Data Link Protocols

Link Layer Services

- Framing, Addressing, link access:
  - encapsulate datagram into frame, adding header, trailer
  - channel access if shared medium
  - "MAC" addresses used in frame headers to identify source, dest
    - different from IP address!
- *Error Detection*:
  - errors caused by signal attenuation, noise.
  - receiver detects presence of errors:
    - signals sender for retransmission or drops frame

Medium Access Control (MAC) Protocols

MAC Protocols: a taxonomy

Three broad classes:

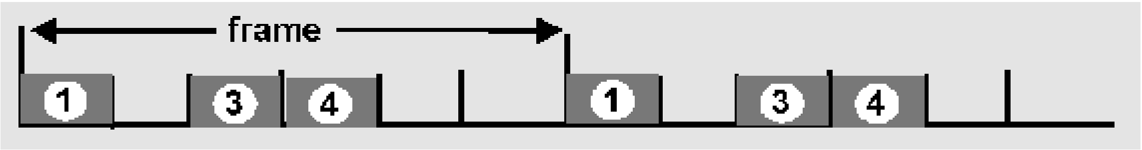
- Channel Partitioning
  - divide channel into smaller "pieces" (time slots, frequency, code)
  - allocate piece to node for exclusive use
- Random Access
  - channel not divided, allow collisions
  - "recover" from collisions
- "Taking turns"
  - Nodes take turns, but nodes with more to send can take longer turns

Channel Partitioning MAC protocols: TDMA

TDMA: time division multiple access

channel divided into N time slots, one per user; inefficient with low duty cycle users and at light load.

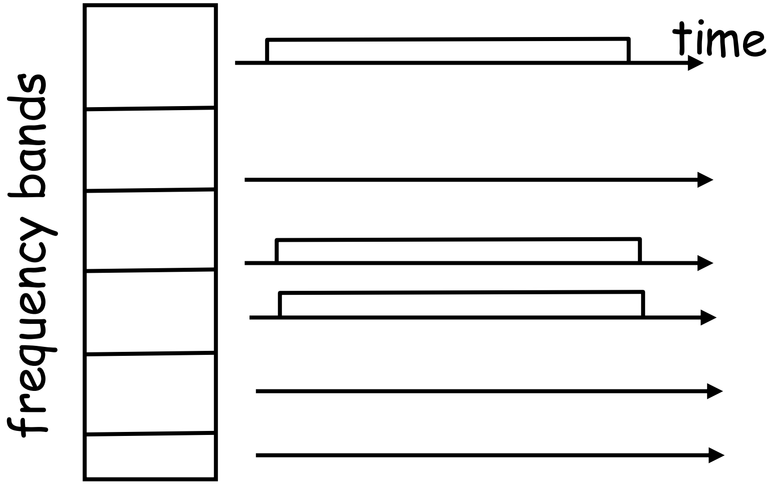
- access to channel in "rounds"
- each station gets fixed length slot (length = pkt trans time) in each round
- unused slots go idle
- example: 6-station LAN, 1,3,4 have pkt, slots 2,5,6 idle



Channel Partitioning MAC protocols: FDMA

FDMA: frequency division multiple access (frequency subdivided.)

- 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



- TDM (Time Division Multiplexing): channel divided into N time slots, one per user; inefficient with low duty cycle users and at light load.
- FDM (Frequency Division Multiplexing): frequency subdivided.

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

Ethernet uses CSMA/CD

- No slots
- adapter doesn't transmit if it senses that some other adapter is transmitting, that is, carrier sense
- transmitting adapter aborts when it senses that another adapter is transmitting, that is, collision detection
- Before attempting a retransmission, adapter waits a random time, that is, random access

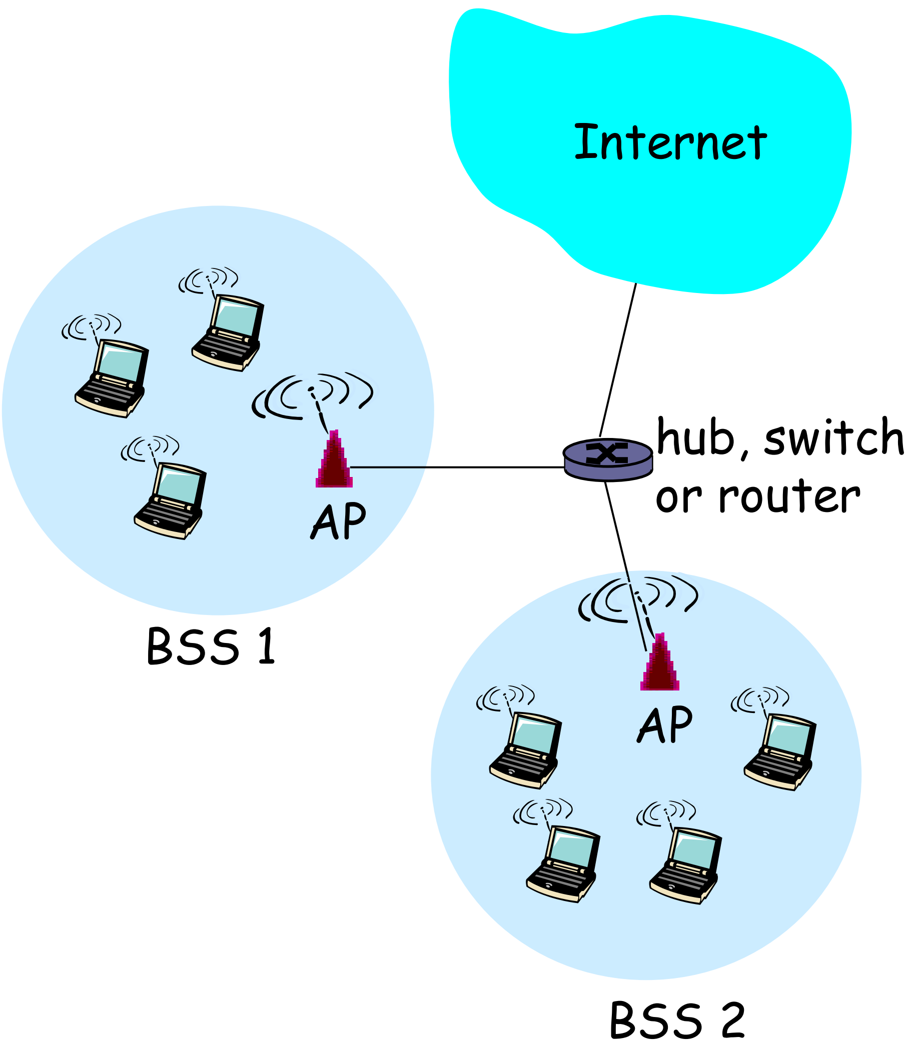
Ethernet CSMA/CD algorithm

1. Adaptor receives datagram from net layer & creates frame
2. If adapter senses channel idle, it starts to transmit frame. If it senses channel busy, waits until channel idle and then transmits
3. If adapter transmits entire frame without detecting another transmission, the adapter is done with frame !
4. If adapter detects another transmission while transmitting, aborts and sends jam signal
5. After aborting, adapter enters **exponential backoff**: after the mth collision, adapter chooses a K at random from $\{0,1,2,\ldots,2^m-1\}$. Adapter waits K·512 bit times and returns to Step 2

IEEE 802.11 Wireless LAN

- 802.11b
  - 2.4-5 GHz unlicensed radio spectrum
  - up to 11 Mbps
  - direct sequence spread spectrum (DSSS) in physical layer
    - all hosts use same chipping code
  - widely deployed, using base stations
- 802.11a
  - 5-6 GHz range
  - up to 54 Mbps
- 802.11g
  - 2.4-5 GHz range
  - up to 54 Mbps
- All use CSMA/CA for multiple access
- All have base-station and ad-hoc network versions

802.11 LAN architecture



- wireless host communicates with base station
  - base station = access point (AP)
- Basic Service Set (BSS) (aka "cell") in infrastructure mode contains:
  - wireless hosts
  - access point (AP): base station
  - ad hoc mode: hosts only

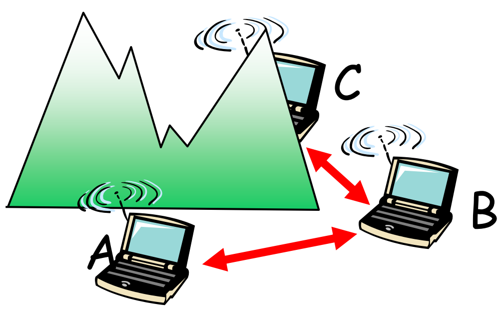
802.11: Channels, association (الارتباط)

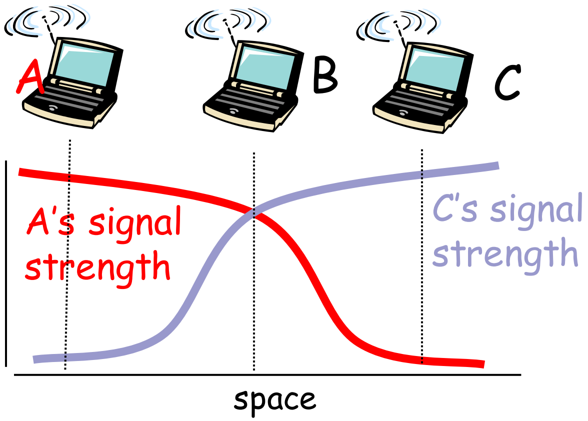
- 802.11b: 2.4GHz-2.485GHz spectrum divided into 11 channels at different frequencies
  - AP admin chooses frequency for AP
  - interference possible: channel can be same as that chosen by neighboring AP!
- host: must *associate* with an AP
  - scans channels, listening for *beacon frames* containing AP's name (SSID) and MAC address

    (SSID) service set identification
  - selects AP to associate with
  - may perform authentication [Chapter 8]
  - will typically run DHCP to get IP address in AP's subnet

