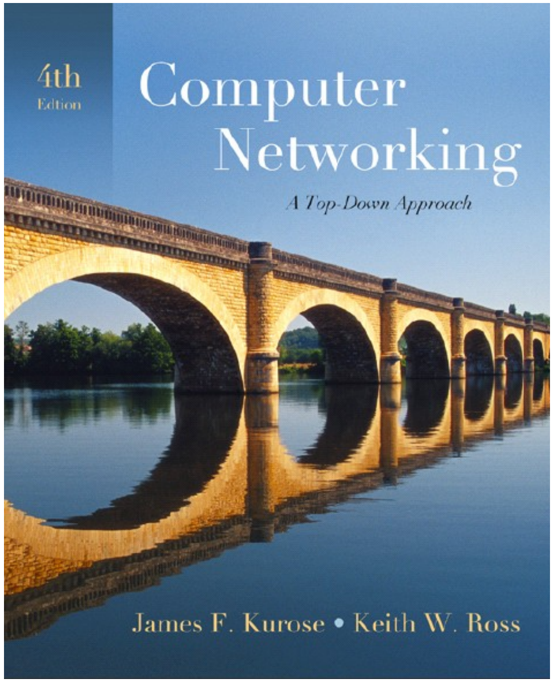
Chapter 5
Link Layer and LANs



Computer Networking: A Top Down Approach
4th edition.
Jim Kurose, Keith Ross
Addison-Wesley, July 2007.

Chapter 5: The Data Link Layer

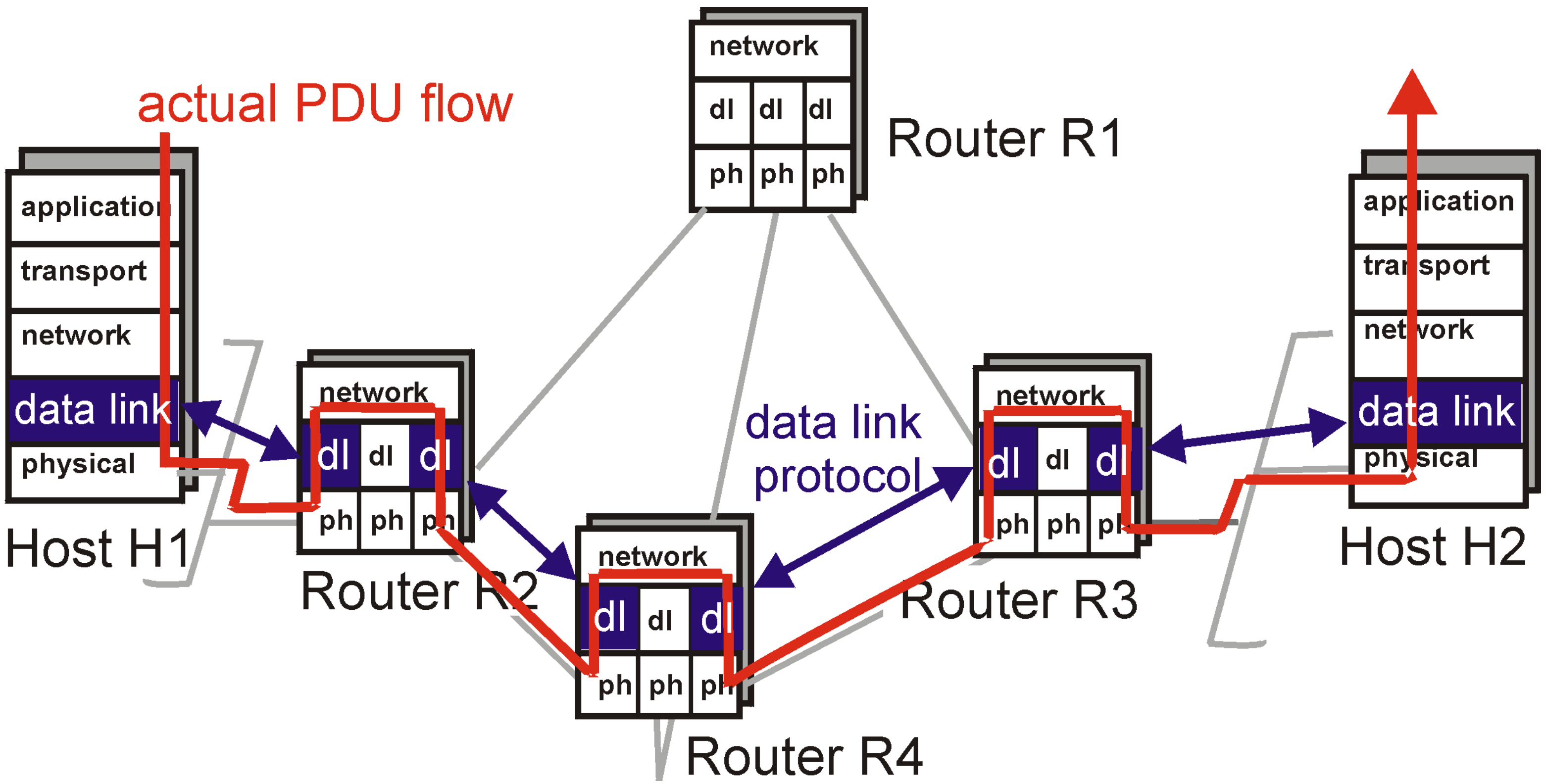
Our goals:

- understand principles behind data link layer services:
  - error detection, correction
  - sharing a broadcast channel: multiple access
  - link layer addressing
  - reliable data transfer, flow control: *done!*
- instantiation and implementation of various link layer technologies

Overview:

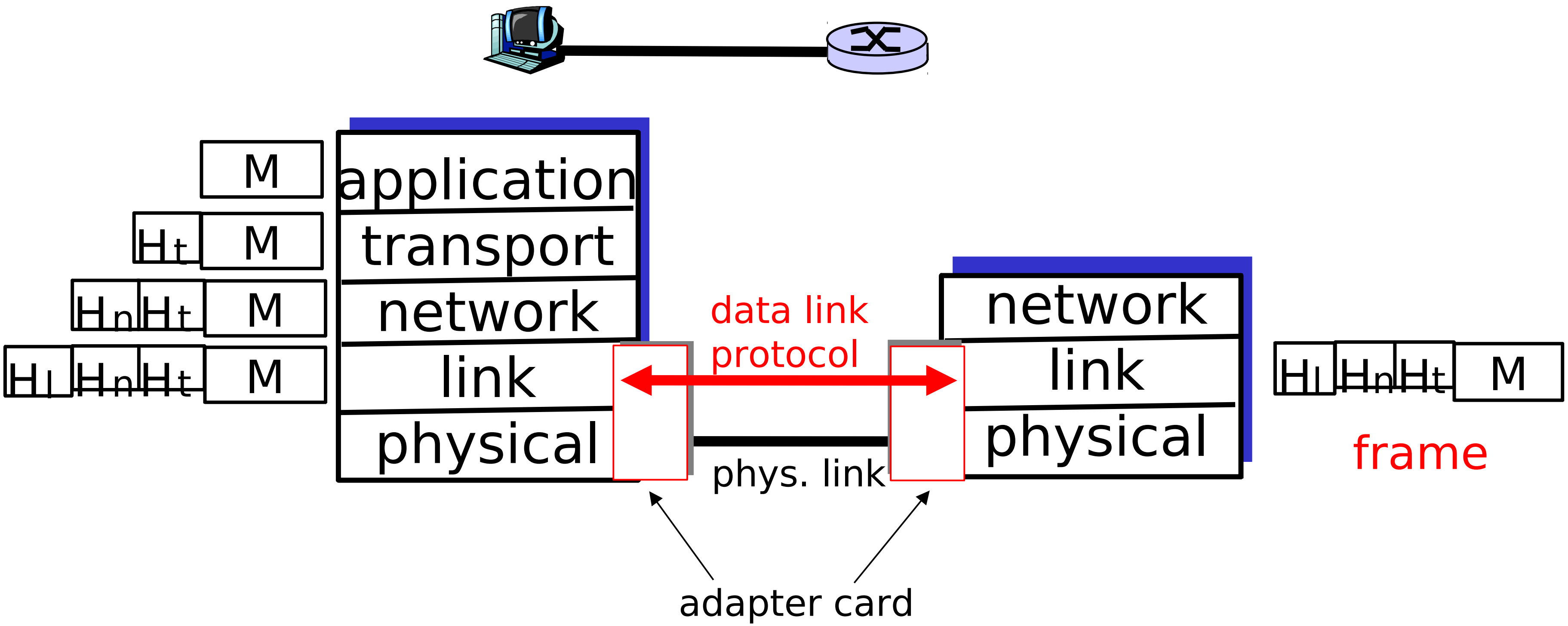
- link layer services
- error detection, correction
- multiple access protocols and LANs
- link layer addressing, ARP
- specific link layer technologies:
  - Ethernet
  - hubs, bridges, switches
  - IEEE 802.11 LANs
  - PPP

Link Layer: setting the context



Link Layer: setting the context

- two *physically connected* devices:
  - host-router, router-router, host-host
- unit of data: *frame*



