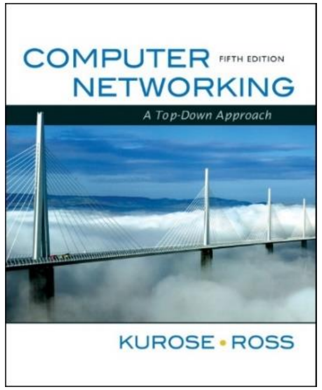


Computer Networks: Link Layer and LANs

Rajesh Palit, Ph.D.
North South University, Dhaka

Link Layer

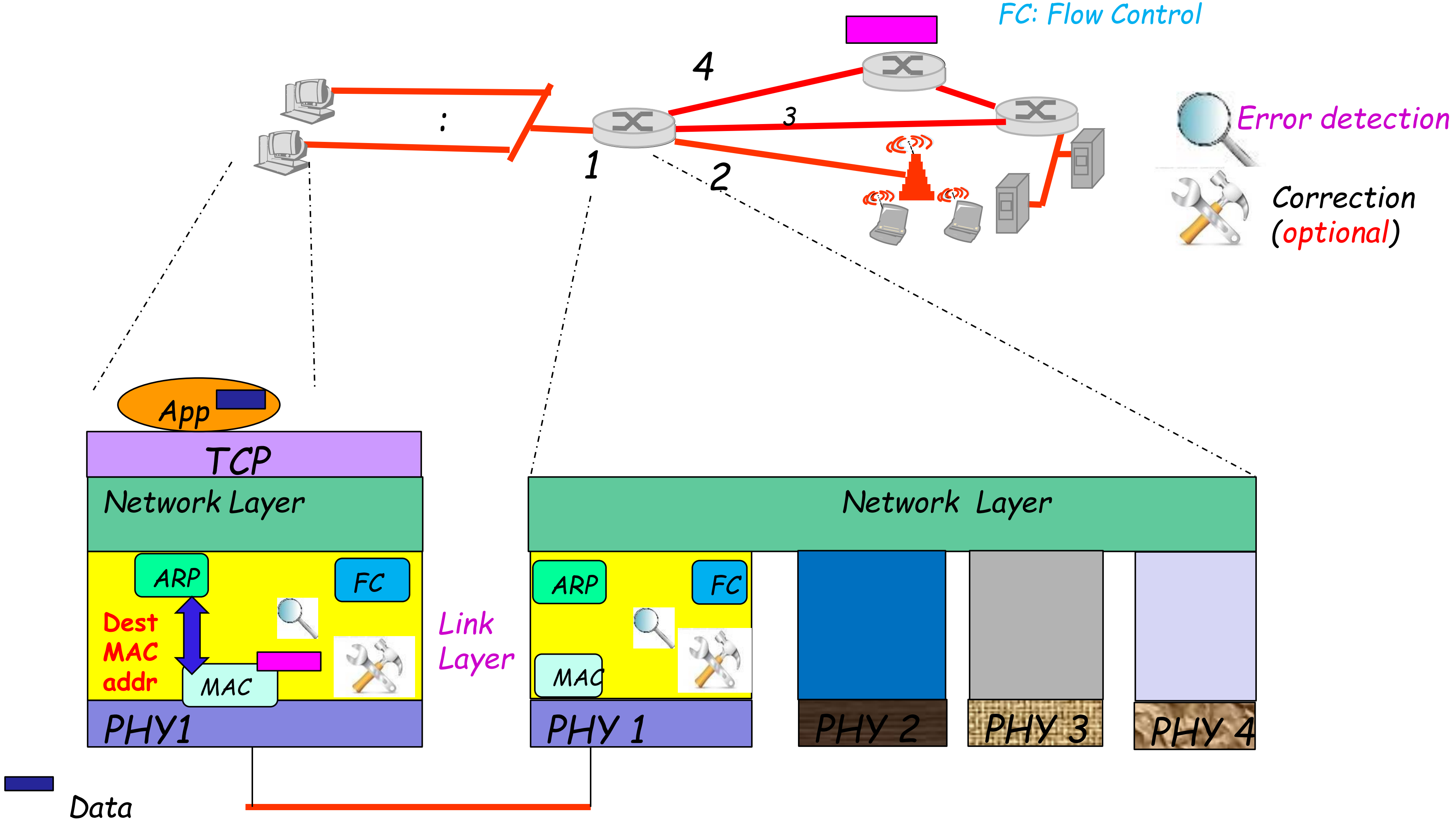
- 5.1 Introduction and services
- 5.2 Error detection and correction
- 5.3 Multiple access protocols
  - WiFi
- 5.4 Link-layer Addressing
- 5.5 Ethernet
- 5.6 Link-layer switches

- 3.4 Reliable data transfer + flow control

Link layer: context

MAC: Medium Access Control

FC: Flow Control



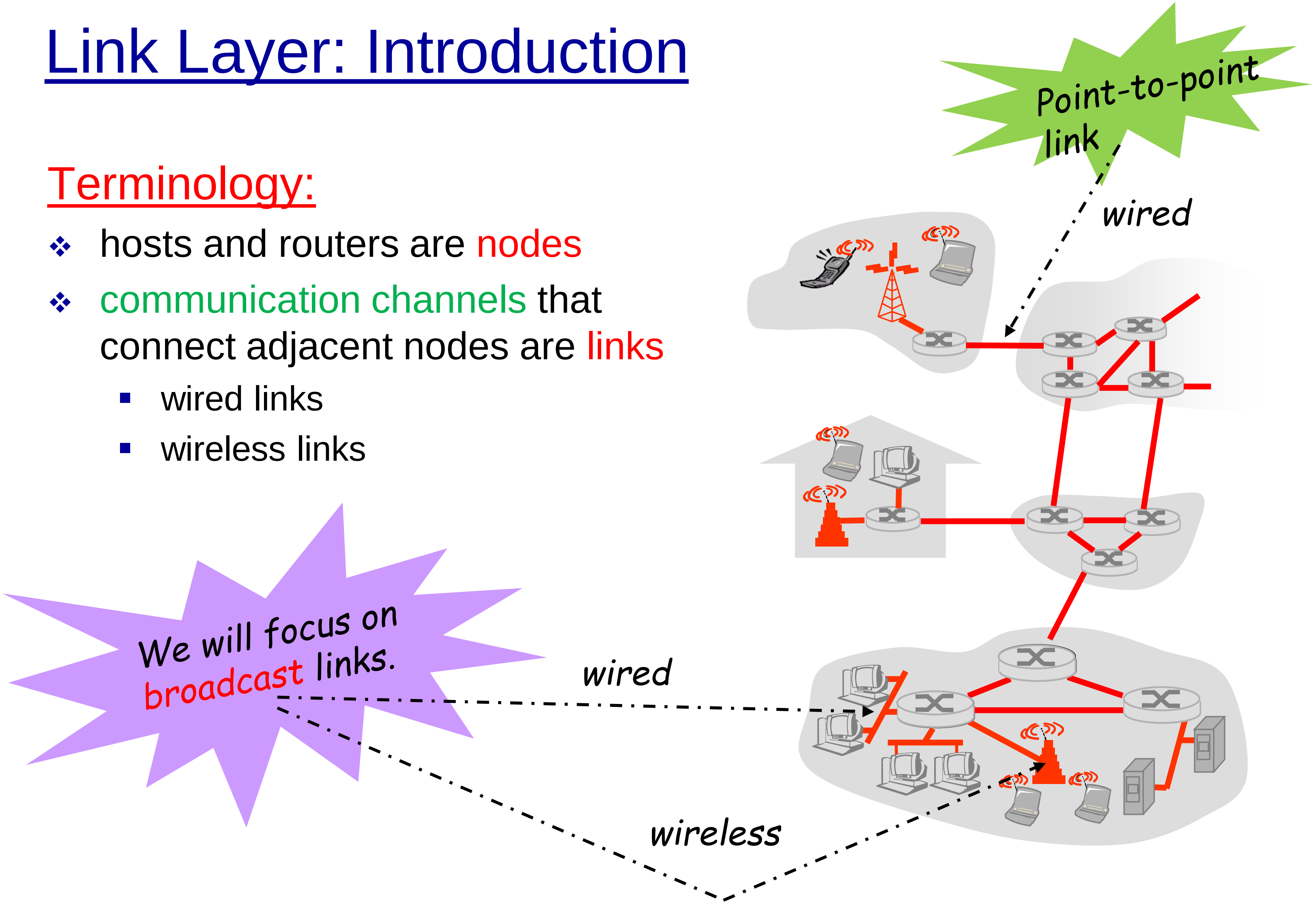
ARP (Address Resolution Protocol): IP address ➔ MAC address
(%ipconfig /all ← for MAC addresses.)

PHY: Physical layer ← hardware

Link Layer: Introduction

Terminology:

- hosts and routers are nodes
- communication channels that connect adjacent nodes are links
  - wired links
  - wireless links

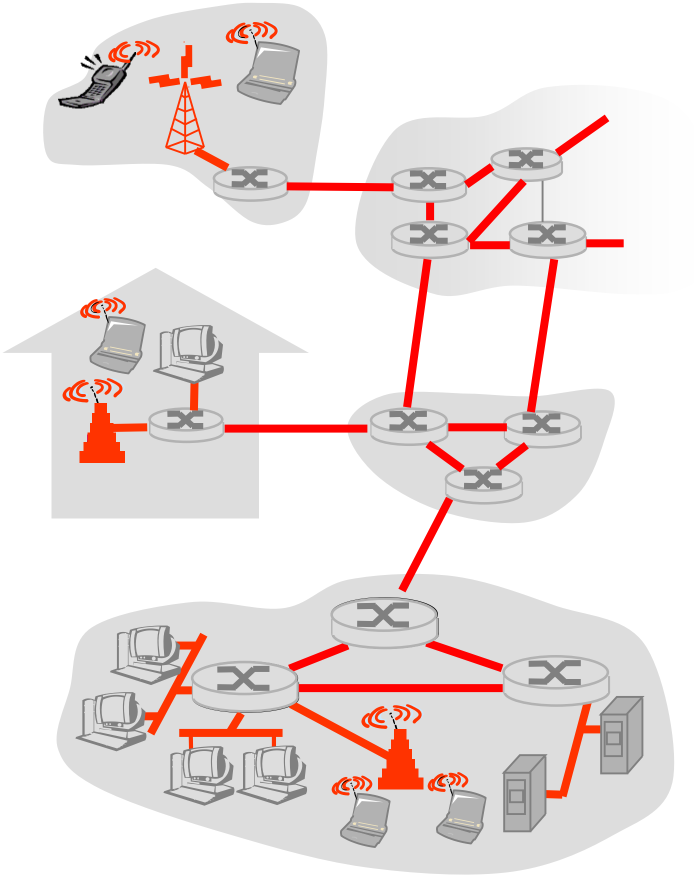


Our goals:

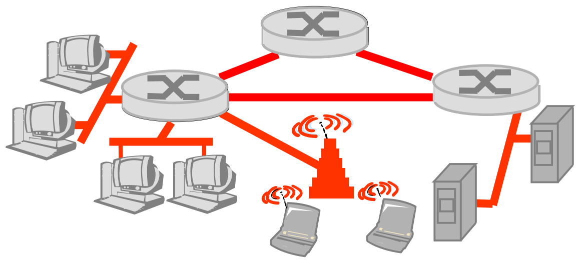
- understand principles behind data link layer services:

1. link access by sharing a broadcast channel: multiple access
   - Instruct the hardware (PHY layer) **when** to transmit (… MAC protocols)

2. link layer addressing



Link Layer Services (more)



- *error detection*:
  - errors caused by signal attenuation and noise
  - receiver detects presence of errors

3

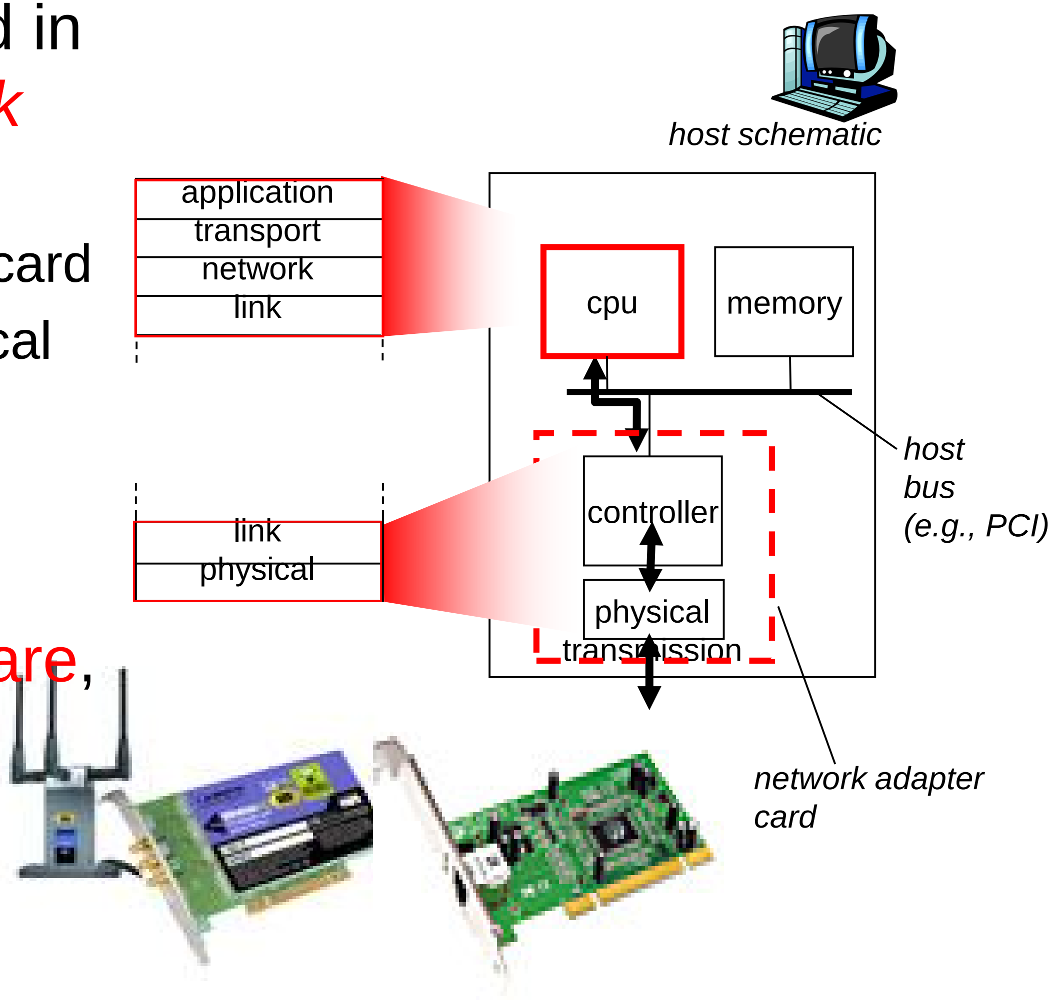
- error correction:
  - receiver identifies *and corrects* bit error(s) without resorting to retransmission
  - receiver signals sender for retransmission

4

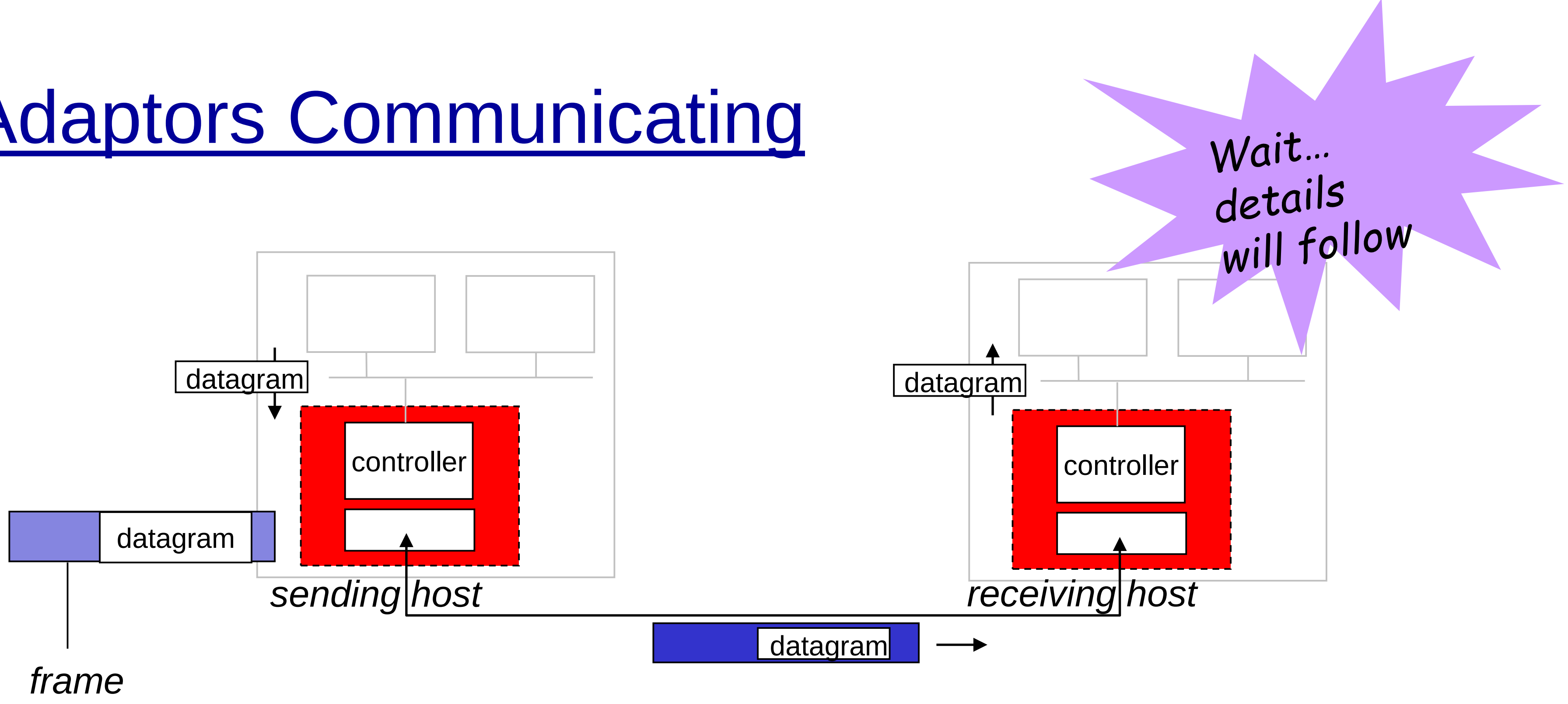
- *flow control:*
  - pacing between (adjacent) sending and <u>receiving</u> nodes

Where is the link layer implemented?

- in each and every host
- link layer implemented in "adaptor" (aka *network interface card* NIC)
  - Ethernet 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, and sequence # for flow control
- receiving side
  - looks for errors
  - extracts datagram, passes to upper layer at receiving side

Link Layer

5.1 Introduction and services

5.2 Error detection and correction

5.3Multiple access protocols

5.4 Link-layer Addressing

5.5 Ethernet

5.6 Link-layer switches

5.7 PPP

3.4 Reliable data transfer

Bit errors in frame (packet) transmissions

New

Transmitted: 1 0 1 1 1 0 0 1

Received: 1 0 0 1 1 0 1 1

Bit error is generally bursty

Tx: 1 0 1 1 0 1 0 0 1 1 1 0 0 1 1 1

Rx 1 0 0 0 1 0 0 0 1 1 1 0 0 1 1 1

Metric used to represent transmission media

BER: Bit Error Rate

Example: 4/16 = 0.25

BER = # of bit errors / Total # of bits transmitted

BER (copper): 10^{-8}

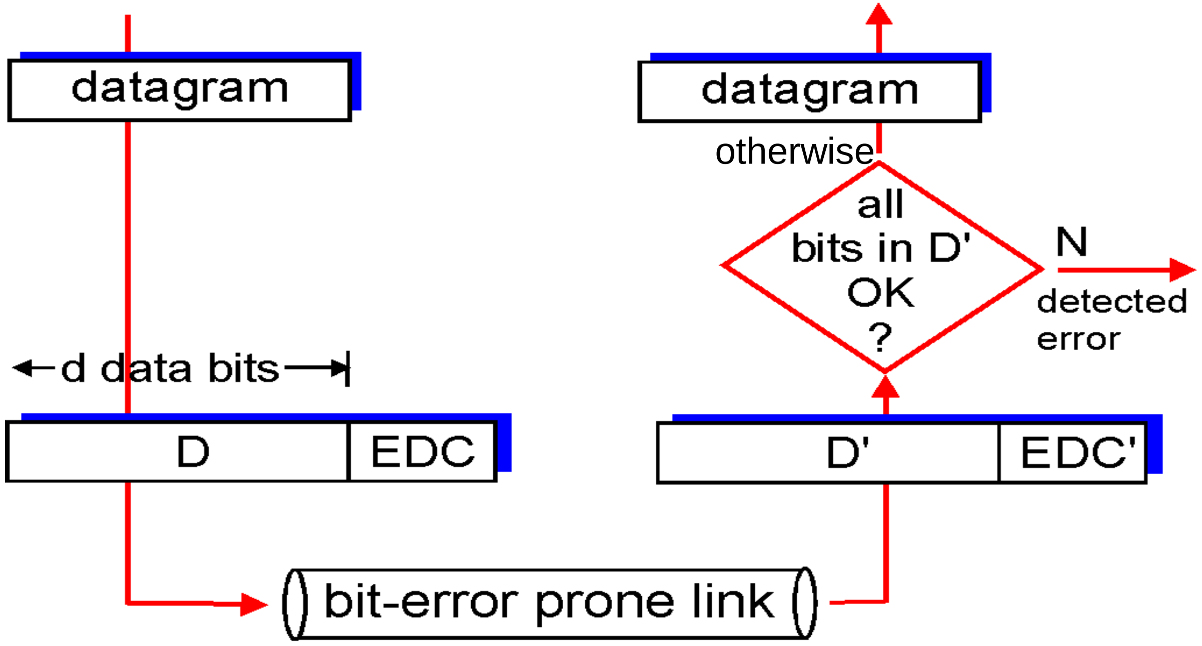
BER (wireless): 10^{-5}

BER (fibre optics): 10^{-12}

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



What are all the error detection mechanisms that I will learn

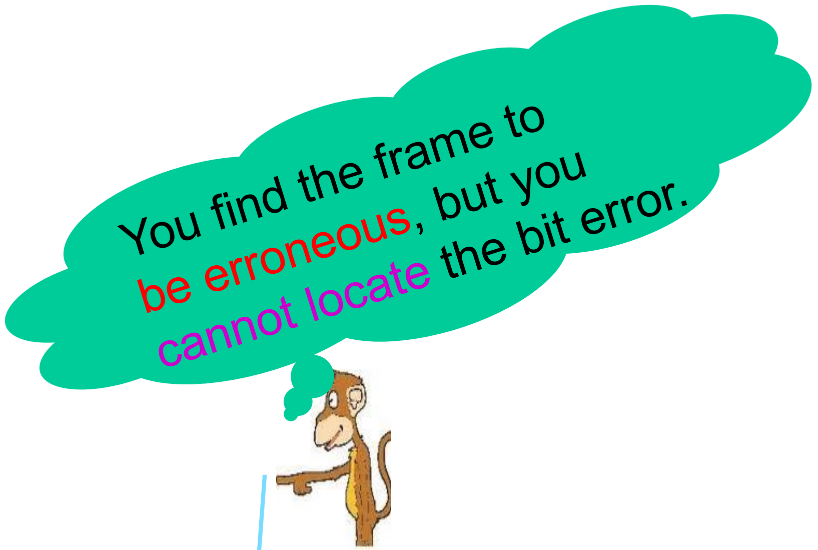
You will learn …

Parity bits (today …)

CRC:
Cyclic Redundancy Check (Link layer)

Internet Checksum
(Network Layer, Transport Layer)

Parity Checking



Single Bit Parity:

Detect single bit errors

d data bits | parity bit

0111000110101011	0

Send this →

………… But, this is received

01110 1 0110101011	0

(Example of odd parity)

Two kinds of parity:

* **Odd parity:** Set the parity bit to 1 or 0 to make the total # of 1's an odd number.