IEEE 802.11: multiple access

- avoid collisions: 2^+ nodes transmitting at same time
- 802.11: CSMA - sense before transmitting
  - don't collide with ongoing transmission by other node
- 802.11: *no collision detection*!
  - difficult to receive (sense collisions) when transmitting due to weak received signals (fading)
  - can't sense all collisions in any case: hidden terminal, fading
  - goal: *avoid collisions:* CSMA/C(ollision)A(voidance)





IEEE 802.11 MAC Protocol: CSMA/CA

802.11 sender

1 if sense channel idle for **DIFS** (Distributed Inter-Frame Space). then

transmit entire frame (no CD)

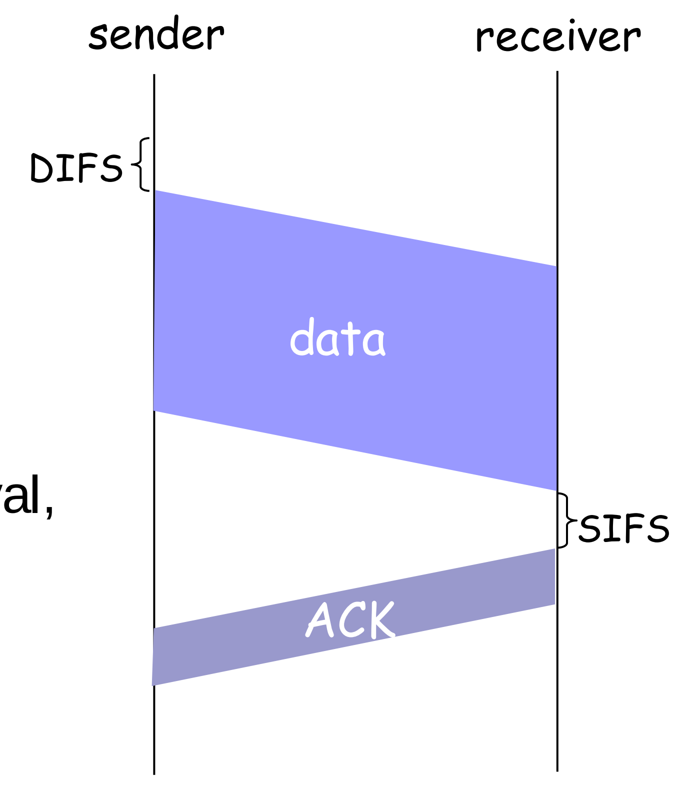
2 if sense channel busy then

start random backoff time

timer counts down while channel idle

transmit when timer expires

if no ACK, increase random backoff interval, repeat 2



802.11 receiver

- if frame received OK

return ACK after **SIFS** (Short Inter-frame Spacing)(ACK needed due to hidden terminal problem)

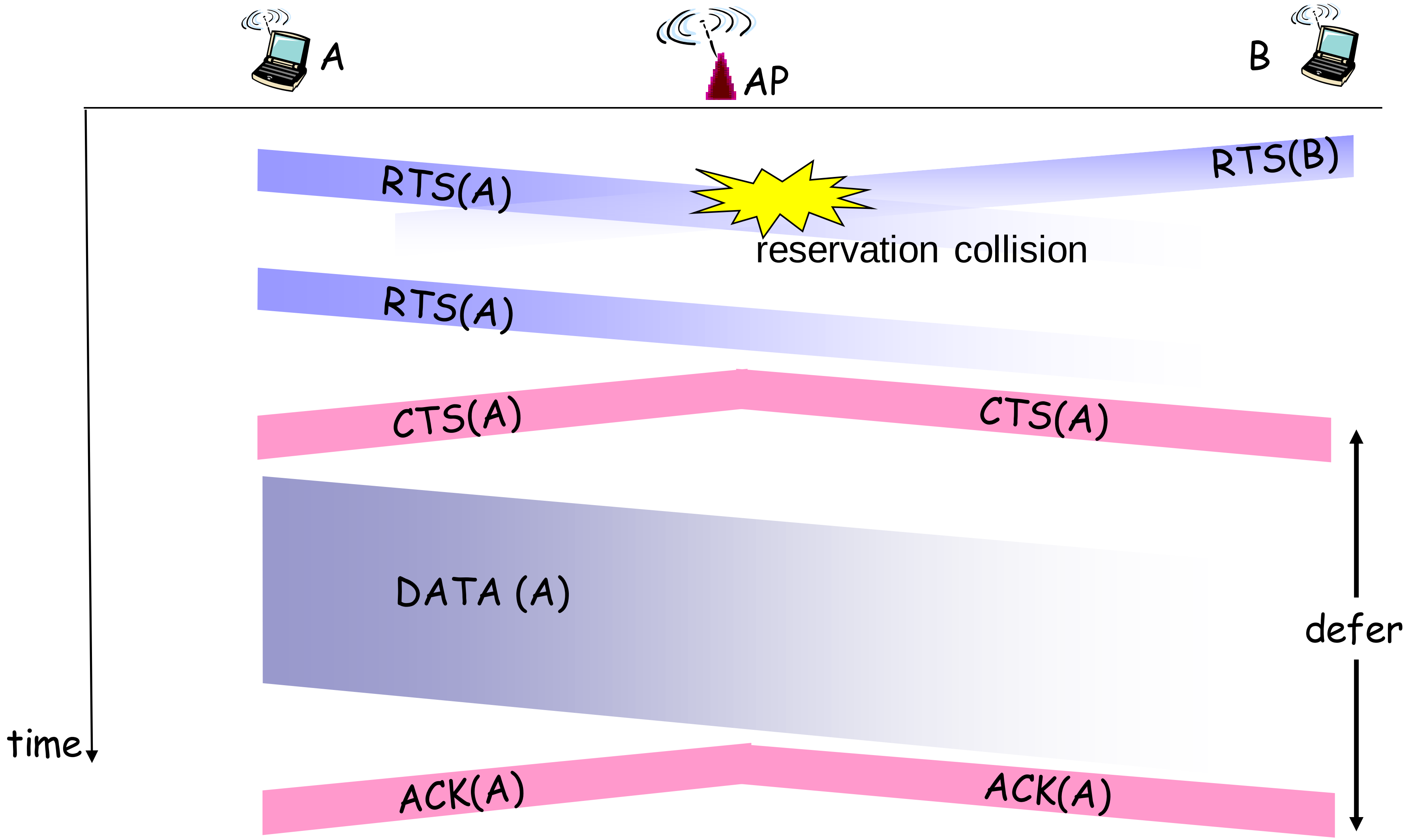
Avoiding collisions (more)

idea: allow sender to "reserve" channel rather than random access of data frames: avoid collisions of long data frames

- sender first transmits *small* request-to-send (RTS) packets to BS using CSMA
  - RTSs may still collide with each other (but they're short)
- BS broadcasts clear-to-send (CTS) in response to RTS
- RTS heard by all nodes
  - sender transmits data frame
  - other stations defer transmissions

Avoid data frame collisions completely using small reservation packets!

Collision Avoidance: RTS-CTS exchange



802.11 frame: addressing

2	2	6	6	6	2	6	0 - 2312	4
frame control	duration	address 1	address 2	address 3	seq control	address 4	payload	CRC

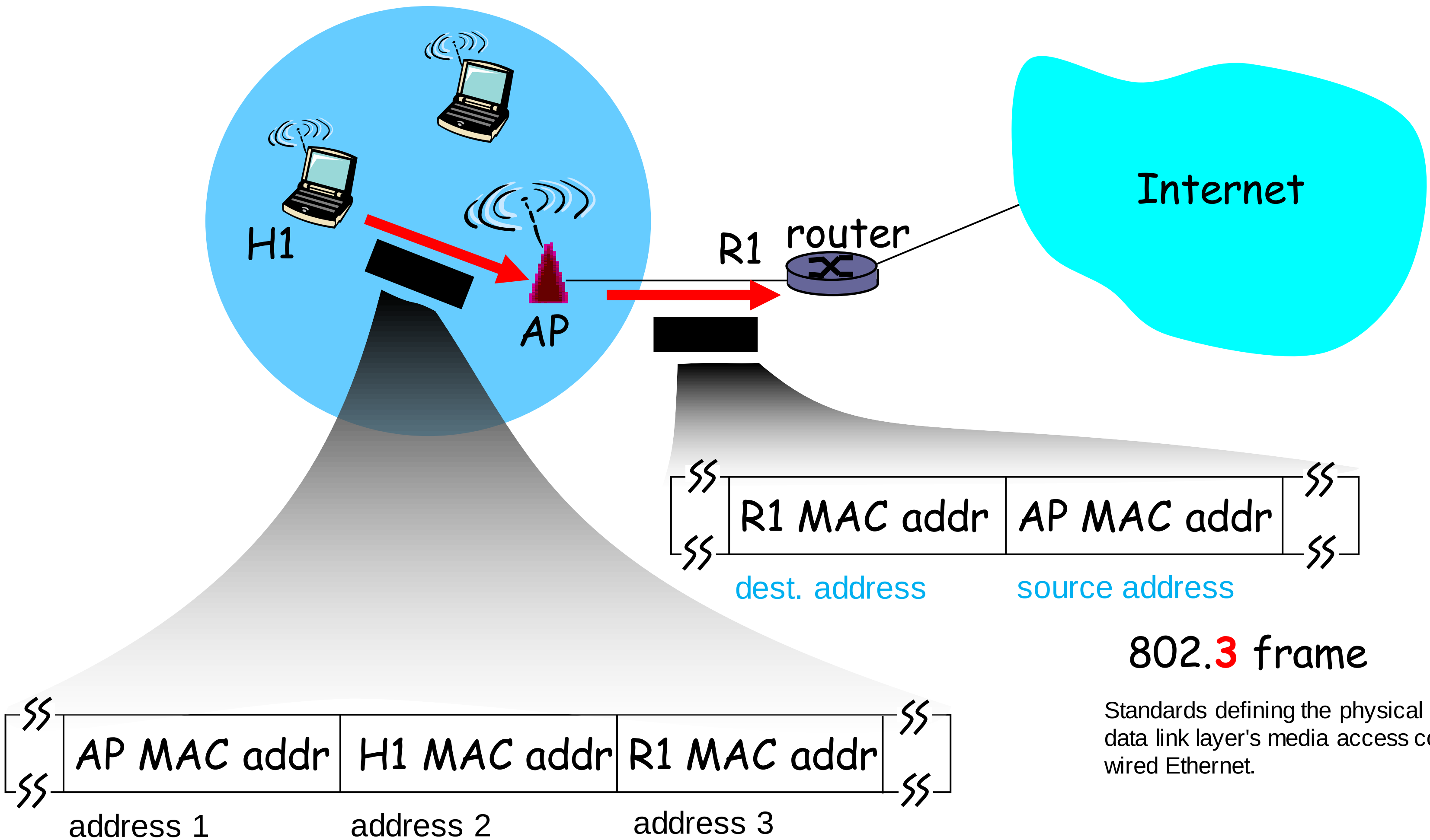
Address 1: MAC address of wireless host or AP to receive this frame

