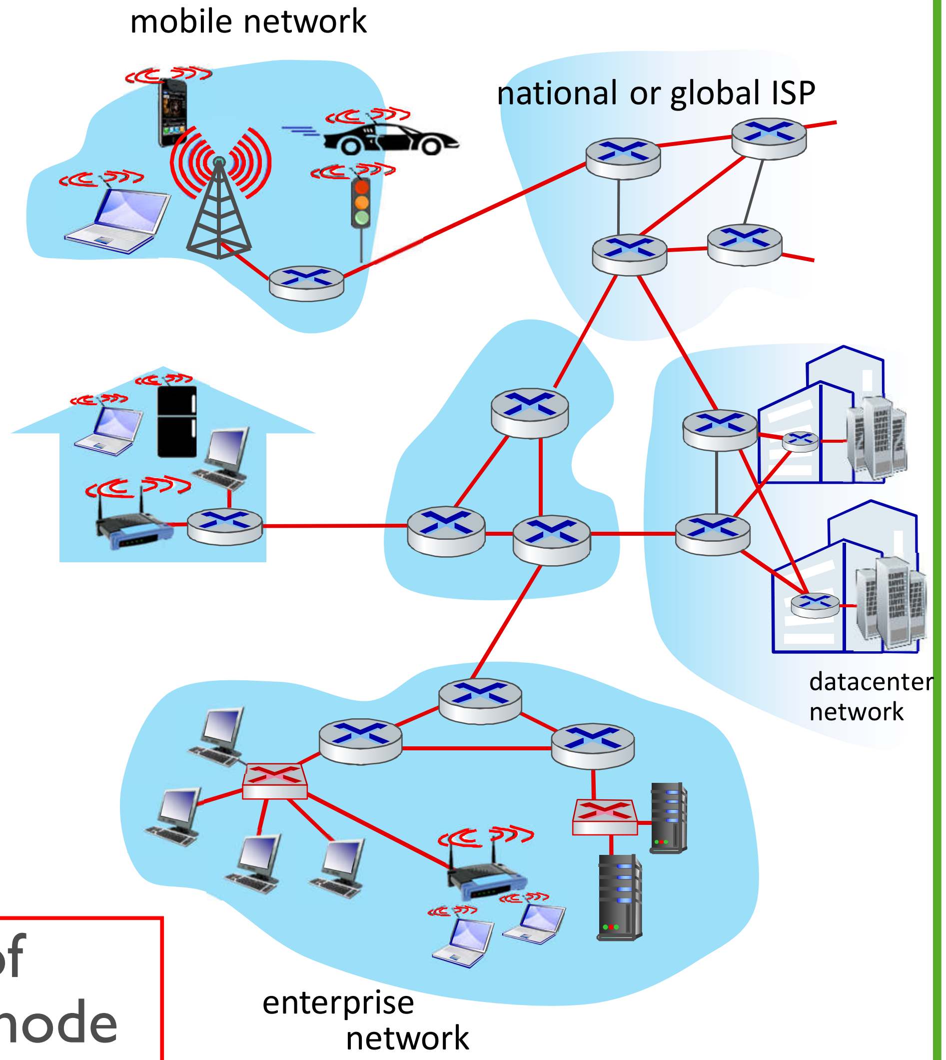
Computer Networks
Chap 6 Link Layer
P1

Computer Networking: A Top-Down Approach
8^{th} edition, Global Edition
Jim Kurose, Keith Ross

Link layer: introduction

terminology:

- **hosts and routers: nodes**
- **communication channels that connect adjacent nodes along communication path: links**
  - wired links
  - wireless links
  - LANs
- **layer-2 packet: frame, encapsulates datagram**



data-link layer has responsibility of transferring datagram from one node to *physically adjacent* node over a link

Link layer: context

- **datagram transferred by different link protocols over different links:**
  - e.g., Ethernet on first link, frame relay on intermediate links, 802.11 on last link
- **each link protocol provides different services**
  - e.g., may or may not provide rdt over link

transportation analogy:

- **trip from Princeton to Lausanne**
  - limo: Princeton to JFK
  - plane: JFK to Geneva
  - train: Geneva to Lausanne
- **tourist = datagram**
- **transport segment = communication link**
- **transportation mode = link layer protocol**
- **travel agent = routing algorithm**

