Data Link Layer
IK2218/EP2120

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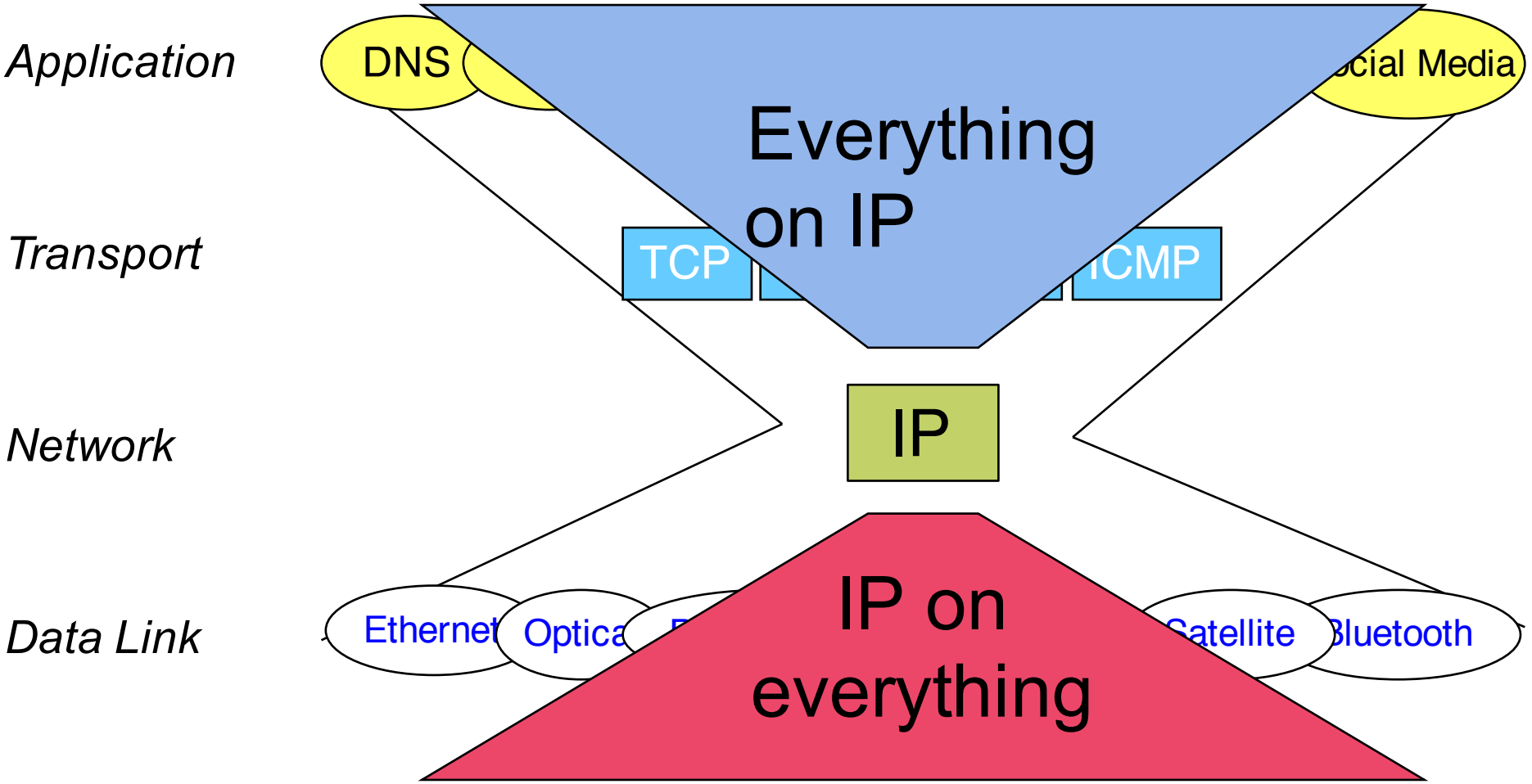
Acknowledgements

- The presentation builds upon material from
  - Previous slides by Markus Hidell, Björn Knutsson and Peter Sjödin
  - *Computer Networking: A Top Down Approach*, 5th ed. Jim Kurose, Keith Ross. Addison-Wesley.
  - *TCP/IP Protocol Suite*, 4th ed, Behrouz Foruzan. McGraw-Hill.

Outline

- Data Link Layer
  - Introduction
  - Scope and functions
- Ethernet
  - Principles
  - Implementation
- Wireless LAN
  - Principles
  - Implementation
- Personal Area Network
  - Bluetooth