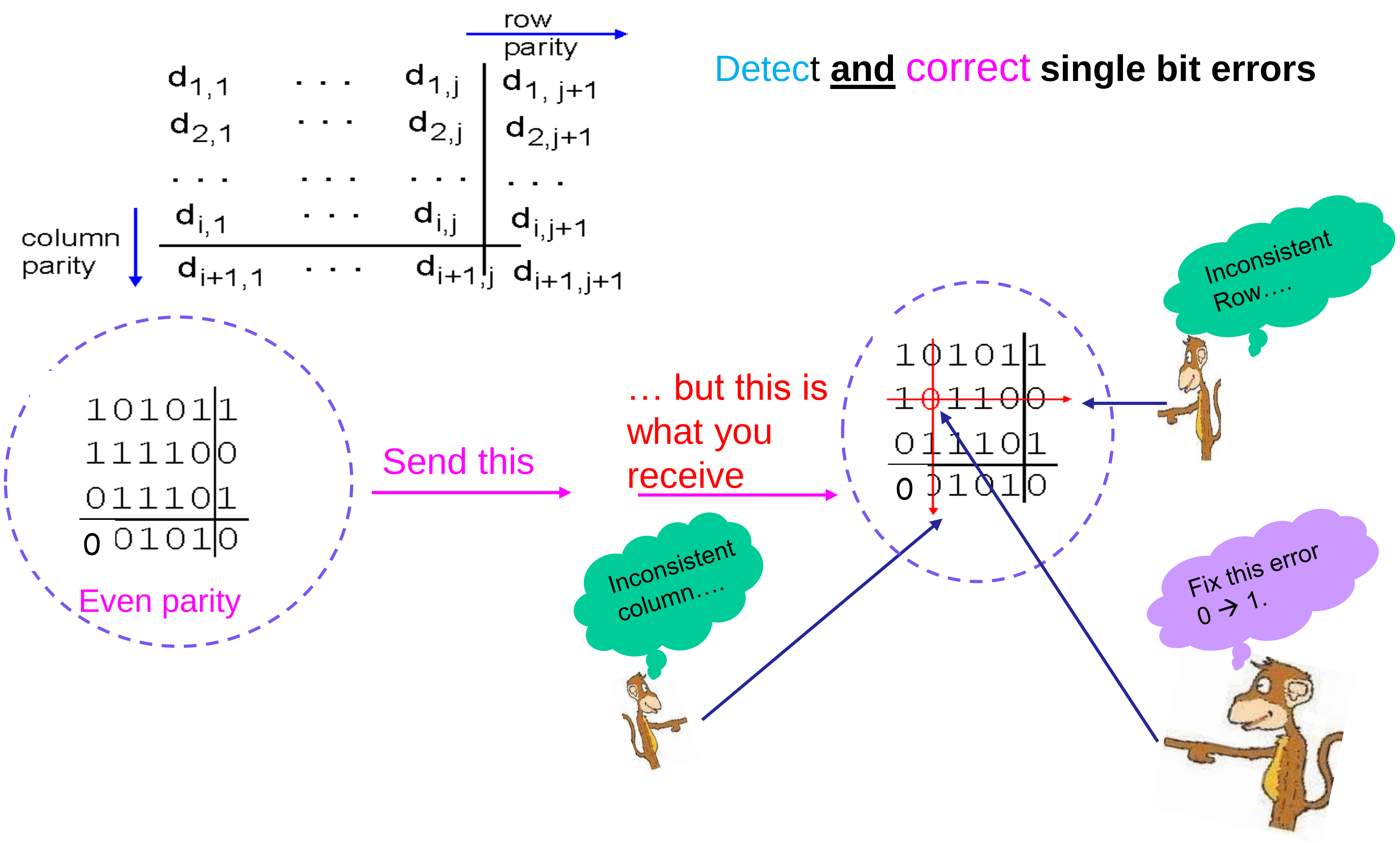
* **Even parity:** Set the parity bit to 1 or 0 to make the total # of 1's an even number

When you compute the parity bit, you know that it should be a '1'.

Use two-dimensional bit parity to **detect and correct single bit errors**

Parity Checking (Two dimensional)

Detect and correct single bit errors



Applications of Parity Checking

Where is parity checking used?

Not generally in network protocols these days...

But, it is used here and here and here ....

RAID: Redundant Array of Inexpensive Drives

DES: Data Encryption Standard for symmetric-key cryptography

Media access is a noisy process..... because of imperfect fabrication and hardware aging.

What kinds of questions
can be asked on the exams?

ECE358
Mid-term S'12

For the following **four bytes** of data, compute the two dimensional *odd* parity bits.

1 1 0 0 1 1 0 1 |
1 0 1 1 1 0 1 1 |
0 1 1 0 1 0 1 1 |
1 0 0 0 0 1 0 1 |

ECE358
Mid-term F'12

For the data and parity bits generated above, introduce four bit errors that the receiver will not be able to detect…

Checksumming: Cyclic Redundancy Check

- view data bits, D, as a binary number
- **choose** r+1 bit pattern (generator), G
- **goal: compute** r CRC bits, R, such that
  - <D,R> is exactly divisible by G (modulo 2) ← zero remainder
  - 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 (Ethernet LAN, 802.11 WiFi, …)

← d bits → ← r bits →

D: data bits to be sent	R: CRC bits

bit pattern

$D * 2^r$ XOR R

mathematical formula

CRC Example:

Want:

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

equivalently:

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

equivalently:

if we divide $D \cdot 2^r$ by G, we get remainder R

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

Properties of XOR:

A XOR A = 0

A XOR 0 = A

(A XOR B) XOR C = A XOR (B XOR C)

Process: Calculation of CRC

If the input bit above the leftmost divisor bit is 1,
the divisor is XORed into the input.
Else (the input bit above the leftmost divisor bit is 0) do nothing.
The divisor is then shifted one bit to the right (➔)
The process is repeated until
the divisor reaches the right-hand end of the input row.

Input: D.2^r ⟶
Divisor: G ⟶
Align input and divisor on MSB

```
1 0 1 1  1 0  0 0 0
1 0 0 1
------------------
0 0 1 0 10  0 0 0
  1 00 1
------------------
0 0 1 0 10  0 0 0
    1 0 01
------------------
0 0 0 0 11  0 0 0
      1 00  1
------------------
0 0 0 0 11  0 0 0
        10  0 1
------------------
0 0 0 0 01  0 1 0
          1  0 0 1
------------------
0 0 0 0 00 0 1 1    R
```

D = 101110

G = 1001

Detailed Calculation of CRC

Transmit <D,R>: 101110011

What questions can be asked on the exams?

ECE358 Mid-term S'12

For the data bits D = 11001101 and generator bits G = 1011, compute the CRC bits.

What is the disadvantage of making the CRC field as long as the data portion of a frame?

```
D.2^r: 1 1 0 0 1 1 0 1  0 0 0 ?
G:     1 0 1 1
------------------
```

What is the length of the CRC field?

Link Layer

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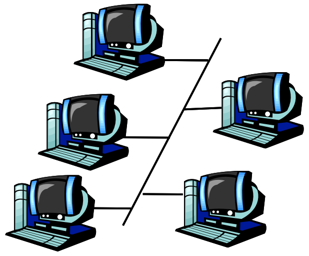
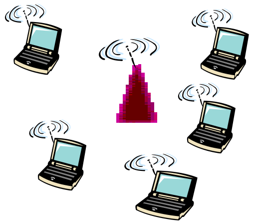
Multiple Access Links and Protocols

Two types of "links":

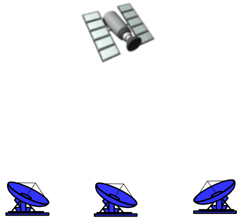
- point-to-point
  - PPP for dial-up access
- broadcast (shared wire or medium)
  - old-fashioned Ethernet
  - 802.11 wireless LAN



shared wire (e.g., cabled Ethernet)



shared RF (e.g., 802.11 WiFi)

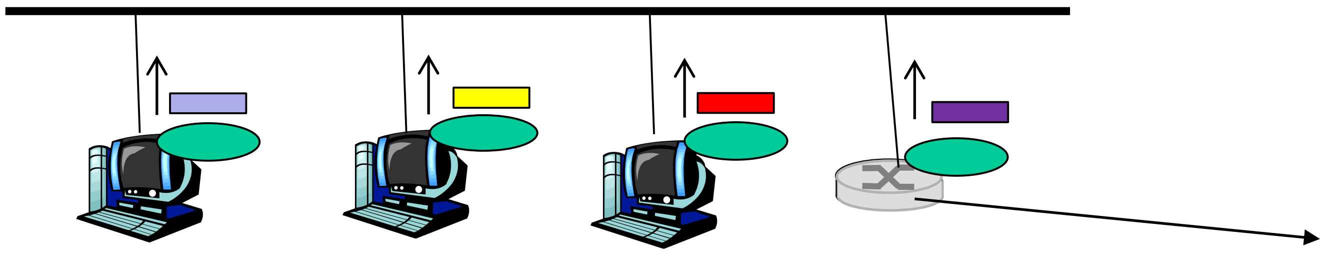


shared RF (satellite)

humans at a cocktail party (shared air, acoustical)

Multiple Access protocols

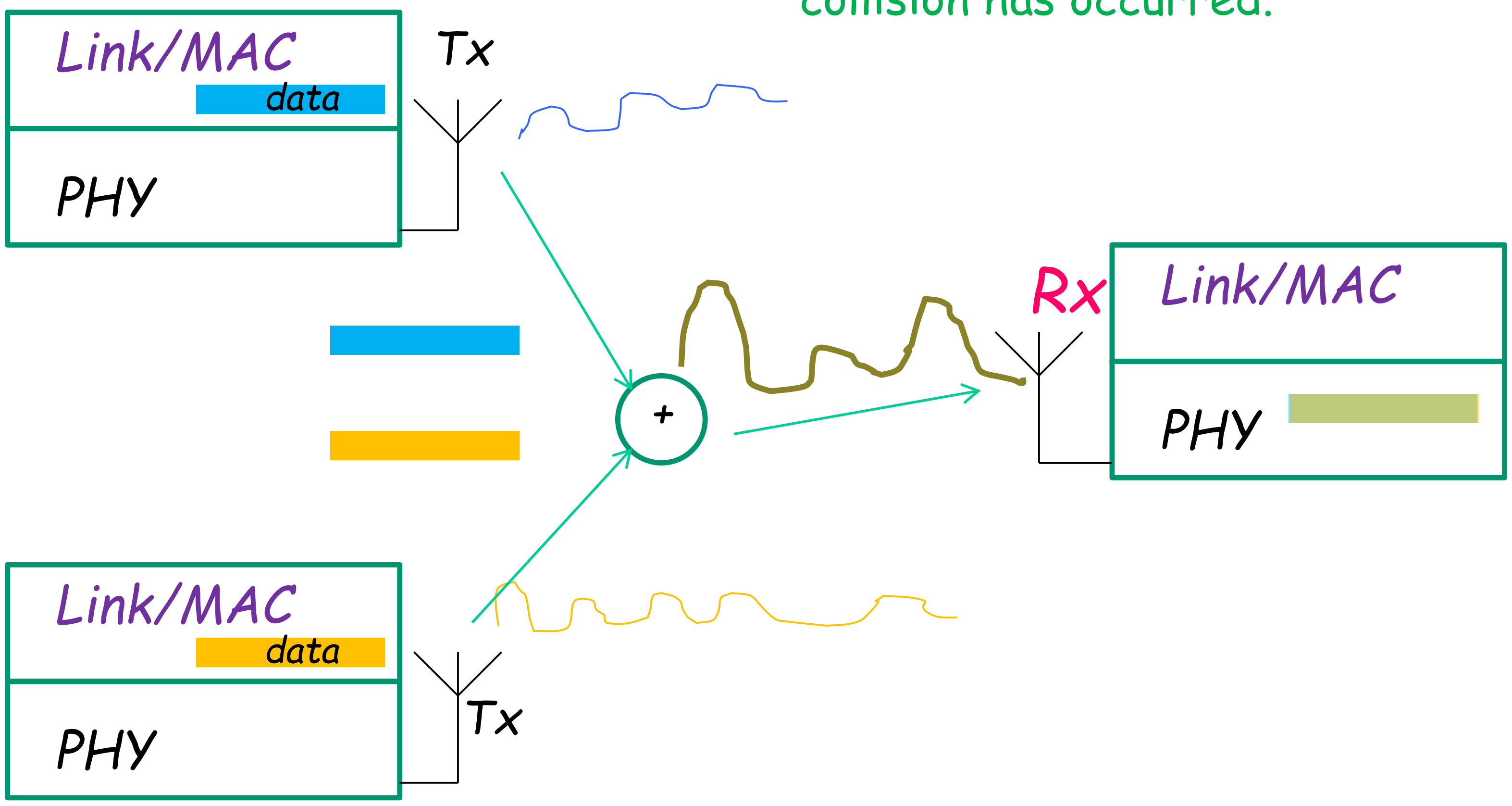
- single shared broadcast channel
- two or more simultaneous transmissions cause collision
- *multiple access protocol*
  - distributed algorithm that determines **when** a node can transmit



Packet Collision

Note

Packet collision occurs at the receiver, but transmitters must know that collision has occurred.



Ideal Multiple Access Protocol

Broadcast channel of rate R bps

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 (plug-and-play, no complex hardware, …)

MAC Protocols: a taxonomy

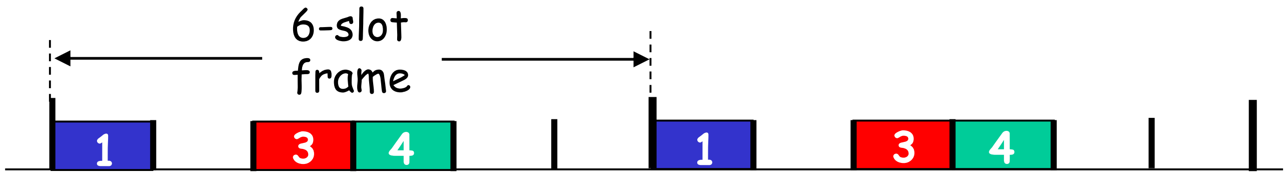
Three broad classes:

- Channel Partitioning (Commonly done in cellular networks)
  - divide channel into smaller "pieces" (time slots, frequency)
  - allocate piece to node for exclusive use
- Random Access
  - channel not divided, allow collisions
  - "recover" from collisions OR do not let collision happen
- "Taking turns"
  - nodes take turns

Channel Partitioning MAC protocols: TDMA

TDMA: time division multiple access

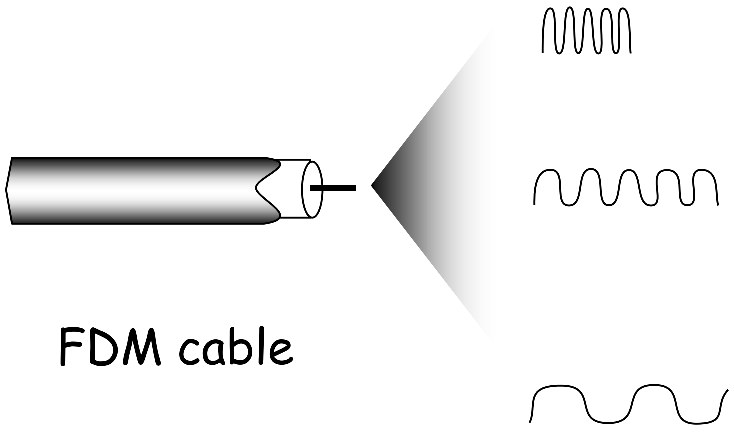
- access to channel in "rounds"
- each station gets fixed length slot (length = pkt trans time) in each round
- unused slots go idle
- example: 6-station LAN, 1,3,4 have pkt, slots 2,5,6 idle

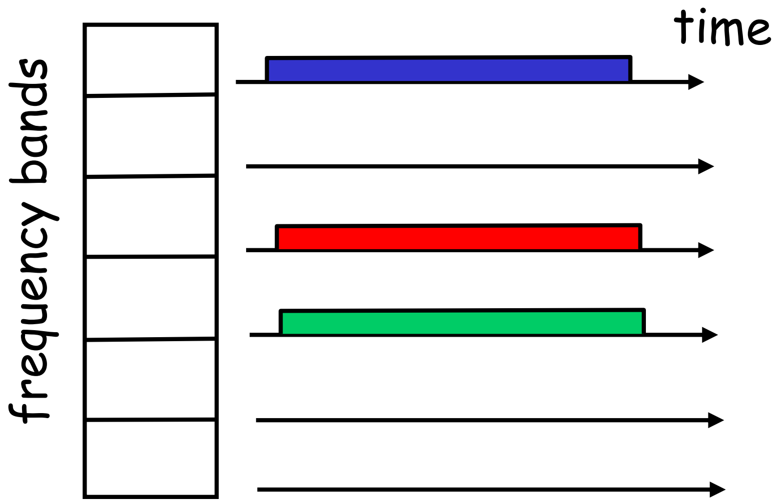


Channel Partitioning MAC protocols: FDMA

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





Random Access Protocols

- When node has packet to send
  - transmit at full channel data rate R.
  - no *a priori* coordination among nodes (…partial exception in WiFi)
- two or more transmitting nodes ➜ "collision",
- random access MAC protocol specifies:
  - **how** to detect collisions
  - **how** to recover from collisions (or, even avoid collision)
- Examples of random access MAC protocols:
  - ALOHA and slotted ALOHA
  - CSMA/CD, CSMA/CA

    CSMA: Carrier Sense Multiple Access

    - CD: Collision **Detection** ← **Reactive scheme**
    - CA: Collision **Avoidance** ← **Preventive scheme**

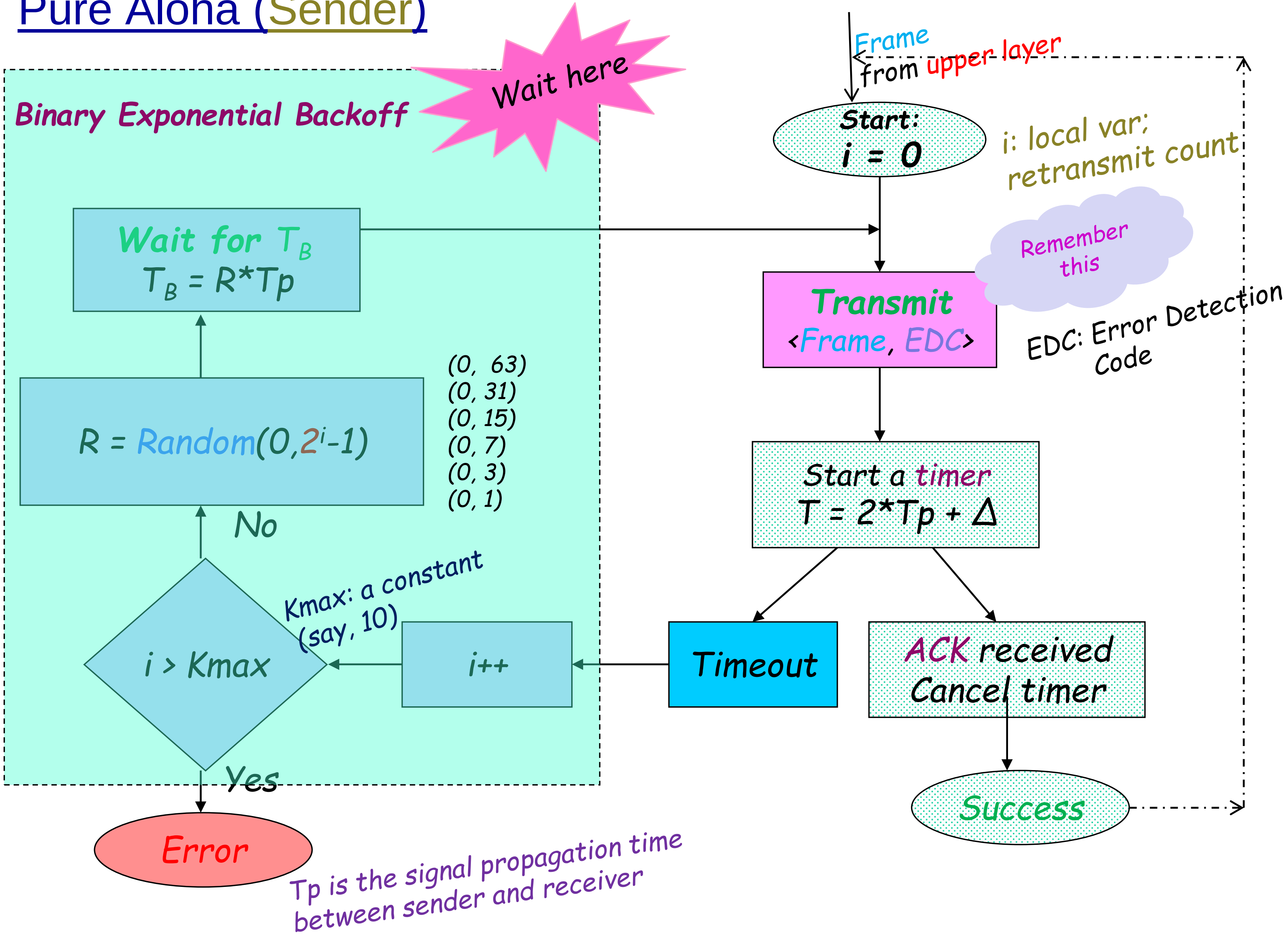
Aloha Protocol

- Developed in the 1970s at U of Hawaii
- To interconnect terminals with mainframes
- LAN/ WLAN: Possible, but not used

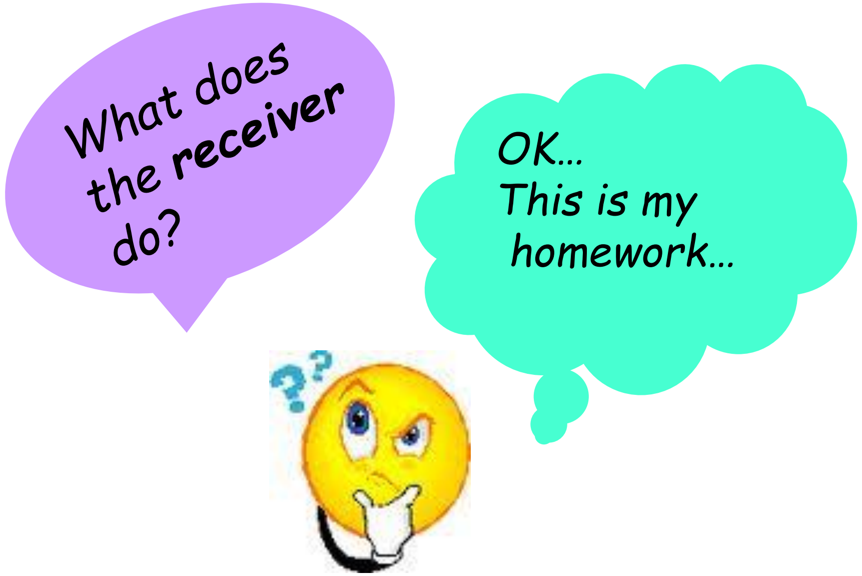
- GSM: Cell phones use this protocol to **request a channel** from the base stations

- Two types
  - Pure Aloha (Continuous time)
  - Slotted Aloha

Pure Aloha (Sender)

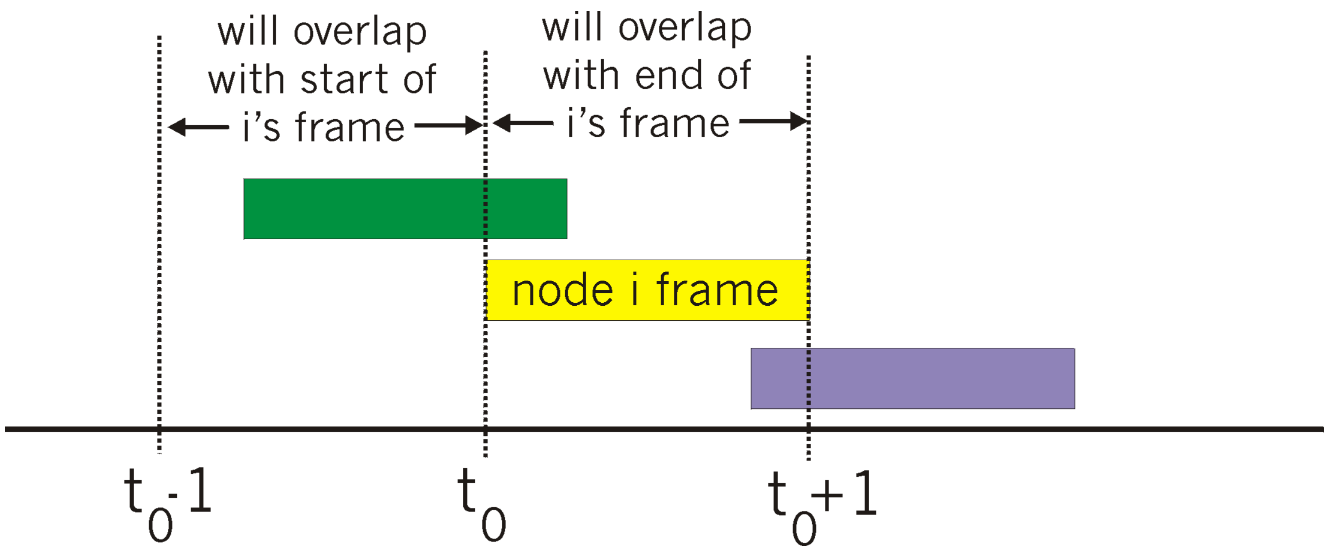


Pure Aloha



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 $[t_0-1, t_0+1]$



Pure Aloha efficiency

$e = 2.71828$

Throughput of Pure Aloha =

Total input rate (G) * Prob. of successful Packet Trans.

