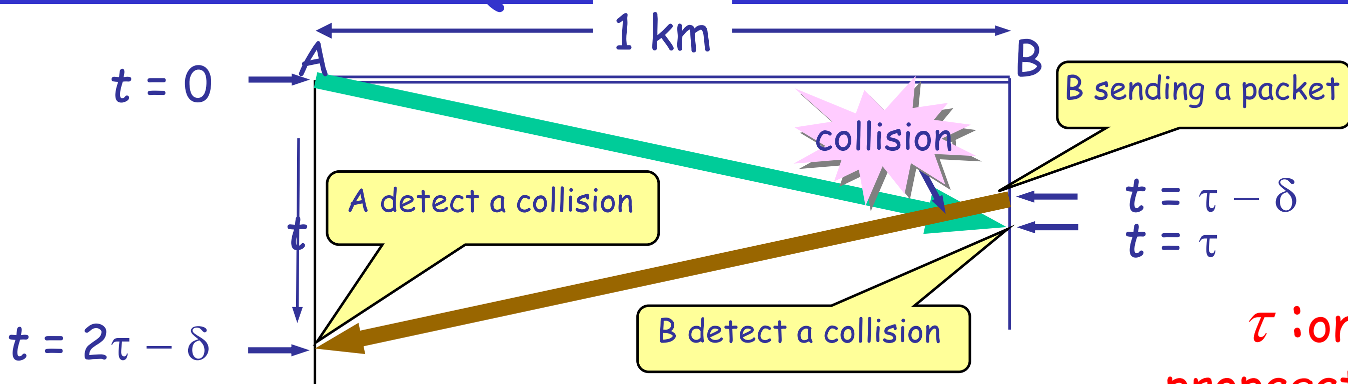
CSMA/CD: carrier sensing, deferral as in CSMA
- collisions *detected* within short time
- colliding transmissions aborted, reducing channel wastage
- persistent or non-persistent retransmission

- collision detection:
  - easy in wired LANs: measure signal strengths, compare transmitted, received signals
  - difficult in wireless LANs: receiver shut off while transmitting
- human analogy: the polite conversationalist

CSMA/CD collision detection

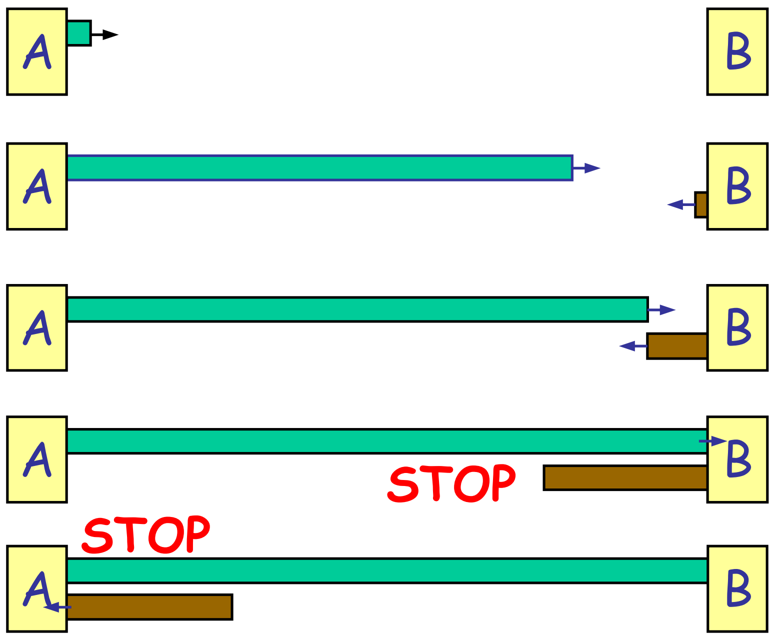


CSMA/CD (Collision Detection)



τ :one way propagation delay

$t = 0$, A find that the channel is idle, then sending data



$t = \tau - \delta$
B find that the channel is idle, then sending data

$t = \tau - \delta / 2$
collision

$t = \tau$
B detect the collision, then stop sending

$t = 2\tau - \delta$
A detect the collision, then stop sending

2τ :Contention Period

CSMA/CD efficiency

- T_{prop} = max prop delay between 2 nodes in LAN
- t_{trans} = time to transmit max-size frame

$$efficiency = \frac{1}{1 + 5t_{prop}/t_{trans}}$$

- efficiency goes to 1
  - as t_{prop} goes to 0
  - as t_{trans} goes to infinity
- better performance than ALOHA: and simple, cheap, decentralized!