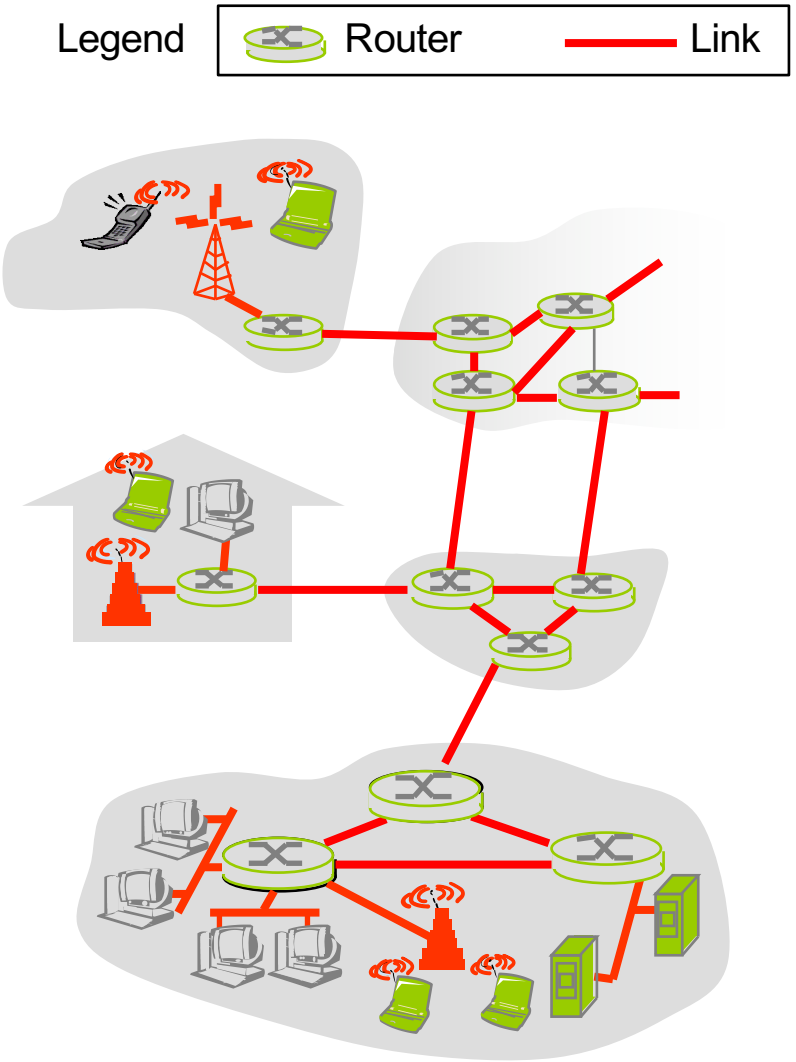
The Internet Hourglass



Based on slide by Guru Parulkar and John Doyle

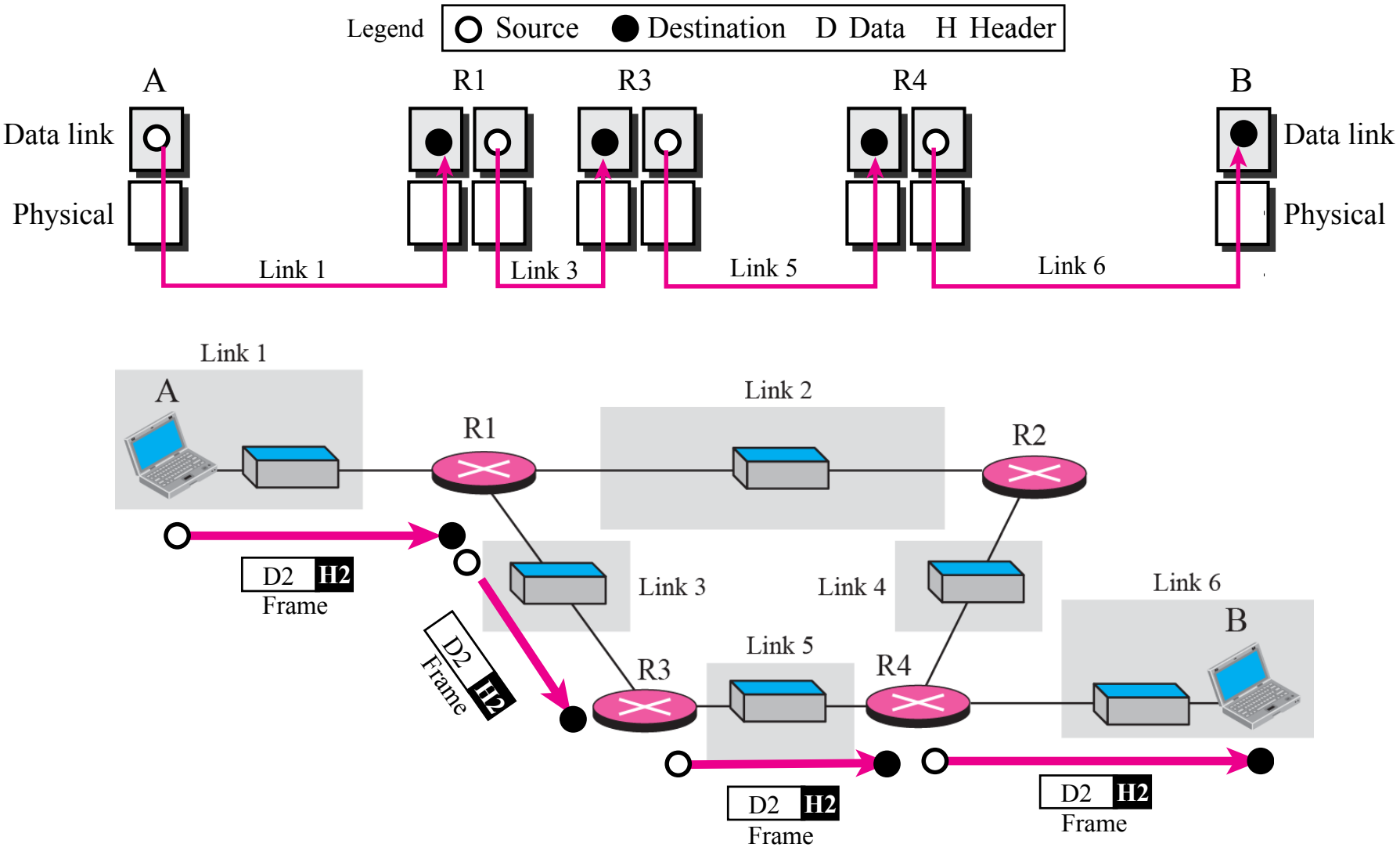
Data Link Layer: Introduction

- Some terminology:
- hosts and routers are nodes
- communication channels that connect adjacent nodes along communication path are links
  - wired links
  - wireless links
  - LANs
- Data link layer packet is a frame, encapsulates datagram



Data Link Layer has responsibility of transferring datagram between adjacent nodes over a link

Data Link Layer



Data Link Layer: Context

- Datagram transferred by different link protocols over different links:
  - e.g., Ethernet on first link, ADSL on intermediate link, 802.11 Wireless LAN on last link
- each link protocol provides different services

transportation analogy

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

Data Link Layer Scope

- Given a physical medium that can transfer raw bits between adjacent nodes
  - How can this be transformed into a reliable link suitable for computer networking?

Link Layer Services

- *Framing*
  - Encapsulate datagram into frame
  - Adding header and trailer
- *Access control*
  - Coordinate access from multiple nodes on shared medium
  - Half duplex – both sides can send, but not at the same time
  - Full duplex – both sides can send at the same time
- *Link addressing*
  - "MAC" addresses used in frame headers to identify source and destination nodes
    - Specific for link
    - Different from Internet (IP) address
    - "Physical addressing" in Forouzan
    - (MAC stands for Media Access Control)

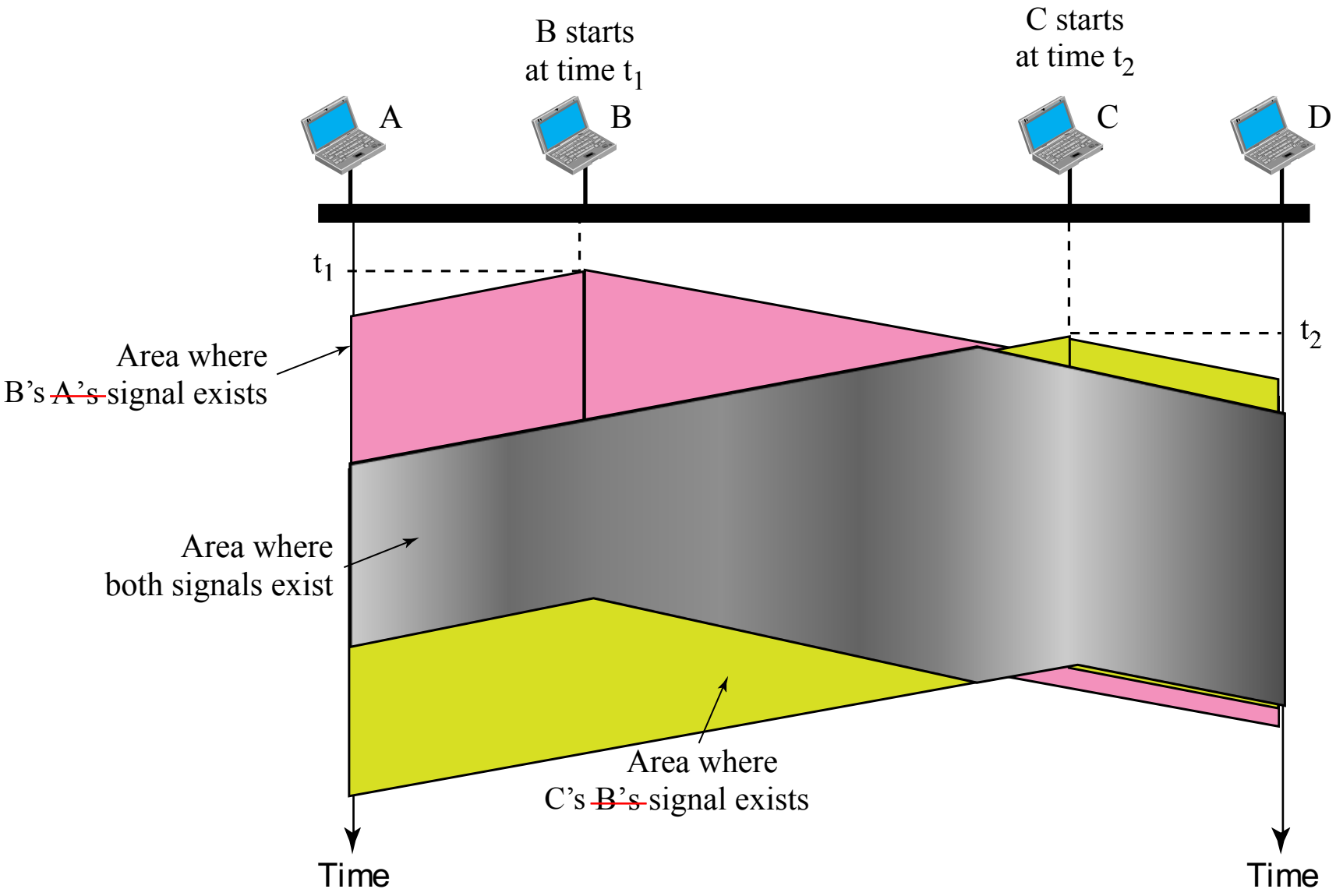
Link Layer Services (continued)

- *Flow control*
  - Rate control
    - Prevent receiver from being overrun by faster sender
- *Error detection*
  - Errors caused by signal attenuation, noise, etc.
    - Bit values are altered in transit
  - Receiver detects presence of errors
    - Signals sender for retransmission, or drops frame
- *Error correction*
  - Detect error and repair frame

Media Access Protocols

- Channel Partitioning
  - divide channel into smaller “pieces” (time slots, frequency, code)
  - allocate piece to node for exclusive use
    - For example, radio spectrum is divided into bands
      - Often government-regulated and licensed for specific purposes
  - FDMA, WDMA, TDMA, CDMA, …
    - Frequency/Wavelength/Time/Code Division Multiple Access
- Random Access
  - channel not divided, allow collisions
  - “recover” from collisions

Collision

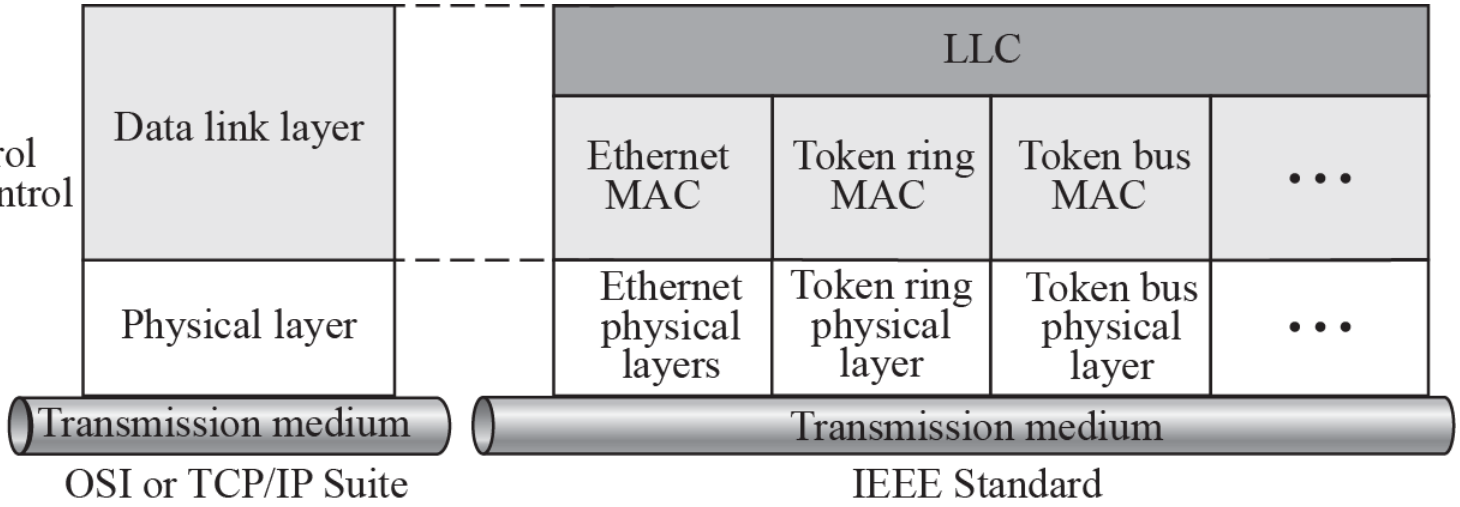

B starts
at time t_1
C starts
at time t_2
A
B
C
D
t_1
t_2
Area where
B's ~~A's~~ signal exists
Area where
both signals exist
Area where
C's ~~B's~~ signal exists
Time
Time