$= \; G * e^{-2G}$

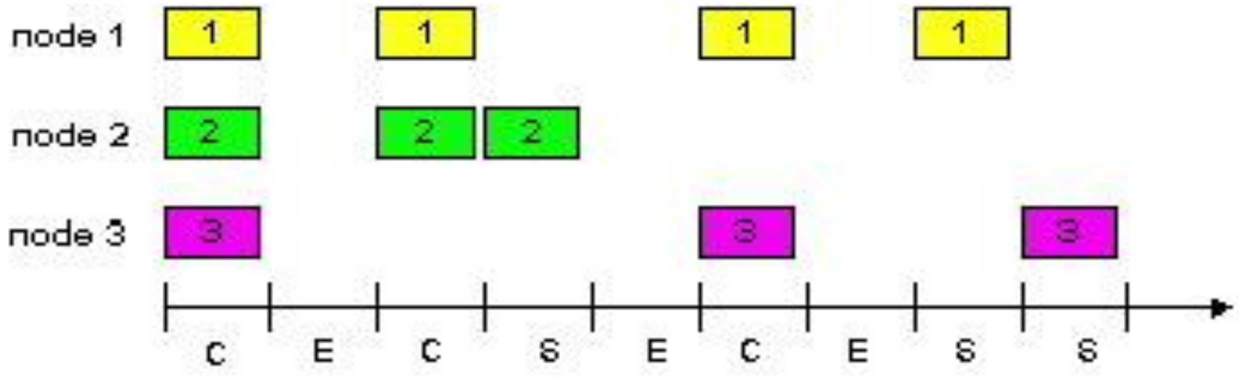
G: Number of packets in X sec.

where X is the packet Tx time.

Max throughput occurs at G = 0.5.

Max Throughput = 1/(2e) = .18

Slotted ALOHA



Assumptions:

- all frames are same size
- time divided into equal size slots (time to transmit 1 frame)
- nodes start to transmit only at slot beginning
- nodes are synchronized

Operation:

- when node obtains fresh frame, transmit in next slot
- if Tx is not successful, retransmit in following slots after some wait..

Slotted Aloha efficiency

e = 2.71828

Throughput of Slotted Aloha =

Total input rate (G) * Prob. of successful Packet Trans.

$= G * e^{-G}$

G: Number of packets in X sec.

Max throughput occurs at G = 1.

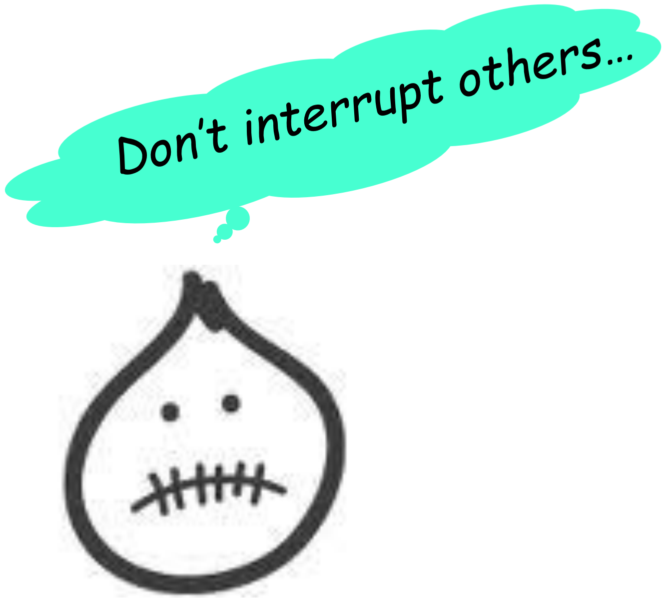
where X is the packet Tx time.

Max Throughput = 1/e = .37

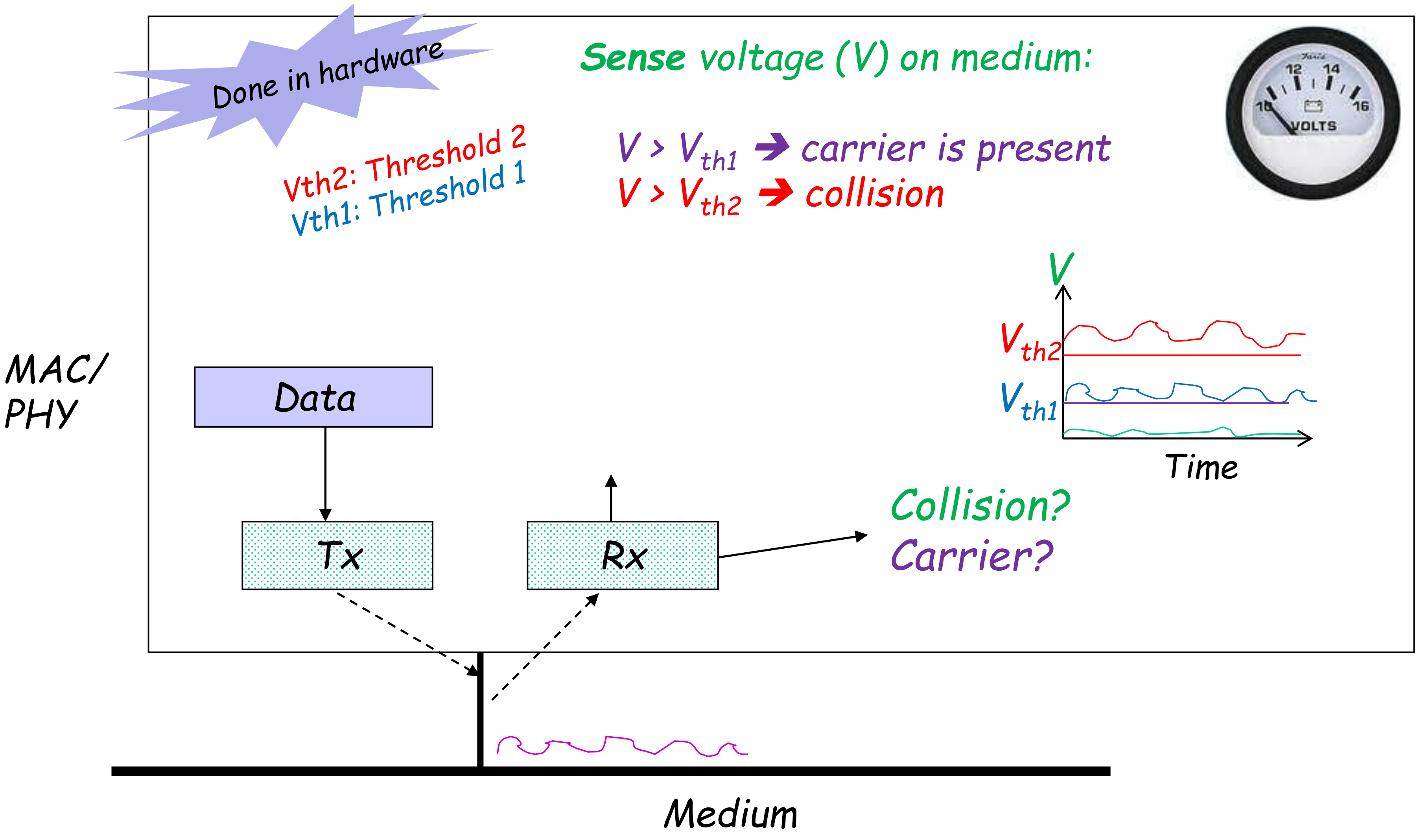
CSMA (Carrier Sense Multiple Access)

CSMA: listen before you transmit:

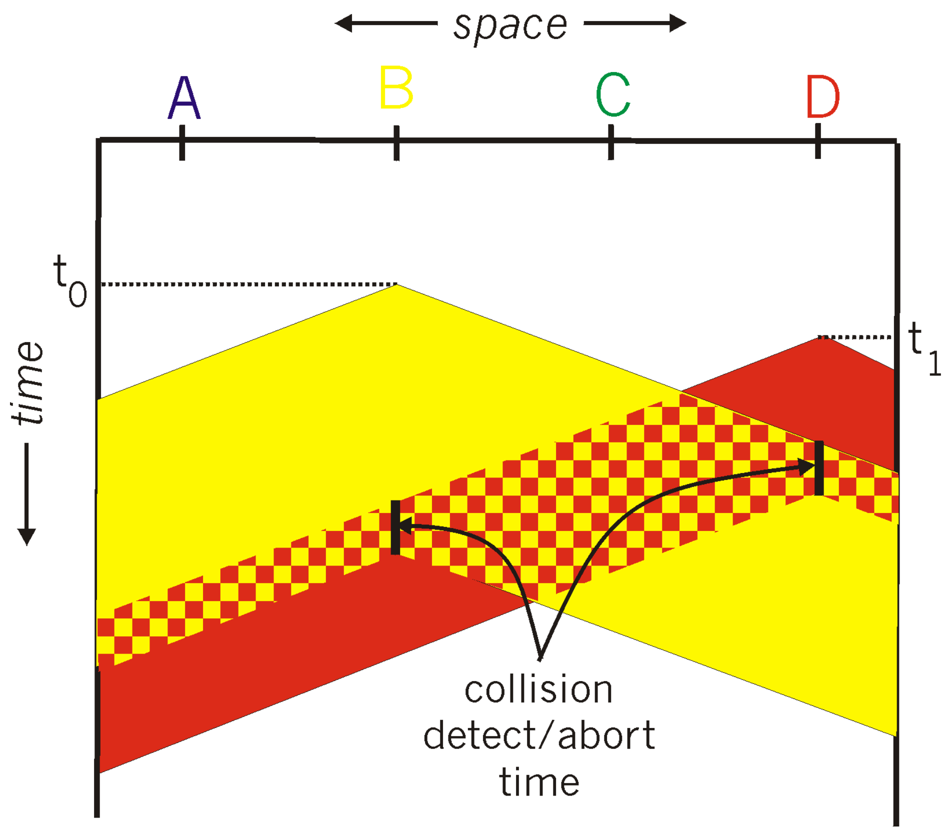
- If channel is sensed idle: transmit entire frame
- If channel is sensed busy, defer transmission



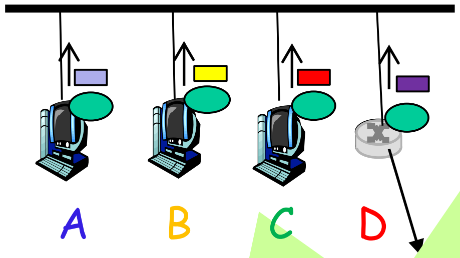
CSMA/CD Concepts of Carrier Sense and Collision Detection



CSMA/CD collision detection



Signal from all nodes must reach all others



Therefore, **collision** occurring at a receiving node is detected by the frame's sender.... after some delay..

CSMA/CD (Collision Detection)

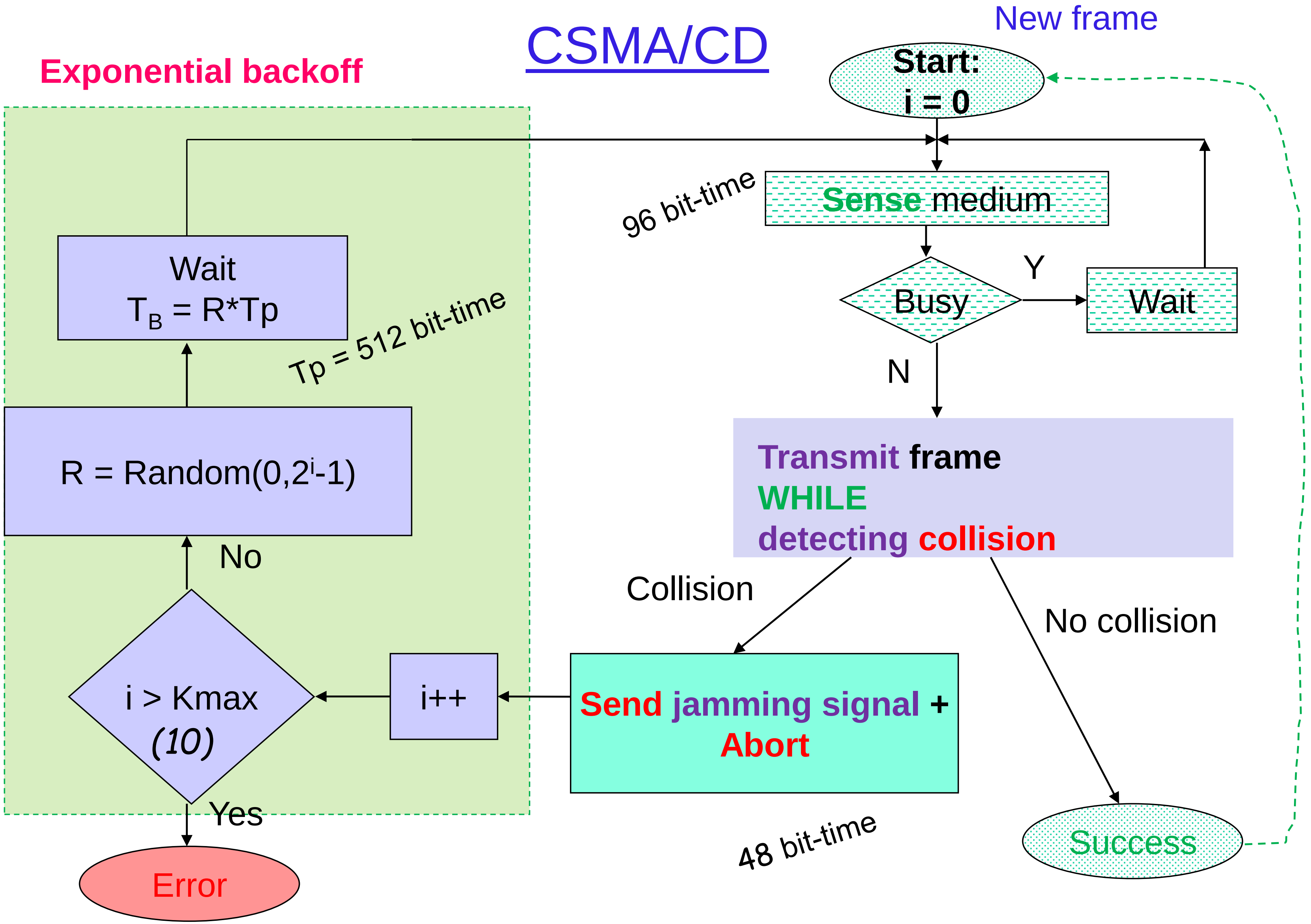
CSMA/CD: **C**arrier **S**ense **M**ultiple **A**ccess with CD

- Tx attempts multiple times (multiple access)
- Collisions are *detected* within short time
- A colliding transmission is aborted ← don't keep wasting channel resource

❖ Collision detection:

- Easy in wired LANs: explained before …
- Not possible in wireless LANs: will be explained …

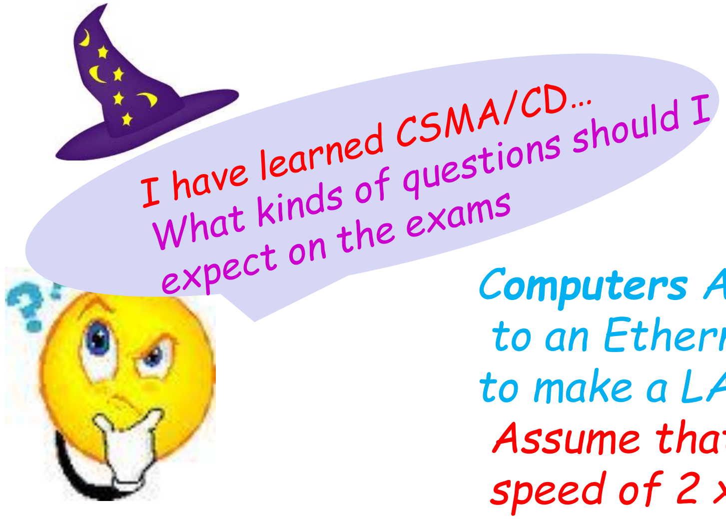
CSMA/CD



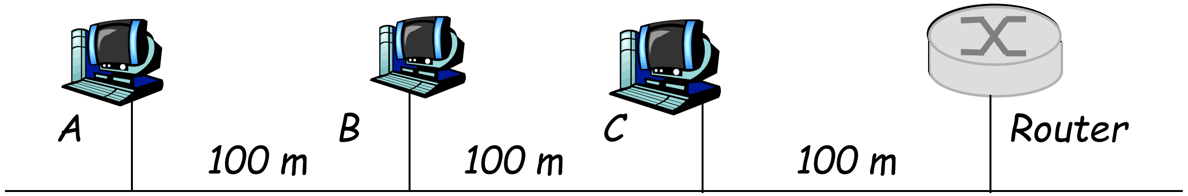
New frame
Start:
i = 0
Exponential backoff
Sense medium
96 bit-time
Busy
Y
Wait
N
Wait
T_B = R*Tp
Tp = 512 bit-time
R = Random(0,2^i-1)
No
Transmit frame
WHILE
detecting collision
Collision
No collision
i > Kmax
(10)
i++
Send jamming signal +
Abort
Yes
Error
48 bit-time
Success

CSMA/CD

- Medium sensing is done for **96** bit-times.
- Jamming signal length is **48** bits. Jamming signal creates enough energy on the medium for collision detection.
- Tp is equated with 512 bit-times.
- “i” saturates at 10.



***Computers** A, B, and C and one **router** are connected to an Ethernet bus **100 metres** apart to make a LAN using the <u>CSMA/CD protocol</u>.*
Assume that signal propagates on the Ethernet bus at a speed of 2 x 10^8 m/sec, and all nodes can transmit data at the rate of 100 Mbps .



- *After finding the bus to be idle for a little while, A and the router start transmitting their frames <u>exactly at the same time</u>. **How many bits of data** can node A transmit before detecting collision?*
- *What is the **maximum time gap** between the start of transmission and detection of collision by A?*
- *What is the **length of the smallest frame** that A can transmit while knowing whether or not it collided with a transmission from the router?*

“Taking Turns” MAC protocols

channel partitioning MAC protocols:

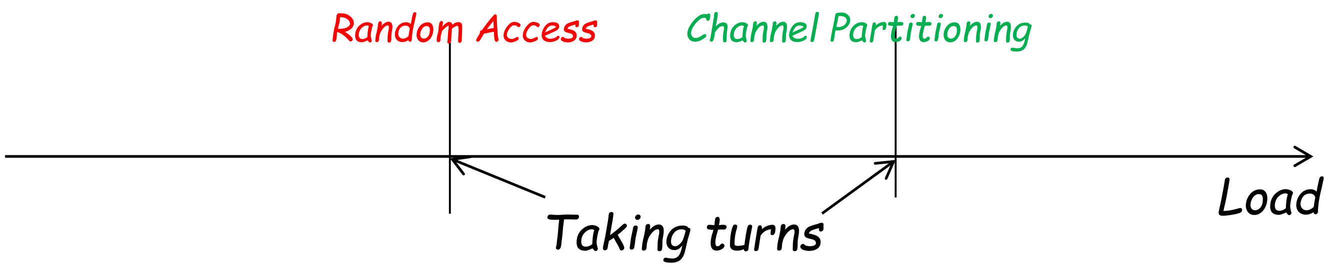
- share channel *efficiently* and *fairly* at high load
- inefficient at low load: 1/N bandwidth allocated even if only 1 active node!

random access MAC protocols:

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

“taking turns” protocols

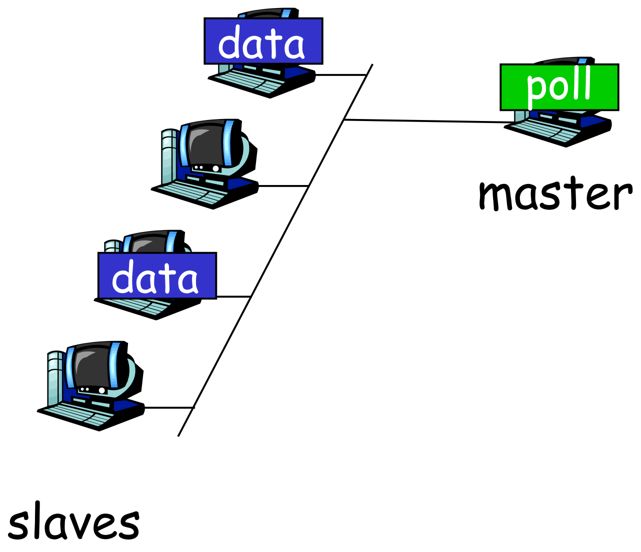
look for best of both worlds!