Link Layer Services

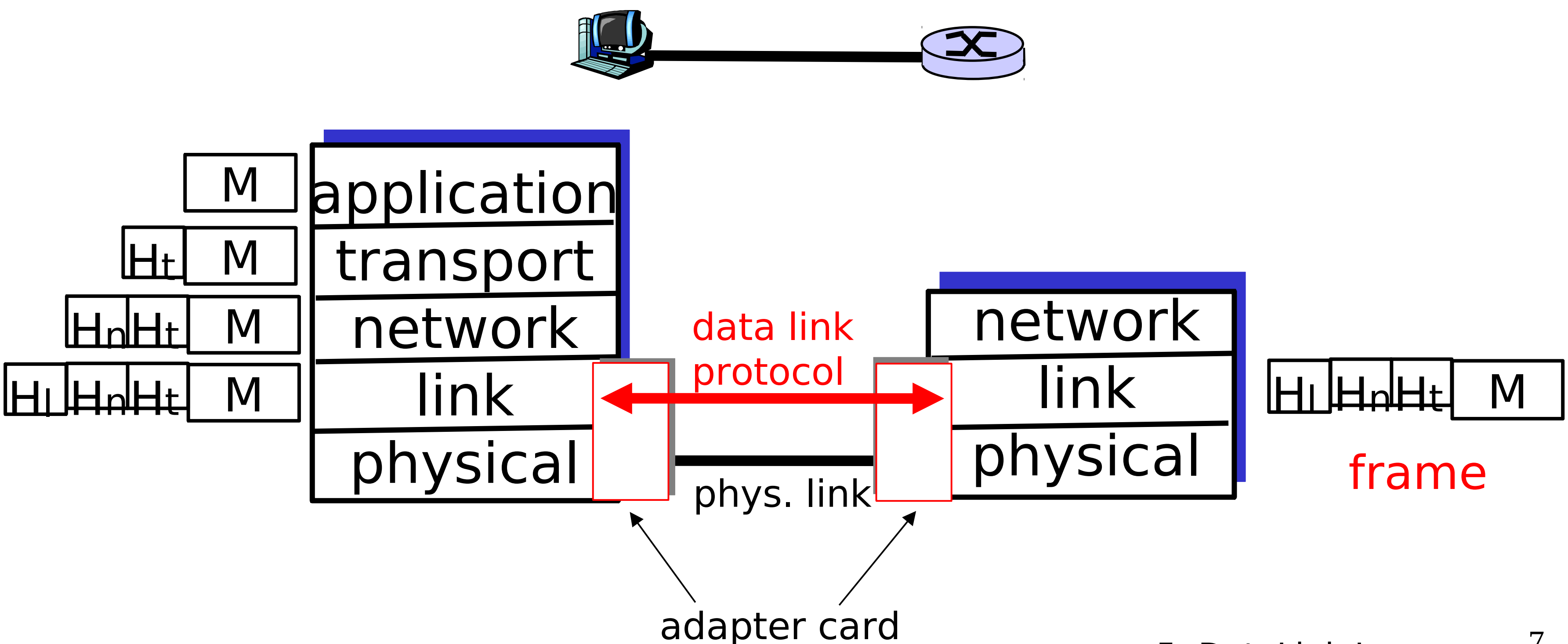
- Framing, link access:
  - encapsulate datagram into frame, adding header, trailer
  - implement channel access if shared medium,
  - 'physical addresses' used in frame headers to identify source, destination
    - different from IP address!
- Reliable delivery between two physically connected devices:
  - we learned how to do this already (chapter 3)!
  - seldom used on low bit error link (fiber, some twisted pair)
  - wireless links: high error rates
    - Q: why both link-level and end-end reliability?

Link Layer Services (more)

- Flow Control:
  - pacing between sender and receivers
- *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

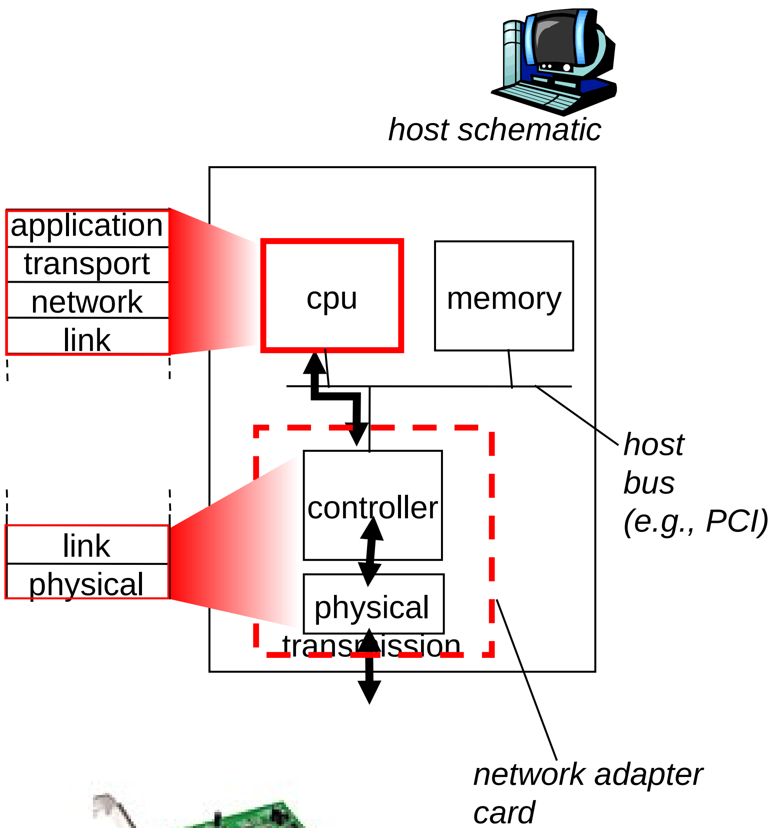
Link Layer: Implementation

- implemented in adapter
  - e.g., PCMCIA card, Ethernet card
  - typically includes: RAM, DSP chips, host bus interface, and link interface

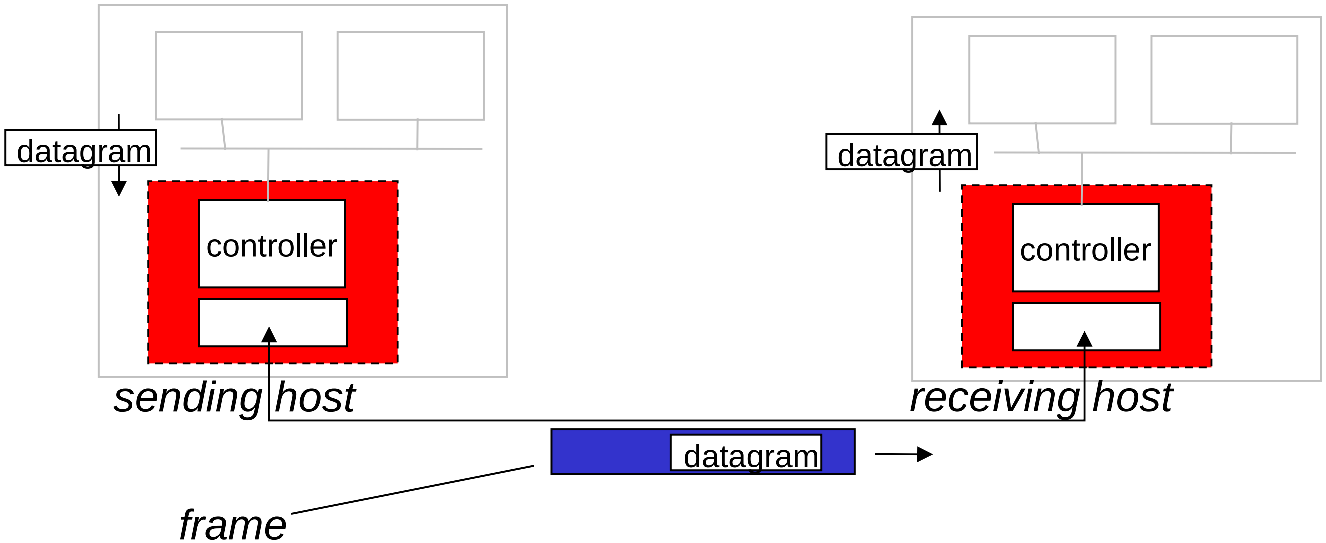


Where is the link layer implemented?