Link layer services

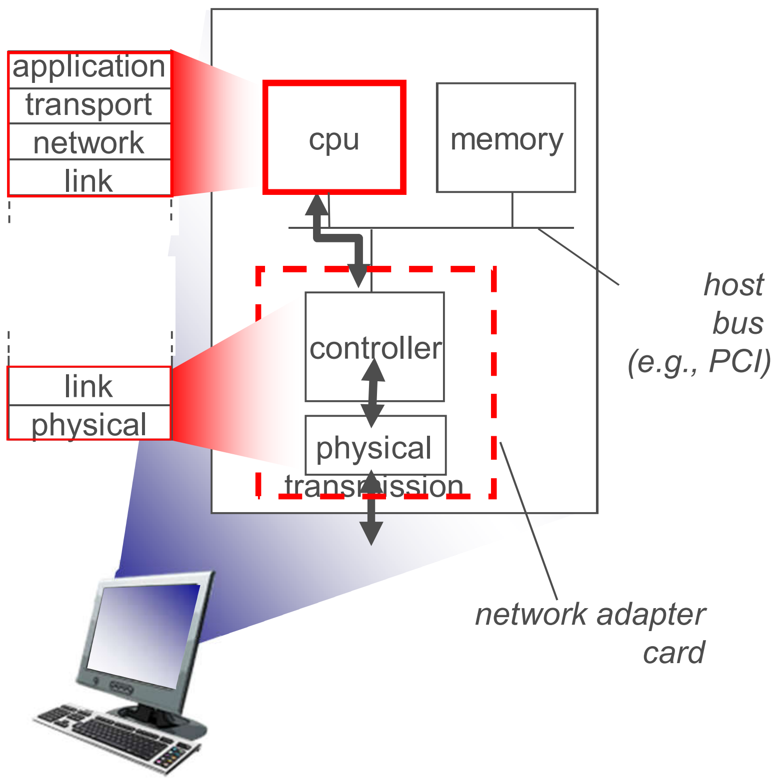
- ***framing, link access:***
  - encapsulate datagram into frame, adding header, trailer
  - channel access if shared medium
  - "MAC" addresses (Media Access Control) used in frame headers to identify source, destination
    - different from IP address!
- ***reliable delivery between adjacent nodes***
  - we learned how to do this already
  - seldom used on low bit-error link (fiber, twisted pair)
  - wireless links: high error rates
    - *Q:* why both link-level and end-end reliability?

Link layer services (more)

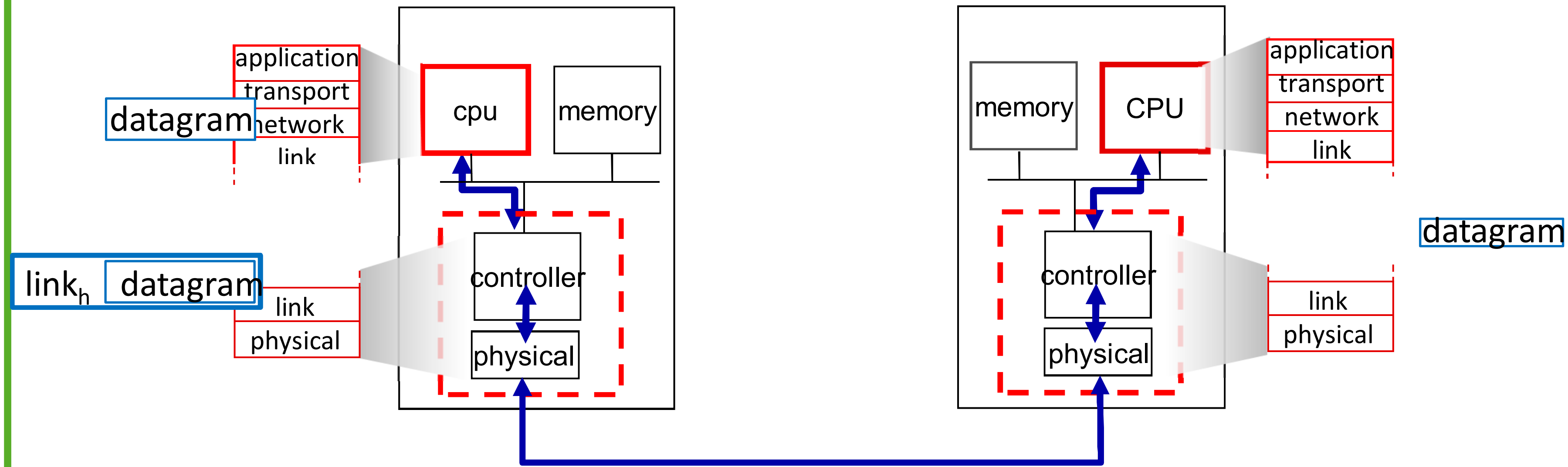
- ***flow control:***
  - pacing between adjacent sending and receiving nodes
- ***error detection:***
  - errors caused by signal attenuation, noise.
  - receiver detects presence of errors:
    - signals sender for retransmission or drops frame
- ***error correction:***
  - receiver identifies *and corrects* bit error(s) without resorting to retransmission
- ***half-duplex and full-duplex***
  - with half duplex, nodes at both ends of link can transmit, but not at same time