Carrier Sense Multiple Access (CSMA)

- Principle for medium access
- Random access
  - Shared medium, no advance reservations
  - Problem: If two (or more) nodes send at the same time, the result is garbage
    - Collision
    - Hence, half-duplex link
- CSMA
  - Sense the medium before trying to use it
    - Listen for activity
  - Reduce probability of collisions
    - Although collisions can still occur
      - Due to propagation delay
      - Time for a signal to travel over the medium
- Ethernet and Wireless LAN use different CSMA variants

IEEE 802 Standard for LANs

LLC: Logical link control
MAC: Media access control



- IEEE 802.3 – Ethernet
- IEEE 802.11 – Wireless LAN
- IEEE 802.15 – Wireless PAN (Personal Area Network)

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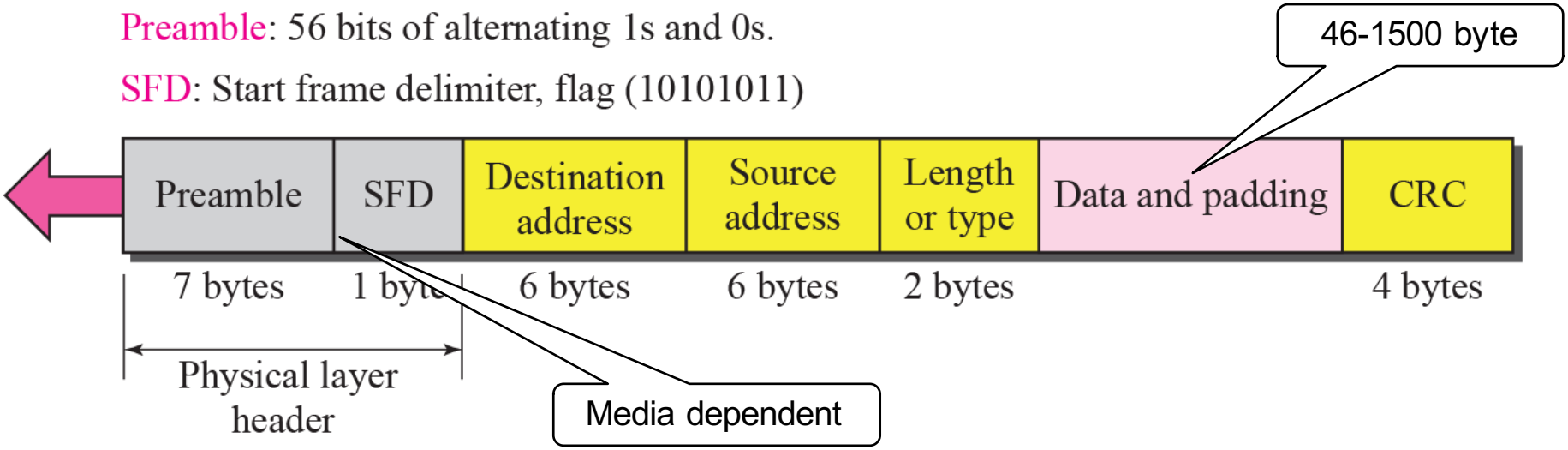
Ethernet Frame

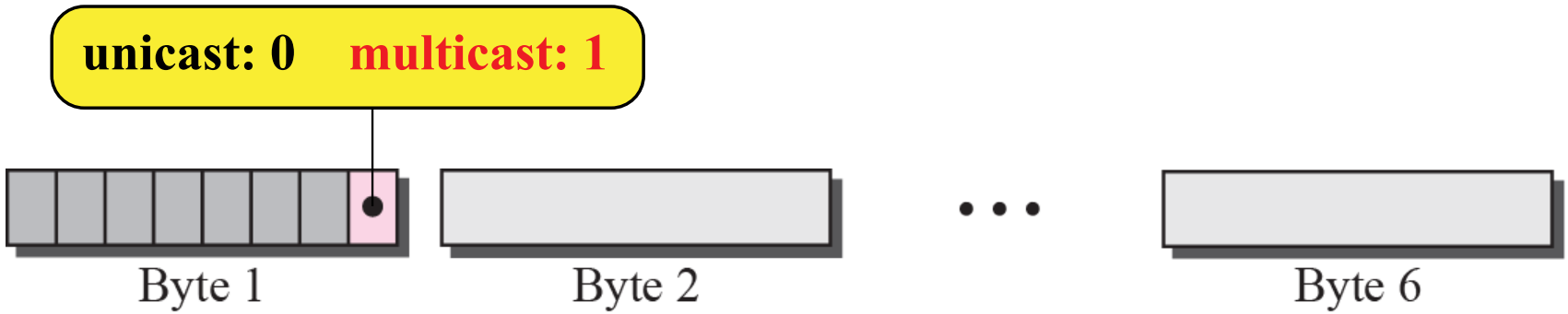


- Two formats
  - IEEE 802.3
    - Length field (max 1518 bytes, not including physical layer header)
  - DIX (DEC, Intel, Xerox)
    - Type field
      - To identify network protocol. For example: network protocol is IP version 4
      - Coding compatible with IEEE 802.3: Type codes always greater than 1518
    - Most common, and often the default format

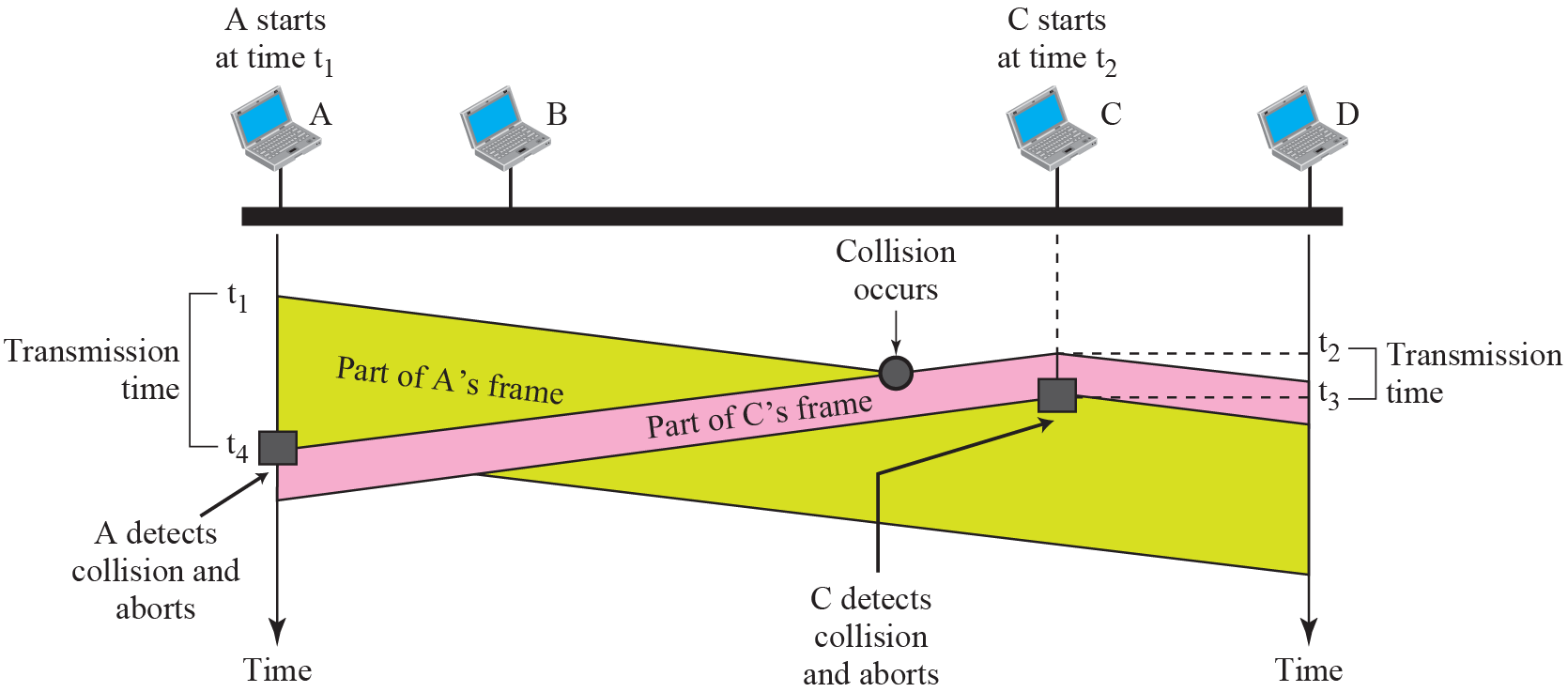
Ethernet Addresses

- 48-bit addresses
- Usually written in hexadecimal notation, in six groups with colon ':' between
- One bit indicates whether the address is multicast (multiple destinations) or unicast (one destination)
  - Least significant bit in first byte
- All-ones is broadcast (multicast to all nodes)

```
4A:30:10:21:10:1A
47:20:1B:2E:08:EE
FF:FF:FF:FF:FF:FF
```