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



Adaptors Communicating

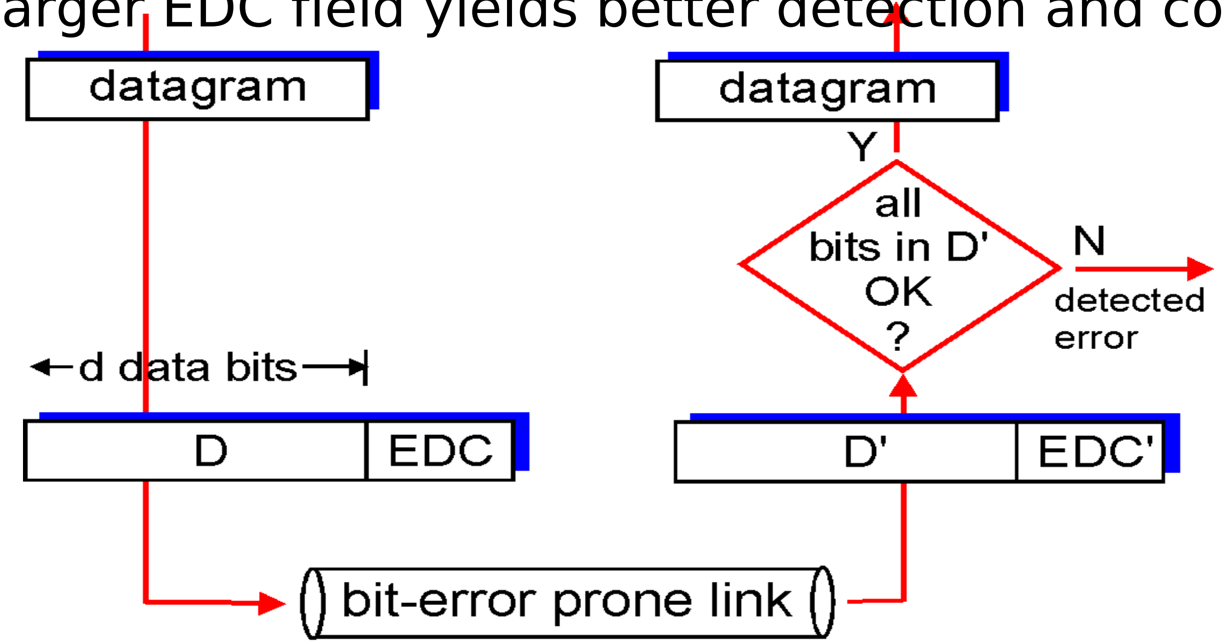


- sending side:
  - encapsulates datagram in frame
  - adds error checking bits, rdt, flow control, etc.
- receiving side
  - looks for errors, rdt, flow control, etc
  - extracts datagram, passes to upper layer at receiving side

Error Detection

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

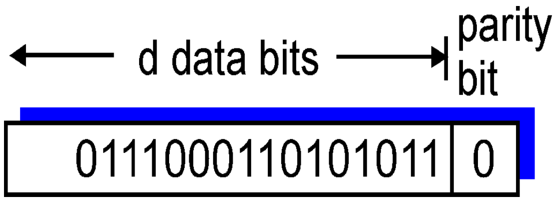
- Error detection not 100% reliable!
  - protocol may miss some errors, but rarely
  - larger EDC field yields better detection and correction



Parity Checking

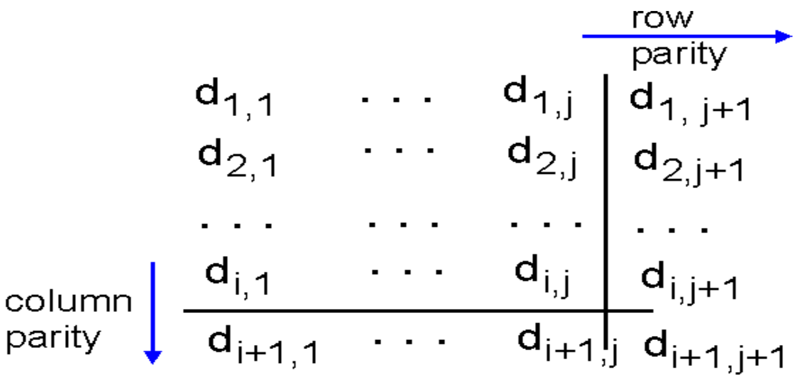
Single Bit Parity:

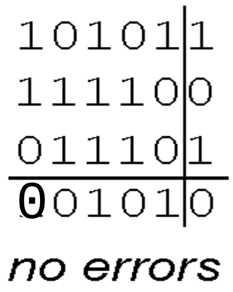
Detect single bit errors

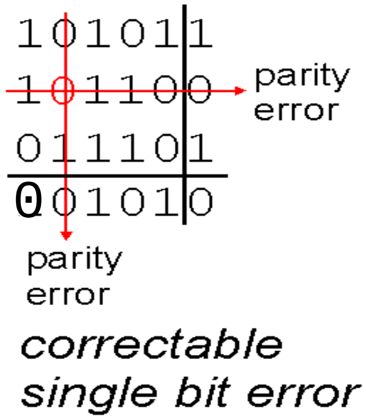


Two Dimensional Bit Parity:

Detect *and correct* single bit errors







Internet checksum

Goal: detect errors (e.g., flipped bits) in transmitted segment (note: used at transport layer *only*)

Sender:

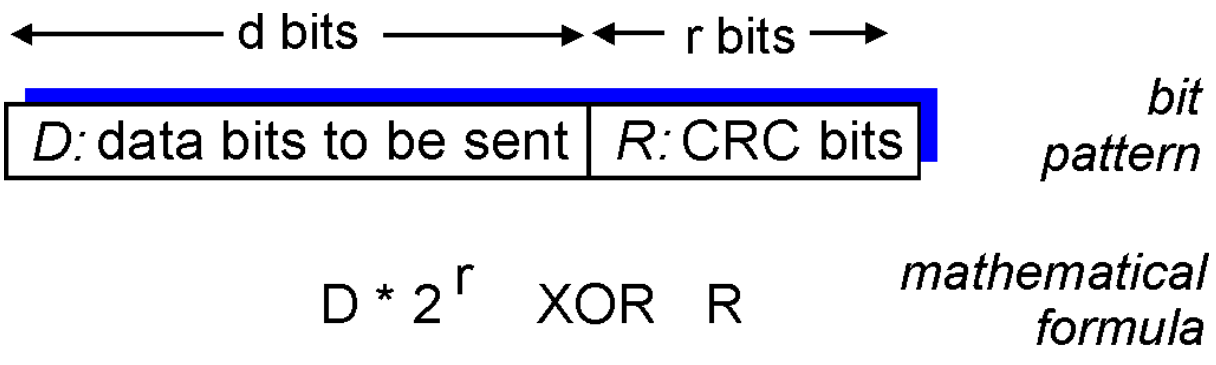
- treat segment contents as sequence of 16-bit integers
- checksum: addition (1's complement sum) of segment contents
- sender puts checksum value into UDP checksum field

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?* More later ....

Check summing: Cyclic Redundancy Check

- view data bits, D, as a binary number
- choose r+1 bit pattern (generator), G
- 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
- widely used in practice (ATM, HDCL)



CRC Example

Want:

$D\cdot 2r$ XOR $R = nG$

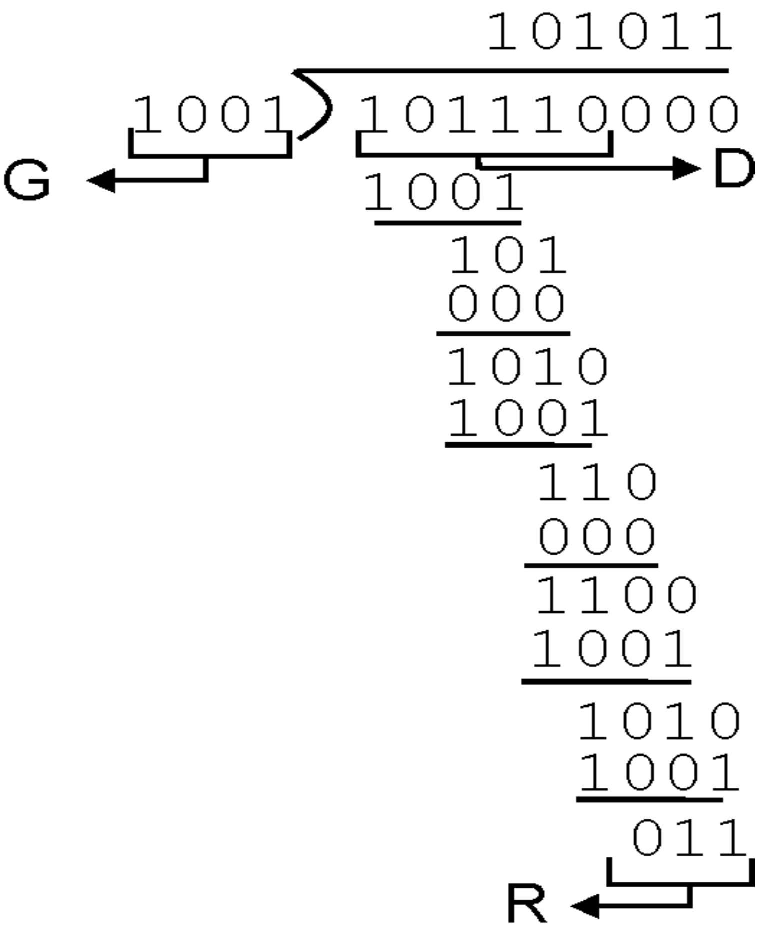
equivalently:

$D\cdot 2r = nG$ XOR R

equivalently:

if we divide $D\cdot 2r$ by G, want reminder R

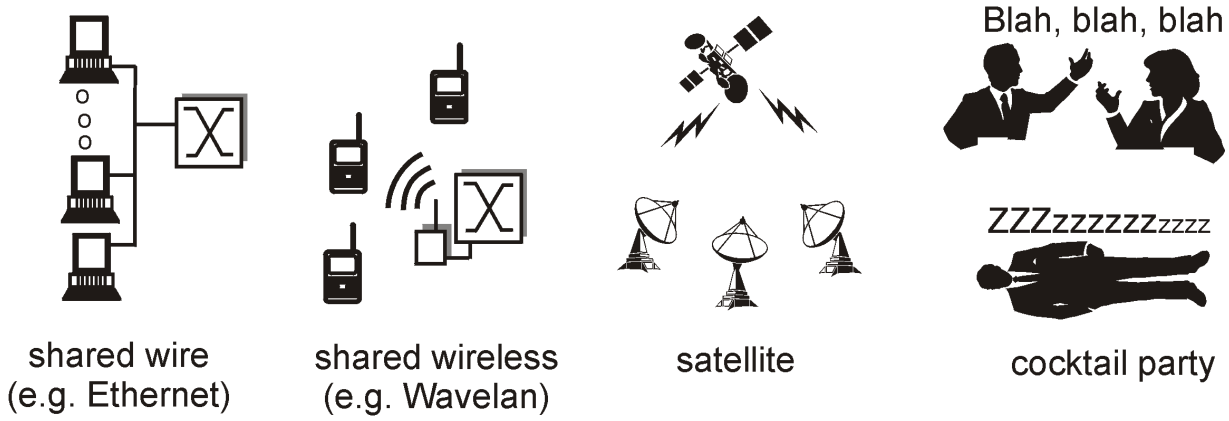
$$R = \text{remainder}\left[\frac{D\cdot 2r}{G}\right]$$



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.)