Address 2: MAC address of wireless host or AP transmitting this frame

Address 3: MAC address of router interface to which AP is attached

Address 3: used only in ad hoc mode

802.11 frame: addressing



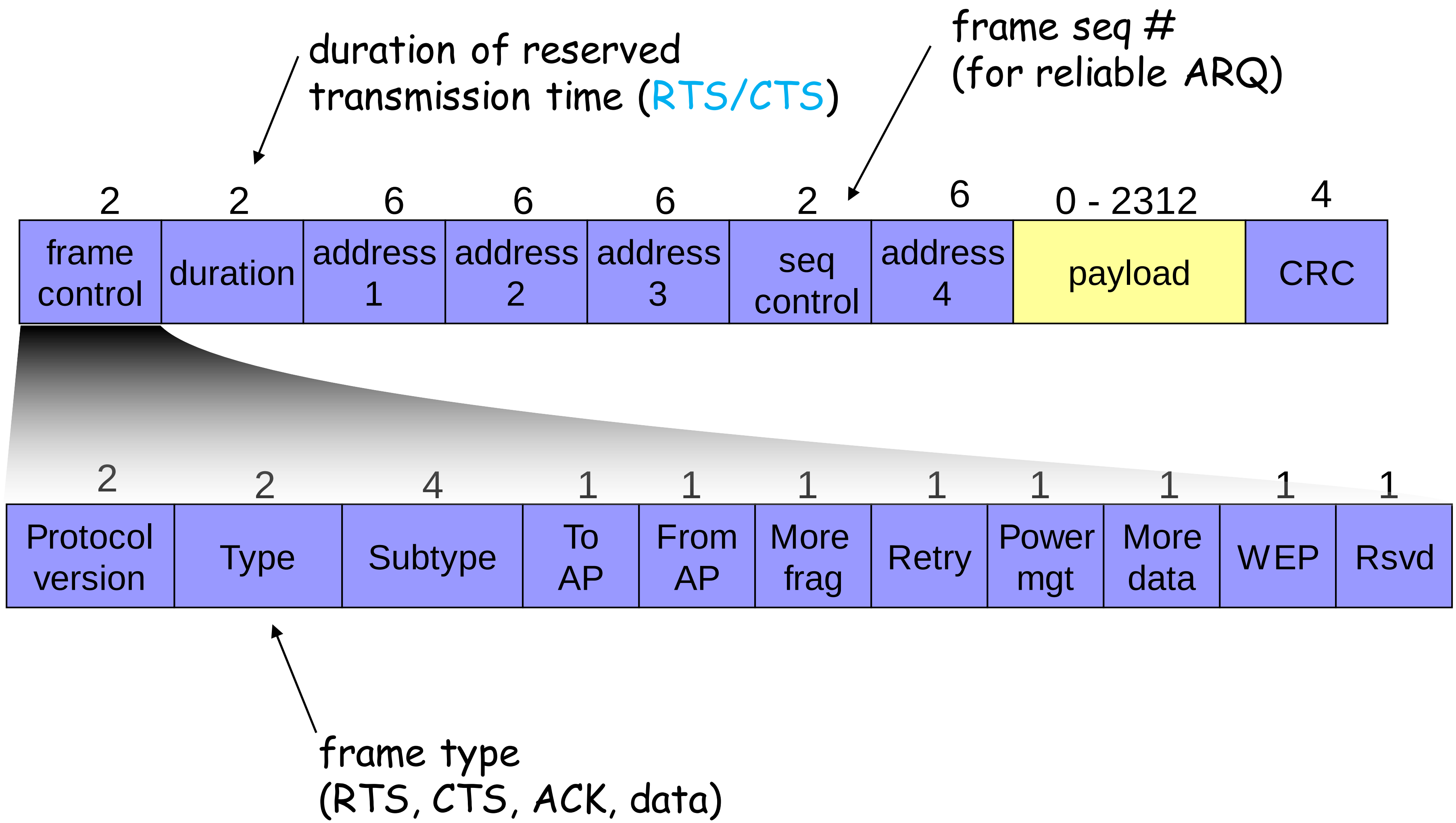
802.3 frame

Standards defining the physical layer and data link layer's media access control of wired Ethernet.

802.11 frame

Specifies the set of media access control and physical layer protocols for implementing wireless local area network computer communication

802.11 frame: more



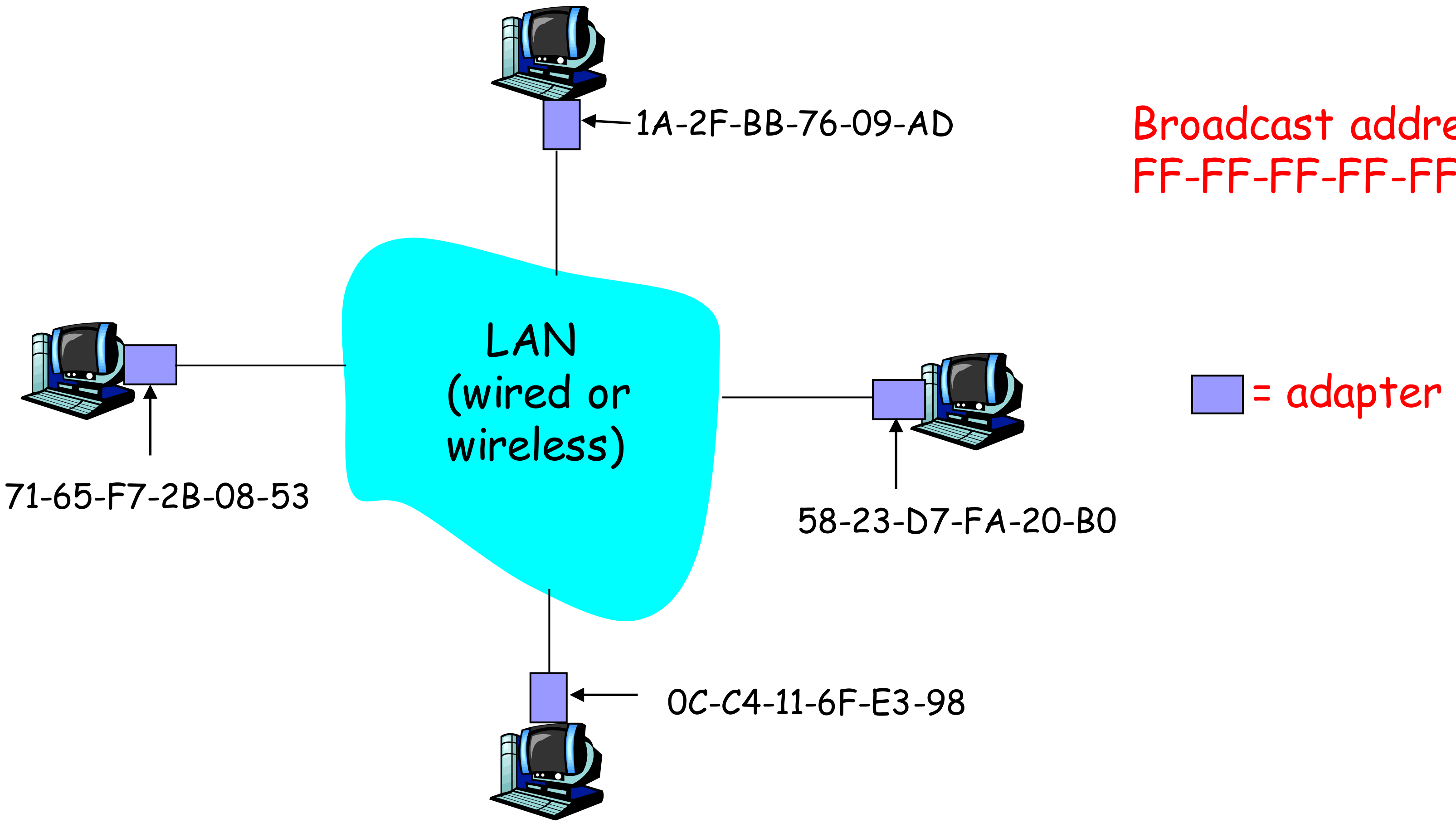
Link Layer Addressing

MAC Addresses and ARP

- 32-bit IP address:
  - *network-layer* address
  - used to get datagram to destination IP subnet
- MAC (or LAN or physical or Ethernet) 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 <u>unique LAN address</u>



Broadcast address =
FF-FF-FF-FF-FF-FF

LAN Address (more)

