南京大学 软件学院
NANJING UNIVERSITY · SOFTWARE INSTITUTE

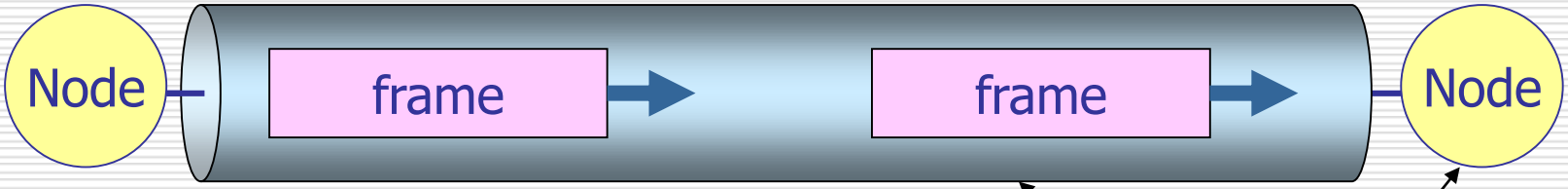
Data Link Layer

Layer2: Data Link Layer

- Overview of the Data Link Layer
- Ethernet and CSMA/CD
  - LLC and MAC Sub-layers
  - Media Access Control in MAC Sub-layer
- Wireless LAN and CSMA/CA
- Layer 2 Devices

Data Link Layer

- Problem:How to transfer data correctly on a instable link?



- The DATA LINK LAYER provides:
  - Access to the networking media
  - Physical transmission across the media
- Layer 2 protocols (procedures) define:
  - The format of data exchanged on a link
  - The action of the two nodes on the link
- In Data Link Layer, 'procedure' = 'protocol'

Node : Host and router in the network

Link : The channel connects the adjacent nodes

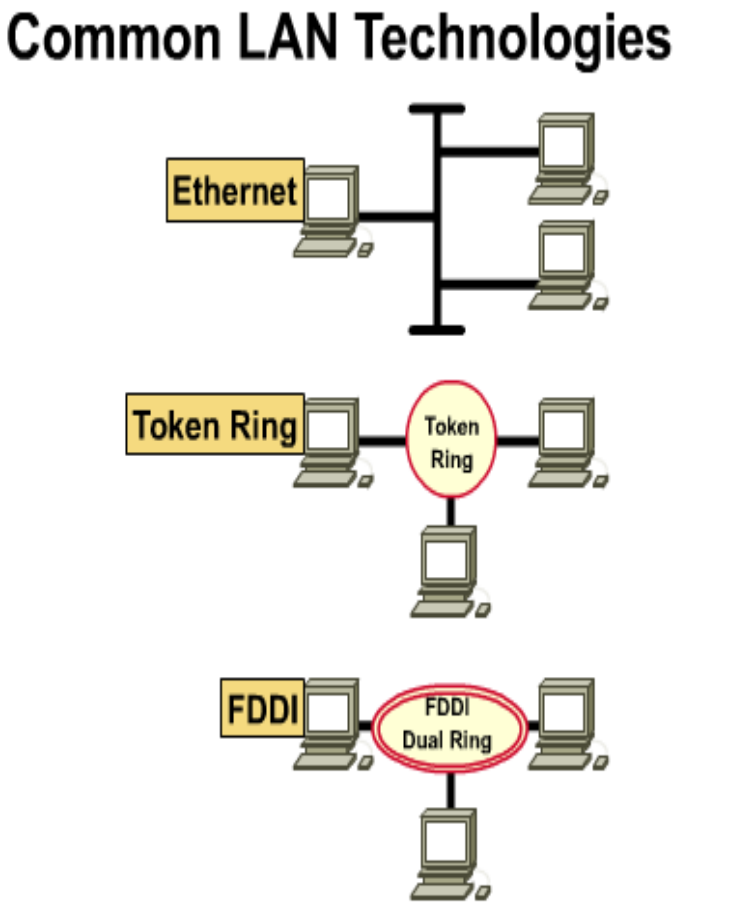
LANS and the Data Link Layer

- Main tasks:
  - Error notification
  - Network topology
  - Flow control
- Differences between Layer 1 and Layer 2:
  - Layer 1 cannot communicate with the upper-level layers; Layer 2 does that with *Logical Link Control* (*LLC*).
  - Layer 1 cannot decide which host will transmit or receive binary data from a group;
    Layer 2 does that with *Media Access Control* (*MAC*)
  - Layer 1 cannot name or identify computers;
    Layer 2 uses an *addressing* (or naming) process.
  - Layer 1 can only describe streams of bits;
    Layer 2 uses *framing* to organize or group the bits.