- 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

MAC Protocols: a taxonomy

Three broad classes:

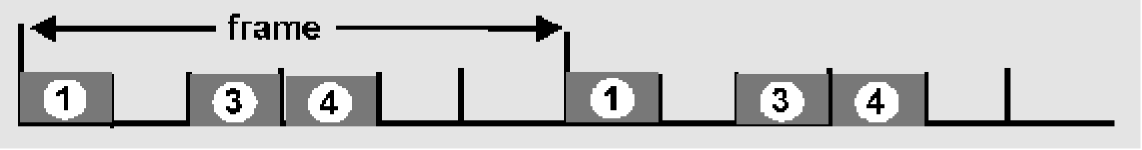
- Channel Partitioning
  - divide channel into smaller pieces (time slots, frequency)
  - allocate piece to node for exclusive use
- Random Access
  - allow collisions
  - recover from collisions
- **Taking turns**
  - tightly coordinate shared access to avoid collisions

Goal: efficient, fair, simple, decentralized

Channel Partitioning MAC protocols: TDMA

TDMA: time division multiple access

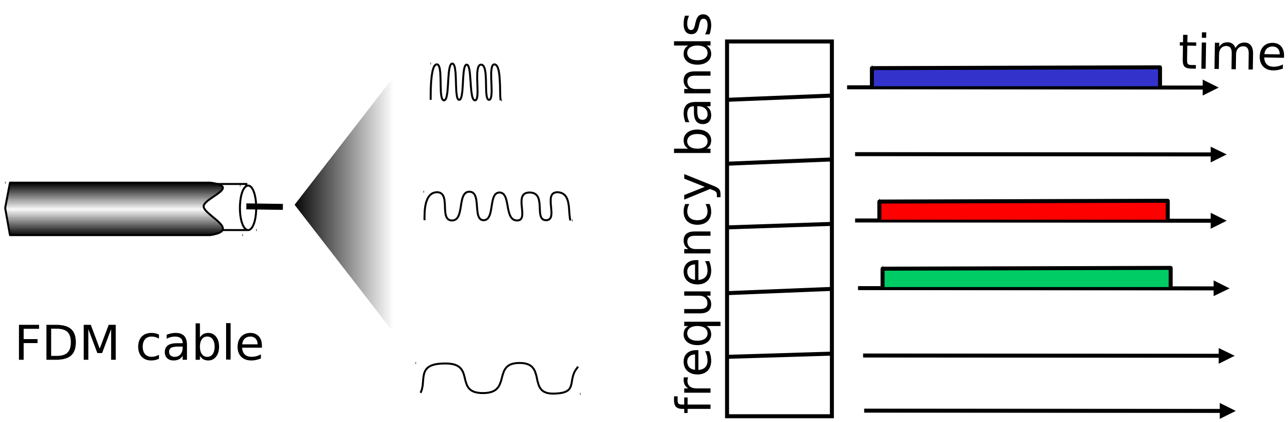
- access to channel in rounds
- each station gets fixed length slot (length = pkt trans time) in each round
- unused slots go idle
- example: 6-station LAN, 1,3,4 have pkt, slots 2,5,6 idle



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

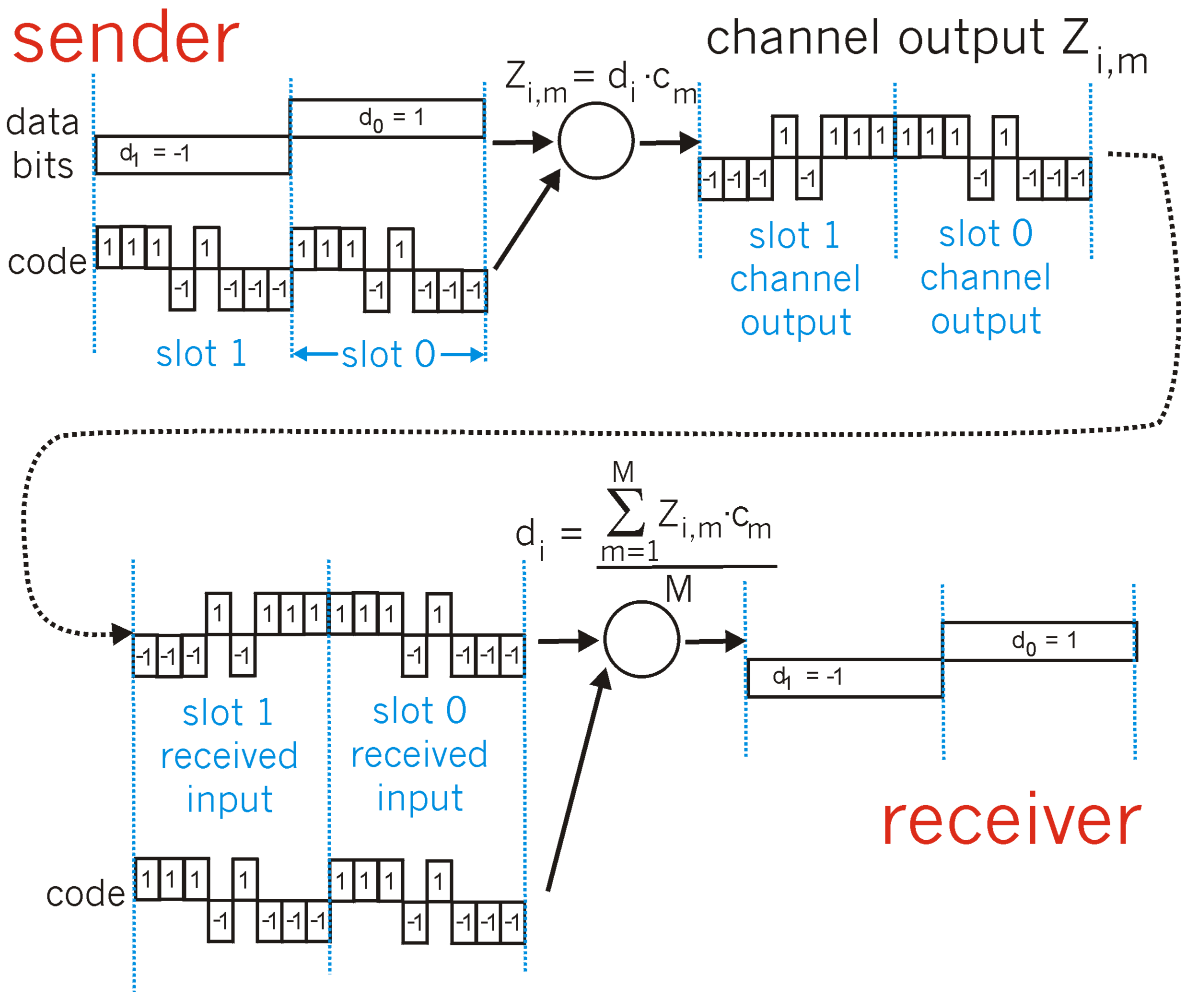


Channel Partitioning (CDMA)