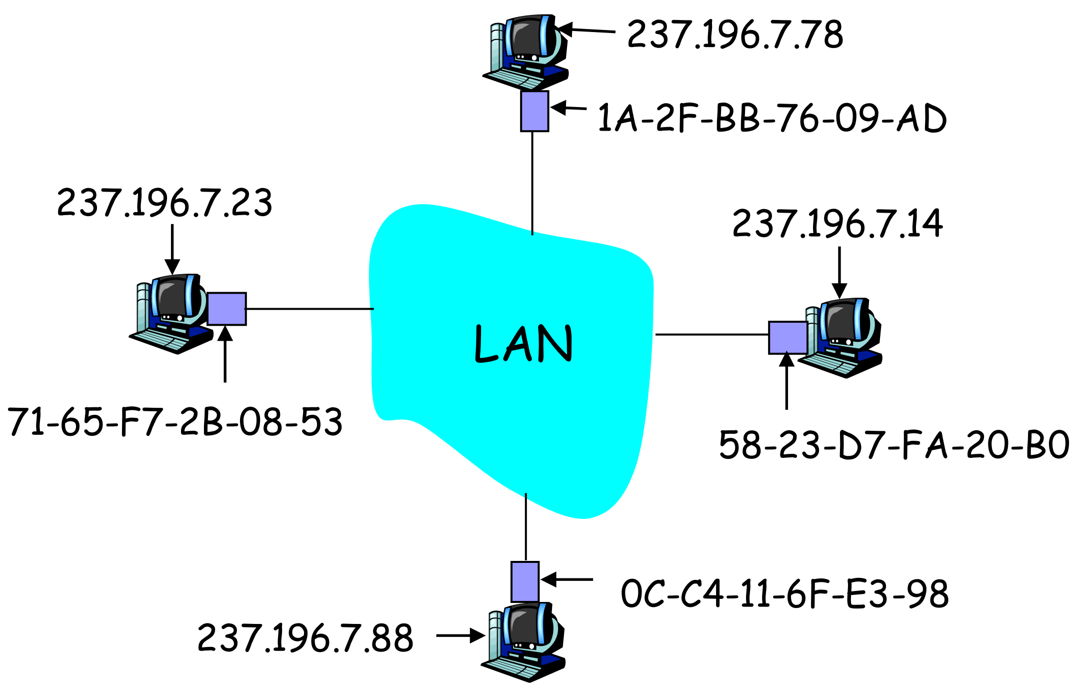
- MAC address allocation administered by IEEE
- manufacturer buys portion of MAC address space (to assure uniqueness)
- Analogy:

  (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 IP subnet to which node is attached

ARP: Address Resolution Protocol

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



- Each IP node (Host, Router) on LAN has ARP 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)
  - RARP?????? MAC/IP

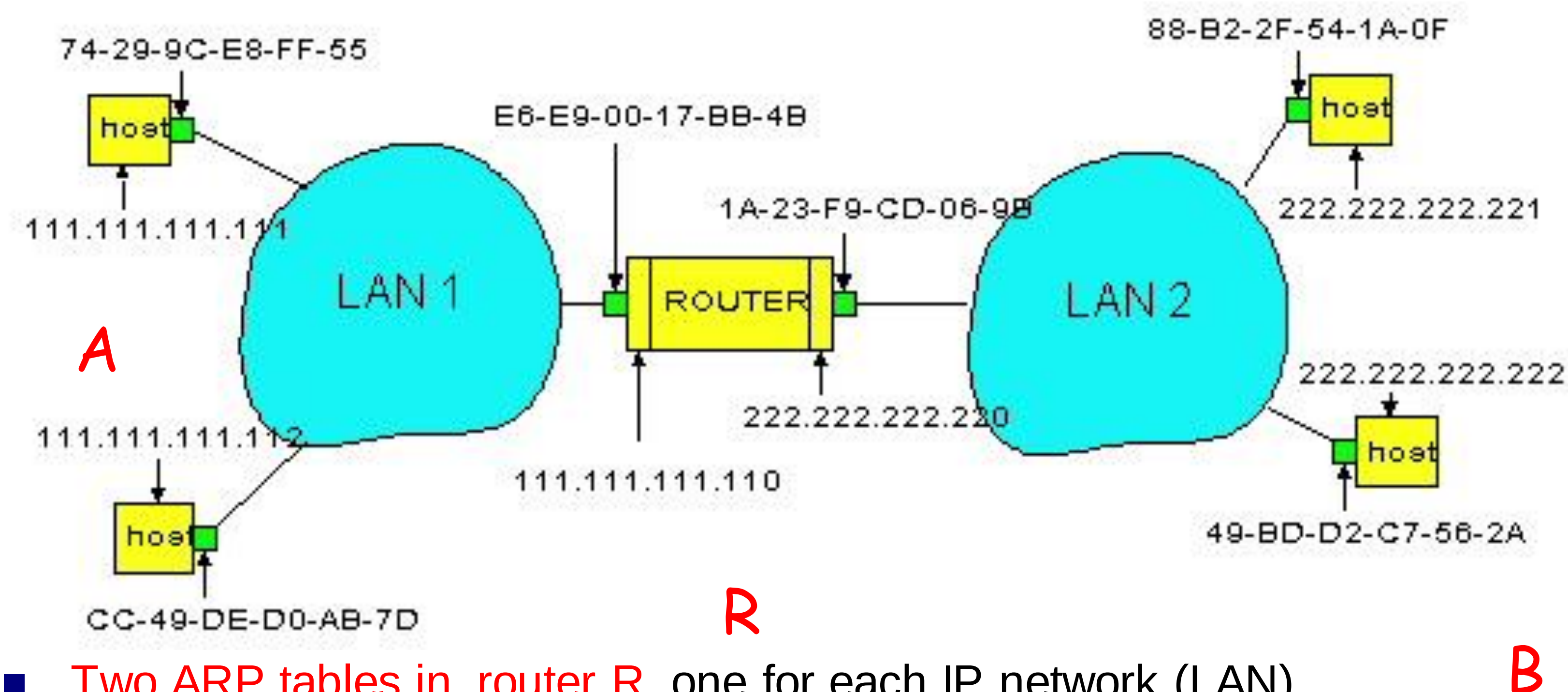
ARP protocol: Same LAN (network)

- A wants to send datagram to B, and B's MAC address not in A's ARP table.
- A **broadcasts** ARP query packet, containing B's IP address
  - Dest MAC address = FF-FF-FF-FF-FF-FF
  - all machines on LAN receive ARP query
- B receives ARP packet, replies to A with its (B's) MAC address
  - frame sent to A's MAC address (**unicast**)
- A caches (saves) IP-to-MAC address pair in its ARP table until information becomes old (times out)
  - soft state: information that times out (goes away) unless refreshed
- ARP is "plug-and-play":
  - nodes create their ARP tables without intervention from net administrator

Routing to another LAN

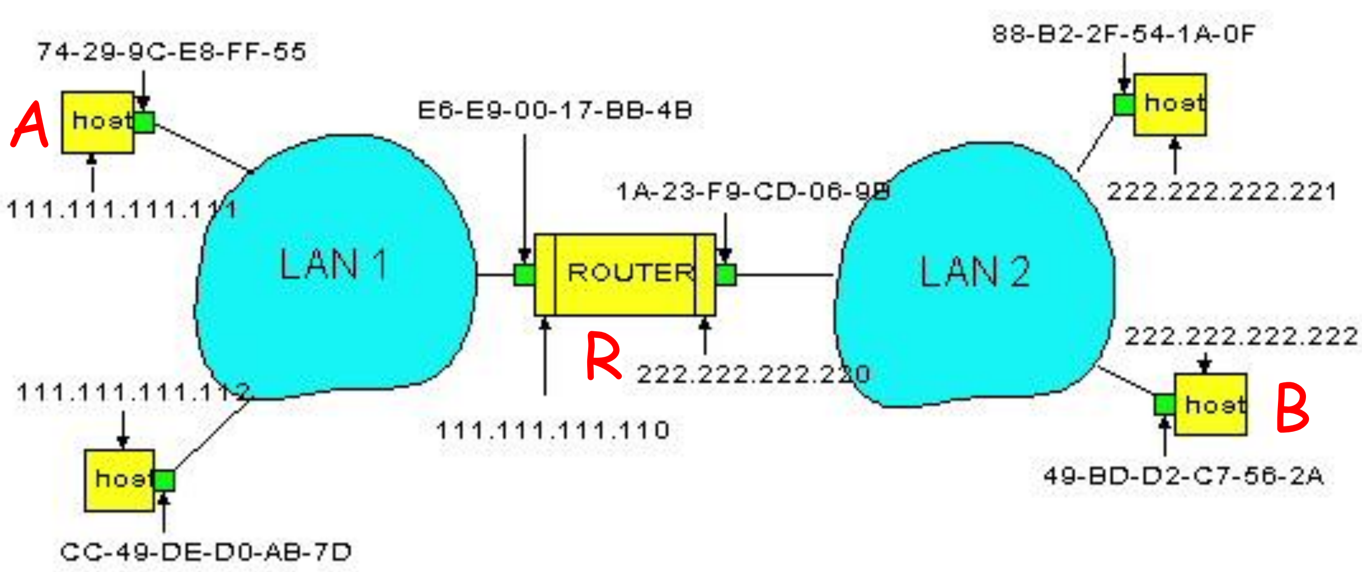
walkthrough: send datagram from A to B via R

assume A know's B IP address



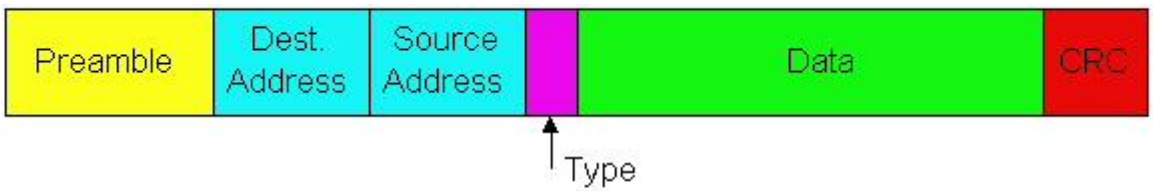
- Two ARP tables in router R, one for each IP network (LAN)
- In routing table at source Host, find router 111.111.111.110
- In ARP table at source, find MAC address E6-E9-00-17-BB-4B, etc