"Taking Turns" MAC protocols

Polling:

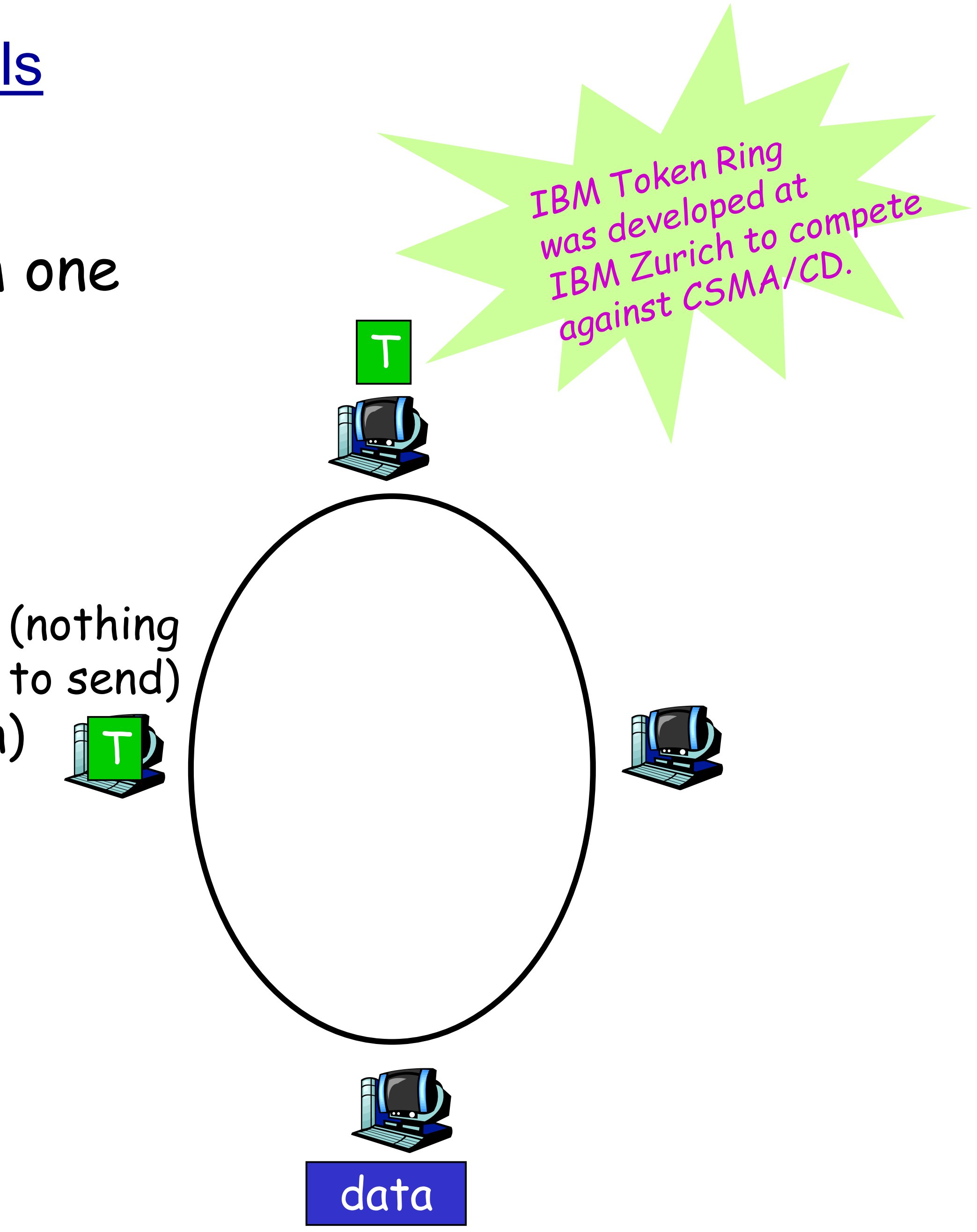
- master node "invites" slave nodes to transmit in turn
- typically used with "dumb" slave devices
- concerns:
  - polling overhead
  - latency
  - single point of failure (master)



“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)



Where are all those different kinds of MAC protocols used

Ch. Partitioning MAC

- Cellphone networks
- Bluetooth

Random access MAC

- LAN (Local Area Network)
- WLAN (Wireless LAN)

Taking turns

- Bluetooth

Link Layer

5.1 Introduction and services

5.2 Error detection and correction

5.3Multiple access protocols

5.4 Link-Layer Addressing

5.5 Ethernet

5.6 Link-layer switches

5.7 PPP

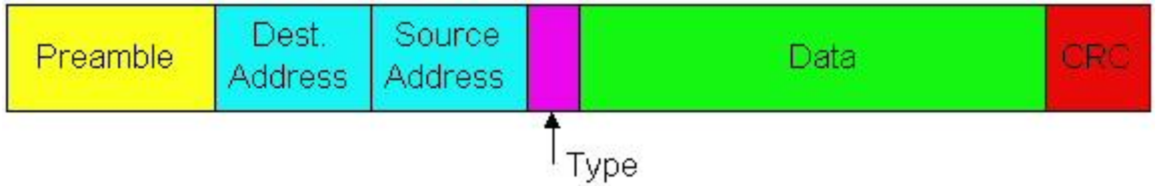
5.8 Link virtualization: MPLS

5.9 A day in the life of a web request

3.4 Reliable data transfer

Ethernet Frame Structure (example)

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

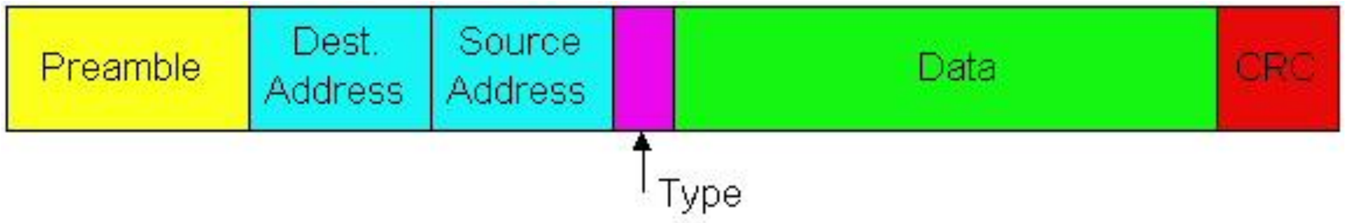


Preamble:

- 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 (e.g. ARP packet), it passes data in frame to upper layer protocol
  - otherwise, adapter discards frame
- Type: indicates higher layer protocol (mostly IP but others possible, e.g., Novell IPX, AppleTalk)
- CRC: checked at receiver;
  - if error is detected, frame is dropped.

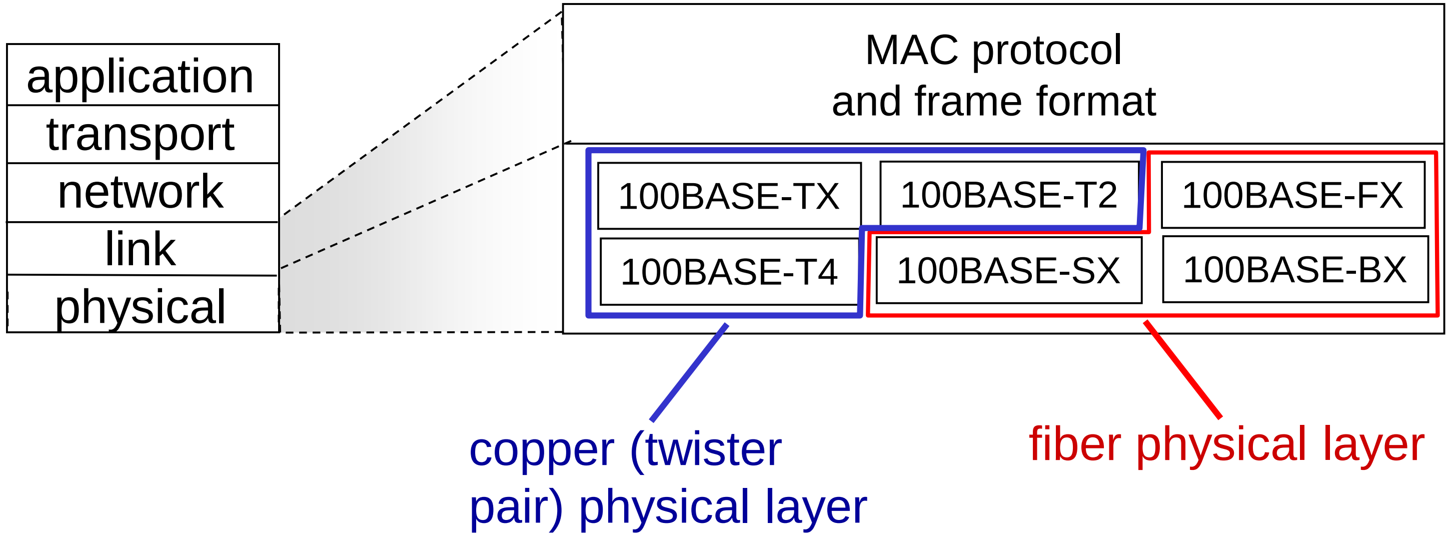


Ethernet: unreliable, connectionless

- *connectionless:* no handshaking between sending and receiving NICs
- *unreliable:* receiving NIC doesnt send acks or nacks to sending NIC
  - data in dropped frames recovered only if initial sender uses higher layer rdt (e.g., TCP), otherwise dropped data lost
- Ethernet's MAC protocol: unslotted *CSMA/CD wth binary backoff*

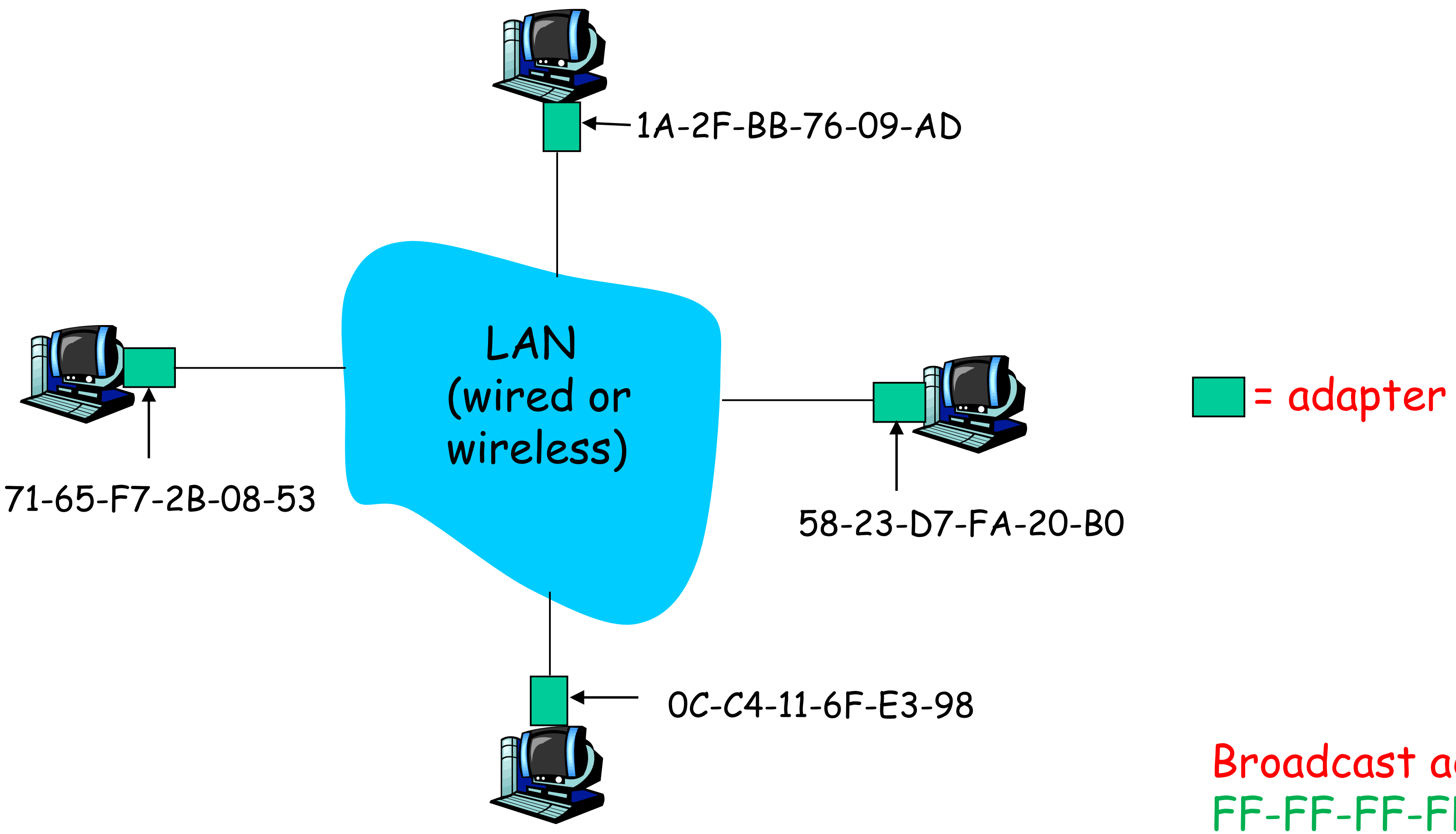
802.3 Ethernet standards: link & physical layers

- *many* different Ethernet standards
  - common MAC protocol and frame format
  - different speeds: 2 Mbps, 10 Mbps, 100 Mbps, 1Gbps, 10G bps
  - different physical layer media: fiber, cable



LAN Addresses and ARP

Each adapter on LAN has unique LAN address

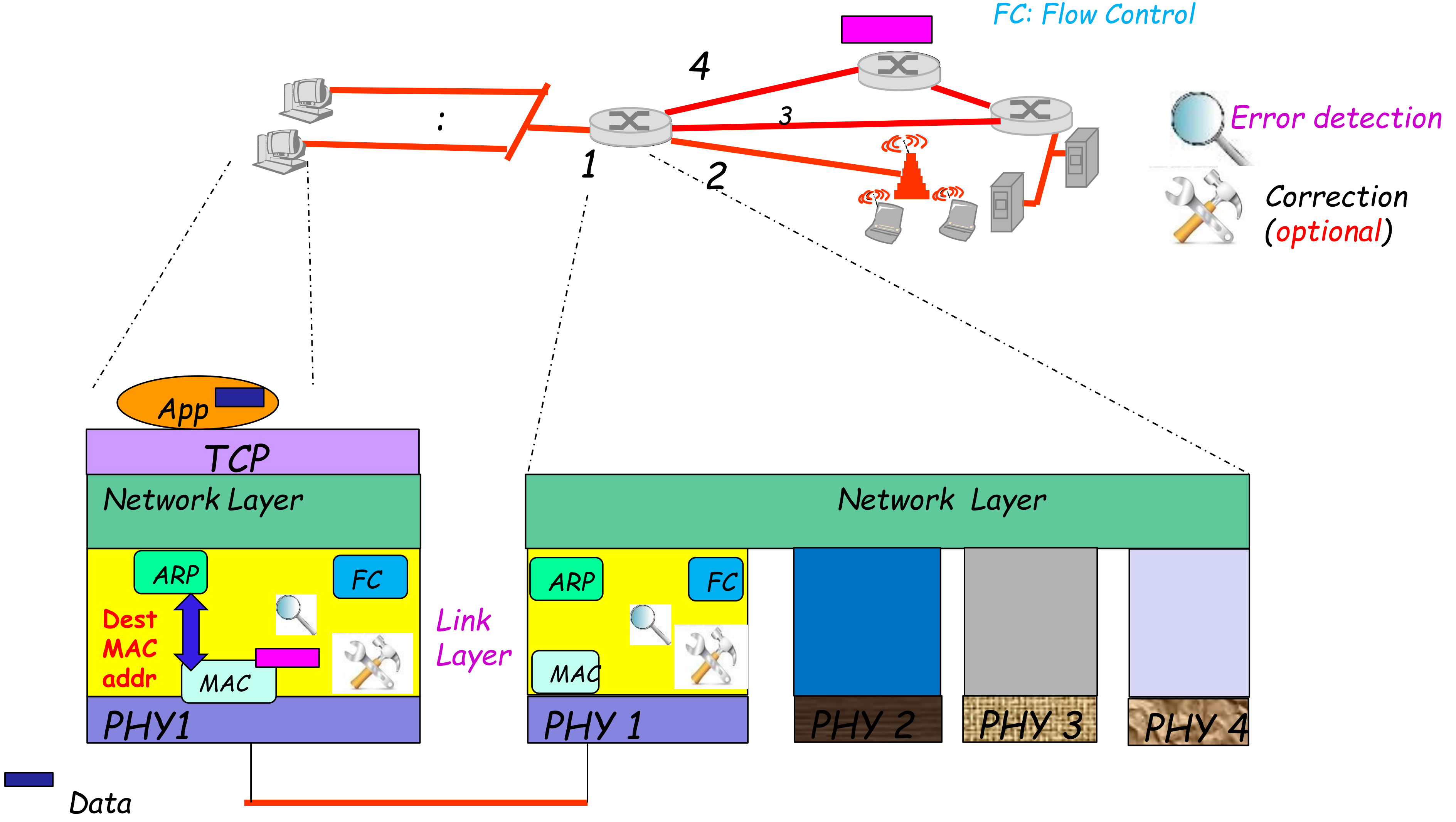


Broadcast addr. =
FF-FF-FF-FF-FF-FF

ARP context

MAC: Medium Access Control

FC: Flow Control



ARP (Address Resolution Protocol): IP address ➔ MAC address
(%ipconfig /all ← for MAC addresses.)

PHY: Physical layer ← hardware

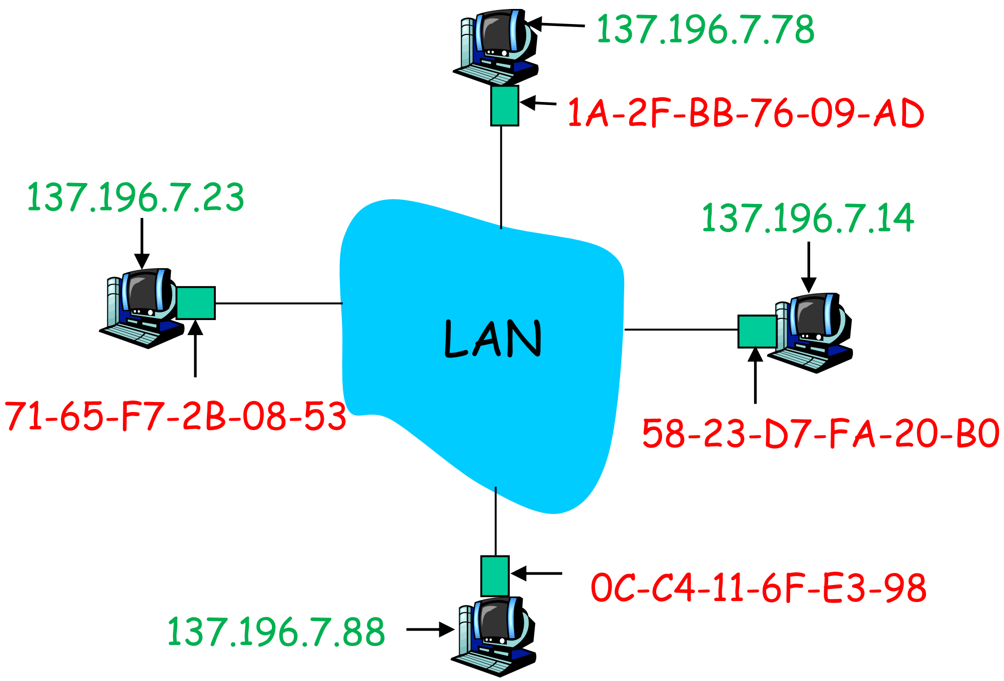
ARP: Address Resolution Protocol

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

- Each IP node (host, router) on LAN has ARP table
- *ARP table: IP/MAC addr. mappings for LAN nodes*

  < IP address; MAC address; TTL>

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



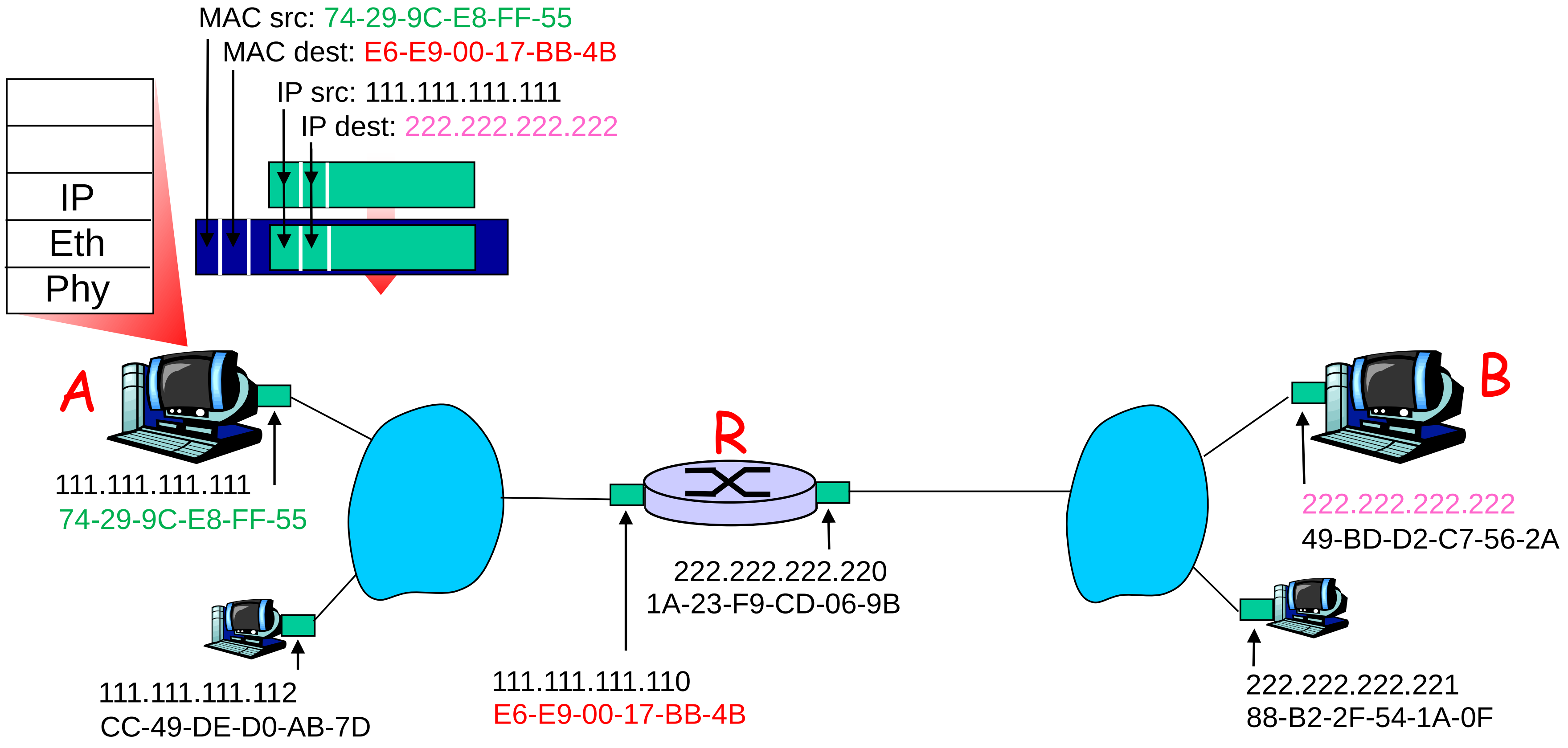
ARP protocol: Same LAN (network)

- **A** wants to send datagram to **B**, and B's MAC address not in A's ARP table.
- A broadcasts ARP query pkt containing B's IP addr
  - dest MAC address = FF-FF-FF-FF-FF-FF
  - all machines on LAN receive ARP query
- B receives ARP query, replies to A with its (B's) MAC addr
  - frame sent to A's MAC address (unicast)

- A caches (saves) IP-to-MAC addr pair in its ARP table until this becomes old
- ARP is "plug-and-play":
  - nodes create their ARP tables without intervention from net administrator

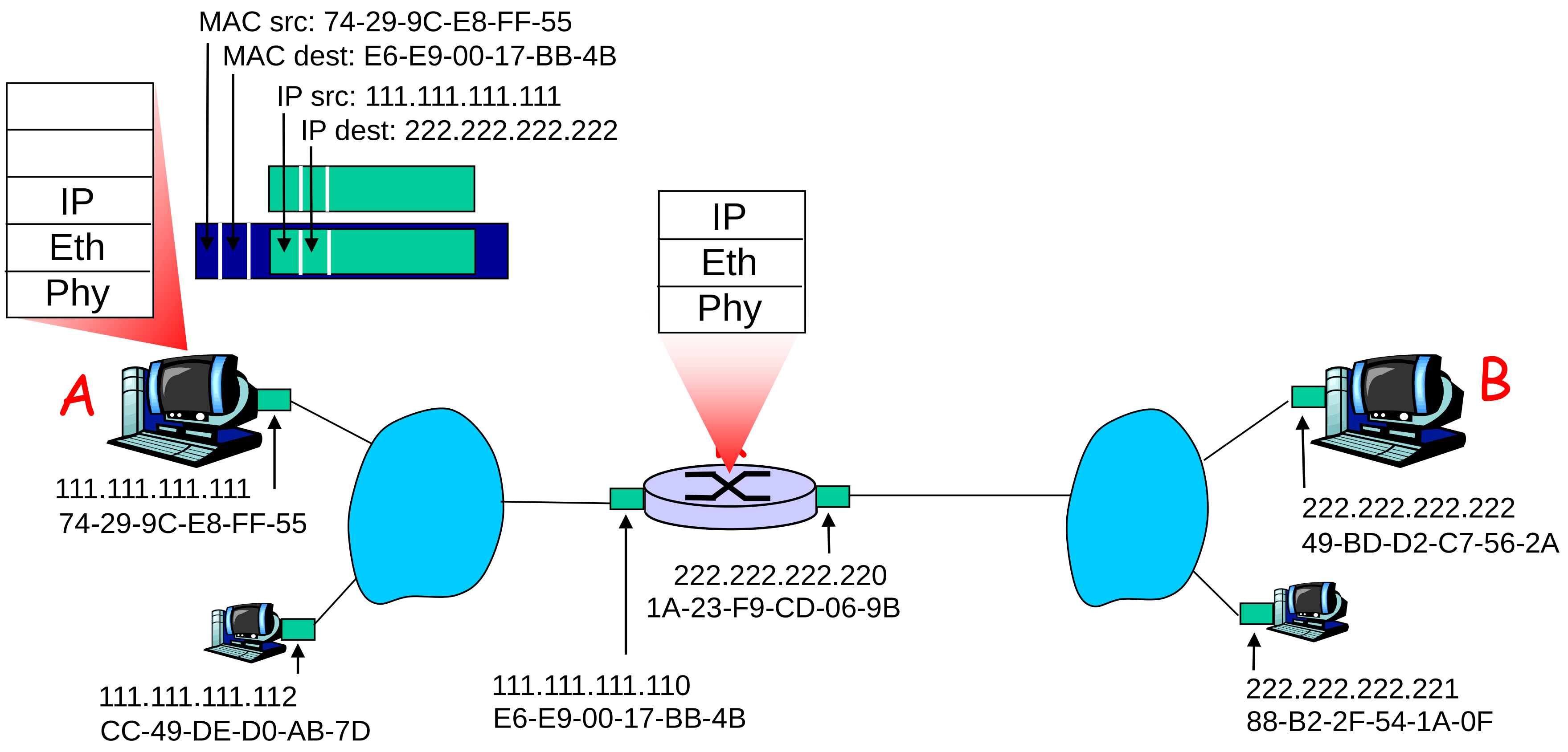
Addressing: routing to another LAN

- A creates IP datagram with IP source A, destination B
- A creates link-layer frame with R's MAC address as dest, frame contains A-to-B IP datagram