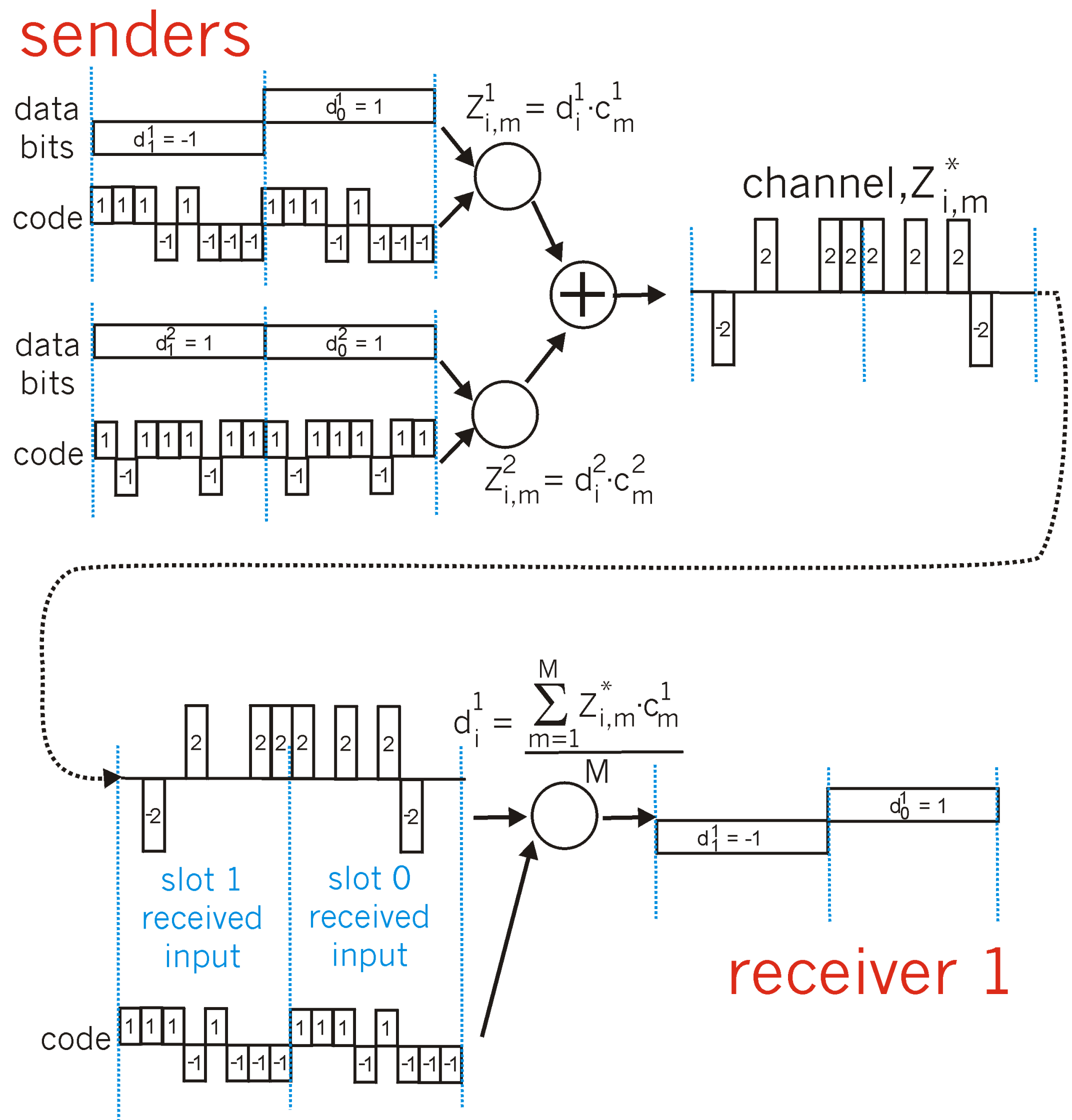
CDMA (Code Division Multiple Access)

- unique code assigned to each user; i.e., 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)

CDMA Encode/Decode



CDMA: two-sender interference



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:
  - slotted ALOHA
  - ALOHA
  - CSMA, CSMA/CD, CSMA/CA

Slotted ALOHA

Assumptions:

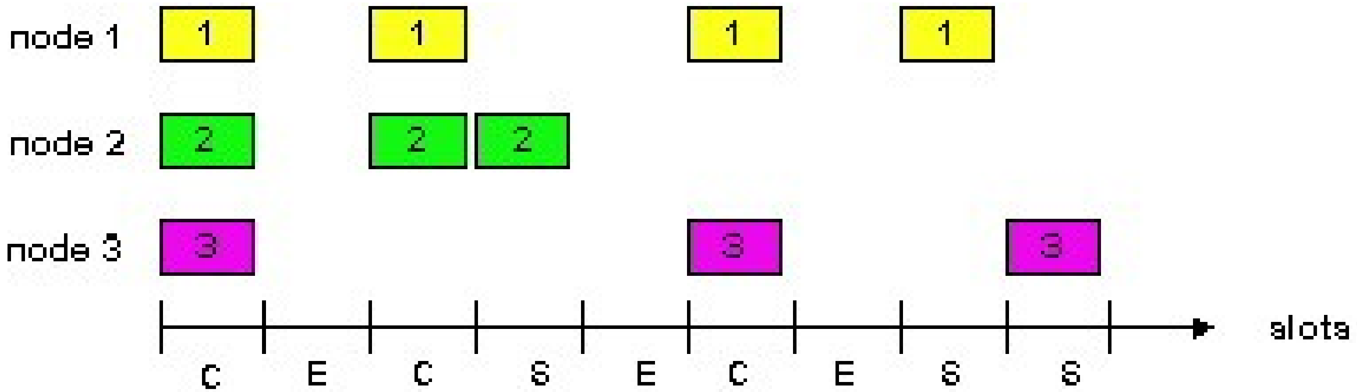
- all frames same size
- time divided into equal size slots (time to transmit 1 frame)
- nodes start to transmit only slot beginning
- nodes are synchronized
- if 2 or more nodes transmit in slot, all nodes detect collision

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

- e.g.



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)

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

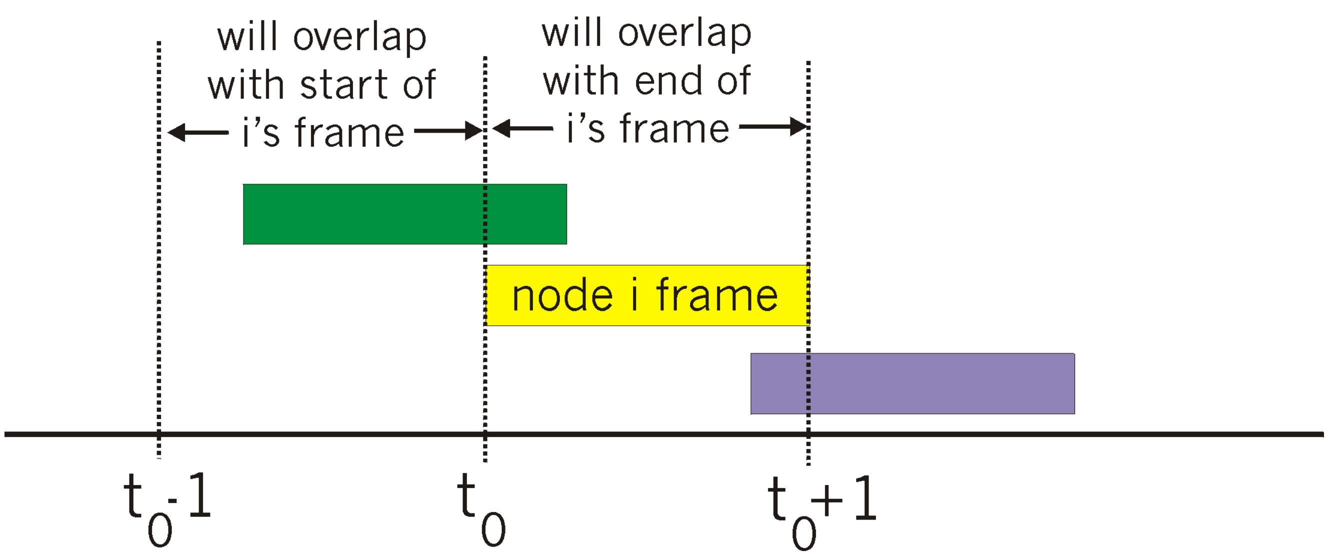
... choosing optimum p as n -> infty ...

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

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

Pure (unslotted) 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) .

P(no other node transmits in [p0-1,p0] .

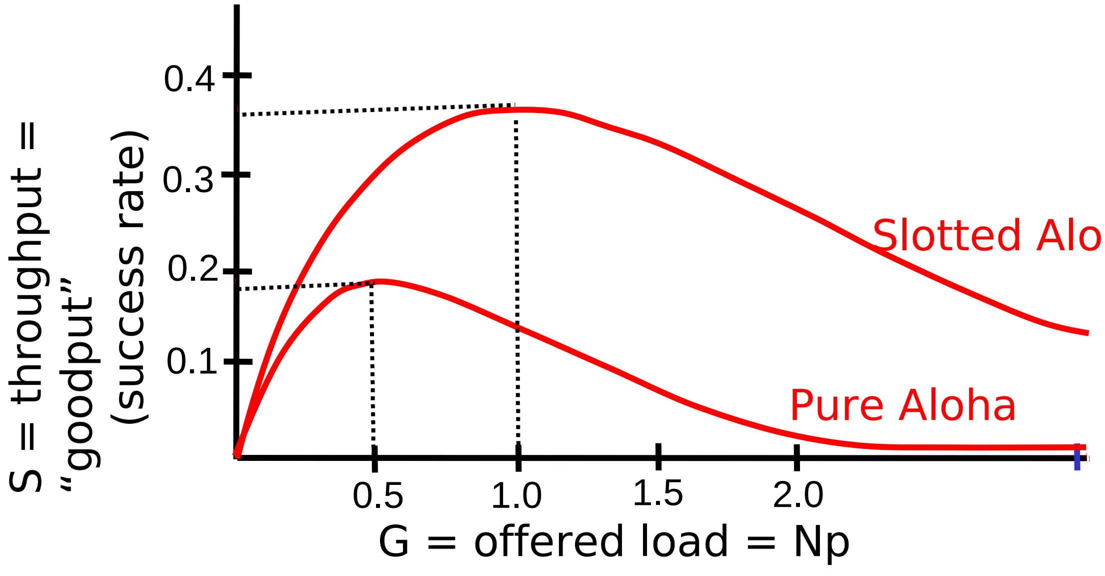
P(no other node transmits in [p0-1,p0]

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

P(success by any of N nodes) = $p \cdot (1-p)^{2(N-1)}$

… choosing optimum p as n -> infty …

= 1/(2e) = .18



protocol constrains effective channel throughput!