Where is the link layer implemented?

- in each and every host
- link layer implemented in "adaptor" (aka ***network interface card*** NIC) or on a chip
  - Ethernet card, 802.11 card; Ethernet chipset
  - implements link, physical layer
- attaches into host's system buses
- combination of hardware, software, firmware



Adaptors communicating



- **sending side:**
  - encapsulates datagram in frame
  - adds error checking bits, reliable data transfer, flow control, etc.
- **receiving side**
  - looks for errors, reliable data transfer, flow control, etc.
  - extracts datagram, passes to upper layer at receiving side

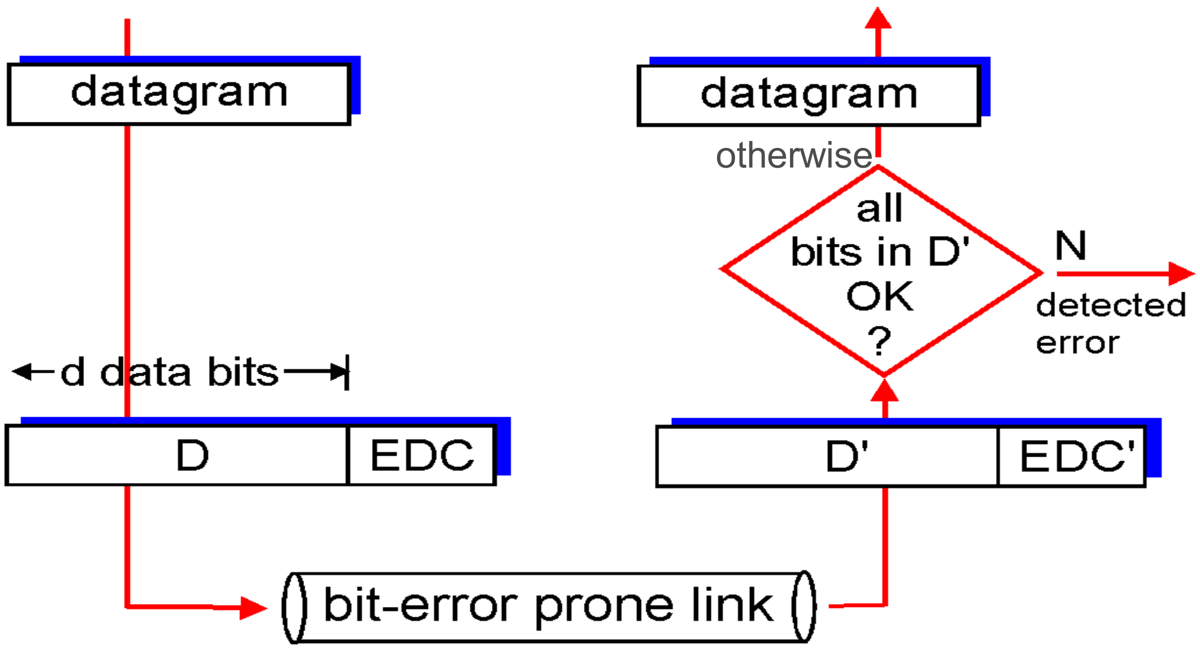
Link layer, LANs: outline

error detection, correction

Error detection

EDC= Error Detection and Correction bits (redundancy)
D = Data protected by error checking, may include header fields