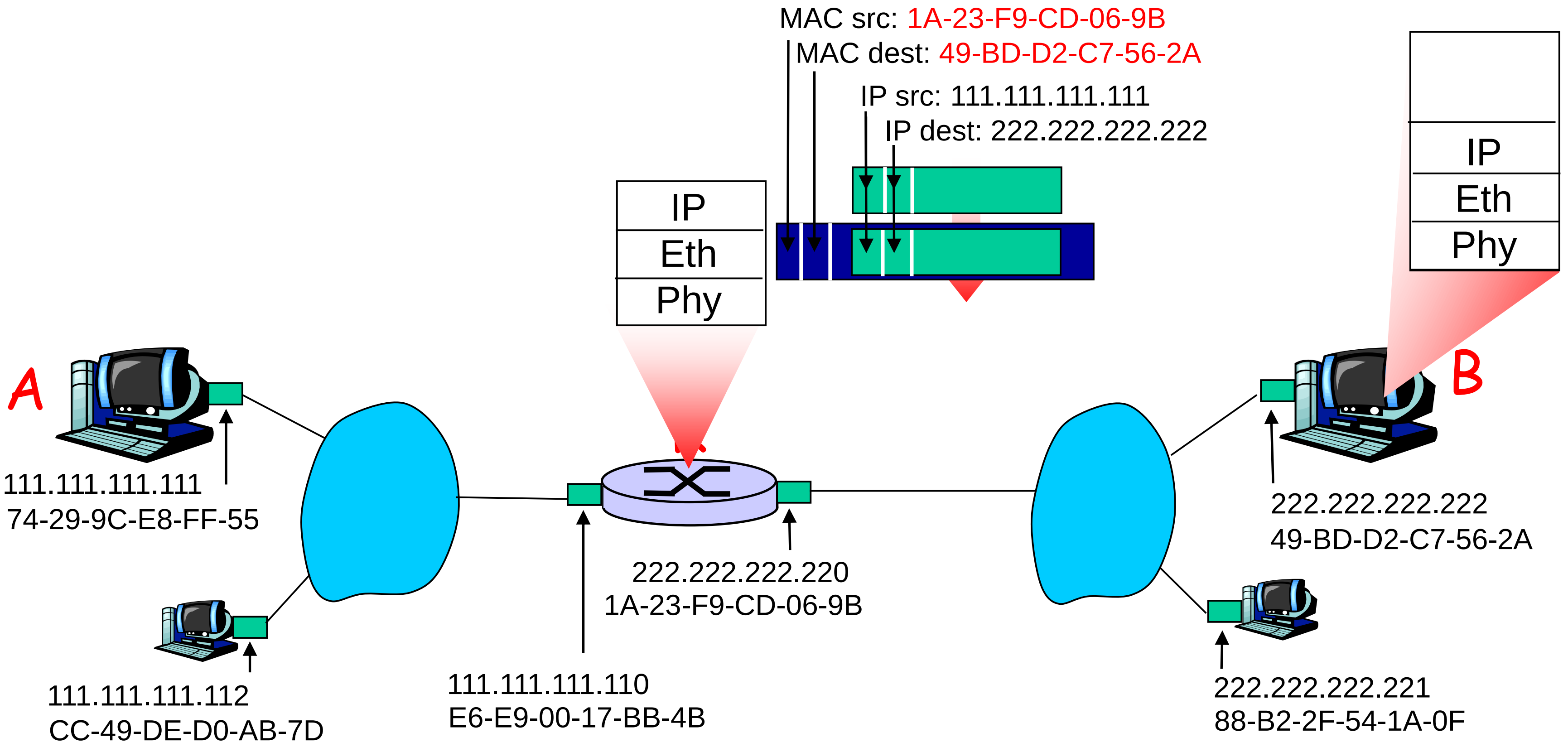
Addressing: routing to another LAN

- frame sent from A to R
- frame received at R, datagram removed, passed up to IP



Addressing: routing to another LAN

- R forwards datagram with IP source A, destination B
- R creates link-layer frame with B's MAC address as dest, frame contains A-to-B IP datagram



Addressing: routing to another LAN

- R forwards datagram with IP source A, destination B
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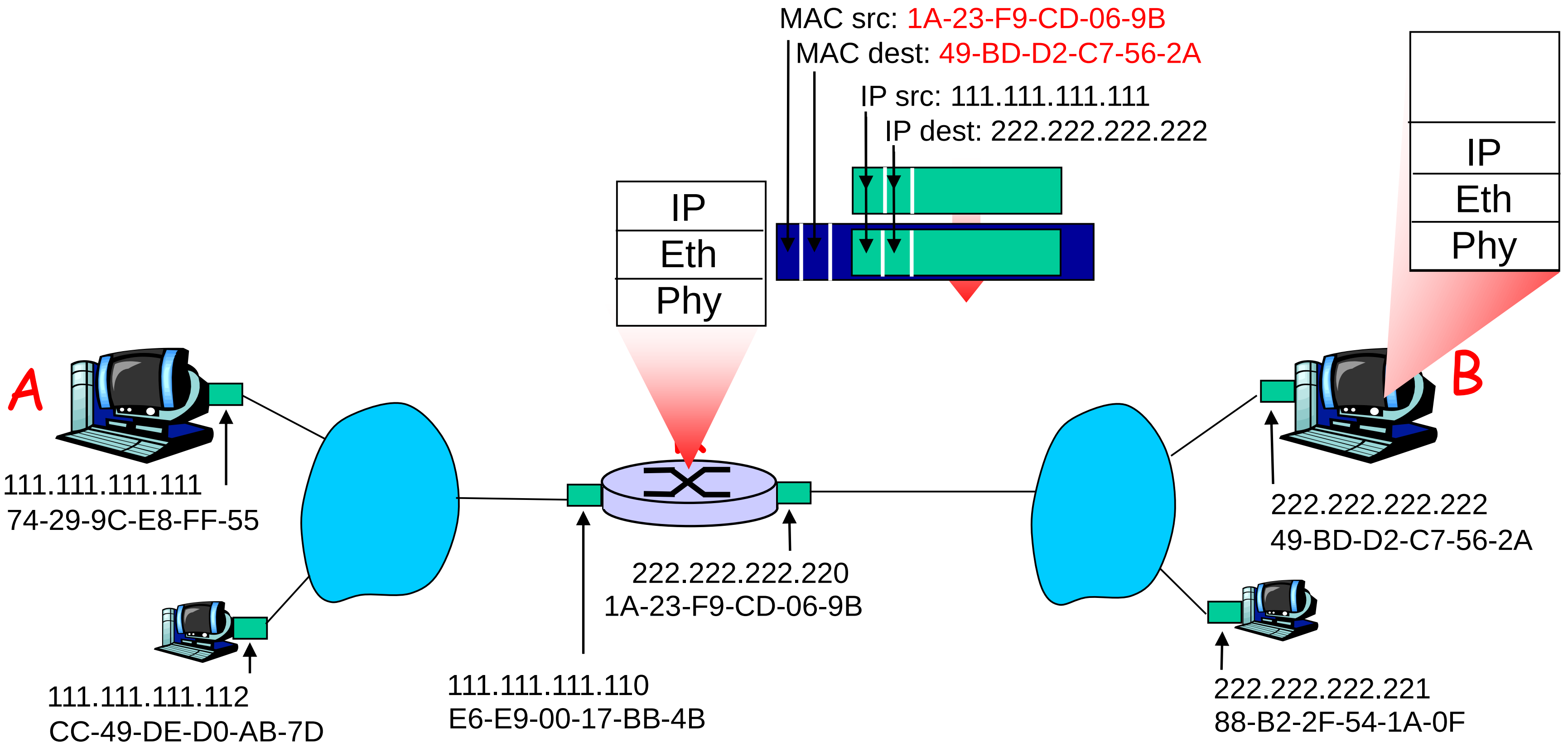

Addressing: routing to another LAN

- R forwards datagram with IP source A, destination B
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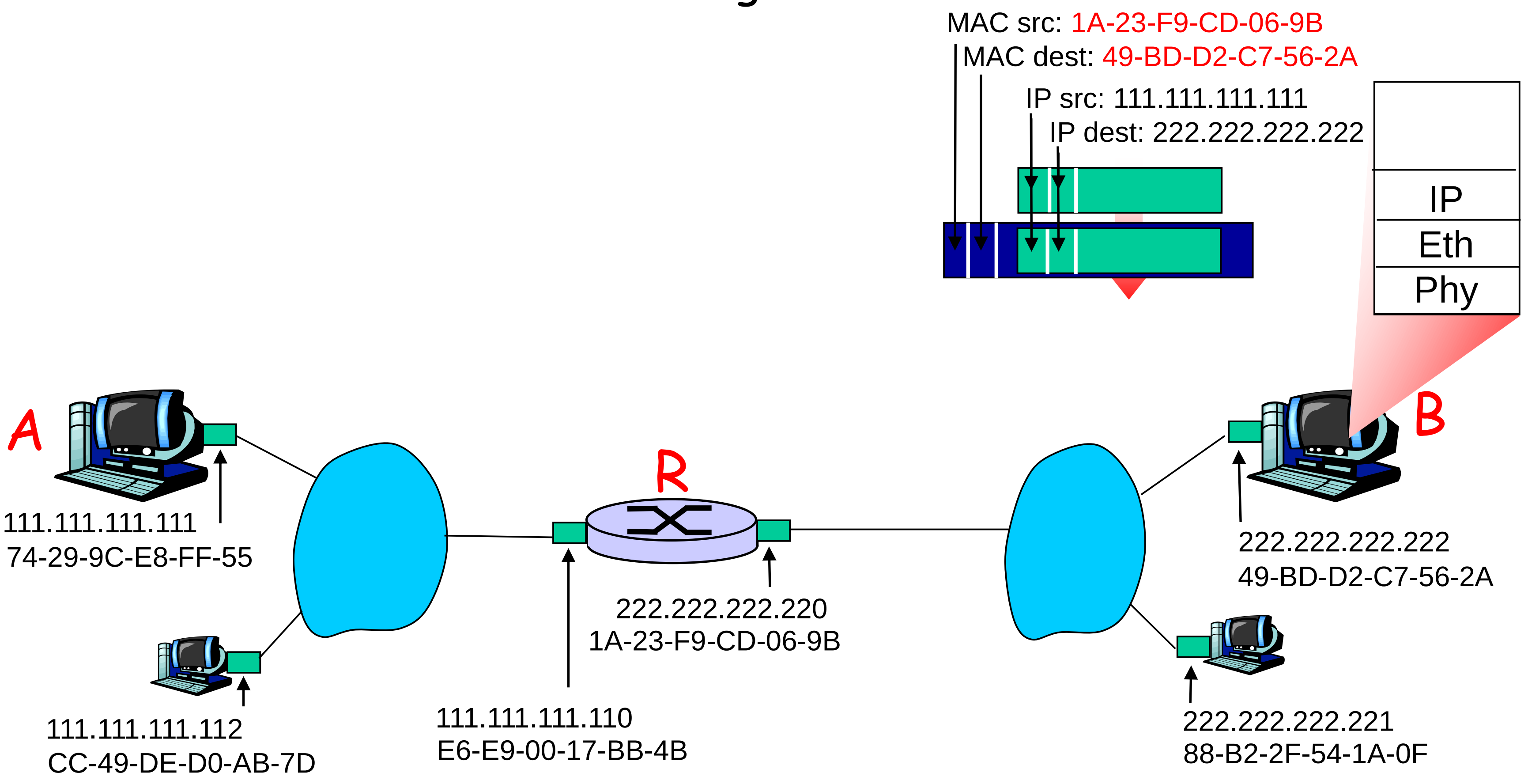
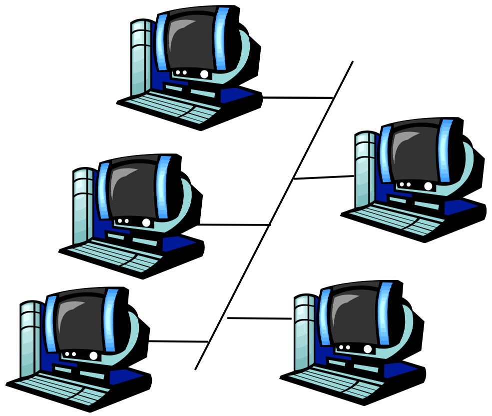


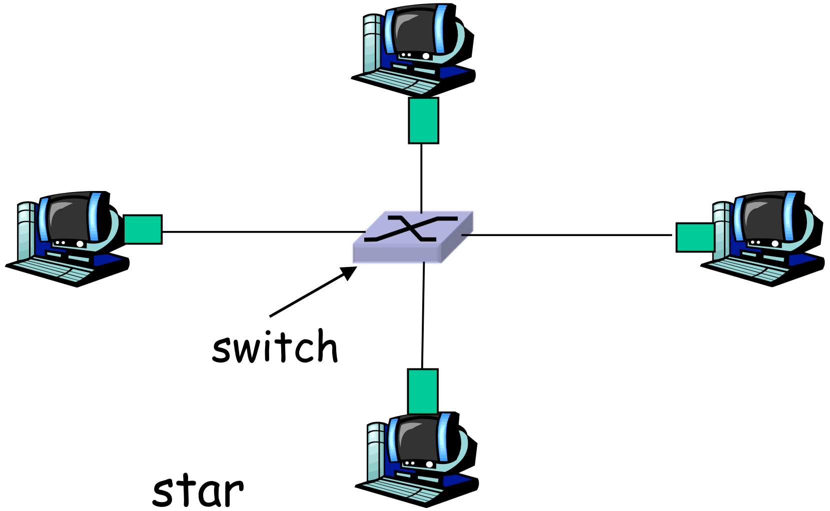
Link Layer

LAN with star topology

- bus topology popular through mid 90s
- today: star topology prevails
  - active switch in centre
  - each "spoke" runs a (separate) Ethernet protocol (nodes do not collide with each other)



bus: coaxial cable

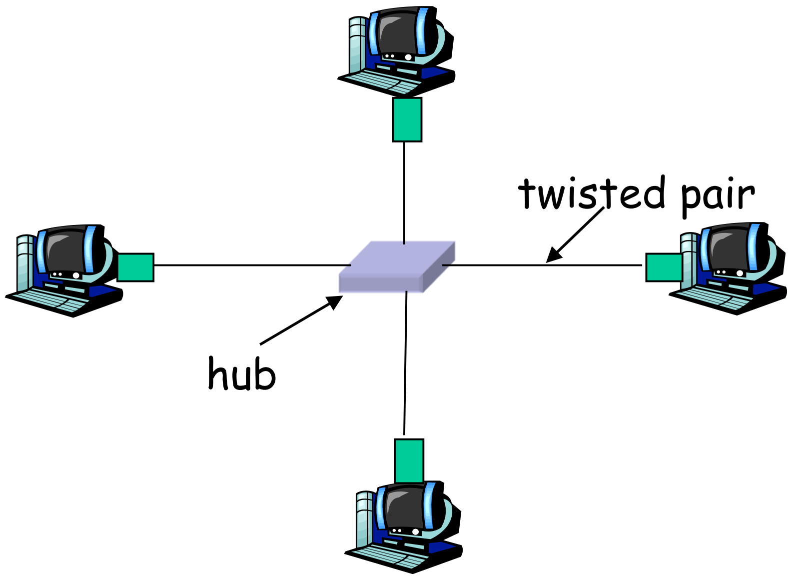


star

Hubs

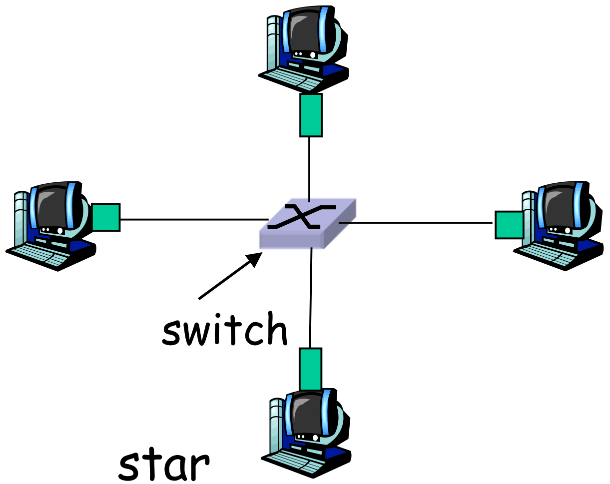
… physical-layer ("dumb") repeaters:

- bits coming in on one link go out *all* other links at same rate
- all nodes connected to hub can collide with one another
- no frame buffering
- no CSMA/CD at hub: host NICs detect collisions



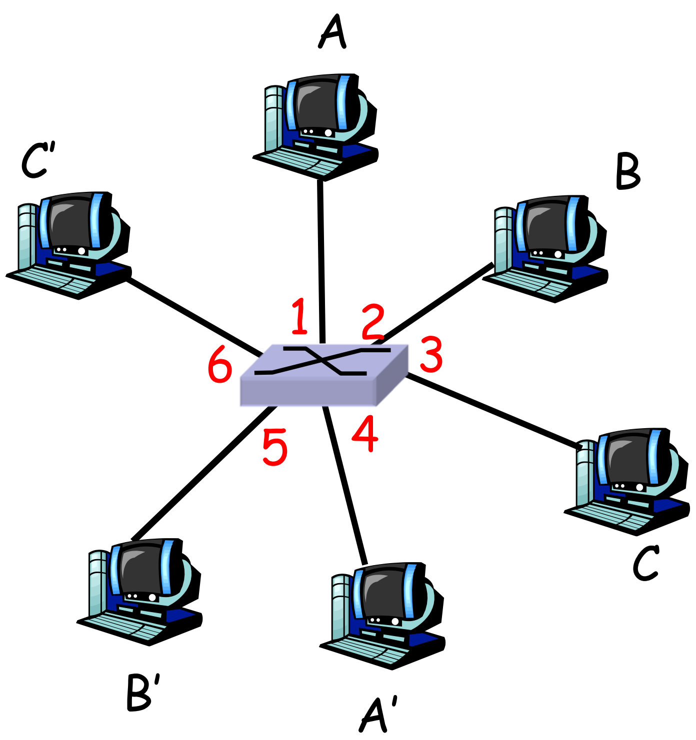
Switch

- smarter than hubs, take *active* role
  - Store and forward frames
  - Examine incoming frame's MAC address, selectively forward frame to one-or-more outgoing links when frame is to be forwarded on segment, using CSMA/CD to access segment
- transparent
  hosts are unaware of presence of switches
- plug-and-play, self-learning
  switches do not need to be configured



Switch: allows *multiple* simultaneous transmissions

- hosts have dedicated, direct connection to switch
- switches buffer packets
- Ethernet protocol is used on each link



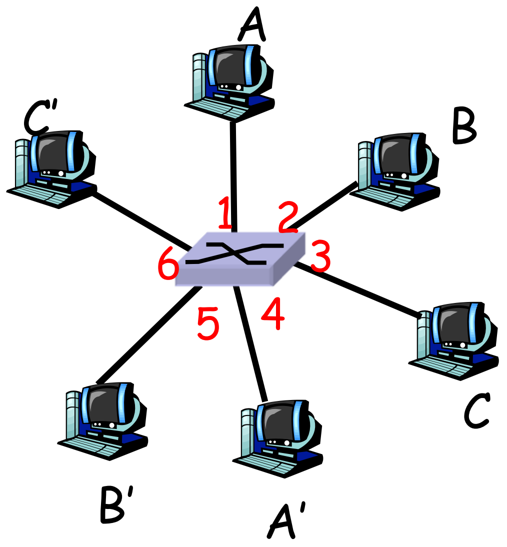
switch with six interfaces (1,2,3,4,5,6)

- *switching:* A-to-A' and B-to-B' simultaneously, without collisions
  - not possible with dumb hub

Switch Table

- *Q:* how does switch know that A' reachable via interface 4, B' reachable via interface 5?
- *A:* *each switch has a switch table*

MAC addr of host	Interface #	Time To Live (TTL)

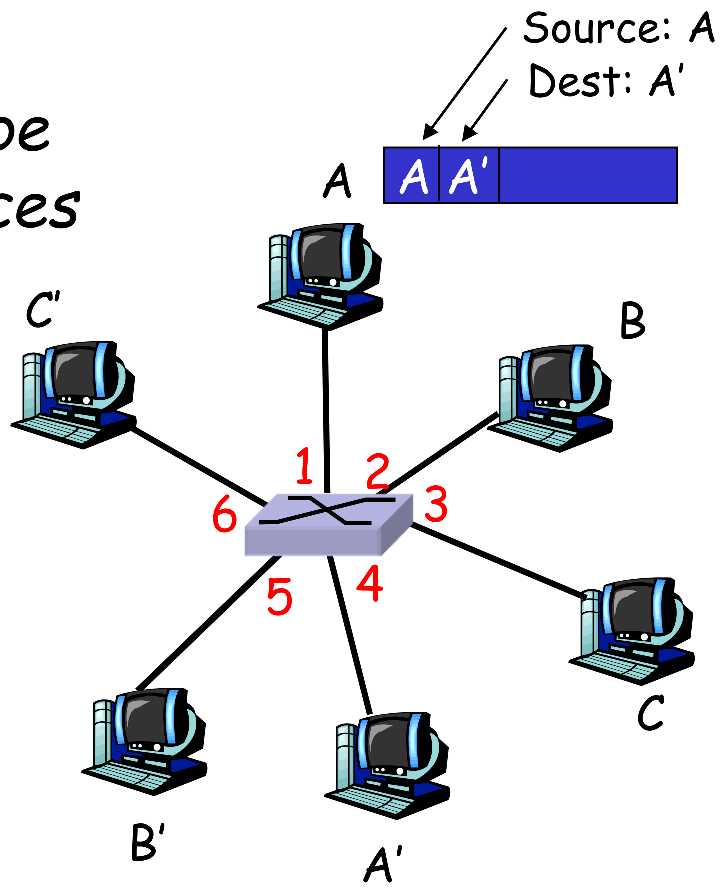


switch with six interfaces (1,2,3,4,5,6)

- *Q: How are entries created and maintained in switch table?*

Switch: self-learning

- *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



MAC addr	interface	TTL
A	1	60

Switch table (initially empty)

Switch: frame filtering/forwarding

When frame received:

1. record link associated with sending host

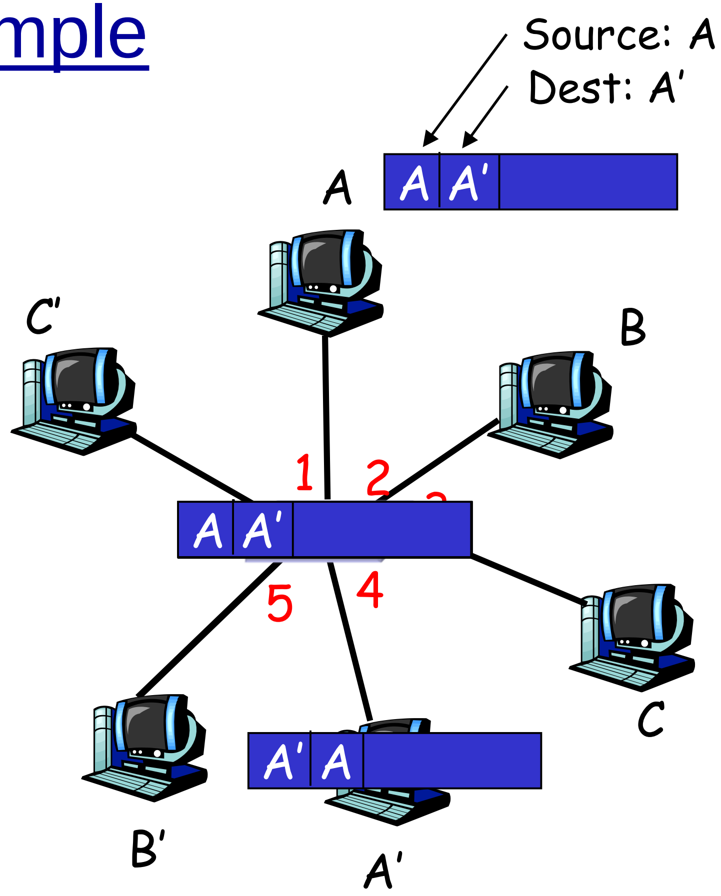
2. index switch table using MAC dest address