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* occur:

propagation delay means two nodes may not year hear each other's transmission

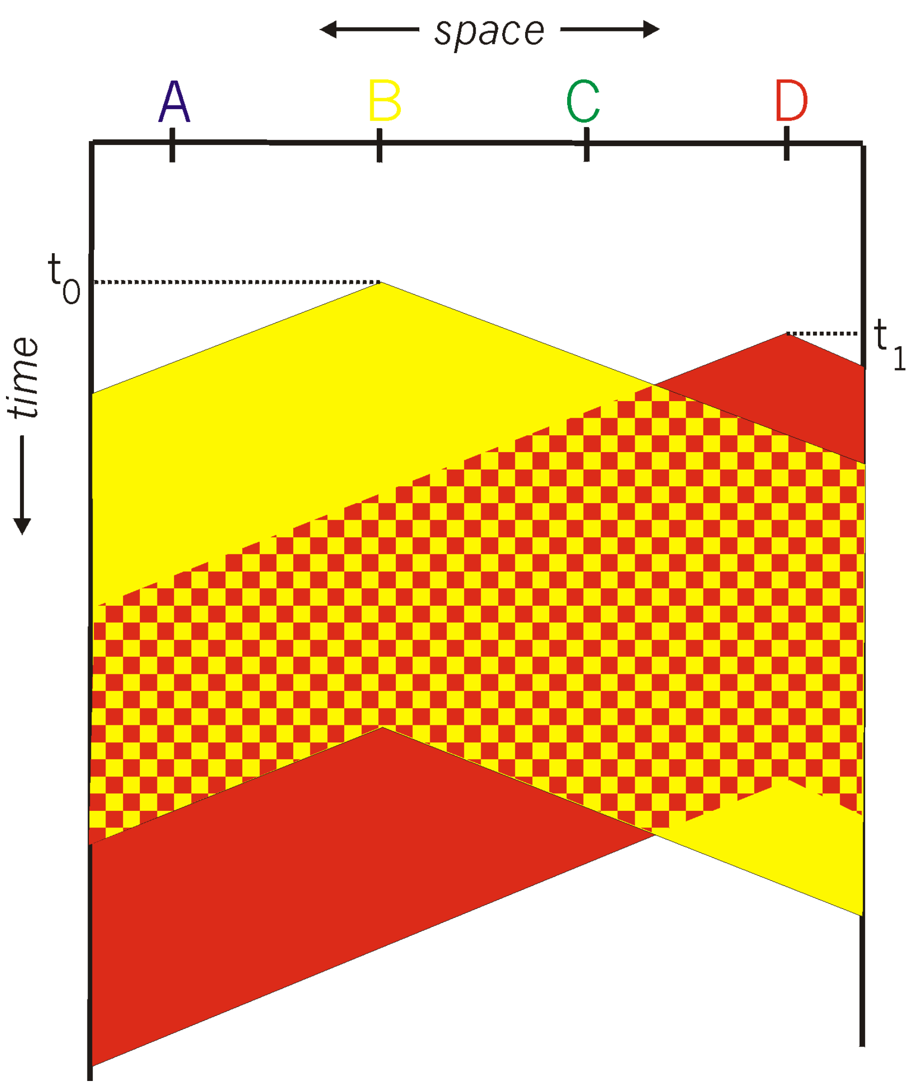
collision:

entire packet transmission time wasted

note:

role of distance and propagation delay in determining collision prob.

spatial layout of nodes along ethernet



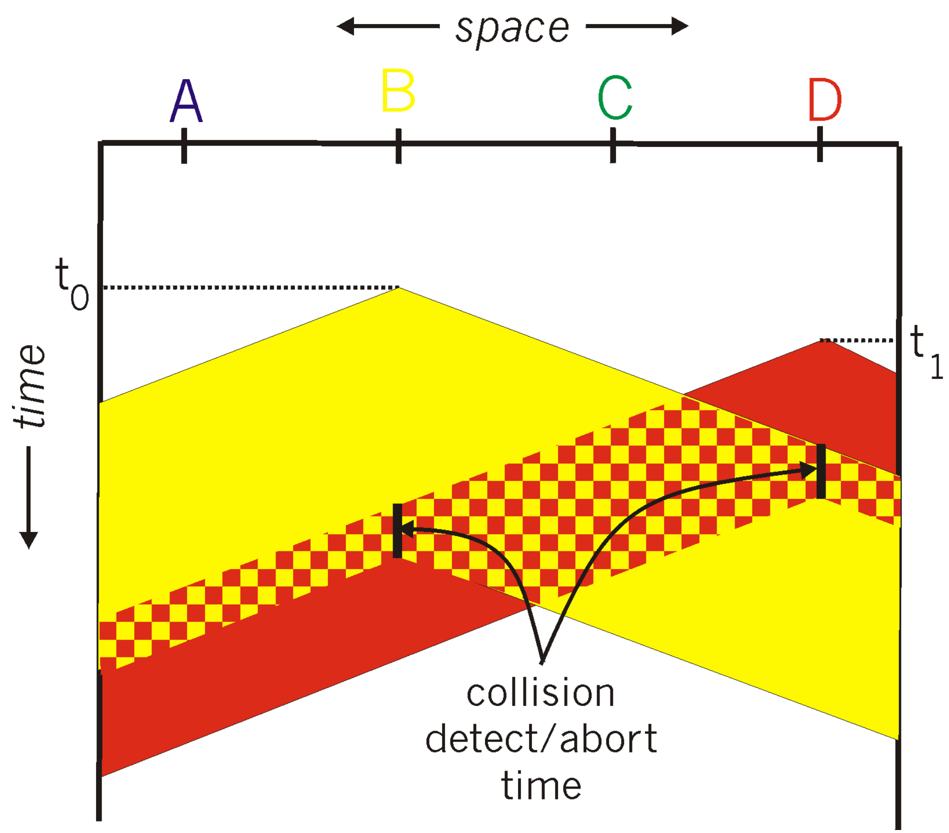
CSMA/CD (Collision Detection)

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 conversation

CSMA/CD collision detection



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!

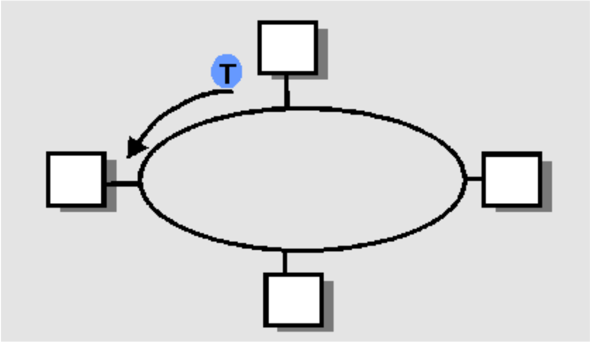
Taking Turns MAC protocols

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:

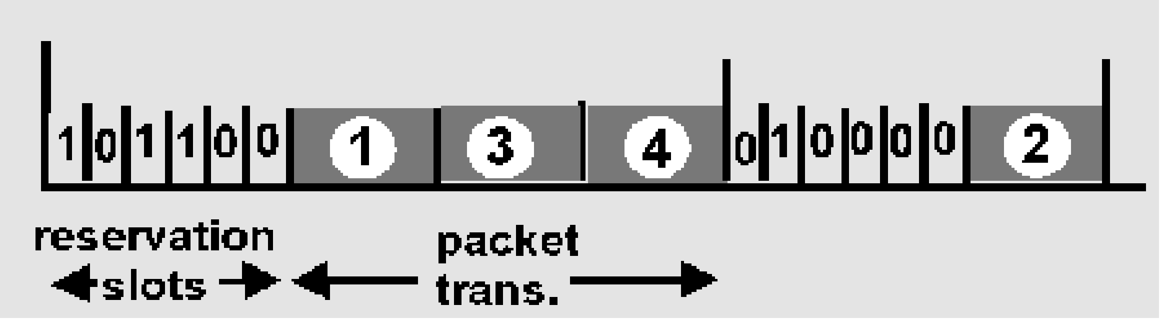
- control **token** passed from one node to next sequentially.
- token message
- concerns:
  - token overhead
  - latency
  - single point of failure (token)



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 technologies (wire), hard in others (wireless)
    - CSMA/CD used in Ethernet
  - Taking Turns
    - polling from a central cite, token passing
    - e.g., Bluetooth, FDDI, IBM Token Ring