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



Ethernet Frame Structure

Sending adapter encapsulates IP datagram (or other network layer protocol packet) in Ethernet frame

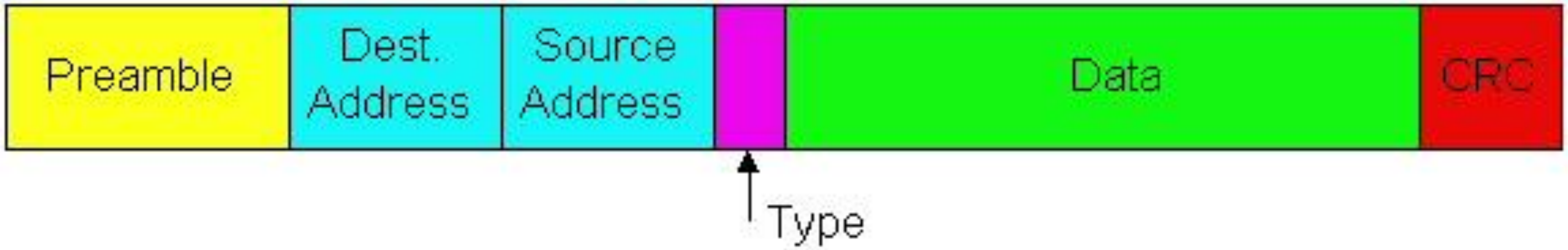


Preamble:

- 7 bytes with pattern 10101010 followed by one byte with pattern 10101011
- used to synchronize receiver, sender clock rates

Ethernet Frame Structure (more)

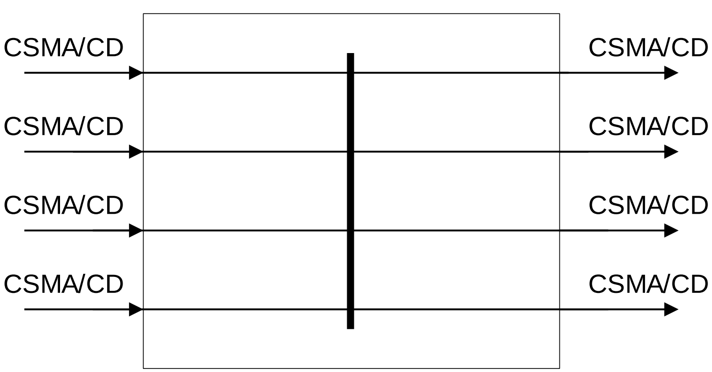
- Addresses: 6 bytes
  - if adapter receives frame with matching destination address, or with broadcast address (eg ARP packet), it passes data in frame to net-layer protocol
  - otherwise, adapter discards frame
- Type: indicates the higher layer protocol (mostly IP but others may be supported such as Novell IPX and AppleTalk)
- CRC: checked at receiver, if error is detected, the frame is simply dropped



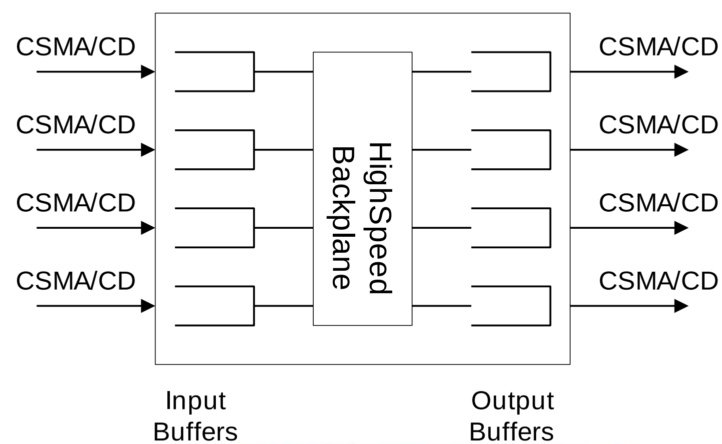
Ethernet Hubs vs. Ethernet Switches

- An **Ethernet switch** is a packet switch for Ethernet frames
  - Buffering of frames prevents collisions.
  - Each port is isolated and builds its own collision domain
- An **Ethernet Hub** does not perform buffering:
  - Collisions occur if two frames arrive at the same time.

Hub



Switch



Self learning

- A switch has a switch table
- entry in switch table:
  - (MAC Address, Interface, Time Stamp)
  - Stale (old) entries in table dropped (TTL can be 60 min)
- switch *learns* which hosts can be reached through which interfaces
  - when frame received, switch “learns” location of sender: incoming LAN segment
  - records sender/location pair in switch table

Filtering/Forwarding

When switch receives a frame:

index switch table using MAC dest address

if entry found for destination

then{

if dest on segment from which frame arrived

then drop the frame

else forward the frame on interface indicated

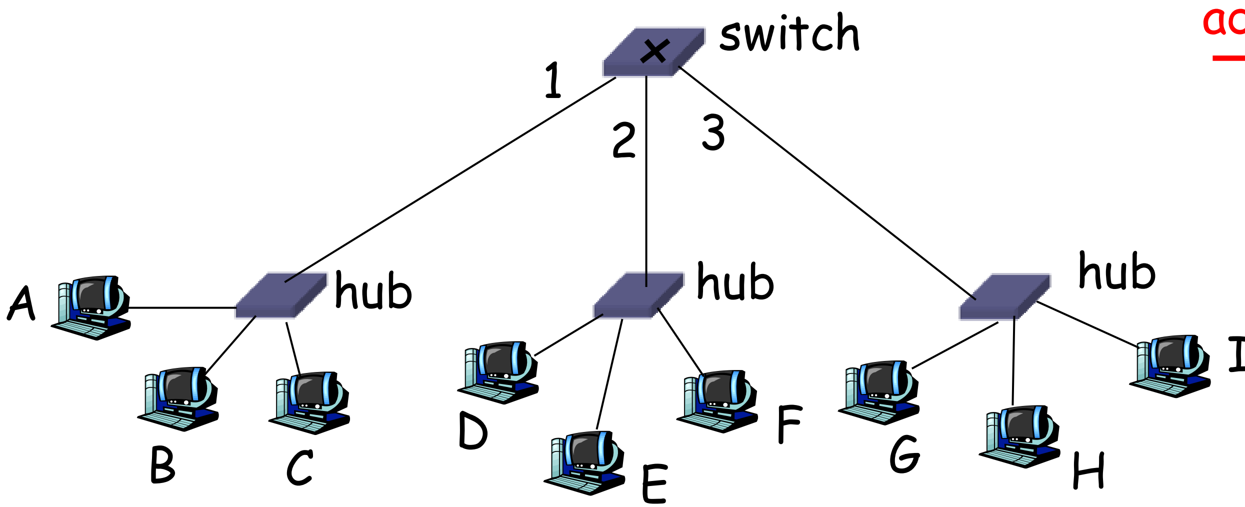
}

else flood

forward on all but the interface on which the frame arrived

Switch example

Suppose C sends frame to D

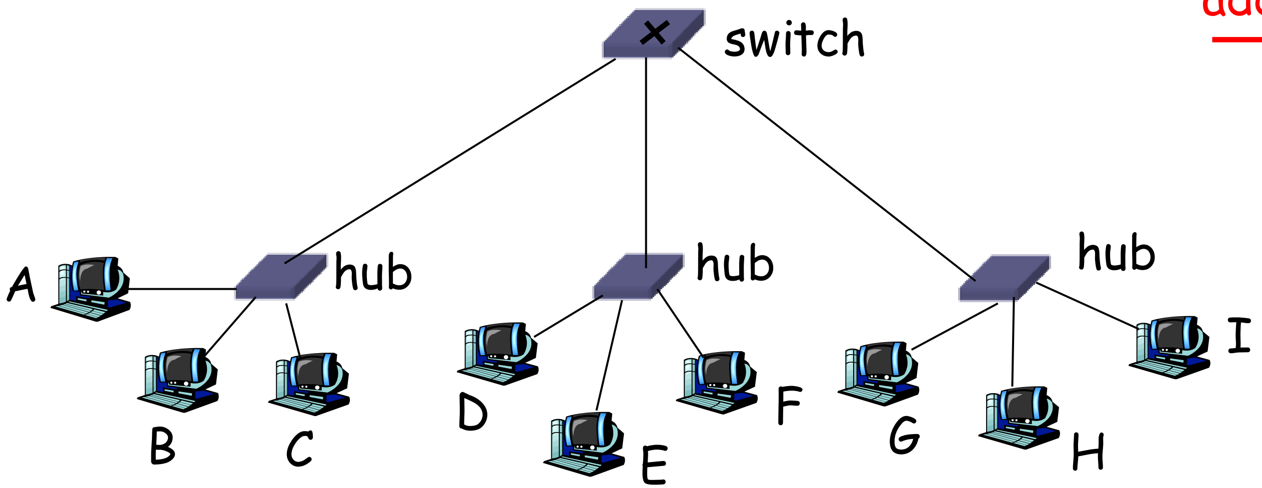


address	interface
A	1
B	1
E	2
G	3

- Switch receives frame from C
  - notes in bridge table that C is on interface 1
  - because D is not in table, switch forwards frame into interfaces 2 and 3
- frame received by D

Switch example

Suppose D replies back with frame to C.