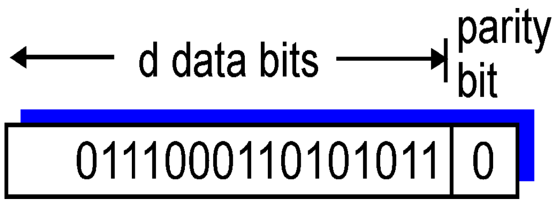
- Error detection not 100% reliable!
  - protocol may miss some errors, but rarely
  - larger EDC field yields better detection and correction



Parity checking

single bit parity:

- detect single bit errors



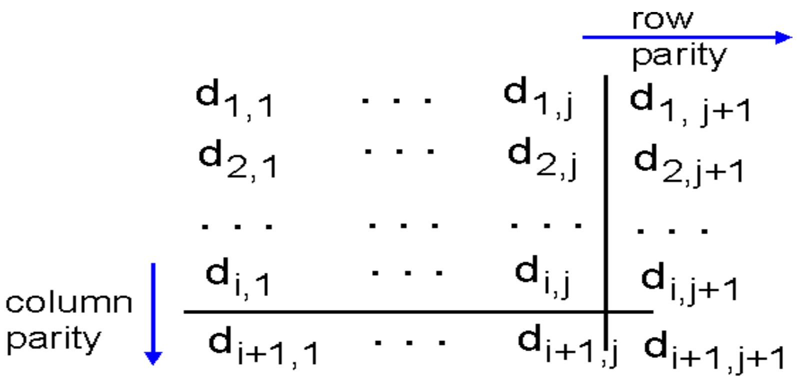
Even/odd parity: set parity bit so there is an even/odd number of 1's

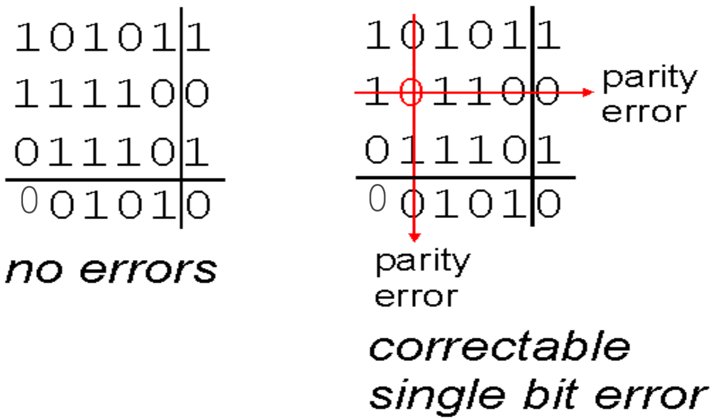
At receiver:

- compute parity of *d* received bits
- compare with received parity bit – if different than error detected

two-dimensional bit parity:

- detect and correct single bit errors





Internet checksum (review)

goal: detect "errors" (e.g., flipped bits) in transmitted packet (note: used at transport layer only)

sender:

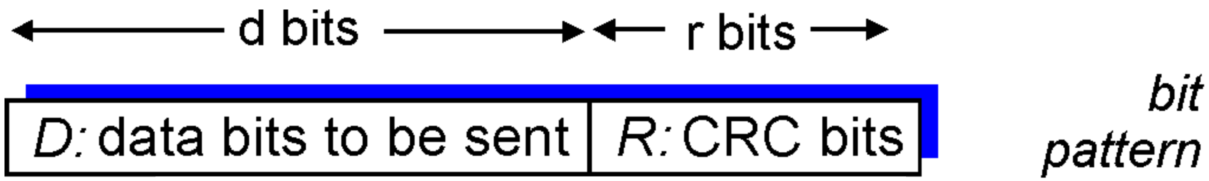
- **treat segment contents as sequence of 16-bit integers**
- **checksum: addition (1's complement sum) of segment contents**
- **sender puts checksum value into UDP checksum field**

receiver:

- **compute checksum of received segment**
- **check if computed checksum equals checksum field value:**
  - NO - error detected
  - YES - no error detected. *But maybe errors nonetheless?*