3. 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

Self-learning, forwarding: example



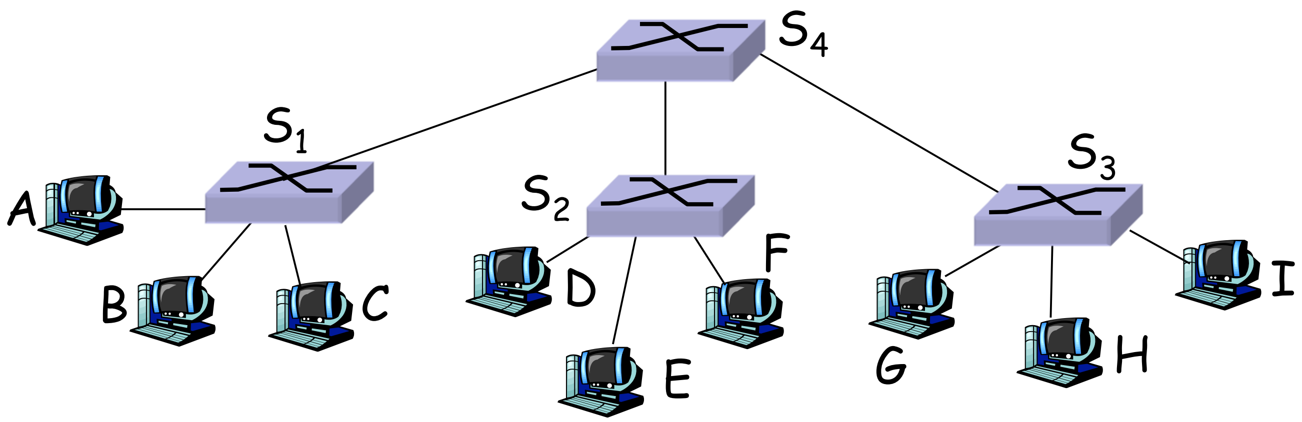
- frame destination unknown: *flood*
- destination A location known:
  selective send

MAC addr	interface	TTL
A	1	60
A'	4	60

Switch table (initially empty)

Interconnecting switches

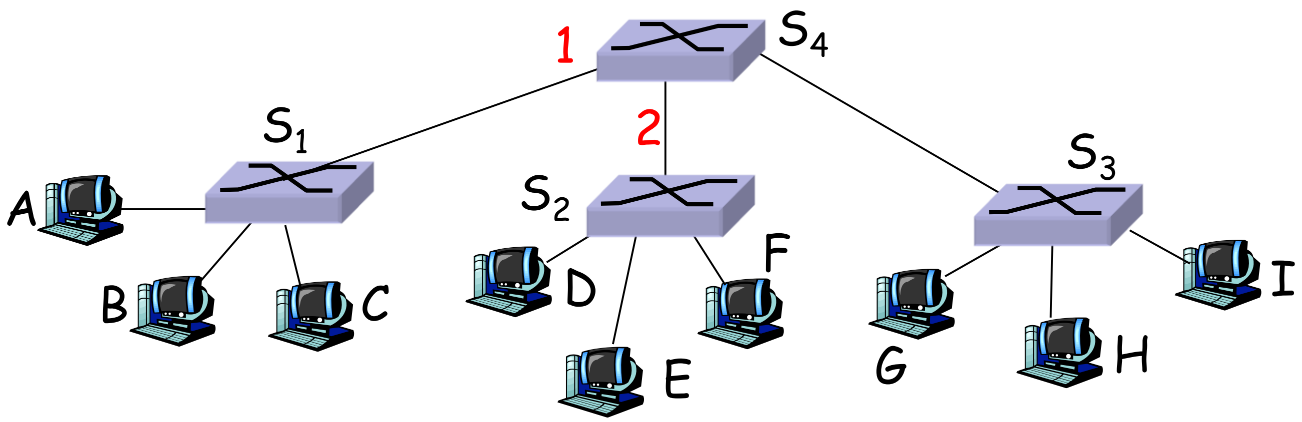
- switches can be connected together



- Q: sending from A to G - how does S_1 know to forward frame destined to G via S_4 and S_3?
- A: self learning! (works exactly the same as in single-switch case!)

Self-learning multi-switch example

Suppose C sends frame to I, I responds to C



- Q: show switch tables and packet forwarding in S_1, S_2, S_3,S_4

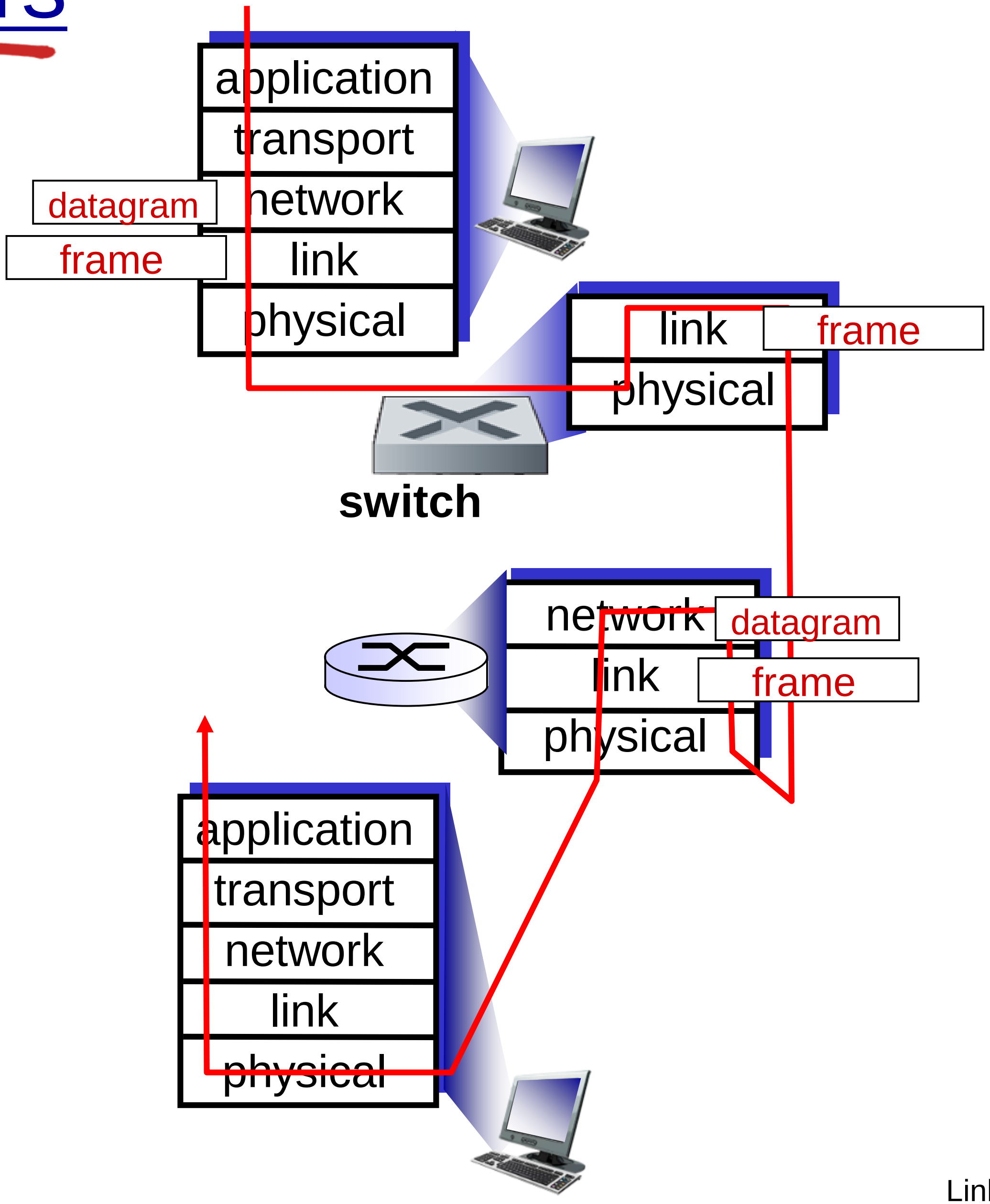
Switches vs. routers

both are store-and-forward:

- *routers:* network-layer devices (examine network-layer headers)
- *switches:* link-layer devices (examine link-layer headers)

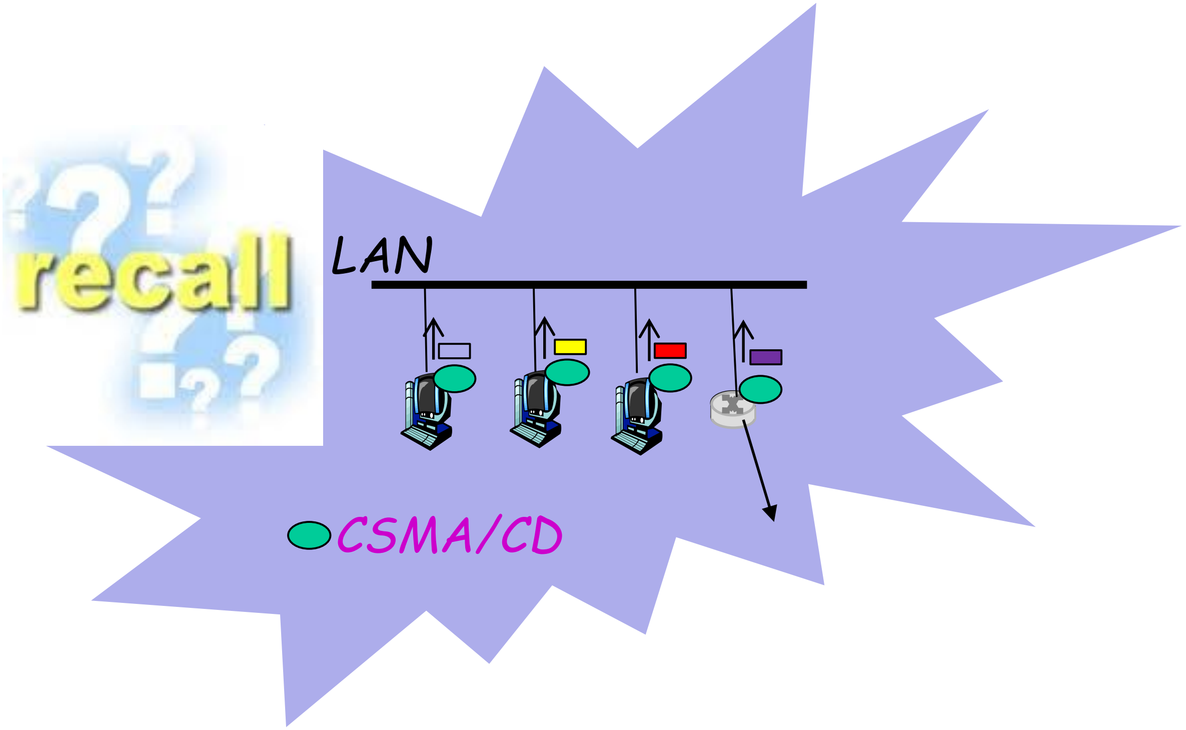
both have forwarding tables:

- *routers:* compute tables using routing algorithms, IP addresses
- *switches:* learn forwarding table using flooding, learning, MAC addresses

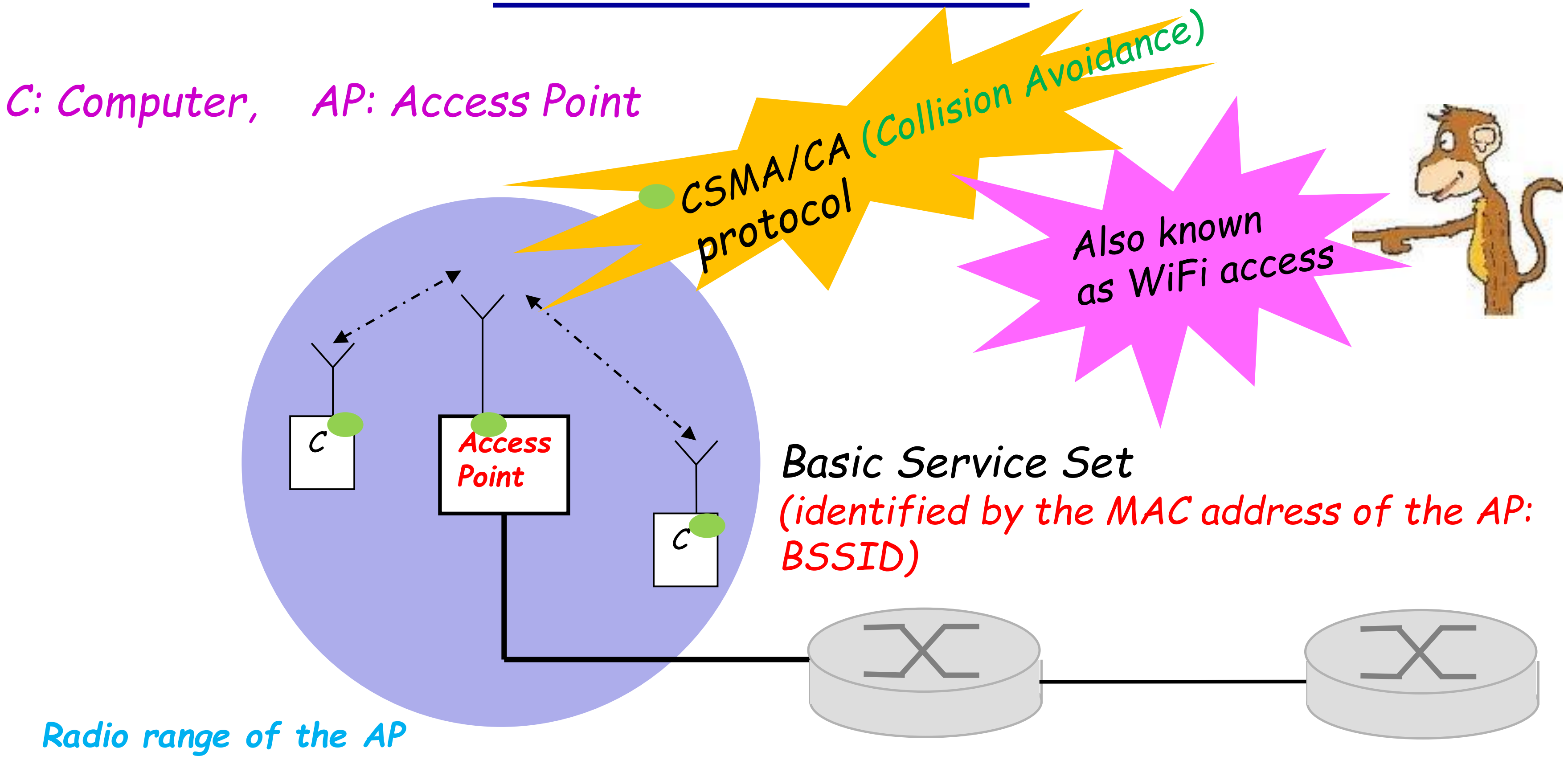


Wireless LAN

Standards: IEEE 802.11/a/b/g/n



WLAN: Basic idea



Independent BSS (IBSS)= BSS – AP

Extended Service Set (ESS): A collection of BSS connected by a Distribution System

Example: The NSU WiFi network is one ESS.

IEEE 802.11/a/b/g/n Family

IEEE	Signal Transmission	Frequency Band	Rate **(Mbps)**
802.11	DSSS FHSS	2.4 GHz 2.4 GHz	1 and 2 1 and 2
802.11b	DSSS	2.4 GHz	5.5 and 11
802.11a	OFDM	5 GHz	6--54
802.11g **802.11n** **802.11ac**	OFDM OFDM OFDM	2.4 GHz 2.4/5 GHz 5 GHz	22 and 54 72 and **150** **6.9 Gbps**

DSSS: Direct Sequence Spread Spectrum
FHSS: Frequency Hopping Spread Spectrum
OFDM: Orthogonal Frequency Division Multiplexing

Are there different MAC protocols in IEEE 802.11/a/b/g/n standards

They have all different PHY layers ……

But, all of them have the same MAC protocol …..

First ….

Different Modes of Operation of MAC in IEEE 802.11

Modes of IEEE 802.11 MAC

- There is no need for an AP.
- If AP is there, it behaves like an **ordinary** node.
- Nodes make their own decisions to Tx.

Distributed Coordination Function (DCF) mode

Point Coordination Function (PCF) mode

The AP is the controller
AP **decides** who transmits and when.

Handshake mode

Without Handshake mode

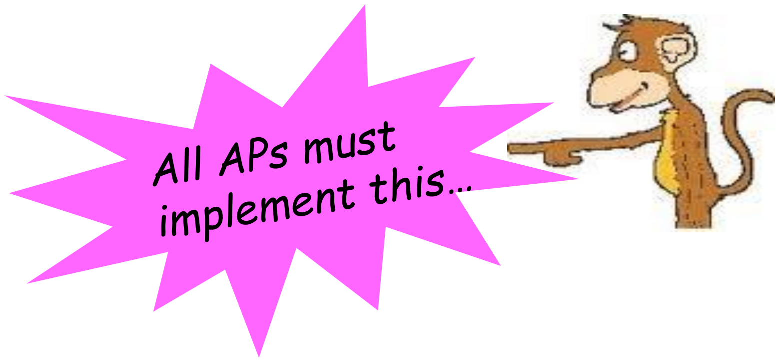
Seek permission from receiver before sending **data**

No prior permission is needed.

PCF Mode

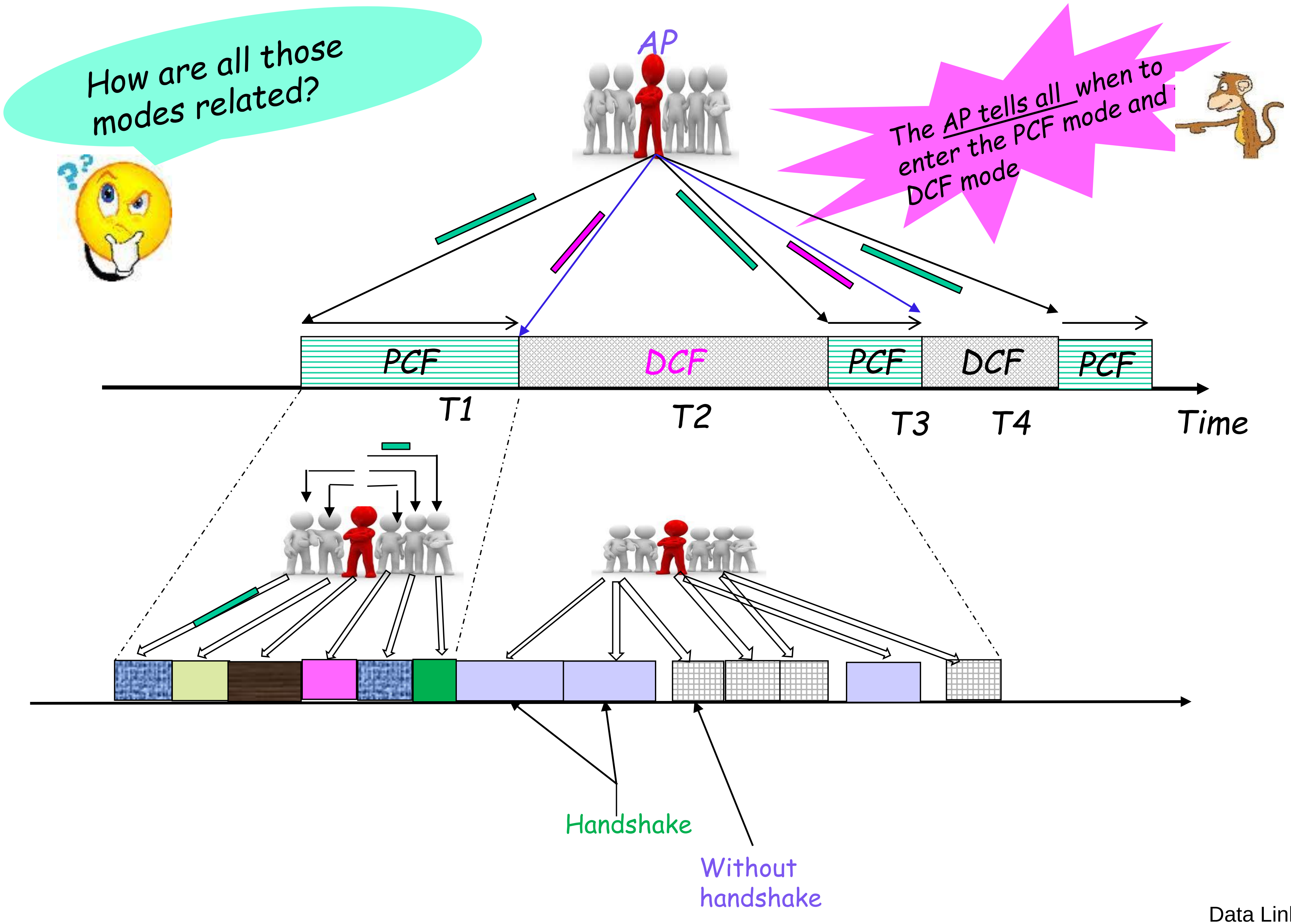
- The AP
  - Operates as the **central controller** in the BSS.
  - Decides who transmits and when.
  - There is no contention for medium access
  - Can follow a round-robin policy to allocate slots.
- This mode
  - Leads to waste of bandwidth if a scheduled node has no traffic.
  - Is based on the idea of polling 🡐 Recall “taking-turns” MAC

DCF Mode



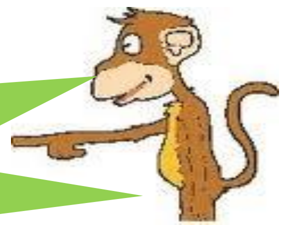
- An AP
  - Need not be used.
    - Computers can directly communicate among themselves <= Ad hoc.
  - Is used to provide connectivity to the Internet.

- In DCF
  - All nodes, including the AP, compete for medium access.
  - The AP does not operate as a central controller.