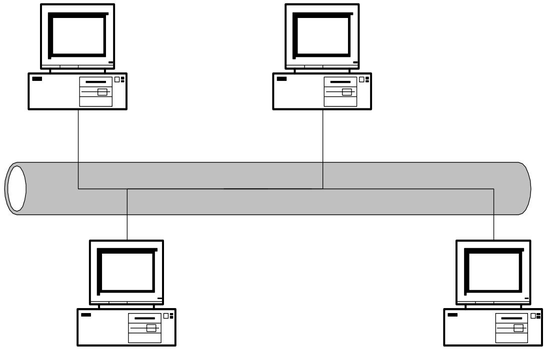
address	interface
A	1
B	1
E	2
G	3
C	1

- Switch receives frame from from D
  - notes in bridge table that D is on interface 2
  - because C is in table, switch forwards frame only to interface 1
- frame received by C

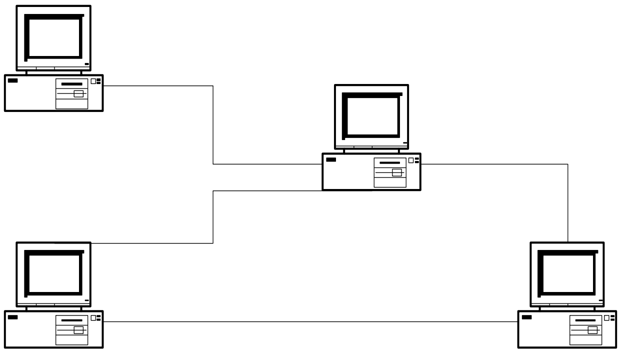
Link Layer Encapsulation

Two types of networks at the data link layer**

- Broadcast Networks: All stations share a single communication channel
- Point-to-Point Networks: Pairs of hosts (or routers) are directly connected



Broadcast Network

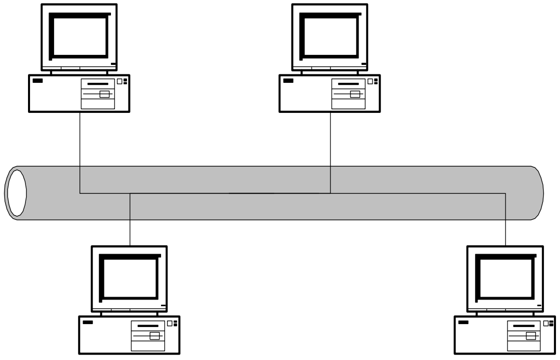


Point-to-Point Network

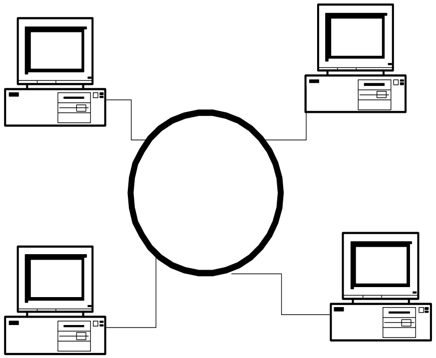
- Typically, local area networks (LANs) are broadcast and wide area networks (WANs) are point-to-point

Local Area Networks

- Local area networks (LANs) connect computers within a building or a enterprise network
- Almost all LANs are <u>broadcast</u> networks
- Typical topologies of LANs are **bus** or **ring** or **star**
- We will work with Ethernet LANs. Ethernet has a bus or star topology.



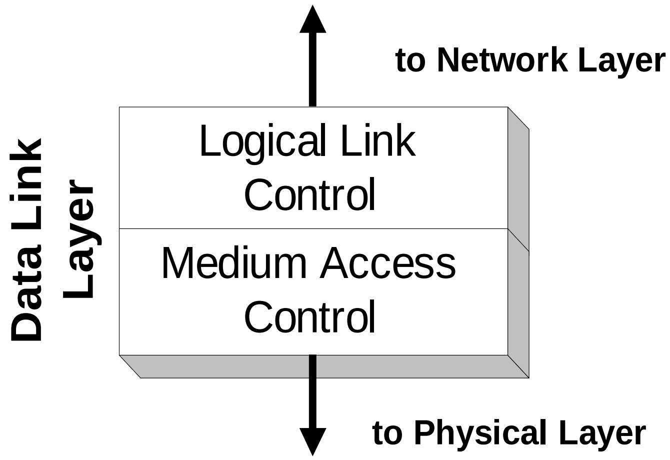
Bus LAN



Ring LAN

MAC and LLC

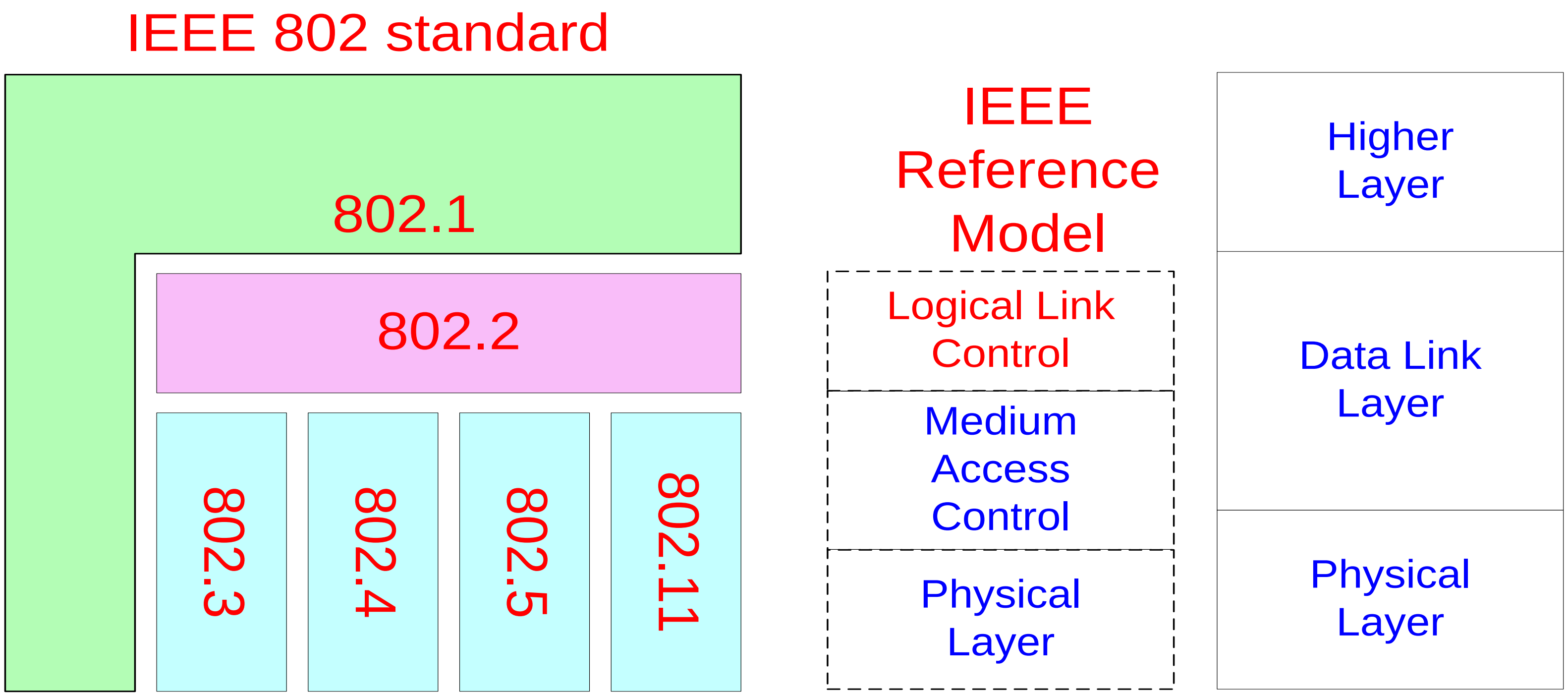
- In any broadcast network, the stations must ensure that only one station transmits at a time on the shared communication channel
- The protocol that determines who can transmit on a broadcast channel are called Medium Access Control (MAC) protocol
- The MAC protocol are implemented in the MAC sublayer which is the lower sublayer of the data link layer
- The higher portion of the data link layer is often called Logical Link Control (LLC)



- The LLC sublayer provides multiplexing mechanisms that make it possible for several network protocols (e.g. IP, IPX and DECnet) to coexist within a multipoint network and to be transported over the same network medium.

IEEE 802 Standards

- IEEE 802 is a family of standards for LANs, which defines an LLC and several MAC sublayers



IEEE 802 Standards

Standard	Purpose
802.1	Internetworking
802.2	Logical Link Control
802.3	Ethernet LAN (CSMA/CD)
802.4	Token-Bus LAN
802.5	Token-Ring LAN
802.6	Metropolitan Area Network
802.7	Broadband Technical Advisory Group
802.8	Fiber-Optic Technical Advisory
802.9	Integrated Voice OR Data Network
802.10	Network Security
802.11	Wireless Networks
802.12	Demand Priority Access LAN
802.15	Wireless Personal Area Network
802.16	Broadband Wireless Metropolitan Area Networks
802.17	Resilient Packet Rings
802.20	Mobile Broadband Wireless Access

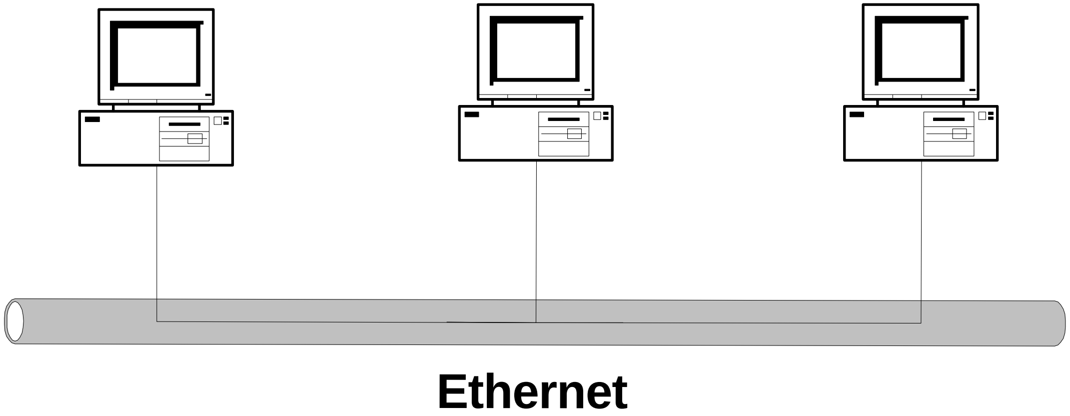
Ethernet

- Speed: 10Mbps -10 Gbps
- Standard: 802.3, Ethernet II (DIX) (Digital, Intel and Xerox)