Cyclic redundancy check

- **more powerful error-detection coding**
- **view data bits, D, as a binary number**
- **G: bit pattern (generator), of r+1 bits (given, specified in CRC standard)**
- **goal: choose r CRC bits, R, such that**
  - <D,R> exactly divisible by G (modulo 2)
  - receiver knows G, divides <D,R> by G. If non-zero remainder: error detected!
  - can detect all burst errors less than r+1 bits



$$R = remainder[\frac{D \cdot 2^r}{G}]$$

Link layer, LANs: outline

multiple access protocols

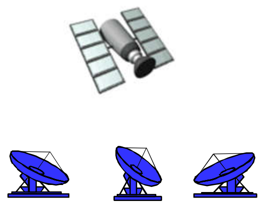
Multiple access links, protocols

two types of "links":

- **point-to-point**
  - PPP for dial-up access
  - point-to-point link between Ethernet switch, host
- ***broadcast (shared wire or medium)***
  - old-fashioned Ethernet
  - upstream hybrid fiber-coaxial (HFC)
  - 802.11 wireless LAN

shared wire (e.g., cabled Ethernet)

shared RF (e.g., 802.11 WiFi)



shared RF (satellite)

humans at a cocktail party (shared air, acoustical)

Multiple access protocols

- single shared broadcast channel
- two or more simultaneous transmissions by nodes: interference
  - *collision* if node receives two or more signals at the same time

multiple access protocol

- distributed algorithm that determines how nodes share channel, i.e., determine when node can transmit
- communication about channel sharing must use channel itself!
  - no out-of-band channel for coordination

An ideal multiple access protocol

given: **broadcast channel of rate R bps**

desiderata:

1. when one node wants to transmit, it can send at rate R.
2. when M nodes want to transmit, each can send at average rate R/M
3. fully decentralized:
   - no special node to coordinate transmissions
   - no synchronization of clocks, slots
4. simple

Media Access Control (MAC) protocols: taxonomy

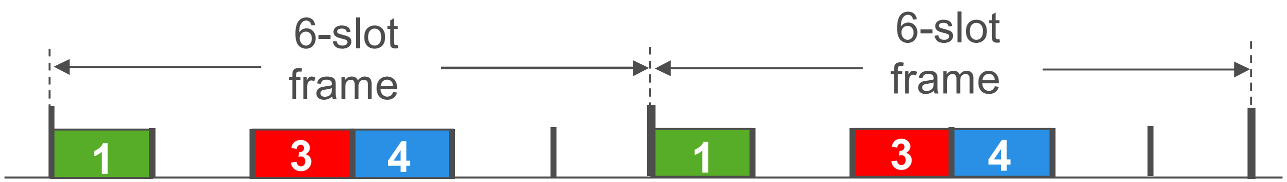
three broad classes:

- ***channel partitioning***
  - divide channel into smaller "pieces" (time slots, frequency, code)
  - allocate piece to node for exclusive use
- ***random access***
  - channel not divided, allow collisions
  - "recover" from collisions
- ***"taking turns"***
  - nodes take turns, but nodes with more to send can take longer turns