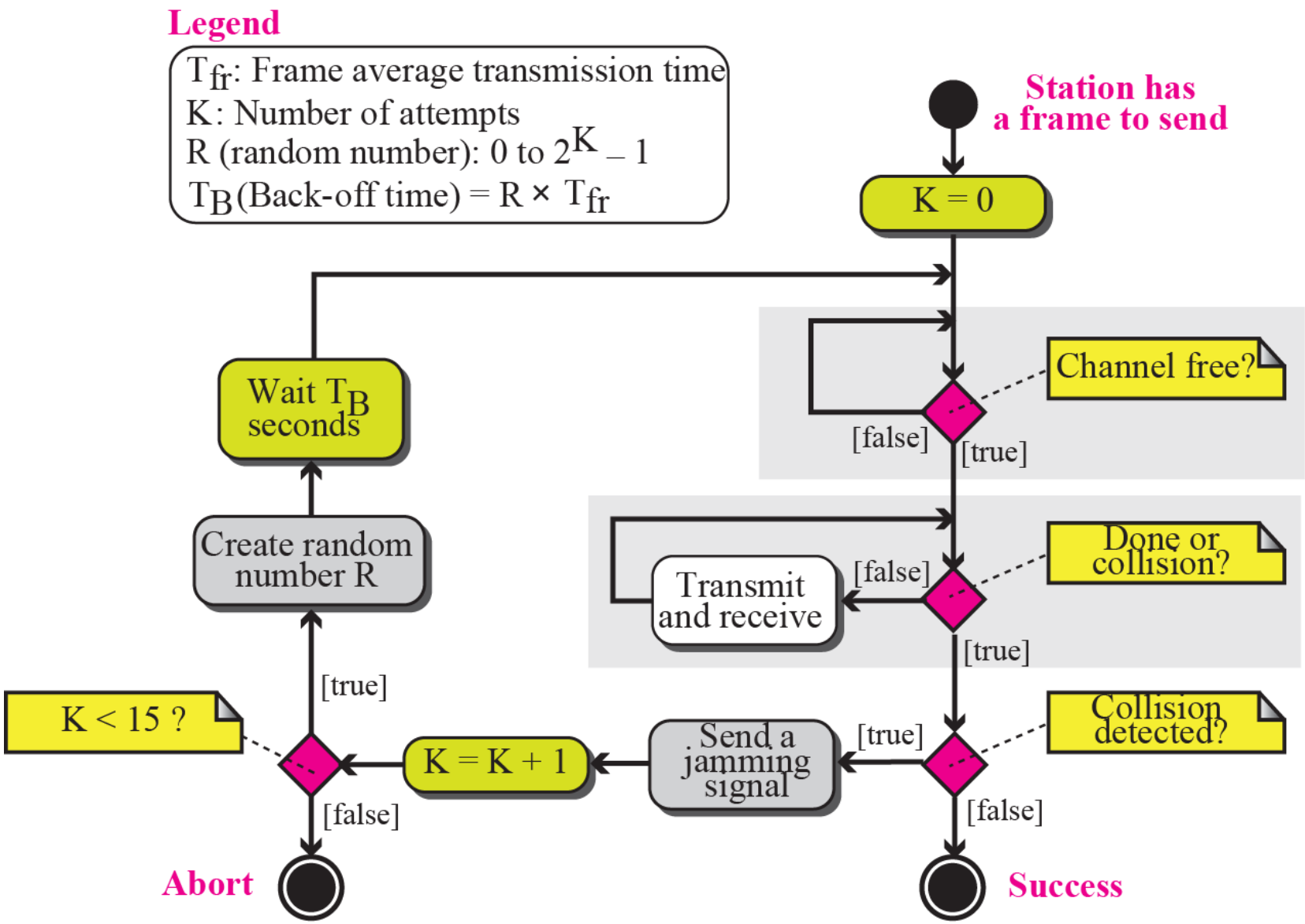


CSMA/CD

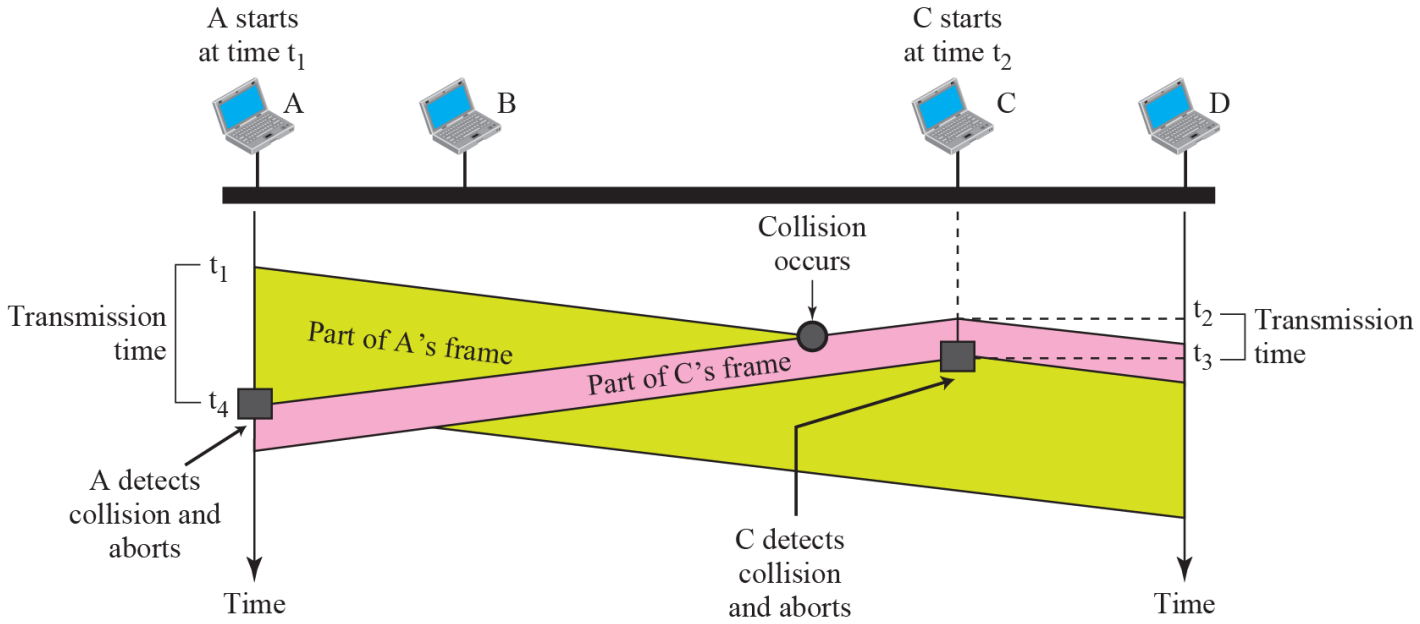


- CSMA with collision detection
- Listen while sending
- If collision is detected:
  - Abort transmission and retry

CSMA/CD Flow Diagram

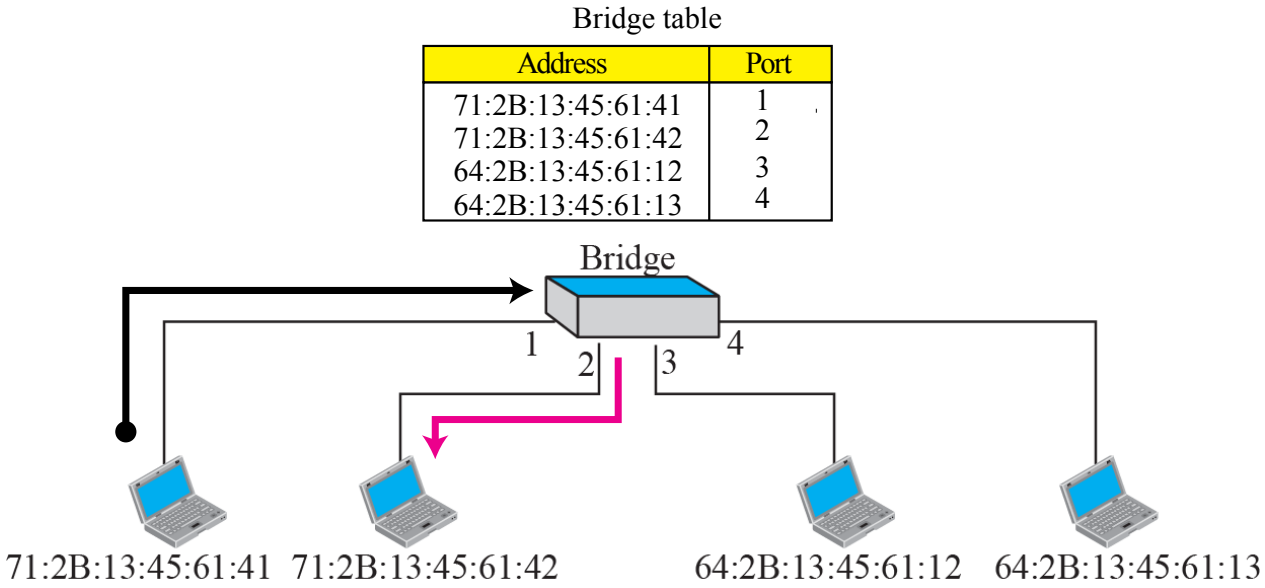


CSMA/CD Remarks



- Requirement on maximum link length versus minimum frame size
  - Not practical for higher speed (Gigabit and beyond)
    - To increase speed, maximum link length must be shortened, or minimum frame size increased
- Nowadays we build Ethernet networks with switches