- Most popular physical layers for Ethernet:
  - 10Base5 **Thick Ethernet:** 10 Mbps coax cable
  - 10Base2 **Thin Ethernet:** 10 Mbps coax cable
  - 10Base-T 10 Mbps Twisted Pair
  - 100Base-TX 100 Mbps over Category 5 twisted pair
  - 100Base-FX 100 Mbps over Fiber Optics
  - 1000Base-FX 1Gbps over Fiber Optics
  - 10000Base-FX 1Gbps over Fiber Optics (for wide area links)

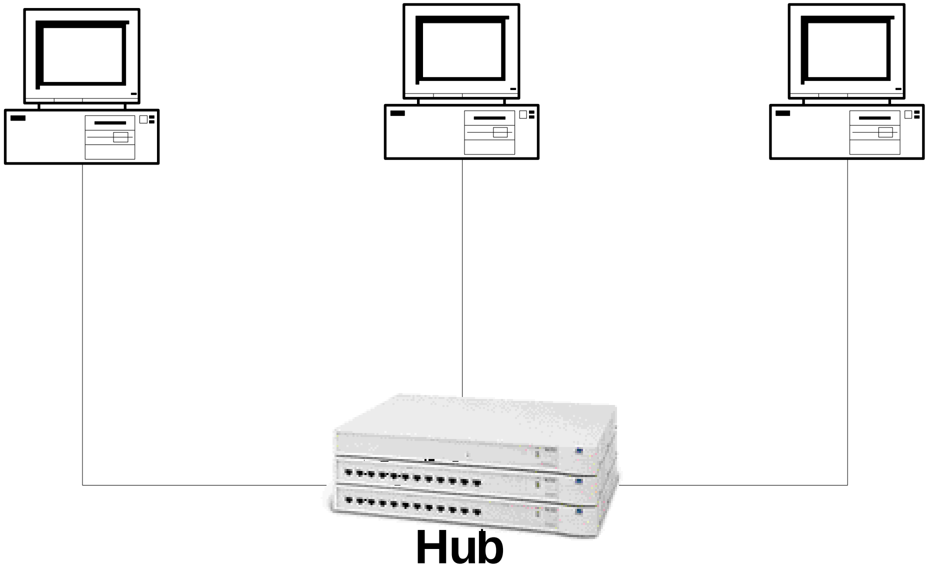
Bus Topology

- 10Base5 and 10Base2 Ethernets has a bus topology



Star Topology

- Starting with 10Base-T, stations are connected to a hub in a star configuration



Ethernet and IEEE 802.3: Any Difference?

- There are two types of Ethernet frames in use, with subtle differences:
- ***"Ethernet" (Ethernet II, DIX)*** *DIX*, (Digital, Intel, and Xerox)
    - An industry standards from 1982 that is based on the first implementation of CSMA/CD by Xerox.
    - Predominant version of CSMA/CD in the US.
- **802.3:**
    - IEEE's version of CSMA/CD from 1985.
    - Interoperates with 802.2 (LLC) as higher layer.

- **Difference for our purposes:** Ethernet and 802.3 use different methods to encapsulate an IP datagram.

Ethernet II, DIX Encapsulation (RFC 894)

destination address	source address	type	data	CRC
6	6	2	46-1500	4

0800	IP datagram
2	38-1492

0806	ARP request/reply	PAD
2	28	10

0835	RARP request/reply	PAD
2	28	10

IEEE 802.2/802.3 Encapsulation (RFC 1042)

Subnetwork Access Protocol (SNAP) frame

←802.3 MAC→←802.2 LLC→←802.2 SNAP→

destination address	source address	length	DSAP AA	SSAP AA	cntl 03	org code 0	type	data	CRC
6	6	2	1	1	1	3	2	38-1492	4

- **destination address, source address:** MAC addresses are 48 bit
- **length:** frame length in number of bytes
- **DSAP, SSAP** : always set to `0xaa`
- **Ctrl:** set to 3
- **org code:** set to 0
- **type field** identifies the content of the data field
- **CRC:** cylic redundancy check

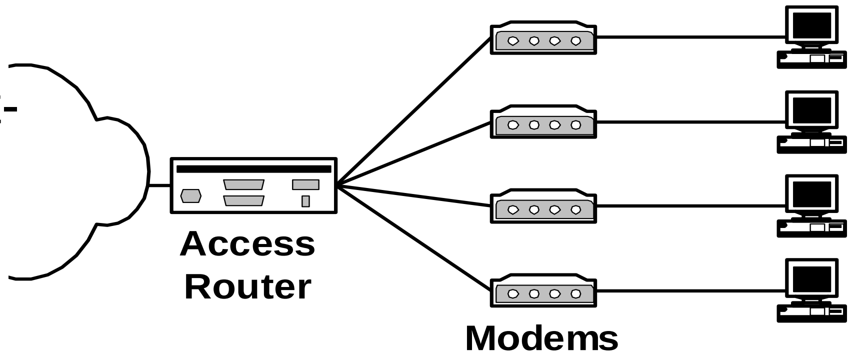
0800	IP datagram
2	38-1492

0806	ARP request/reply	PAD
2	28	10

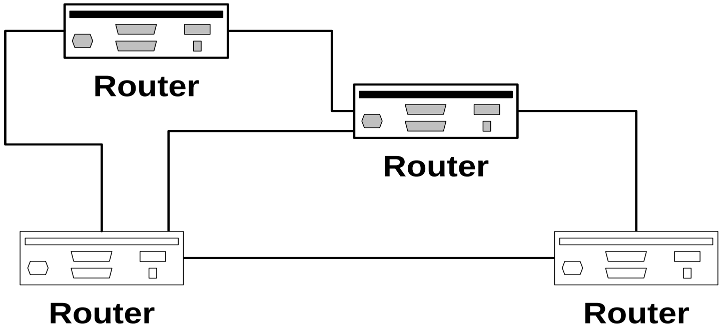
0835	RARP request/reply	PAD
2	28	10

Point-to-Point (serial) links

- Many data link connections are point-to-point serial links:
  - Dial-in or DSL access connects hosts to access routers
  - Routers are connected by high-speed point-to-point links
- Here, IP hosts and routers are connected by a serial cable
- Data link layer protocols for point-to-point links are simple:
  - Main role is encapsulation of IP datagrams
  - No media access control needed



Dial-Up Access



Point-to-Point Links

Data Link Protocols for Point-to-Point links

- **SLIP (Serial Line IP)**
  - First protocol for sending IP datagrams over dial-up links (from 1988)
  - Encapsulation, not much else
- **PPP (Point-to-Point Protocol):**
  - Successor to SLIP (1992), with added functionality
  - Used for dial-in and for high-speed routers
- **HDLC (High-Level Data Link) :**
  - Widely used and influential standard (1979)
  - Default protocol for serial links on Cisco routers
  - Actually, PPP is based on a variant of HDLC

PPP - IP encapsulation

- The frame format of PPP is similar to HDLC and the 802.2 LLC frame format:

flag	addr	ctrl	protocol	data	CRC	flag
7E	**FF**	**03**				**7E**
1	1	1	2	<= 1500	2	1

0021	**IP datagram**

C021	**link control data**

8021	**network control data**

- PPP assumes a duplex circuit
- Note: PPP does not use addresses
- Usual maximum frame size is 1500

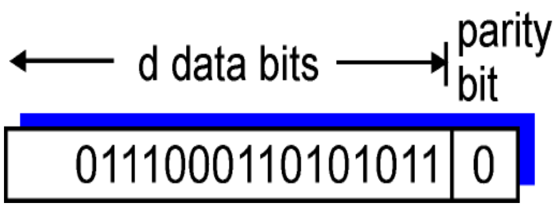
Link Layer Error Control

1. Parity Checking

Parity bit, or check bit is a bit added to a string of binary code, The parity bit ensures that the total number of 1-bits in the string is even or odd

Single Bit Parity:

Detect single bit errors

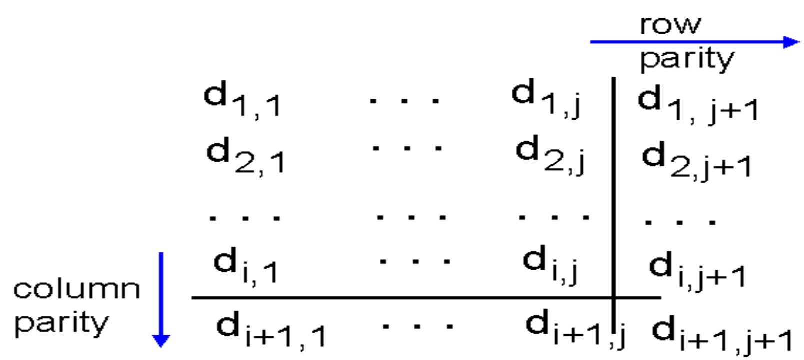


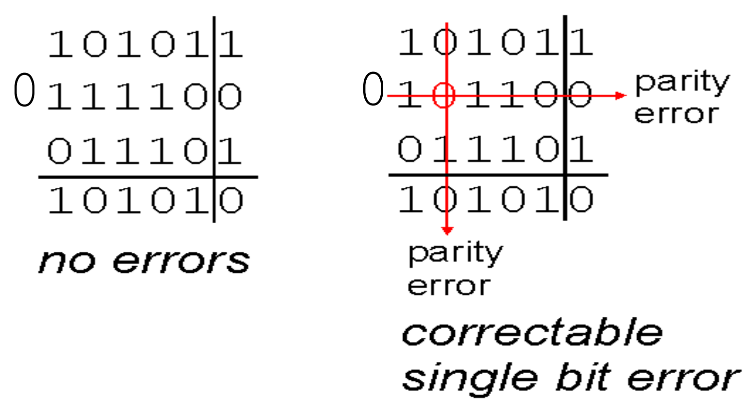
a. 1010001 even 1010001**1**

b. 1010001 odd 1010001**0**

Two Dimensional Bit Parity:

Detect *and correct* single bit errors





2. Internet checksum

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

<u>Sender:</u>

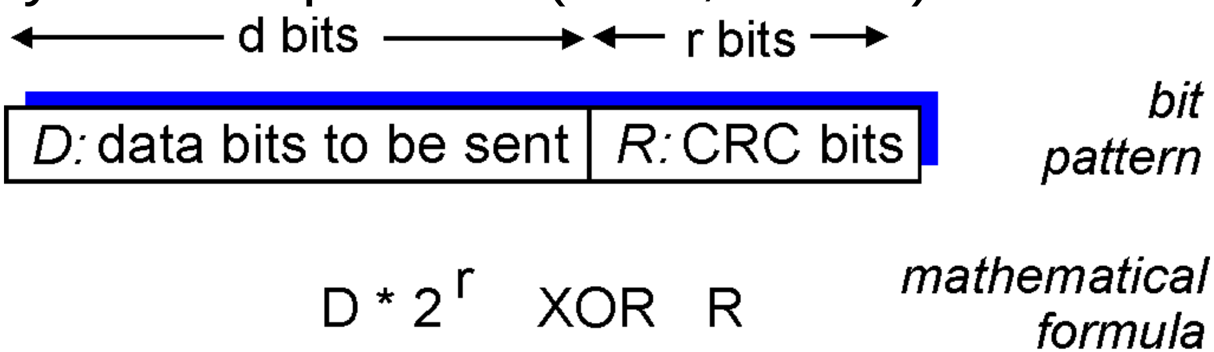
- treat segment contents as sequence of <u>16-bit</u> integers
- checksum: addition (1's complement sum) of segment contents
- sender puts checksum value into UDP checksum field

<u>Receiver:</u>

- 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 ….

3. Cyclic Redundancy Check (CRC)

- 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)

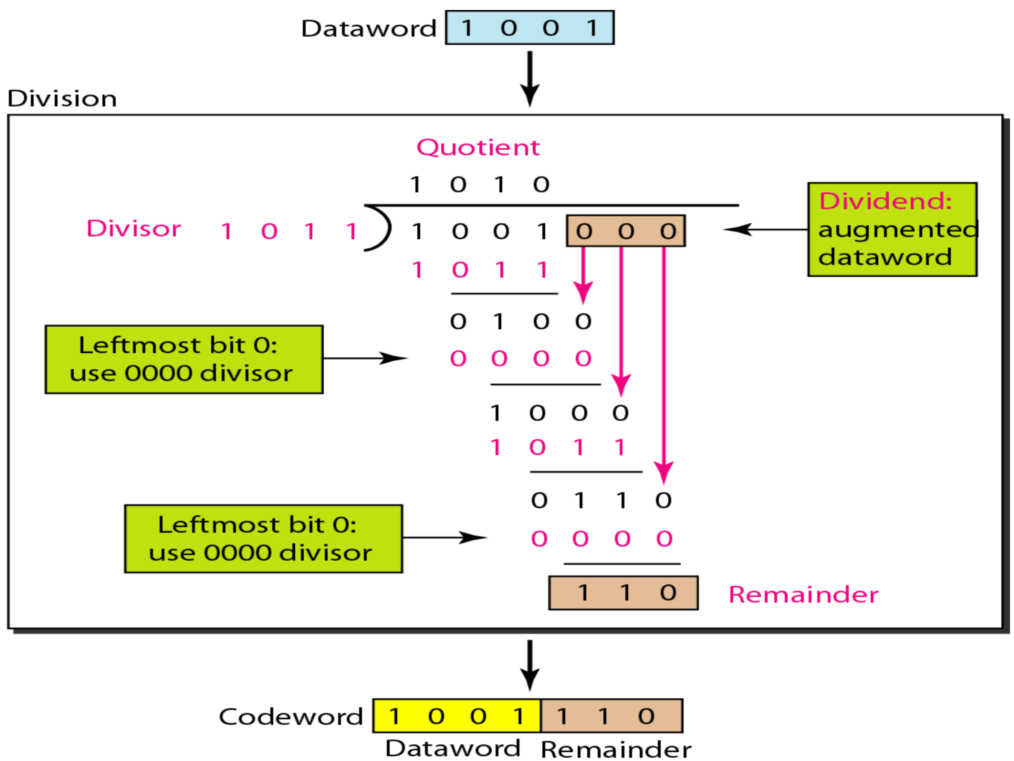


CRC Example

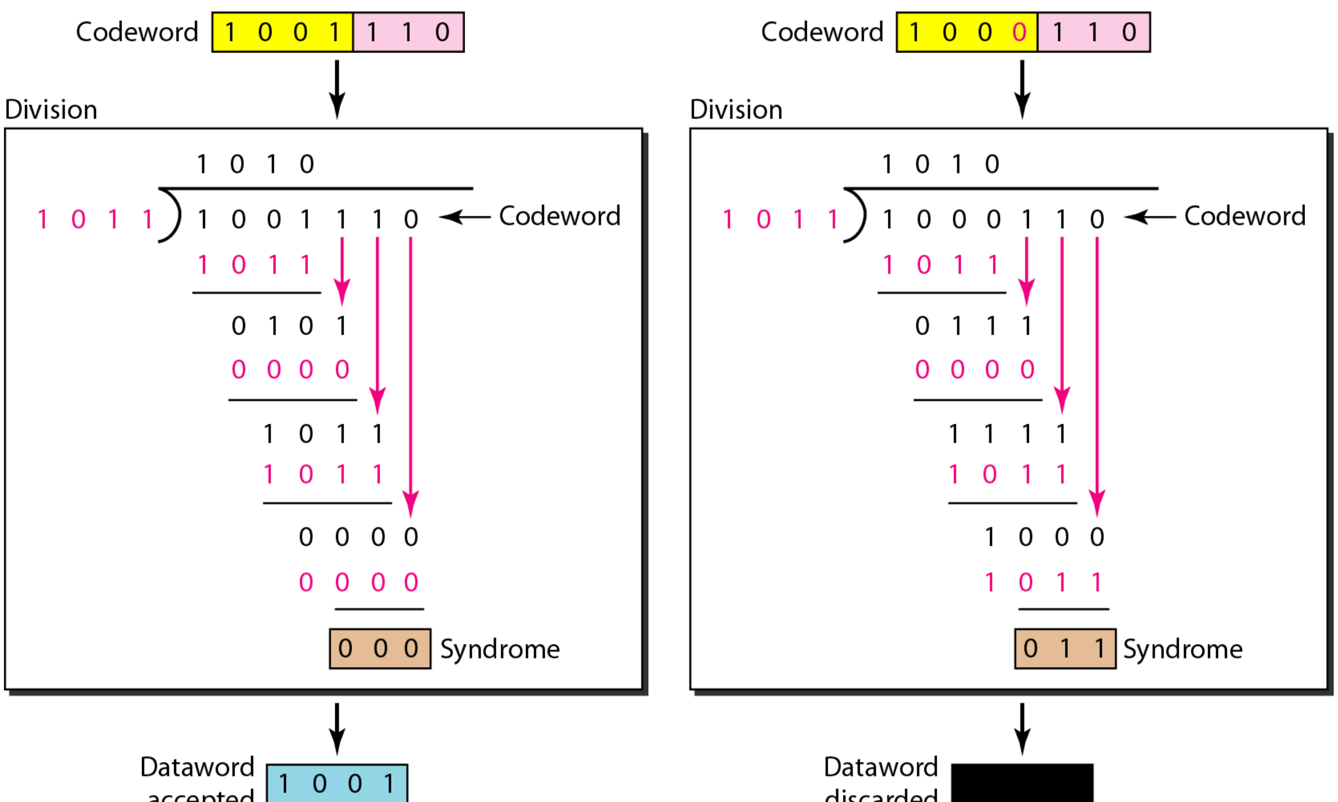
- Cyclic block codes are expressed as **(n, k)** cyclic codes ,where
  - **n** = length of the transmitted code
  - **k** = length of the message.
- For example, a **(7, 4)** code indicates that the total length of the transmit CRC code is 7 and the block check code **(BCC) length = n-k=7-4=3**
- CRC is a division technique where
  - The quotient is not used, and the remainder, which is the CRC block check code (BCC), is attached to the end of the message.

Example 1 (TX)

For a (7, 4) cyclic code and given a message (100 1) and a generator (Divisor) 1011 , Determine the Remainder (BCC) & the code word mathematically



RX


Codeword
1 0 0 1 1 1 0
Division
1 0 1 0
1 0 1 1
1 0 0 1 1 1 0
Codeword
1 0 1 1
0 1 0 1
0 0 0 0
1 0 1 1
1 0 1 1
0 0 0 0
0 0 0 0
0 0 0
Syndrome
Dataword
accepted
1 0 0 1
Codeword
1 0 0 0 1 1 0
Division
1 0 1 0
1 0 1 1
1 0 0 0 1 1 0
Codeword
1 0 1 1
0 1 1 1
0 0 0 0
1 1 1 1
1 0 1 1
1 0 0 0
1 0 1 1
0 1 1
Syndrome
Dataword
discarded