Channel partitioning MAC protocols: TDMA

TDMA: time division multiple access

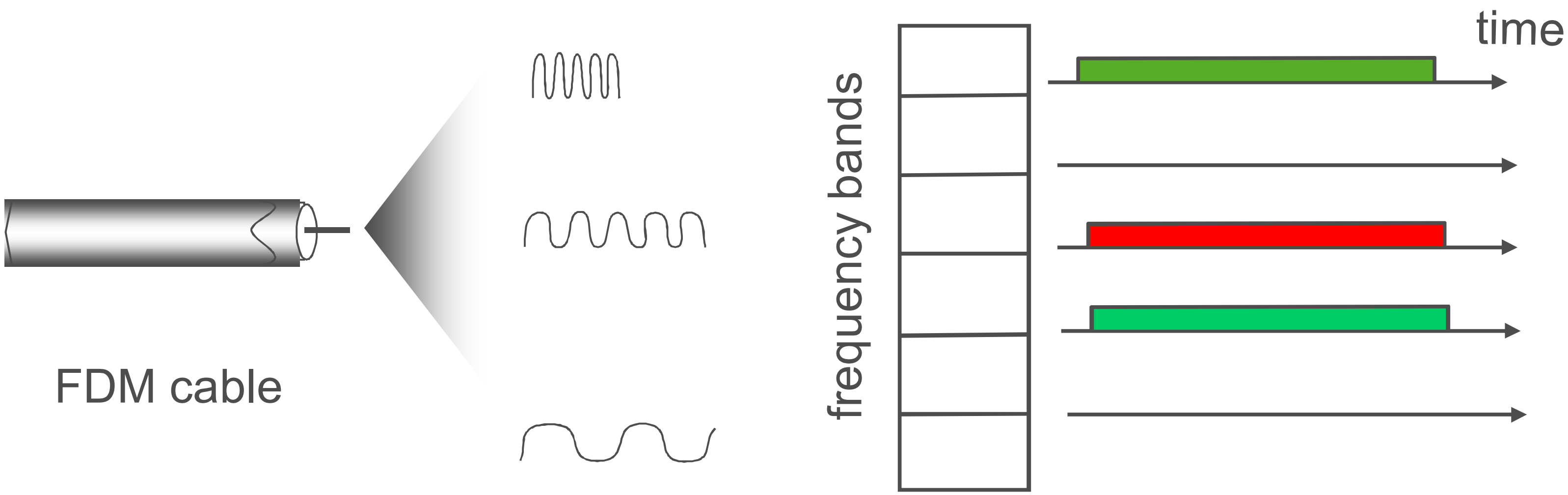
- access to channel in "rounds"
- each station gets fixed length slot (length = packet transmission time) in each round
- unused slots go idle
- example: 6-station LAN, 1,3,4 have packets to send, slots 2,5,6 idle



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 packet to send, frequency bands 2,5,6 idle



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 transmitting 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, CSMA/CD, CSMA/CA

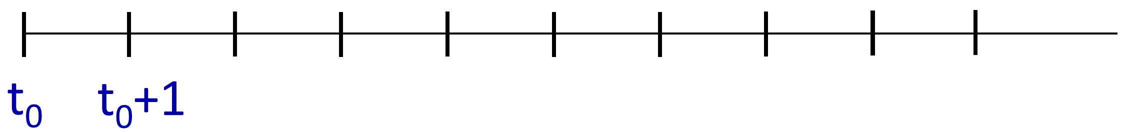
Slotted ALOHA

assumptions:

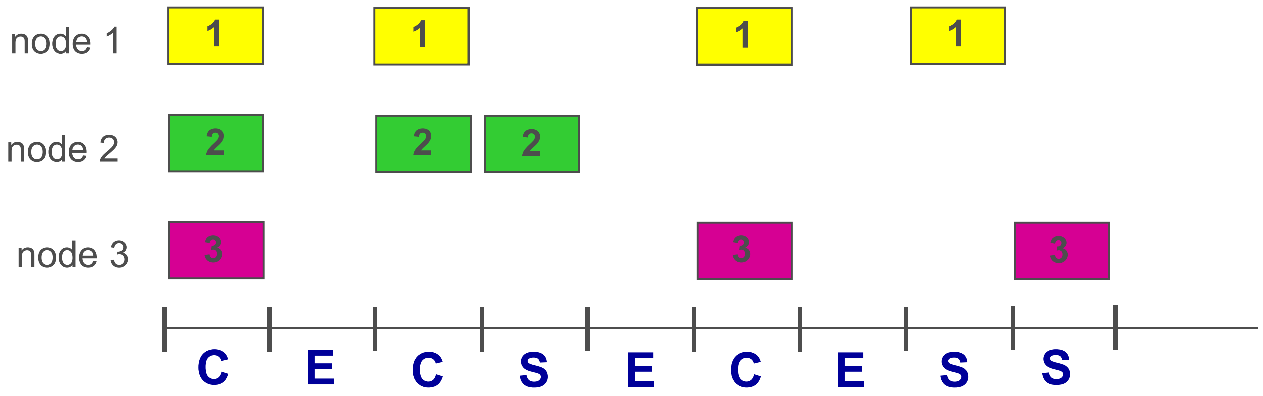
- all frames same size
- time divided into equal size slots (time to transmit 1 frame)
- nodes start to transmit only slot beginning
- nodes are synchronized
- if 2 or more nodes transmit in slot, all nodes detect collision

operation:

- when node obtains fresh frame, transmits in next slot
  - *if no collision:* node can send new frame in next slot
  - *if collision:* node retransmits frame in each subsequent slot with prob. p until success