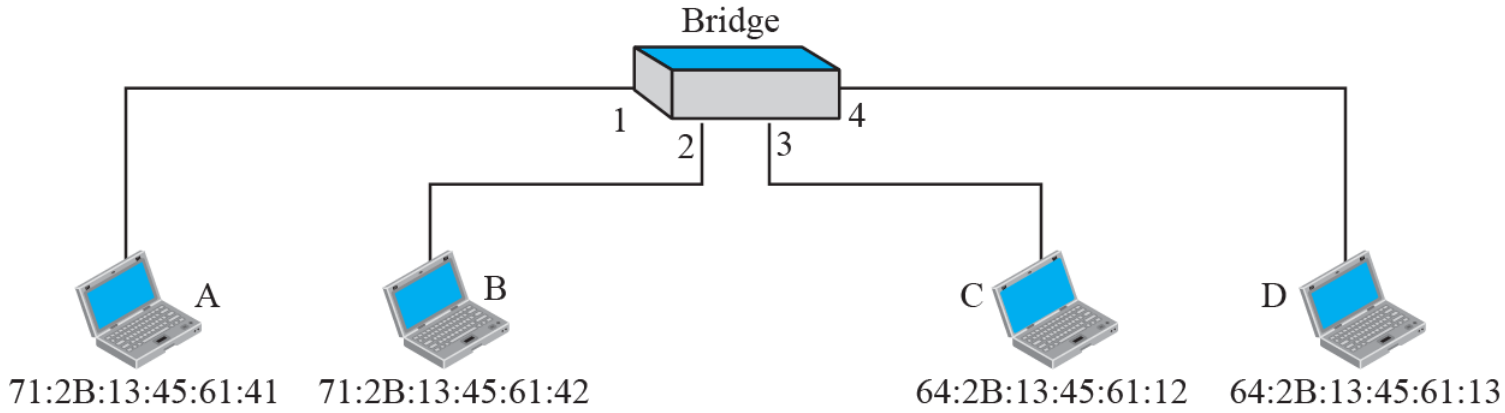
Ethernet Switch (Bridge)



- All links can be used simultaneously
- Links are point-to-point
  - Full duplex mode
  - No CSMA/CD

- Bridge table
  - Bridge examines destination address in incoming frame
  - Frame is sent out on the port for that address
  - Bridge dynamically learns mapping between port and address

Learning Switch (Bridge)



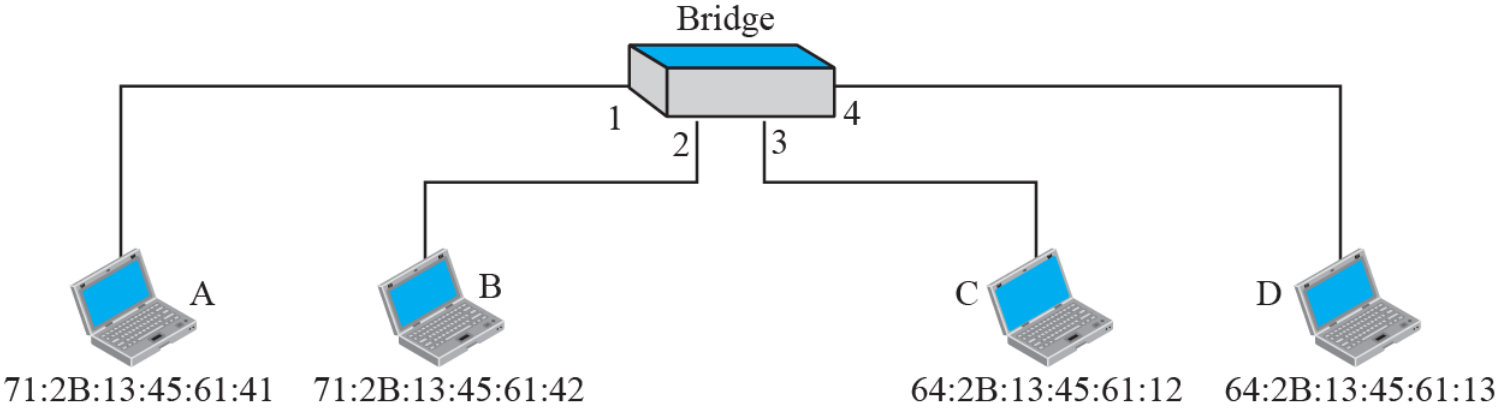
- Bridge learns location of MAC addresses by inspecting source address field in incoming frames

Gradual building of Table

Address	Port

a. Original

Learning Switch (Bridge)



- Bridge learns location of MAC addresses by inspecting source address field in incoming frames

Gradual building of Table

Address	Port

a. Original

Address	Port
71:2B:13:45:61:41	1

b. After A sends a frame to D

Address	Port
71:2B:13:45:61:41	1
64:2B:13:45:61:13	4

c. After D sends a frame to B

Address	Port
71:2B:13:45:61:41	1
64:2B:13:45:61:13	4
71:2B:13:45:61:42	2

d. After B sends a frame to A

Address	Port
71:2B:13:45:61:41	1
64:2B:13:45:61:13	4
71:2B:13:45:61:42	2
64:2B:13:45:61:12	3

e. After C sends a frame to D

Ethernet Standards

- IEEE 802.3
  - First standard in 1983
- Different transmission rates
  - 10 Mb/s, 100 Mb/s, 1 Gb/s, 10 Gb/s, 40 Gb/s, 100 Gb/s
- Different cabling
  - Copper and optical fiber
  - Varying characteristics
    - Maximum length from one meter to tens of kilometers
  - Most common: twister pair cable with RJ45 connector
    - Unshielded (UTP) or shielded (STP)
    - Different quality (Cat 4, 5, 6, 7, …)
- Link auto-negotiation
  - Negotiate speed, duplex mode, and flow control