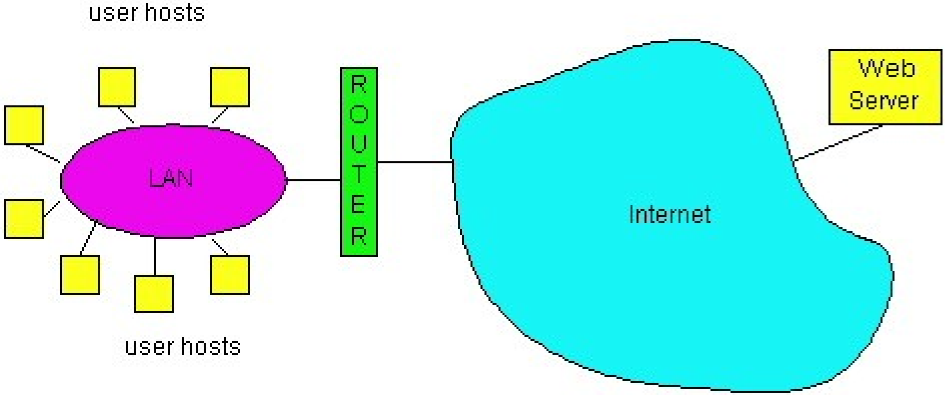
LAN technologies

Data link layer so far:

- services, error detection/correction, multiple access

Next: LAN technologies

- addressing
- Ethernet
- hubs, bridges, switches
- 802.11
- PPP



LAN Addresses and ARP

32-bit IP address:

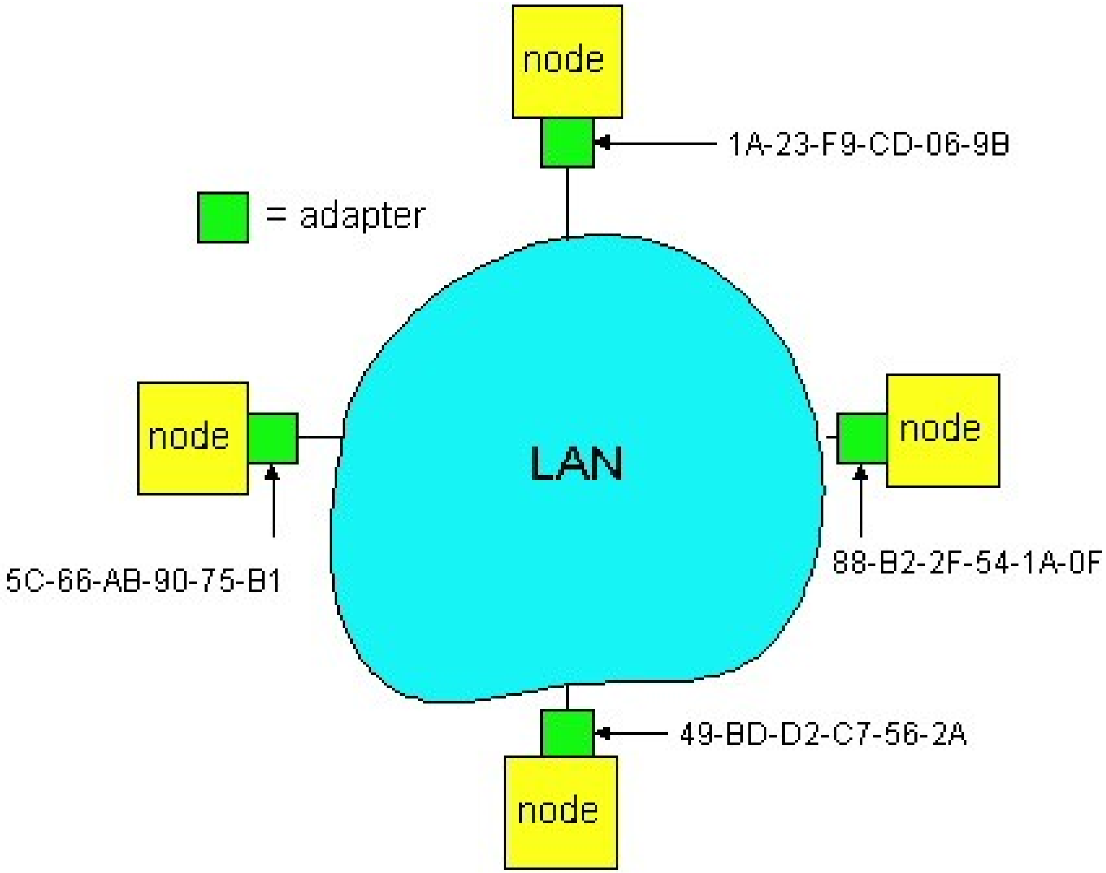
- *network-layer* address
- used to get datagram to destination network (recall IP network definition)

LAN (or MAC or physical) address:

- used to get datagram from one interface to another physically-connected interface (same network)
- 48 bit MAC address (for most LANs) burned in the adapter ROM

LAN Addresses and ARP

Each adapter on LAN has unique LAN address



LAN Address (more)

- MAC address allocation administered by IEEE
- manufacturer buys portion of MAC address space (to assure uniqueness)
- Analogy:

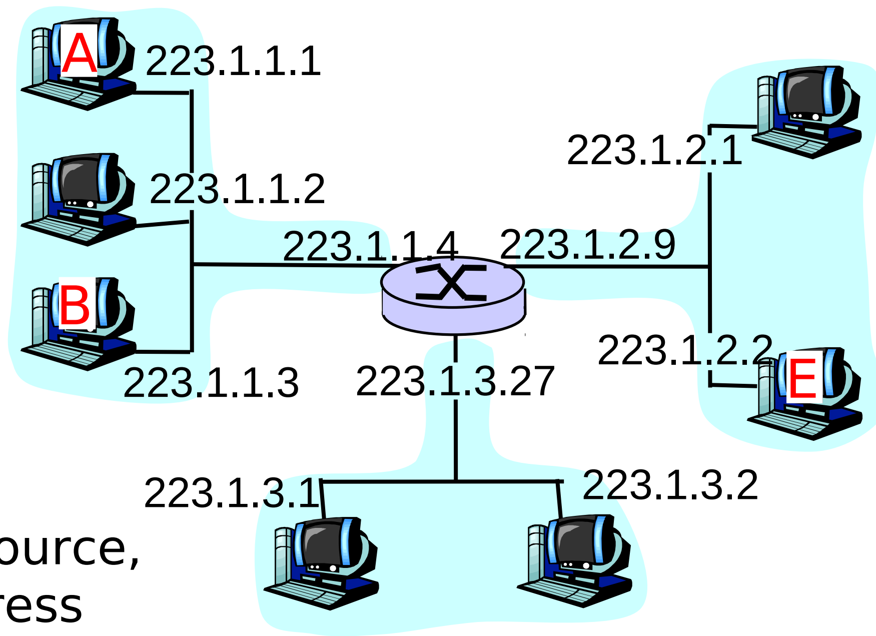
  (a) MAC address: like Social Security Number

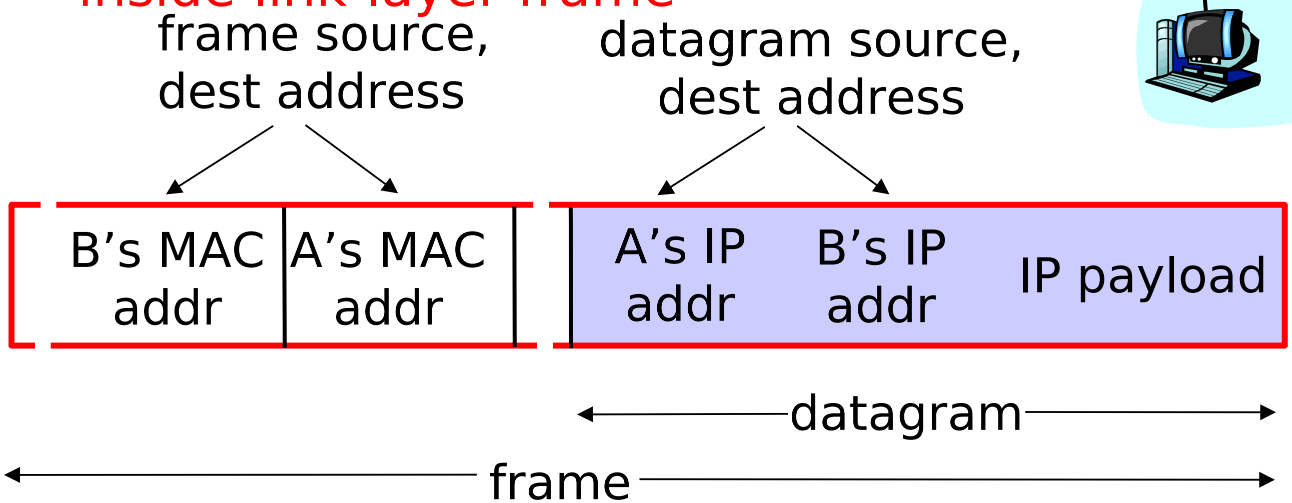
  (b) IP address: like postal address
- MAC flat address => portability
  - can move LAN card from one LAN to another
- IP hierarchical address NOT portable
  - depends on network to which one attach to

Recall earlier routing discussion

Starting at A, given IP datagram addressed to B:

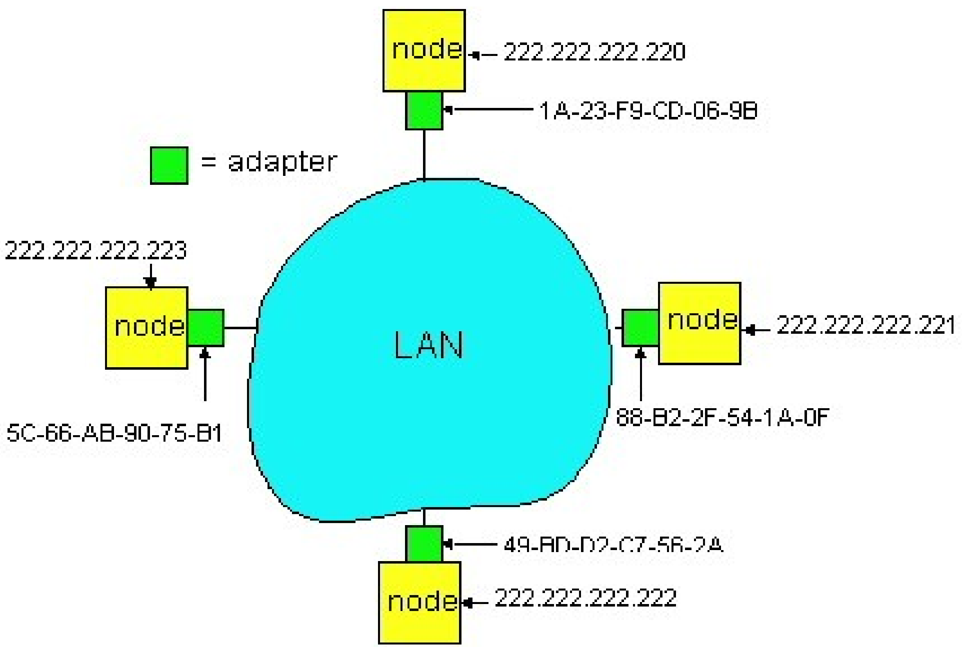
- look up net. address of B, find B on same net. as A
- link layer send datagram to B inside link-layer frame





ARP: Address Resolution Protocol

Question: how to determine
MAC address of B
given B's IP address?



- Each IP node (Host, Router) on LAN has ARP module, table
- ARP Table: IP/MAC address mappings for some LAN nodes

  < IP address; MAC address; TTL>

  < .... >

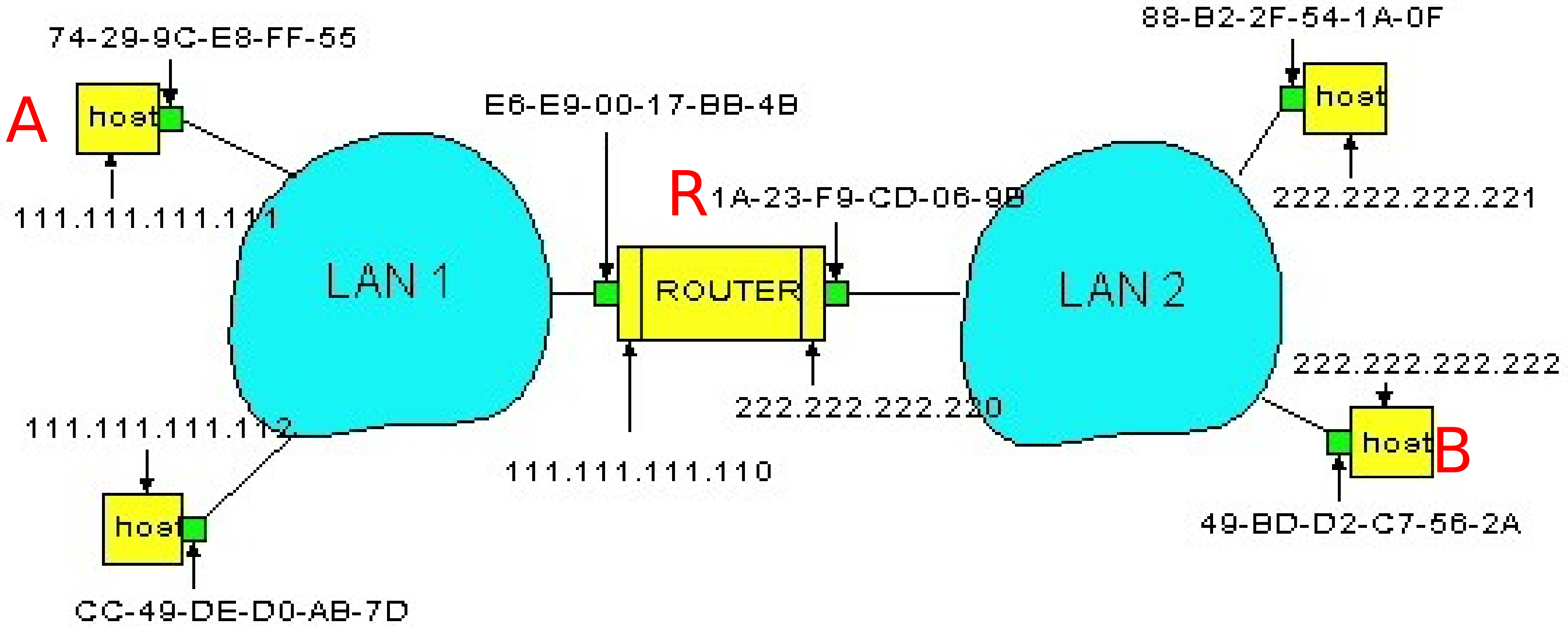
  - TTL (Time To Live): time after which address mapping will be forgotten (typically 20 min)

ARP protocol

- A knows B's IP address, wants to learn physical address of B
- A broadcasts ARP query pkt, containing B's IP address
  - all machines on LAN receive ARP query
- B receives ARP packet, replies to A with its (B's) physical layer address
- A caches (saves) IP-to-physical address pairs until information becomes old (times out)
  - soft state: information that times out (goes away) unless refreshed
- ARP is “plug&play”

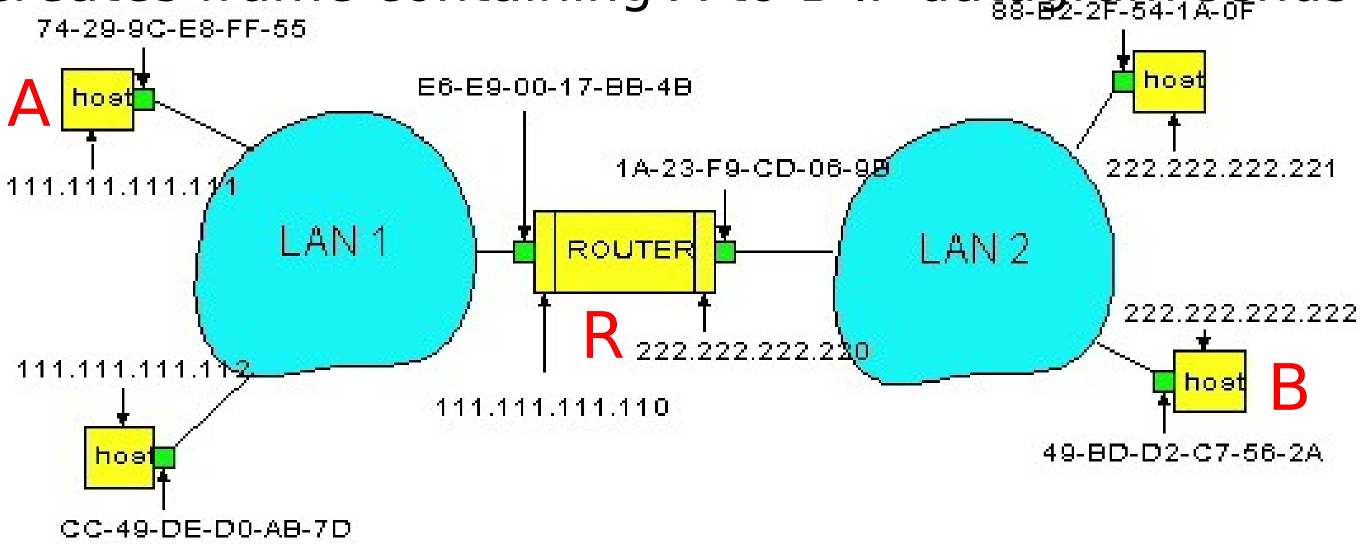
Routing to another LAN

routing from A to B via R



- In routing table at source Host, find router 111.111.111.110
- In ARP table at source, find MAC address E6-E9-00-17-BB-4B, etc

- A creates IP packet with source A, destination B
- A uses ARP to get R's physical layer address for 111.111.111.110
- A creates Ethernet frame with R's physical address as dest, Ethernet frame contains A-to-B IP datagram
- A's data link layer sends Ethernet frame
- R's data link layer receives Ethernet frame
- R removes IP datagram from Ethernet frame, sees its destined to B
- R uses ARP to get B's physical layer address
- R creates frame containing A-to-B IP datagram sends to B



See ARP in action:

- Try that in the labs:
  - arp -a
    - This line prints the arp table
    - Your own physical address should appear
  - Ping <neighbour IP>
  - arp -a
    - A new line should appear if the ping was successful
    - The physical address of your neighbour is now known
    - Wait 60+ seconds
  - arp -a
    - The neighbour's line should have disappeared