Slotted ALOHA



Pros:

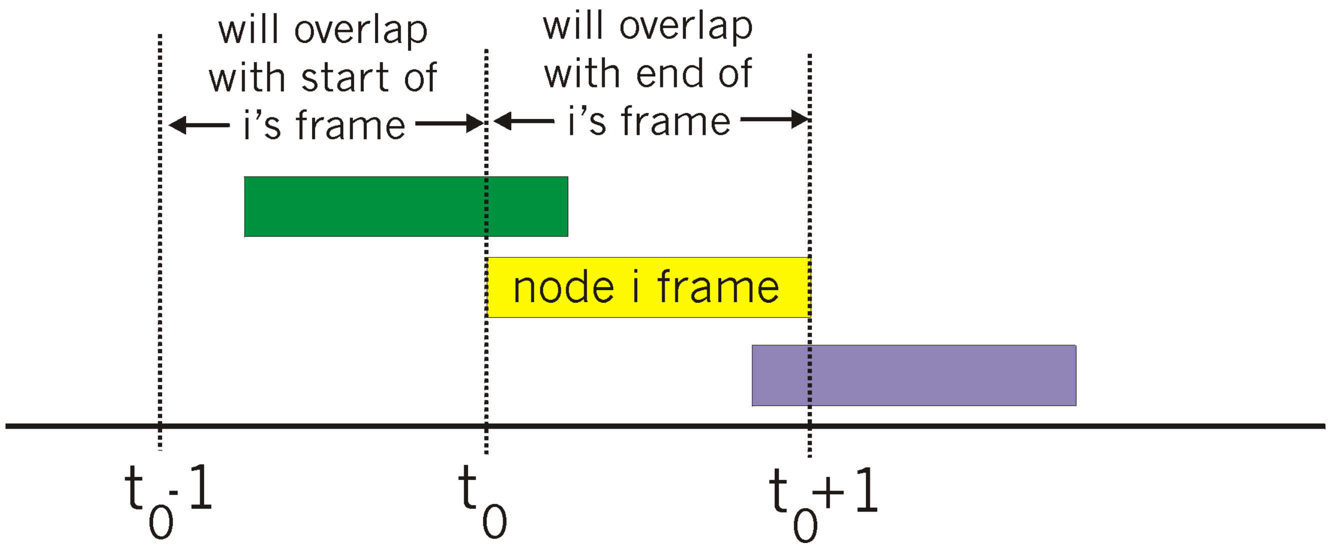
- single active node can continuously transmit at full rate of channel
- highly decentralized: only slots in nodes need to be in sync
- simple

Cons:

- collisions, wasting slots
- idle slots
- nodes may not be able to detect collision in less than time to transmit packet
- clock synchronization

Pure (unslotted) ALOHA

- **unslotted Aloha: simpler, no synchronization**
- **when frame first arrives**
  - transmit immediately
- **collision probability increases:**
  - frame sent at t_0 collides with other frames sent in $[t_0-1, t_0+1]$



CSMA (carrier sense multiple access)

***CSMA*: listen before transmit:**

if channel sensed idle: transmit entire frame

- **if channel sensed busy, defer transmission**

- **human analogy: don't interrupt others!**

CSMA/CD (collision detection)