How are all those modes related?
AP
The AP tells all when to enter the PCF mode and DCF mode
PCF
DCF
PCF
DCF
PCF
T1
T2
T3
T4
Time
Handshake
Without handshake

How do I know when to use handshake and when to use without-handshake

The MAC management database holds a variable: **dotRTSThreshold** (integer in bytes)



Handshake mode

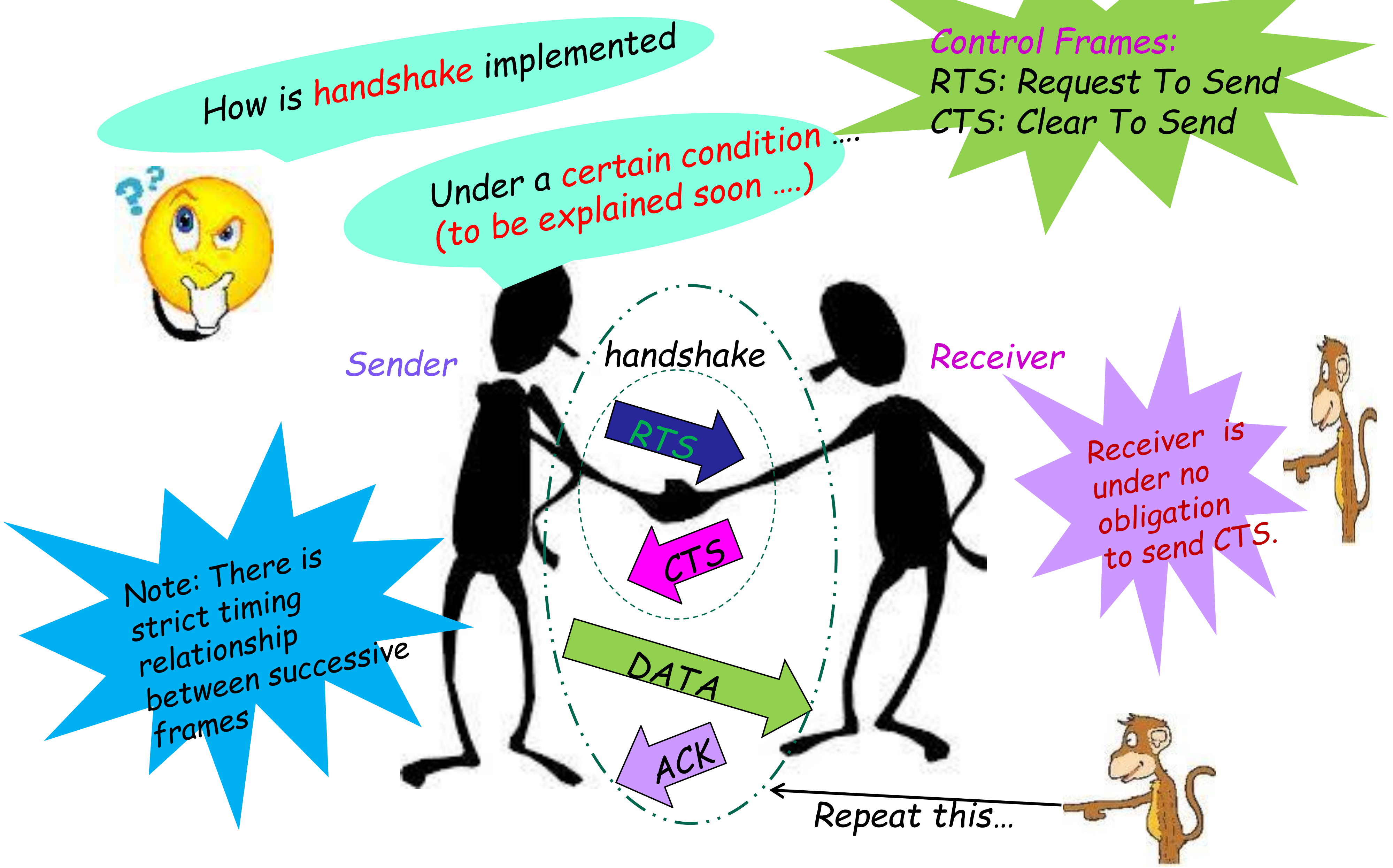
Frame length >= dotRTSThreshold

Without-Handshake mode

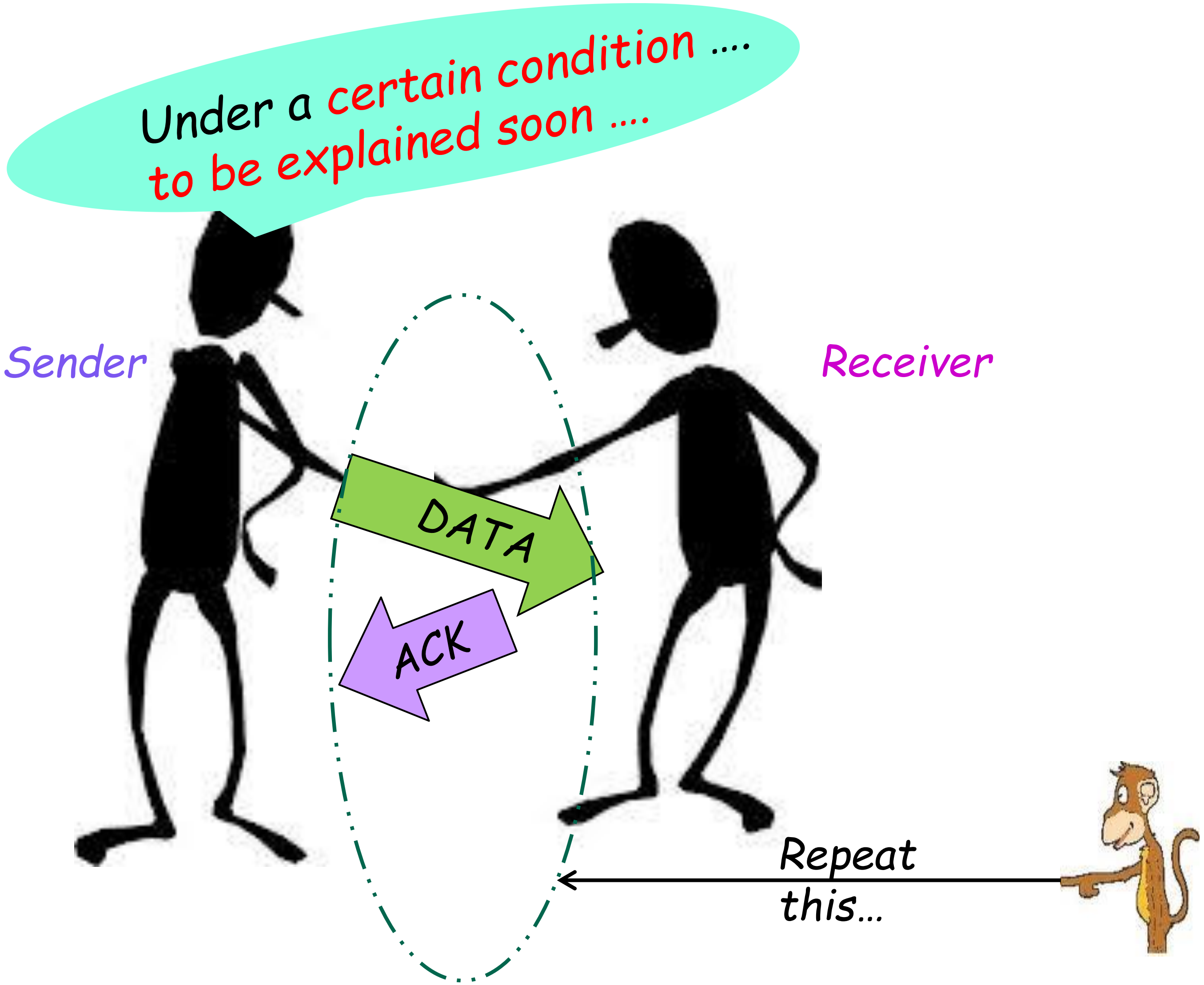
Frame length < dotRTSThreshold

For "long" frames, you want to reduce the prob. of collision… with some overhead

DCF with *handshake*



DCF without *handshake*

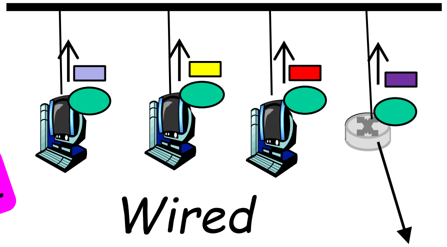


What is the big deal in a WLAN?

What happens to my RTS, CTS, DATA, ACK,…..
Do they collide with Tx from other nodes

Note the diff. between
a wired medium & a wireless medium

Signal from all nodes
must reach all others

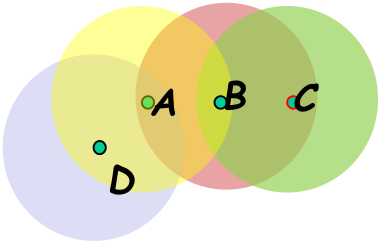


Wired

Remember this diff…

This diff. leads
to some problems

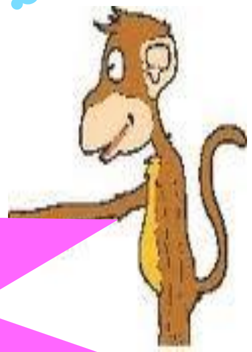
Wireless



Signal from some nodes
may not reach all others

What problems can arise in a wireless net

Collision detection is not always possible in a wireless LAN.



You do not receive the **signal** received by the intended receiver of your frame.

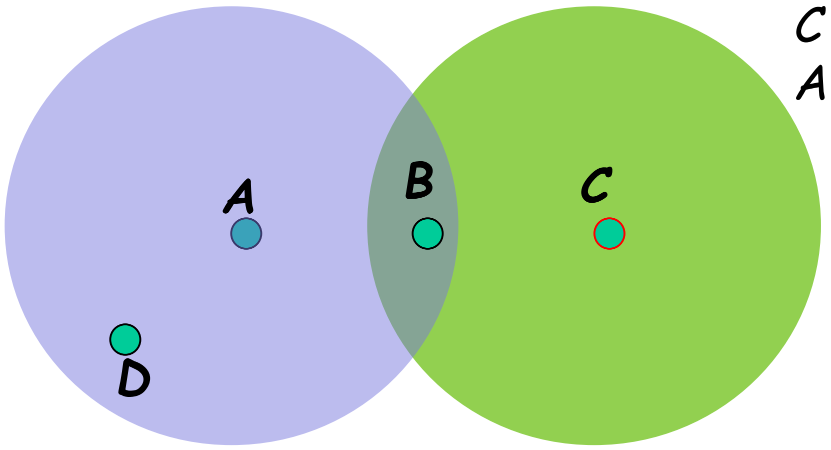
As a result, if your frame encountered collision at the receiver, you are NOT aware of that.

Two Problems in WLAN

- Hidden Terminal Problem

- Exposed Terminal Problem

Hidden Terminal Problem



C is transmitting a frame to B.
A is unaware of C's Tx.

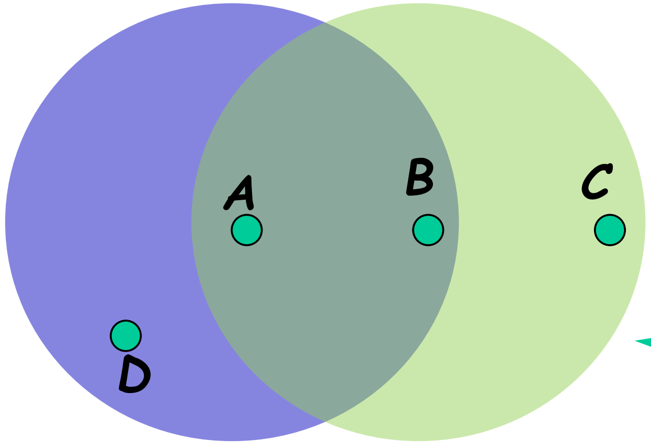
Now, if A transmits, A's frame will collide with C's at B

- This problem is due to C being **hidden** from A.
  - Hidden means being "far away" …

Collision occurs at B, but A cannot detect it…

Solution exists:
CSMA/CA
(Collision Avoidance)

Exposed Terminal Problem



No solution has been provided so far…..

A is transmitting a frame to D.

B knows that someone is transmitting.

If B transmits a frame to C, it does not collide with A's at D.

However, B does not transmit because B is unaware of D's location.

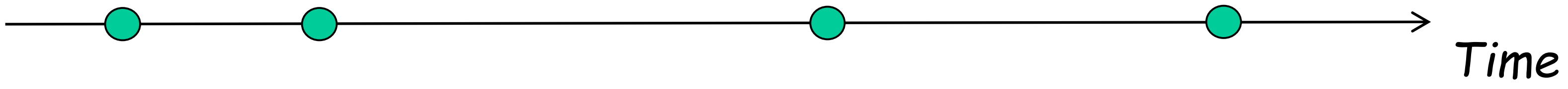
Problem: Loss of opportunity to transmit ➔ Loss of bandwidth ….

*The above problem is due to B being **exposed** to A's Tx.*

WLAN MAC: CSMA/CA (basic idea)

- Collision is avoided by using **two techniques**
  - **PHY-level carrier sensing**: *Done in receiver hardware*
  - **Virtual carrier sensing**:
    - An integer variable in each node - called NAV (Network Allocation Vector) -- indicates whether or not a nearby node is likely to be transmitting now.
      - NAV > 0 ➔ Most likely another node is transmitting.
      - NAV = 0 ➔ No one nearby is transmitting.
      - ~~NAV < 0: This condition does not occur.~~
- *Transmit condition: Medium is idle at the receiver.*

(Carrier is absent) ***AND*** *(NAV = 0)*



CSMA/CA: NAV in detail

- *Recall the handshake mechanism with RTS and CTS*

- A ***duration*** field in frame header indicates the length of time the sender of the frame may use the medium.
- *All nodes which receive RTS and CTS (and DATA) update their NAV as follows*

Events that update NAV: Initially NAV = 0

With each passing μs (micro second)
*If (NAV > 0) **NAV = NAV – 1***
Else stop decrementing NAV

*If a frame (e.g. RTS, CTS) with **duration** field is received*
NAV = Max(NAV, duration)

RTS and CTS Frames

RTS

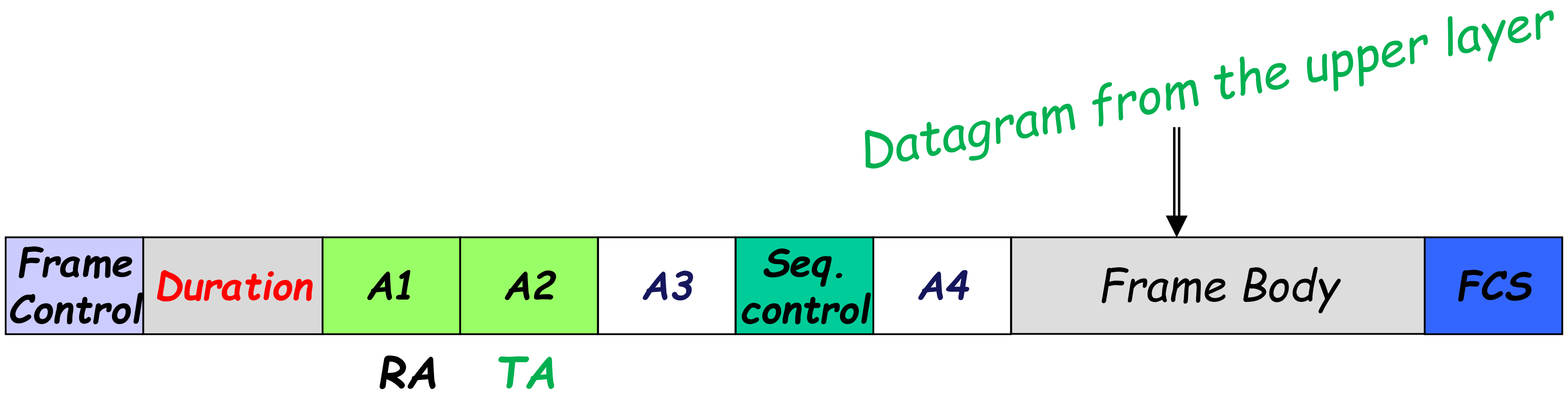
Frame Control	Duration	RA	TA	FCS	
2	2	6	6	4	bytes

CTS/ ACK

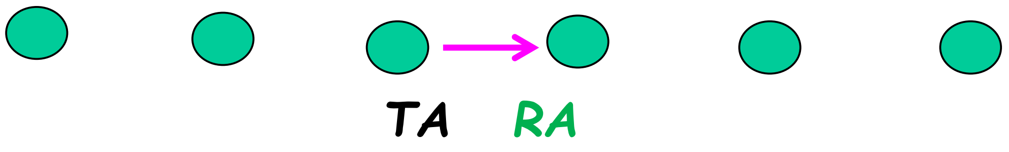
Frame Control	Duration	RA	FCS	
2	2	6	4	bytes

FCS: Frame Check Sequence ← CRC
RA: Receiver Address
TA: Transmitter Address

DATA Frame



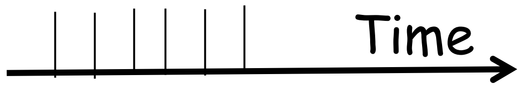
TA: *Physically transmitting the frame.*



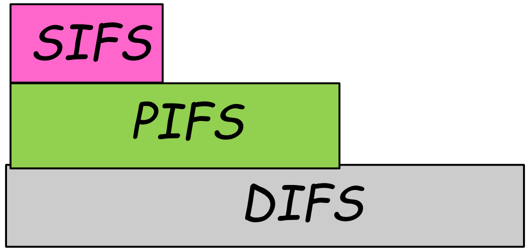
Timing Intervals

- The IEEE 802.11 MAC defines 4 timing intervals
  - *2 at the PHY level*
    - *SIFS: Short Inter-Frame Space (10 micro-sec) between successive frames (RTS, CTS, DATA, ACK, …)*
    - *aSlot (20 micro-sec)*
  - *2 at the MAC level*
    - *PIFS: Priority (in PCF) IFS (SIFS + aSlot)*
    - *DIFS: Distributed IFS (PIFS + aSlot)*

__aSlot__ is chosen s.t. a node can determine if another node initiated a Tx aSlot time before (= propagation time + some hardware delay)



Timing intervals are used to control priority

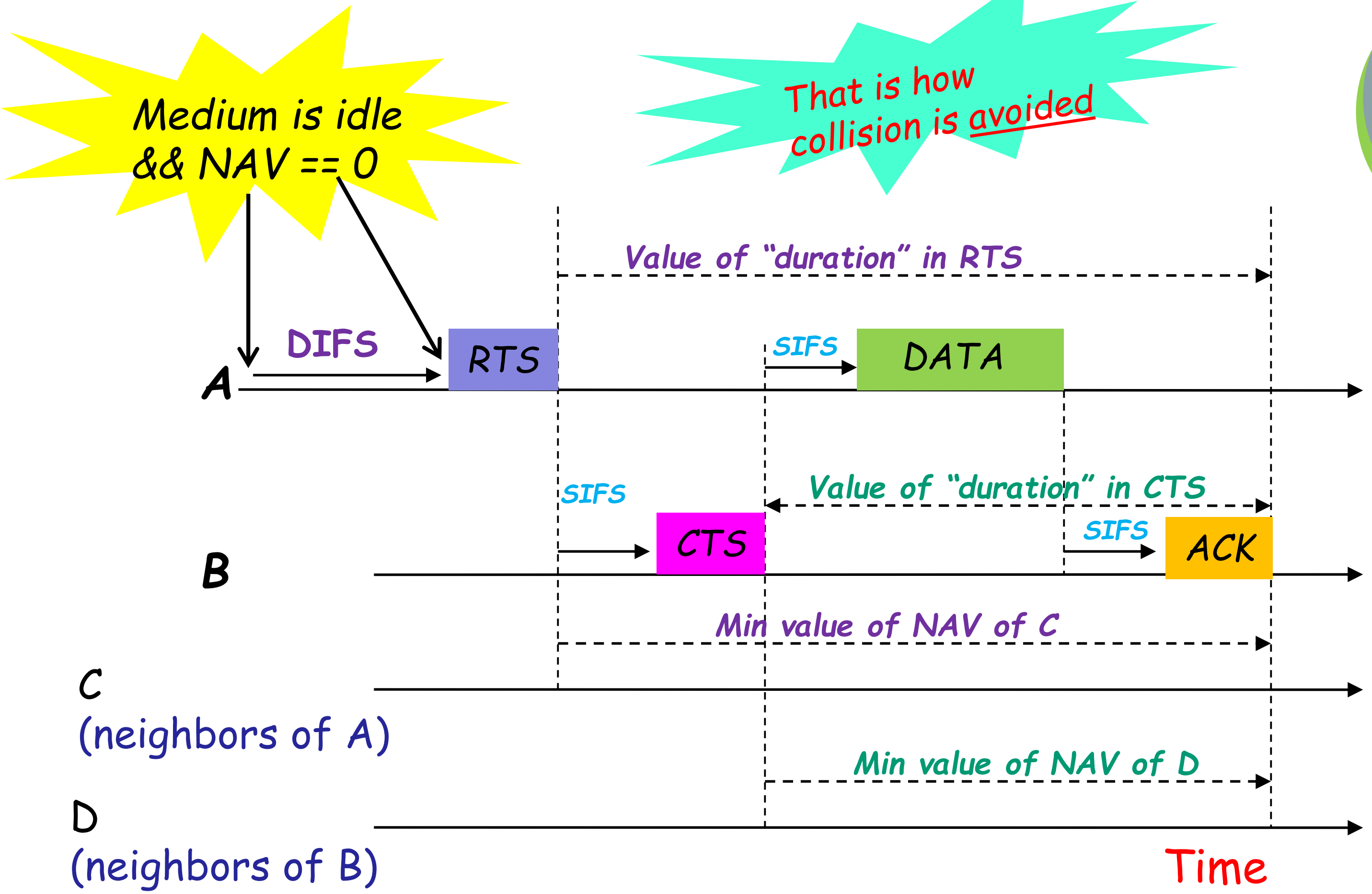


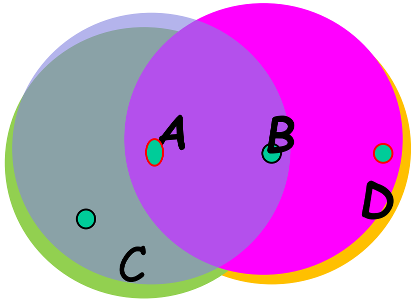
By keeping SIFS shortest, it is ensured that an ongoing cycle of Tx (with handshake or without handshake) is not disturbed ….
No one else can Tx between RTS, CTS, DATA, ACK.

PIFS < DIFS enables an AP to become the controller of a BSS …

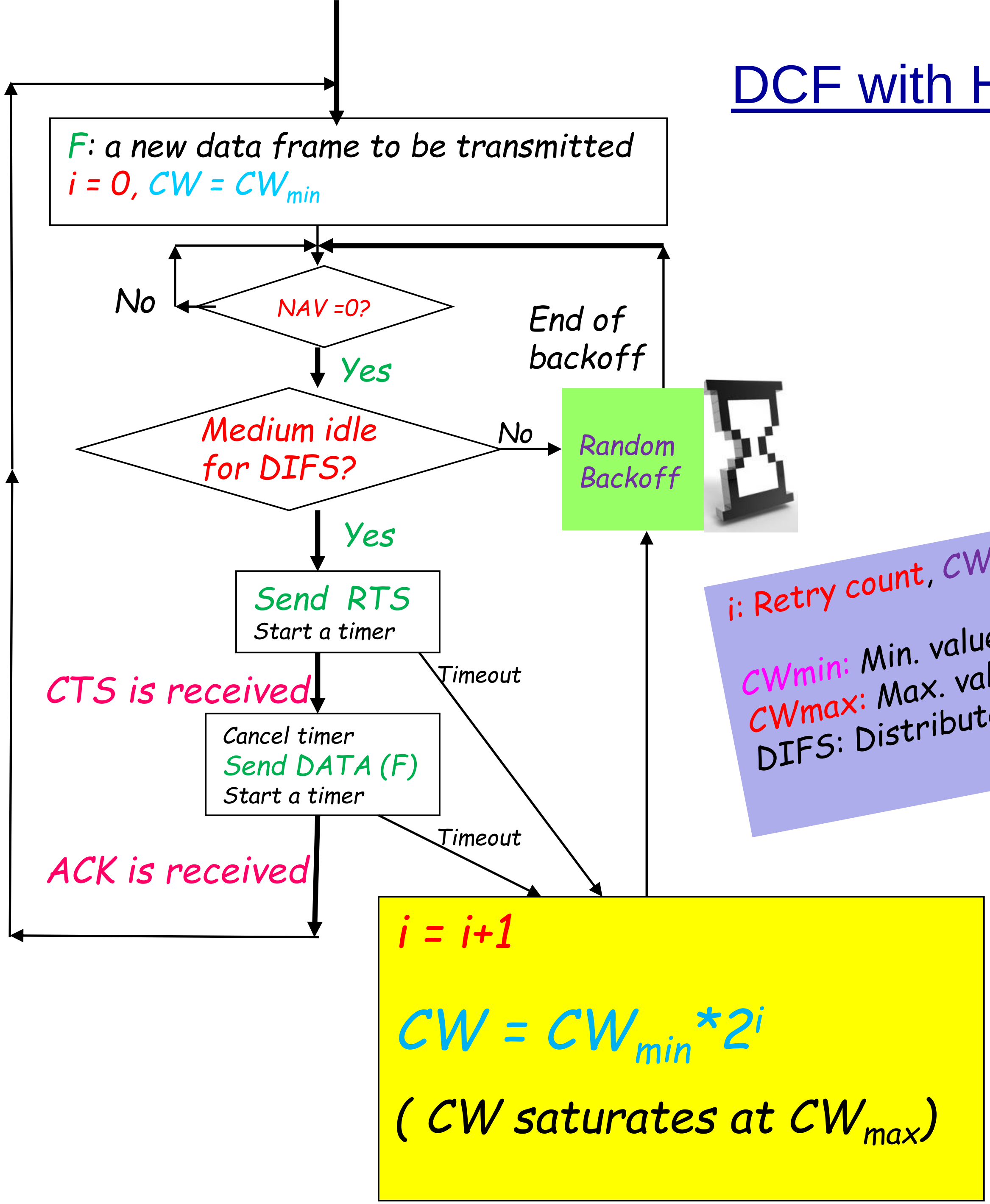
Handshake using RTS/CTS (A wants to send data to B)

(Note: "duration" info in DATA will not be shown.)