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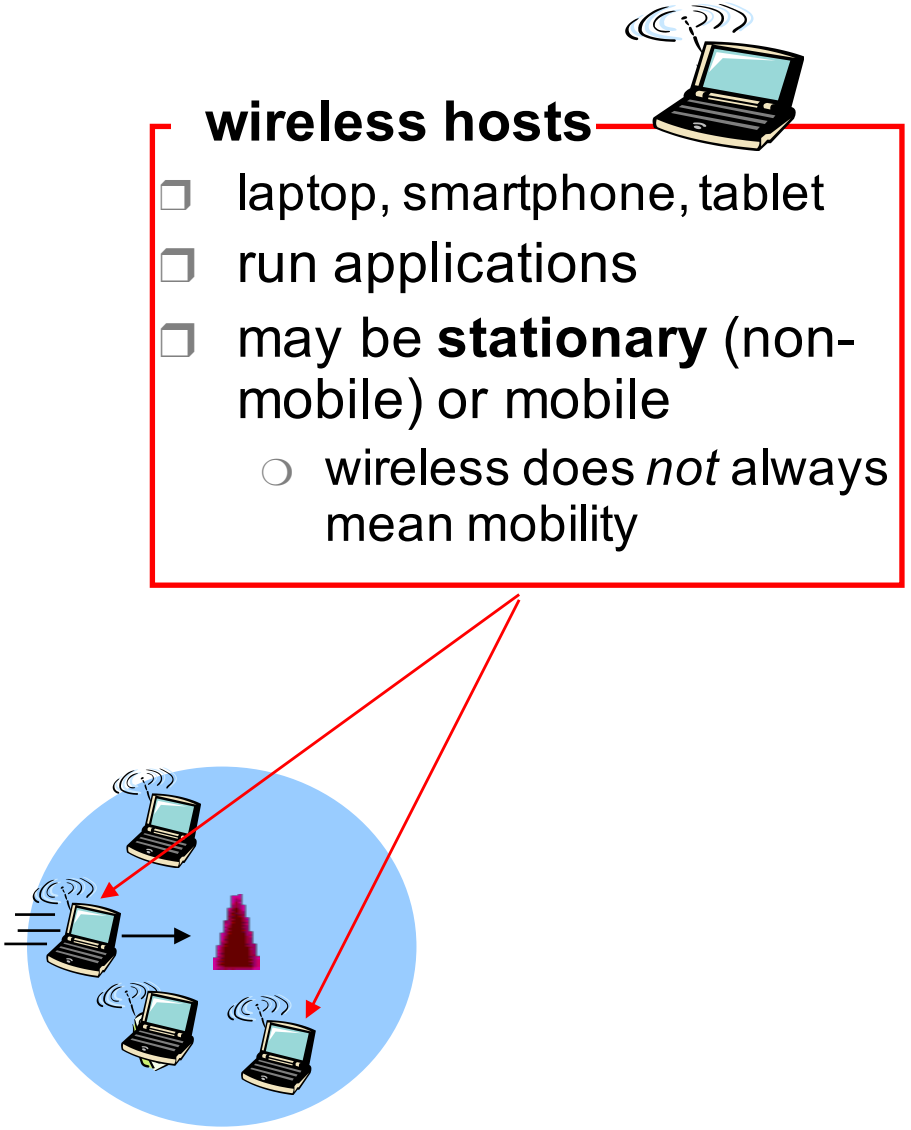
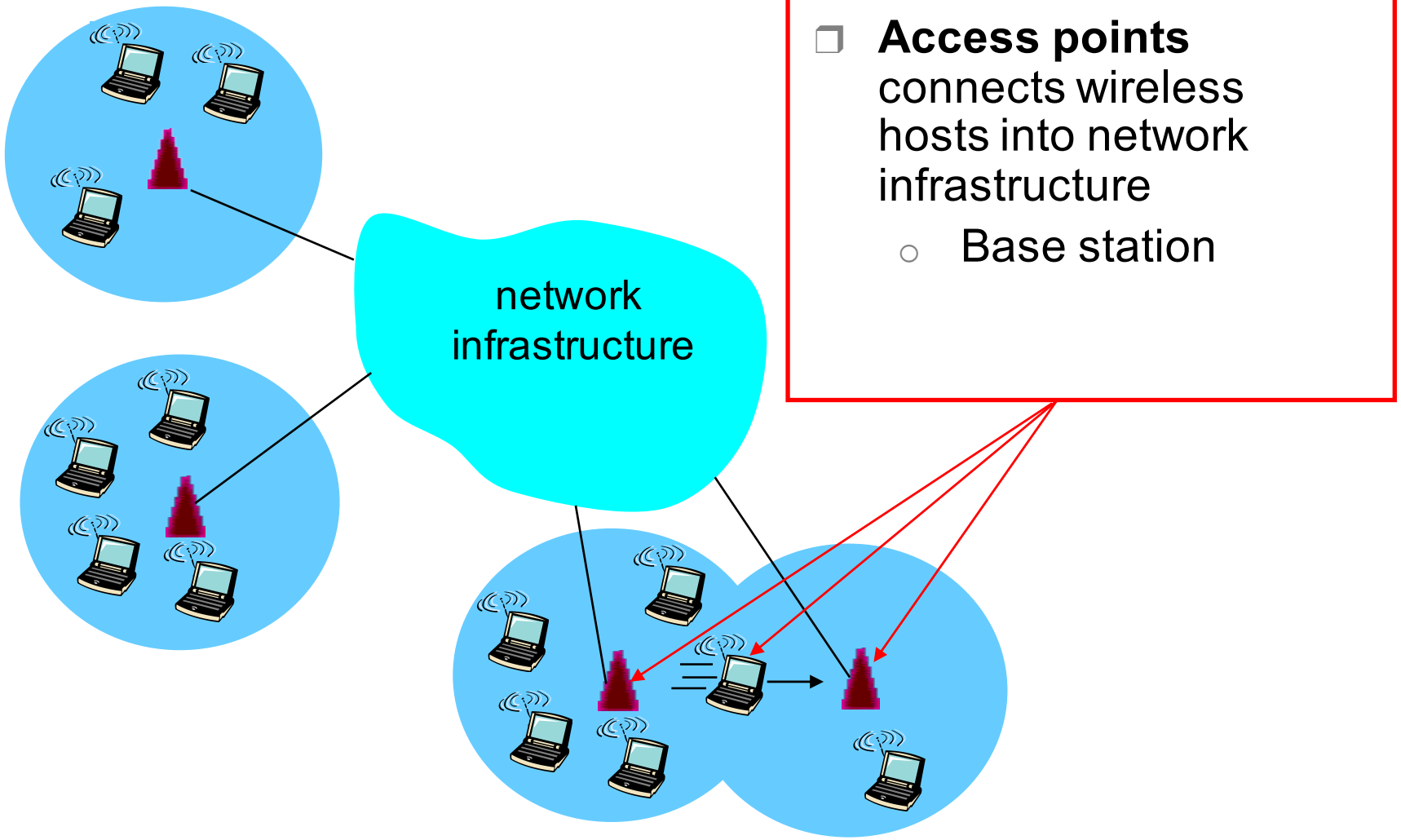
IEEE 802.11 Wireless LAN

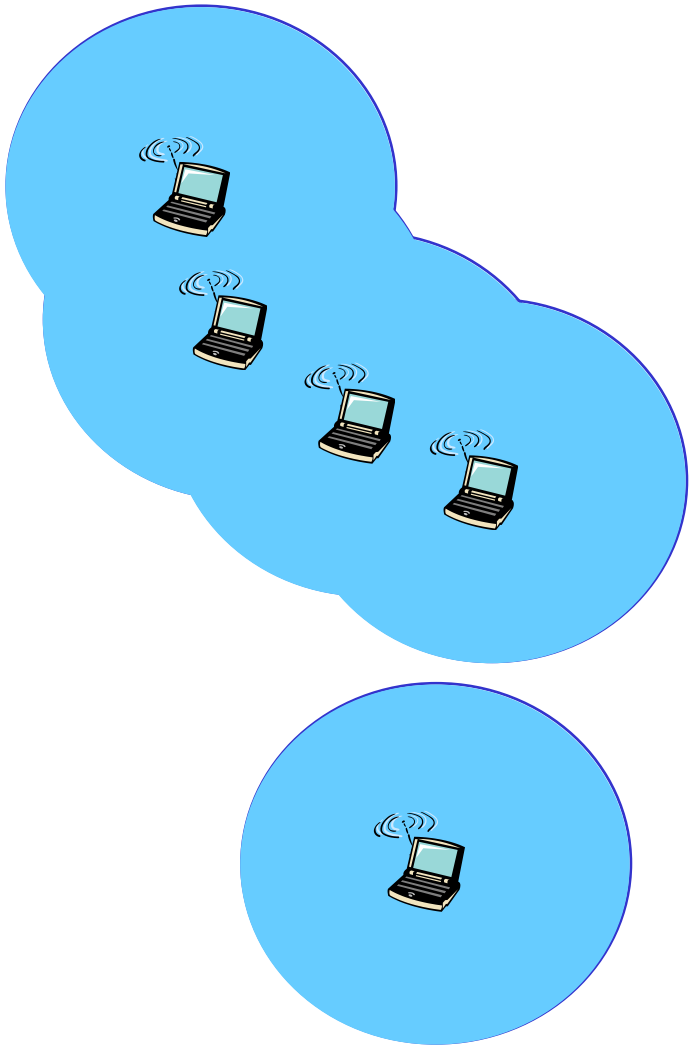
- Building block is a Basic Service Set (BSS)
- Group of wireless nodes
- Possibly with a Base Station
  - Access Point