CSMA/CD: **carrier sensing, deferral as in CSMA**

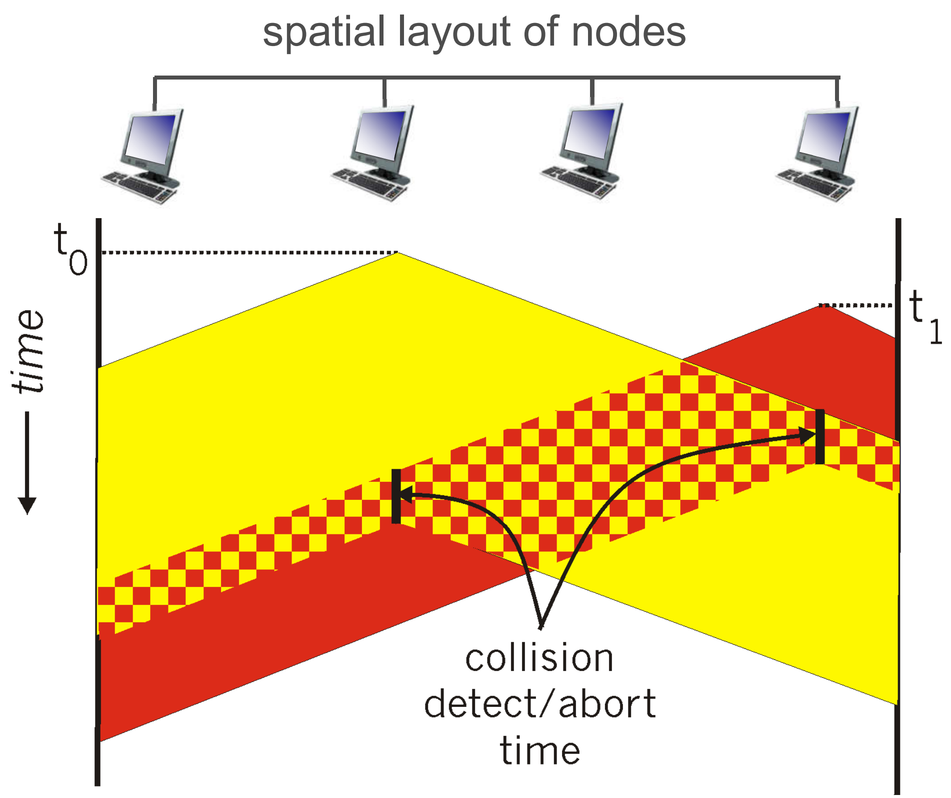
- collisions *detected* within short time
- colliding transmissions aborted, reducing channel wastage

collision detection:

- easy in wired LANs: measure signal strengths, compare transmitted, received signals
- difficult in wireless LANs: received signal strength overwhelmed by local transmission strength

human analogy: the polite conversationalist

CSMA/CD (collision detection)



Ethernet CSMA/CD algorithm

1. **NIC receives datagram from network layer, creates frame**
2. **If NIC senses channel idle, starts frame transmission. If NIC senses channel busy, waits until channel idle, then transmits.**
3. **If NIC transmits entire frame without detecting another transmission, NIC is done with frame !**
4. **If NIC detects another transmission while transmitting, aborts and sends jam signal**
5. **After aborting, NIC enters *binary (exponential) backoff*:**
   - after *m*th collision, NIC chooses *K* at random from $\{0,1,2, \ldots, 2^m-1\}$. NIC waits K·512 bit times, returns to Step 2
   - longer backoff interval with more collisions

"Taking turns" MAC protocols

channel partitioning MAC protocols:

- share channel *efficiently* and *fairly* 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

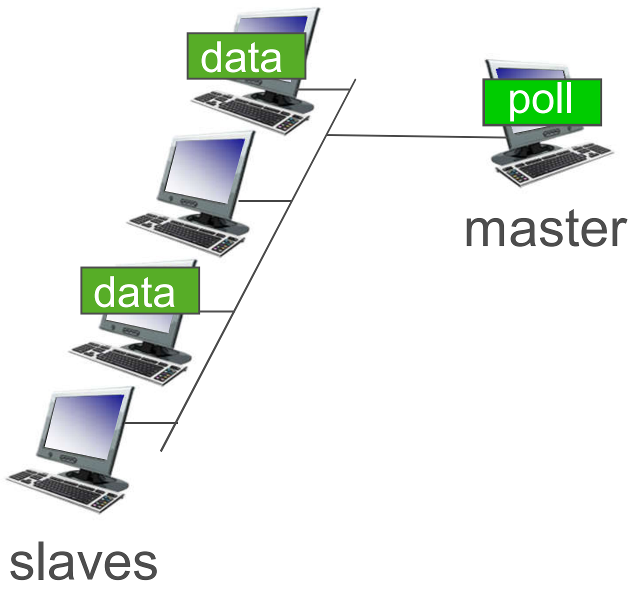
"taking turns" protocols

look for best of both worlds!

"Taking turns" MAC protocols

polling:

- **master node "invites" slave nodes to transmit in turn**
- **typically used with "dumb" slave devices**
- **concerns:**
  - polling overhead
  - latency
  - single point of failure (master)



"Taking turns" MAC protocols

token passing:

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