DCF with Hand-shake: Tx



i: Retry count, CW: Contention Window

CWmin: Min. value of CW (typical: 32)
CWmax: Max. value of CW (typical : 256)
DIFS: Distributed Interframe Space

Backoff Mechanism

- **Initialize** a counter: Backoff Time Counter (BTC)
  - BTC = Random(0,CW-1) ……time unit of BTC is **aSlot**

- *As time passes, BTC is decremented as follows*

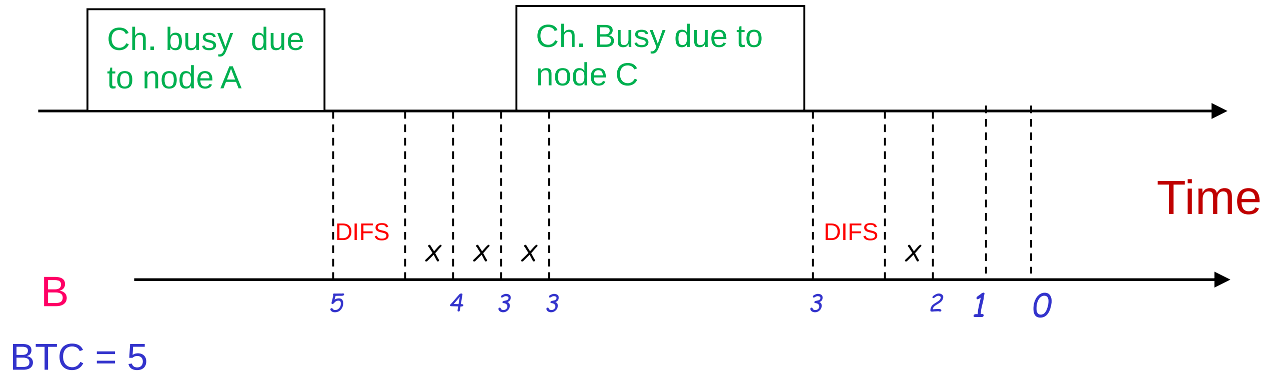
  At the start, let ch. remain idle for DIFS.

  Next, if ch. is idle for aSlot: BTC = BTC -1 ← *Repeat this*

  Anytime the medium is busy: Freeze BTC

- *BTC == 0 → End of backoff*

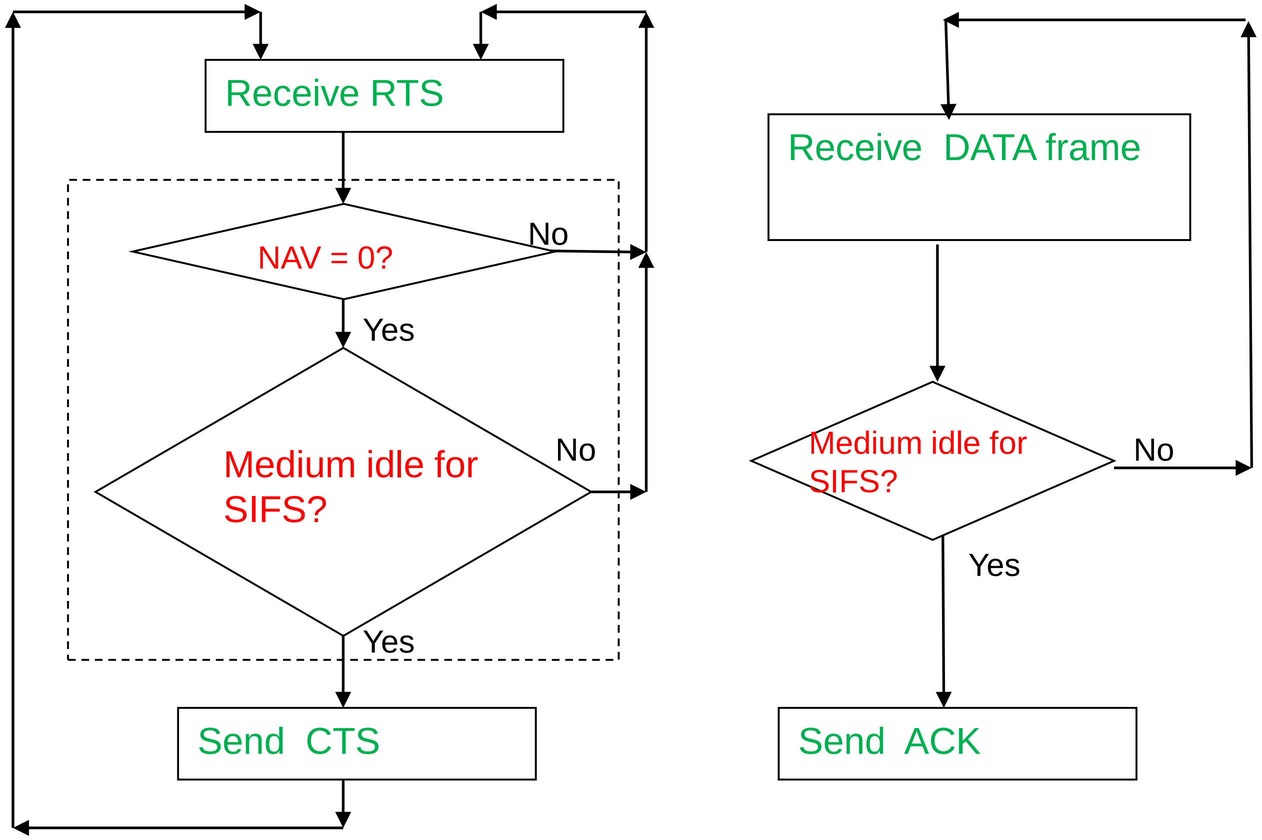
Backoff Mechanism



B is executing backoff

X = aSlotTime

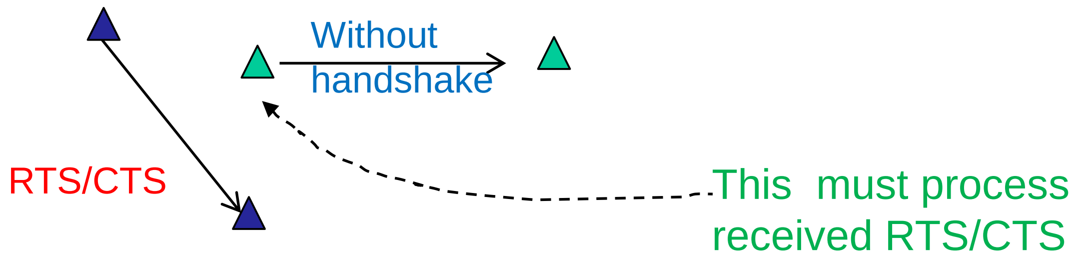
DCF with Handshake: Rx



Note: The above two fragments of flow-charts can be easily merged.

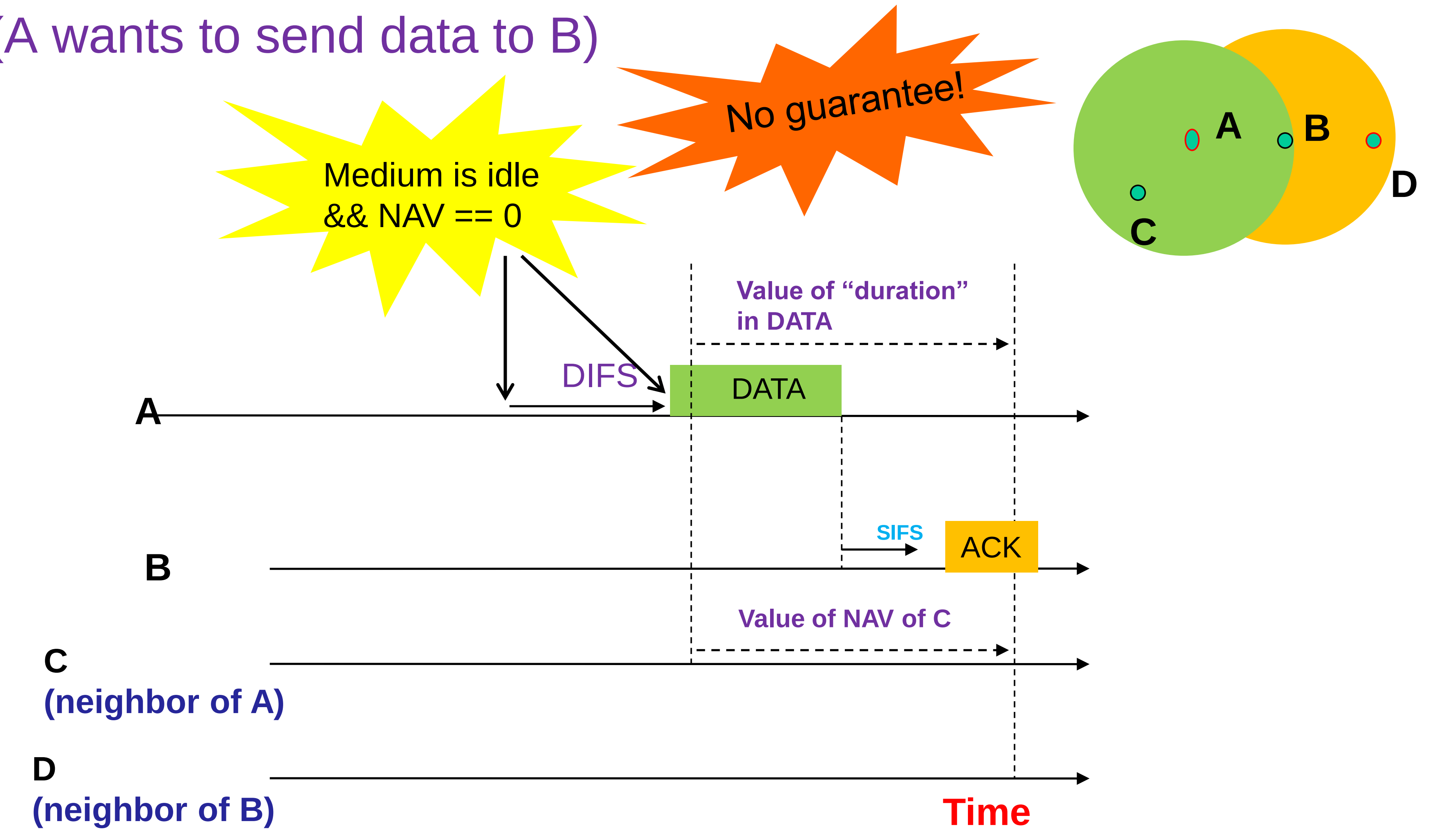
DCF Mode without Handshake

- A special case of DCF without handshake
  - RTS/CTS frames are **not** exchanged.
- The idea of NAV is still used in this mode
  - Recall: All nodes process the received RTS/CTS of others



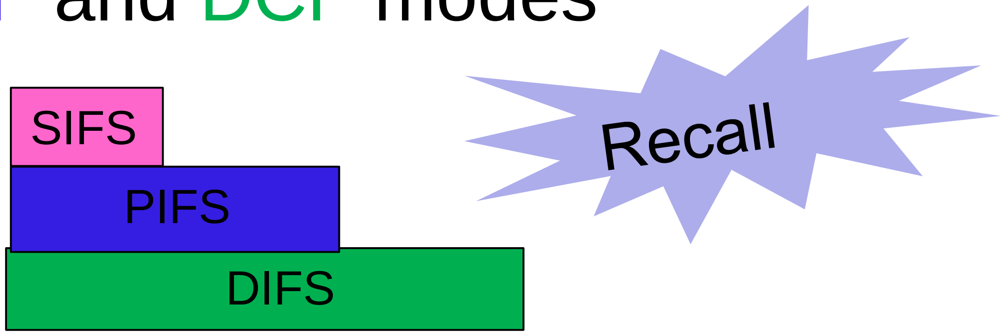
Data transmission without handshake

(A wants to send data to B)



PCF Mode: AP becomes the controller: How?

❖ AP alternates between PCF and DCF modes



❖ AP operates as the **controller** as follows

If AP finds medium to be **idle** **(no carrier && NAV == 0)** for **PIFS**, it transmits a **beacon** frame.
Beacon contains a **CFPMaxDuration** field (CFP: Contention Free Period)

Nodes receiving a beacon update their NAV to **CFPMaxDuration**

These nodes perceive the medium to be busy for CFPMaxDuration
They do not transmit unless asked to do so by the AP.

PCF Mode of Operation (Contd.)

- After **transmitting a** **beacon**, AP waits for PIFS before transmitting one of the following

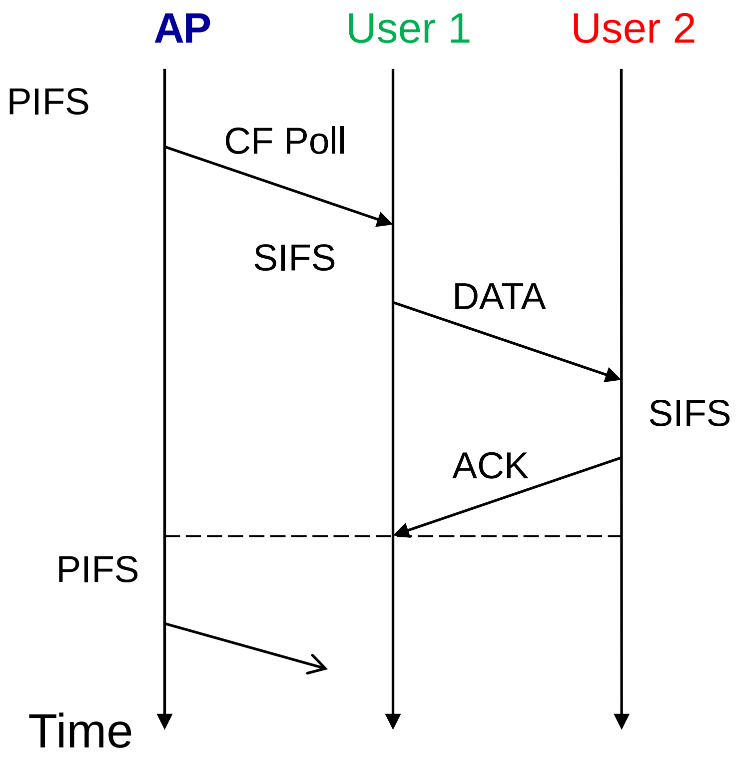
  - DATA frame
  - CF Poll frame
  - DATA+CF Poll frame
  - ACK frame
  - CF End frame

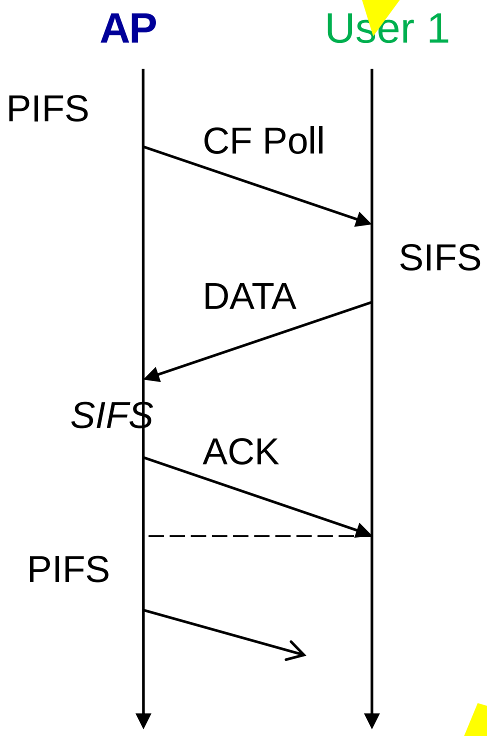
(CF: Contention Free)

PCF Mode of Operation (Contd.)

CF Poll frame

If a user does not have data, it sends a null DATA frame
(A DATA frame with no actual data)

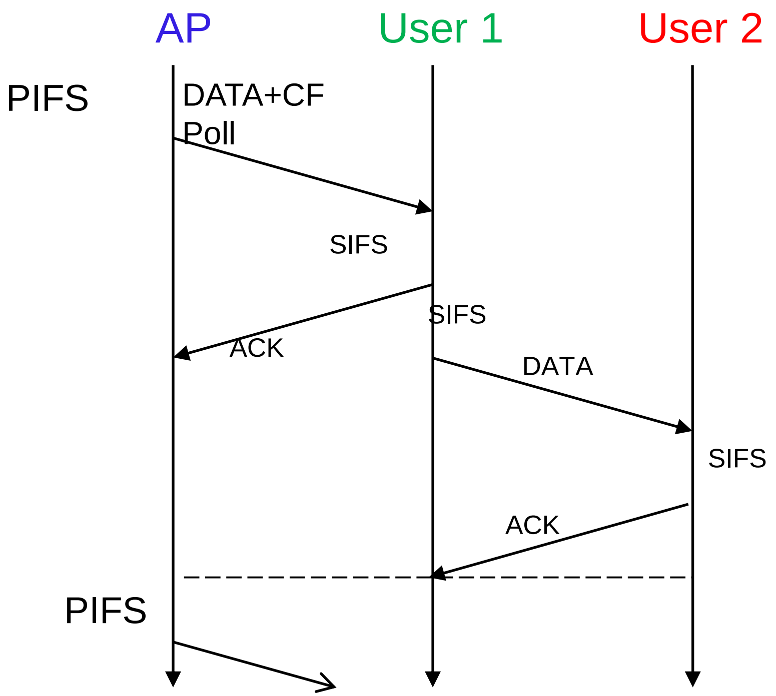




If ACK is not received, user 1 waits until it is polled again.

PCF Mode of Operation (Contd.)

DATA + CF Poll frame



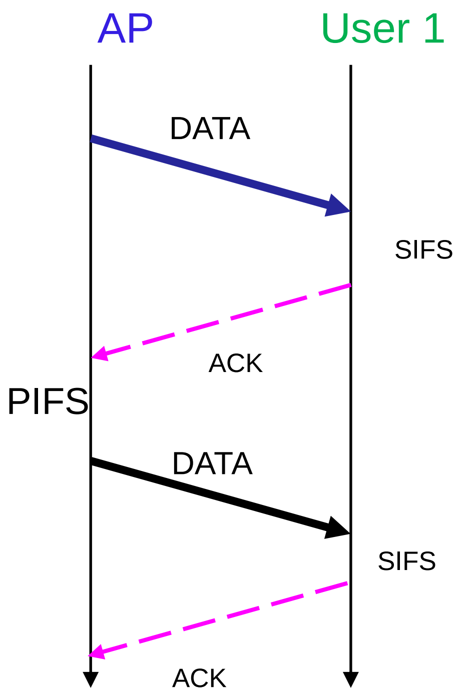
Note 1: If AP does not receive an ACK, it retransmits data after PIFS.

Note 2: If User 1 does not receive ACK, it does not retransmit data.

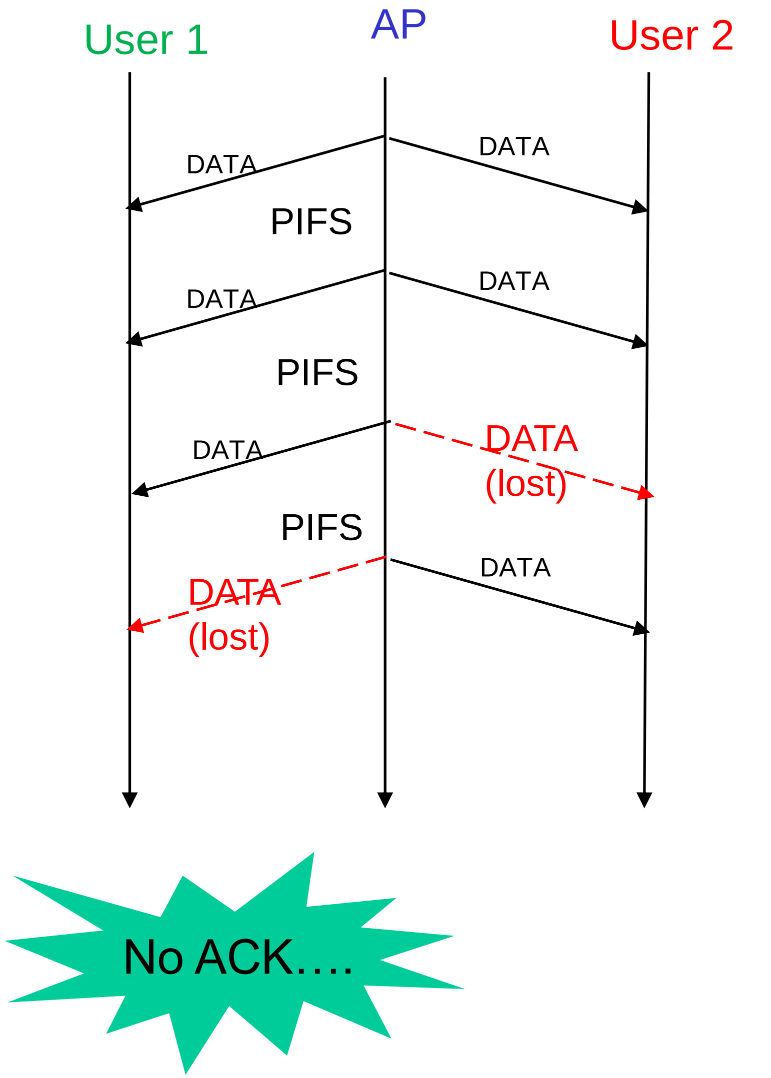
The polled user receives data from the AP and sends data to another user.

PCF Mode of Operation (Contd.)

DATA from AP (unicast): 1 → 1



DATA from AP (broadcast): 1 → all

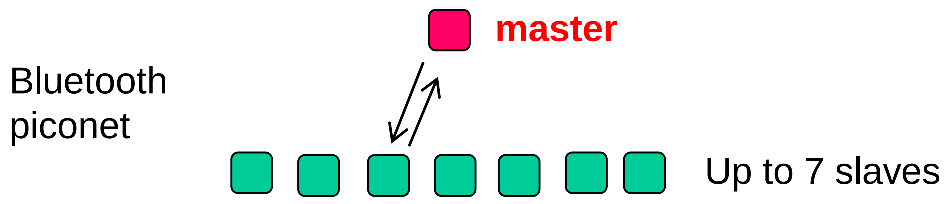


PCF Mode of Operation (Contd.)

- CF End frame
  - Identifies the end of CF period
    - Receiving nodes set NAV = 0.

Summary of MAC protocols

- channel partitioning by time, frequency or code
  - Time Division, Frequency Division, Code Division
- random access (dynamic),
  - ALOHA, S-ALOHA, CSMA/CD, CSMA/CA
  - carrier sensing: easy in some technologies (wire), hard in wireless
  - CSMA/CD used in Ethernet based LAN
  - CSMA/CA used in WiFi (802.11) based WLAN
- taking turns
  - polling from central site, token passing
  - Examples: Bluetooth, IBM Token Ring



More past exam questions …

F'12 Mid-term

Clearly explain why collision detection is not possible in wireless local area networks.

Clearly explain why the timing intervals SIFS, PIFS, and DIFS have been ordered as SIFS < PIFS < DIFS in the CSMA/CA protocol.

Clearly explain the hidden terminal problem.

S'12 Mid-term

Summary

- principles behind data link layer services:
  - error detection, correction
  - sharing a broadcast channel: multiple access
  - link layer addressing
- instantiation and implementation of various link layer technologies
  - Ethernet
  - switched LANS, WLANs
- could stop here …. but *lots* of interesting topics!