Infrastructure Mode



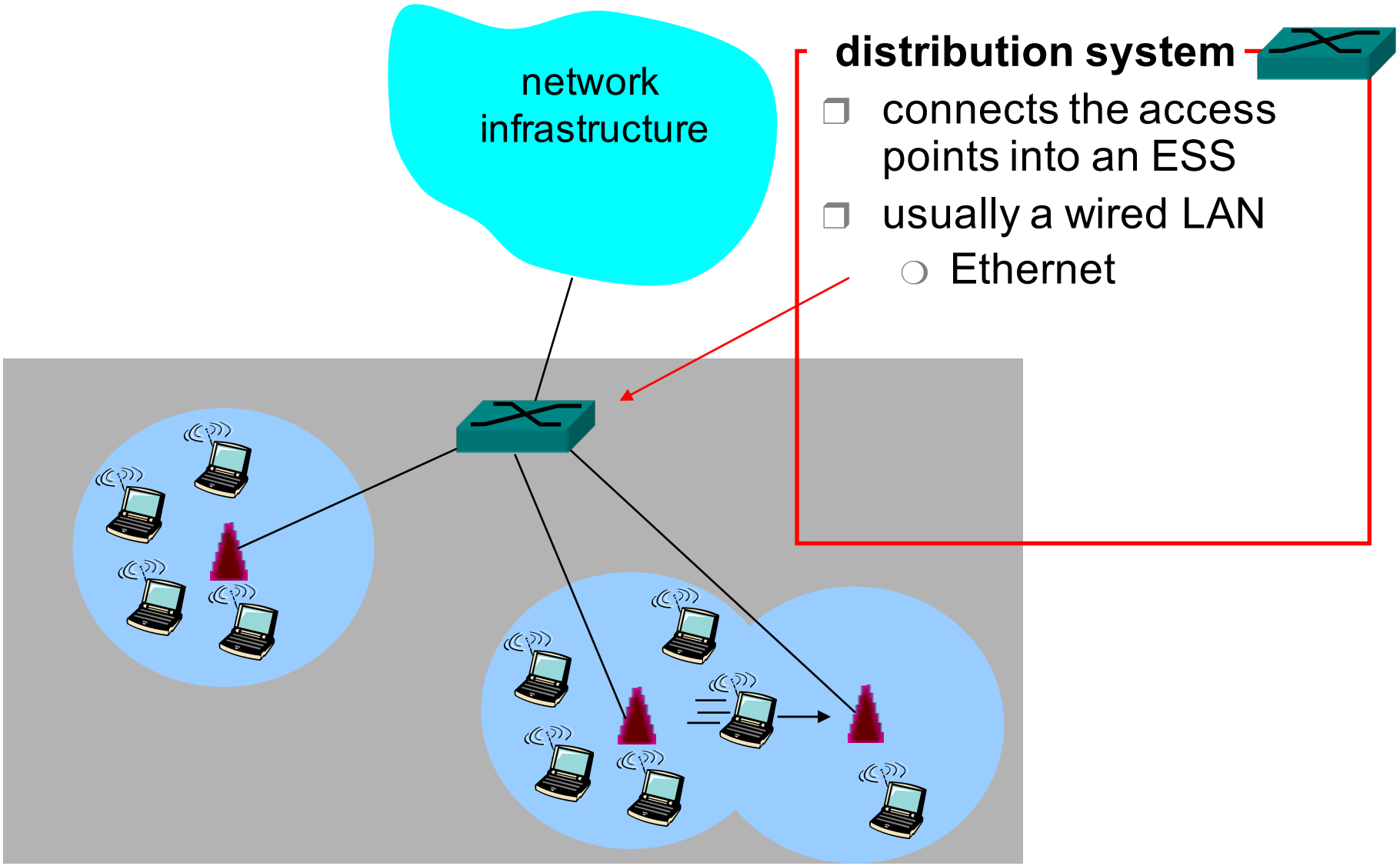
Ad Hoc Mode



ad hoc mode

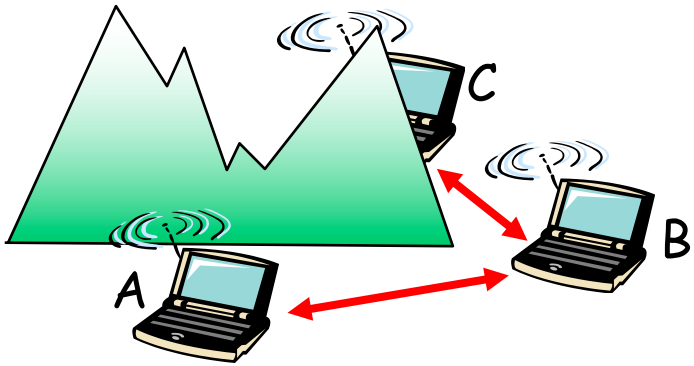
- no access points
- nodes can only transmit to other nodes within link coverage
- nodes **self-organize** themselves into a network: route among themselves

Extended Service Set



Wireless network characteristics

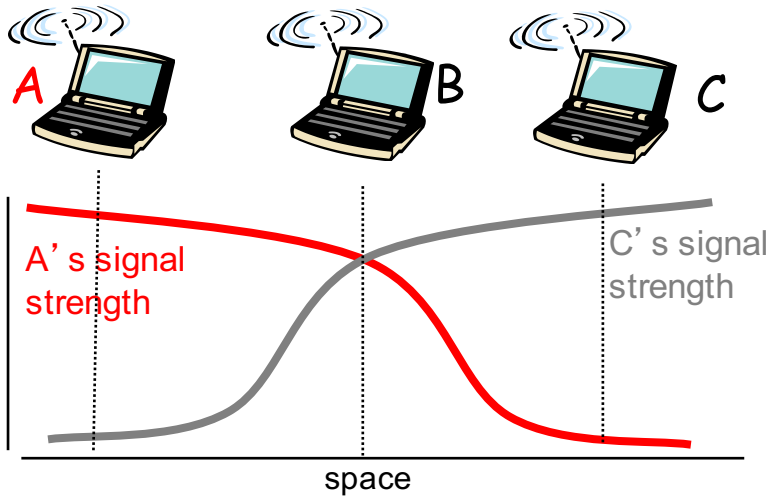
- Multiple wireless senders and receivers create additional problems (beyond multiple access):



Hidden terminal problem

- B, A hear each other
- B, C hear each other
- A, C cannot hear each other

means A, C unaware of their interference at B



Signal attenuation

- B, A hear each other
- B, C hear each other
- A, C cannot hear each other interfering at B

CSMA with Collision Avoidance

802.11 sender

1 if sense channel idle for **DIFS** then

transmit entire frame

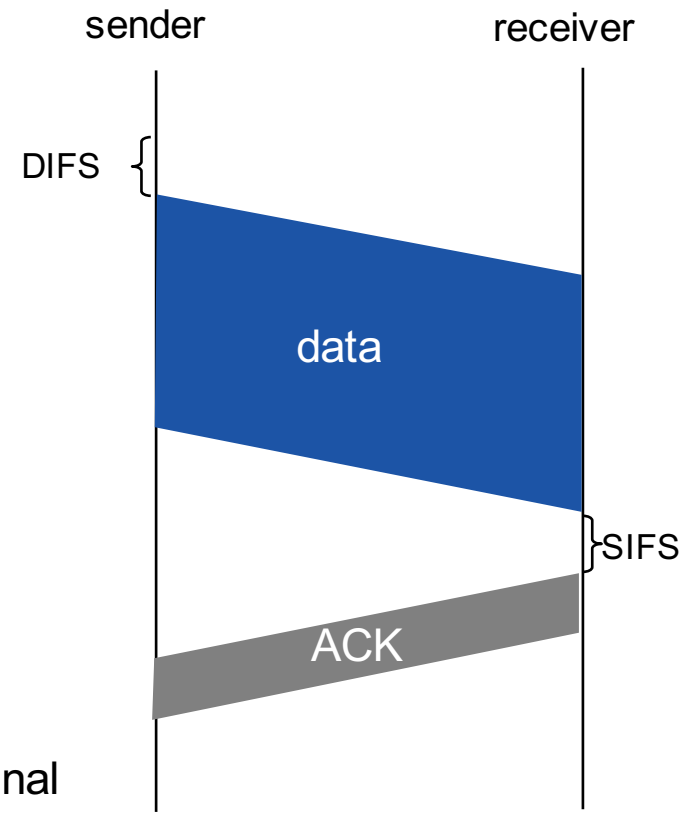
2 else

– start random backoff timer

–count down backoff timer *while channel is not busy*

– transmit entire frame when backoff timer expires

– if no ACK, increase random backoff interval, repeat 2



802.11 receiver

1 if frame received OK

return ACK after **SIFS** (ACK needed due to hidden terminal problem)

CSMA/CA timers

Short InterFrame Spacing (SIFS)

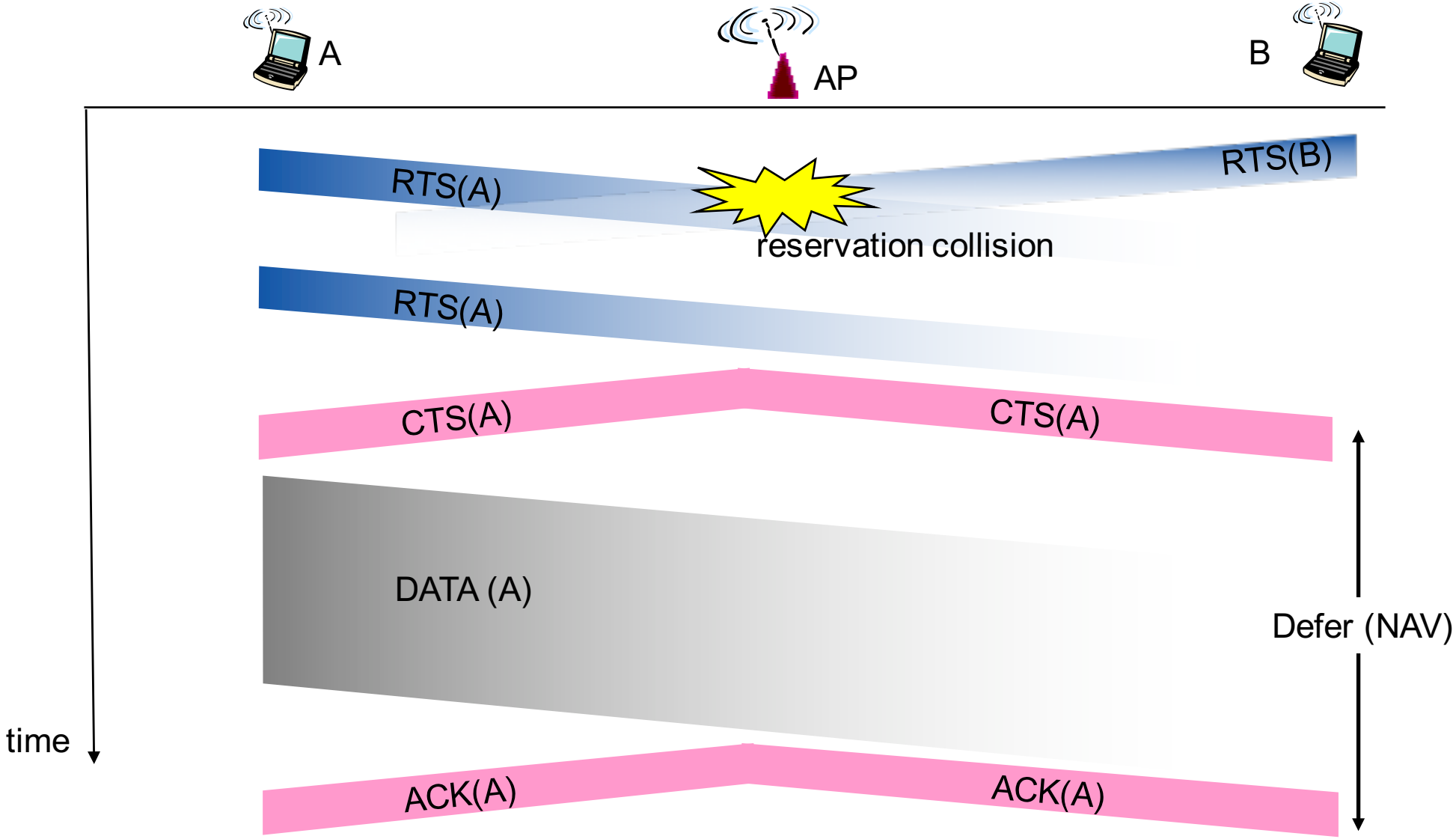
Distributed InterFrame Spacing (DIFS) *Larger than SIFS, to give ACK priority over data*

Avoiding Collisions (more)

- idea: allow sender to "reserve" channel: avoid collisions of long data frames
- sender first transmits small request-to-send (RTS) packets to receiver
- broadcasts clear-to-send CTS in response to RTS
- CTS heard by all nodes
  - sender transmits data frame
  - other stations defer transmissions
- Optional in CSMA/CA
  - More efficient for large frames: configurable RTS threshold

avoid data frame collisions completely using small reservation packets!