"Taking Turns" MAC protocols

channel partitioning MAC protocols:

- share channel efficiently at high load
- inefficient at low load: delay in channel access, 1/N bandwidth allocated even if only 1 active node!

Random access MAC protocols

- efficient at low load: single node can fully utilize channel
- high load: collision overhead

"taking turns" protocols

look for best of both worlds!

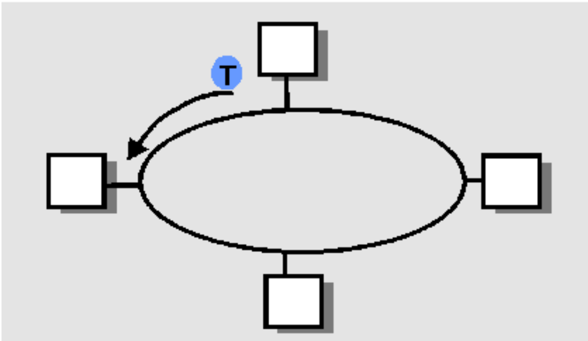
"Taking Turns" MAC protocols

Polling:

- master node "invites" slave nodes to transmit in turn
- Request to Send, Clear to Send msgs
- concerns:
  - polling overhead
  - latency
  - single point of failure (master)

Token passing:

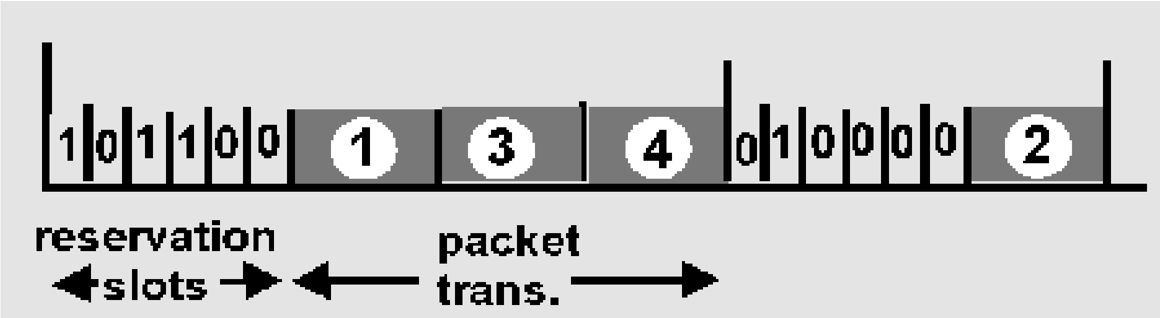
- control **token** passed from one node to next sequentially.
- token message
- concerns:
  - token overhead
  - latency
  - single point of failure (token)



Reservation-based protocols

Distributed Polling:

- time divided into slots
- begins with N short reservation slots
  - reservation slot time equal to channel end-end propagation delay
  - station with message to send posts reservation
  - reservation seen by all stations
- after reservation slots, message transmissions ordered by known priority



Summary of MAC protocols

- What do you do with a shared media?
  - Channel Partitioning, by time, frequency or code
    - Time Division,Code Division, Frequency Division
  - Random partitioning (dynamic),
    - ALOHA, S-ALOHA, CSMA, CSMA/CD
    - carrier sensing: easy in some technoligies (wire), hard in others (wireless)
    - CSMA/CD used in Ethernet
  - Taking Turns
    - polling from a central cite, token passing

Chapter 3: Summary

- principles behind data link layer services:
  - framing
  - error detection, correction
  - reliable data transfer
  - sharing a broadcast channel: multiple access
- Next, various link layer technologies
  - LAN model
  - Ethernet
  - WLAN