Collision Avoidance: RTS-CTS



Wireless LAN Standards

- 802.11a
  - 5-6 GHz range
  - up to 54 Mb/s
- 802.11b
  - 2.4-5 GHz unlicensed spectrum
  - up to 11 Mb/s
- 802.11g
  - 2.4-5 GHz range
  - up to 54 Mb/s
- 802.11n
  - multiple antennae
  - 2.4-5 GHz range
  - up to 200 Mb/s
- 802.11ac
  - 5 GHz range
  - up to 433 Mb/s (per stream)
- 802.11ad/h/j/x/y…

- all use CSMA/CA for multiple access
- all have base-station and ad-hoc network versions

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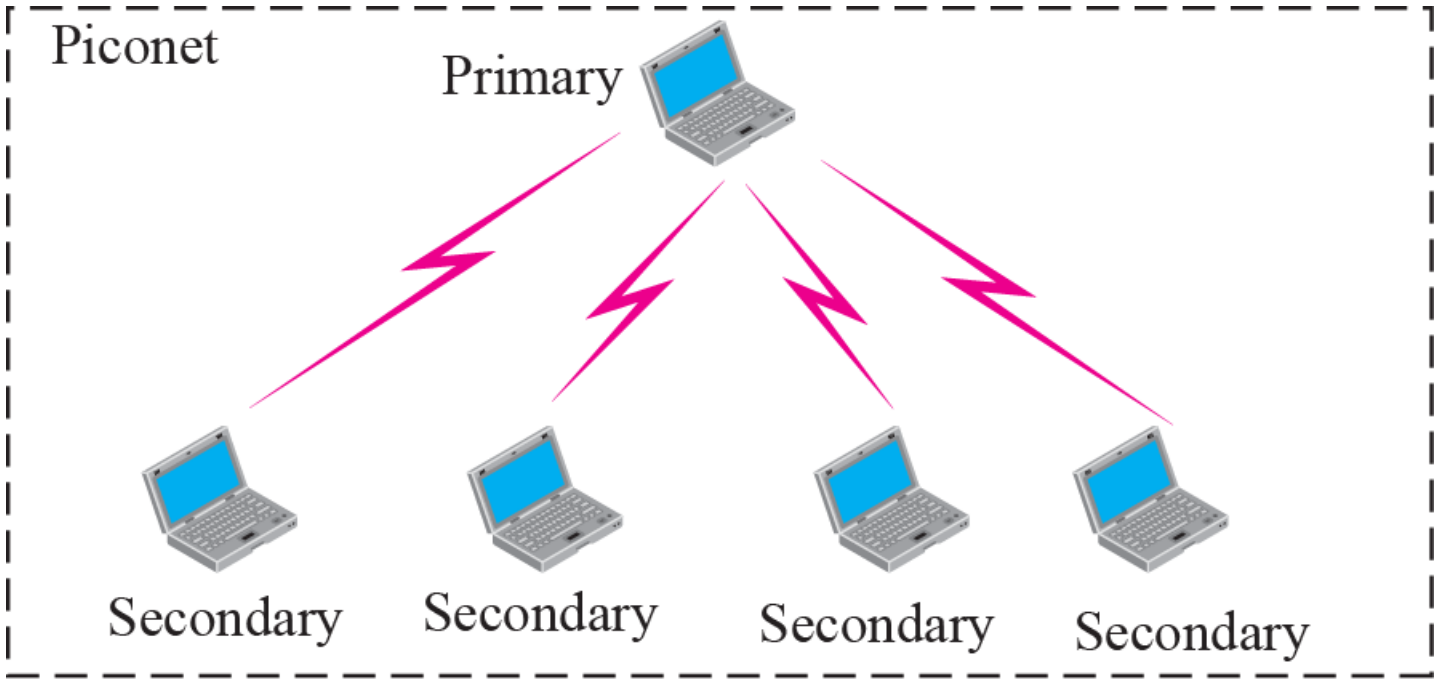
PAN – Personal Area Network

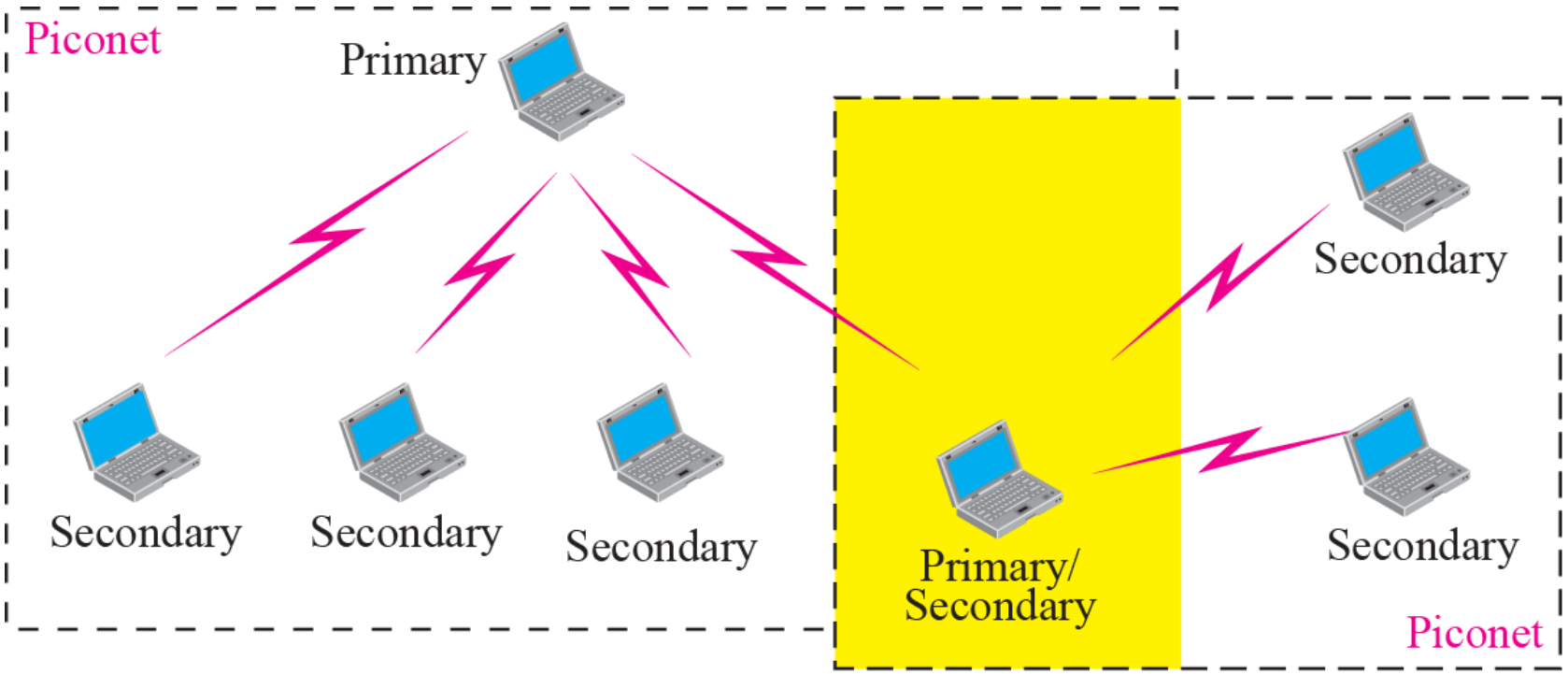
- Bluetooth, Zigbee, WPAN, BAN (Body Area Network), …
- IEEE Standardization in IEEE 802.15
- Short distance, lower rate

Bluetooth Piconet



Coordinated by Primary

Bluetooth Scatternet



One station is Primary in one piconet, Secondary in another

Summary

- Ethernet
  - CSMA/CD
  - 10 Mb/s – 100 Gb/s
  - Bridging
- Wireless LAN
  - BSS, ESS
  - AD hoc and infrastructure mode
  - CSMA/CA
- PAN
  - Bluetooth and other
  - Primary – secondary
  - Piconet, scatternet

Course Material

- Forouzan, Chapter 2
  - Parts about Data Link Layer
- Forouzan Chapter 3
  - Except for… (see next slide)

Not Covered

- Ethernet standards in more detail
  - Fast Ethernet, Gigabit Ethernet, Ten-Gigabit Ethernet
- Wireless LAN
  - frame format
  - Addressing
- Point-to-point WANs
- Switched WANs
- Hubs and routers