Services provided by Layer 2

- Three services provided to the network layer (by LLC)
  - Connectionless service with no acknowledgement, used on:
    - Reliable links (upper layers to ensure the data correctness)
    - Real-time tasks
    - Most of LANs
  - Connectionless service with acknowledgements: unreliable link, such as the wireless network
  - Connection service with acknowledgements

Media Access Control in Common LANs



- *Ethernet* - logical bus topology (information flow is on a linear bus) and physical star or extended star (wired as a star)
- *Token Ring* - logical ring topology (information flow is in a ring) and a physical star topology (wired as a star)
- *FDDI* - logical ring topology (information flow is in a ring) and physical dual-ring topology (wired as a dual-ring)

Access Methods for Media-Access Control

- Two broad categories:
  - *Deterministic*—taking turns
    - Token Ring and FDDI
  - *Non-deterministic (probabilistic)*—first come, first served
    - Ethernet/802.3

Deterministic MAC Protocols

- A special data token circulates the ring.
- When a host receives the token, it can transmit data instead of the token. This is called *seizing the token*.
- When the transmitted frame comes back around to the transmitter, the station transmits a new token; the frame is removed or *stripped* from the ring.

Non-Deterministic MAC Protocols

- This MAC protocol is called ***Carrier Sense Multiple Access with Collision Detection (CSMA/CD)***

- To use this shared-medium technology, Ethernet allows the networking devices to arbitrate for the right to transmit.

LAN Transmission Methods

LAN data transmissions fall into 3 classifications:

- **unicast**--a single packet is sent from the source to a single destination on a network
- **multicast--**consists of a single data packet that is sent to a specific subset of nodes on the network.
- **broadcast--**consists of a single data packet that is transmitted to all nodes on the network.

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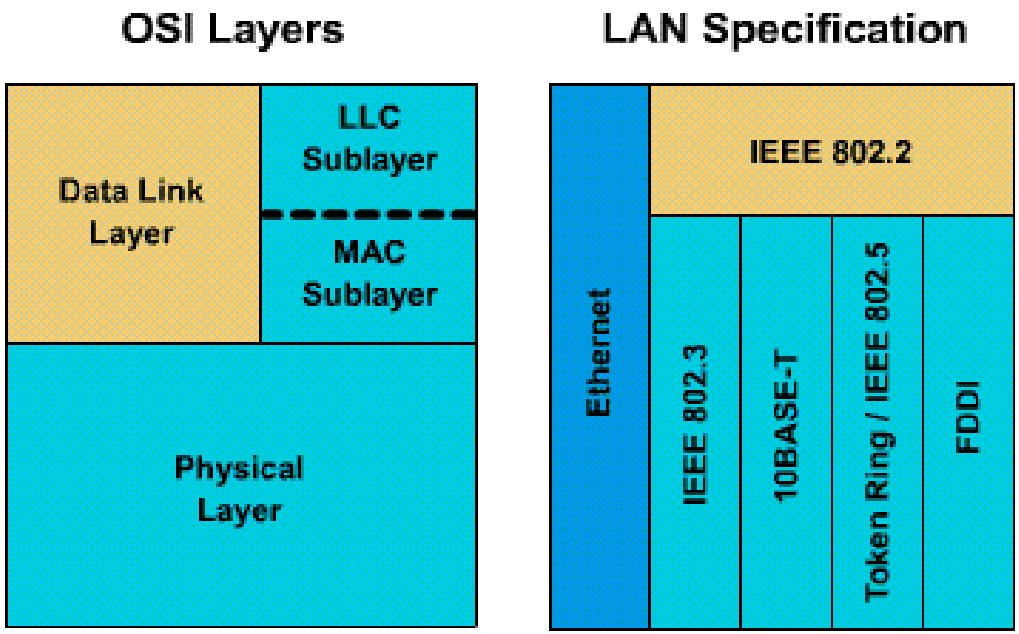
LAN Standards

- Define the physical media and the connectors used to connect devices to media
- Define the way devices communicate at the DATA LINK LAYER
- The DATA LINK LAYER defines how data is transported over a physical media.
- The DATA LINK LAYER also defines how to *encapsulate* protocol-specific traffic in such a way that traffic going to different upper-layer protocols can use the same *channel* as it goes up the stack.

LAN Standards

Compare and Contrast OSI Layers 1 and 2



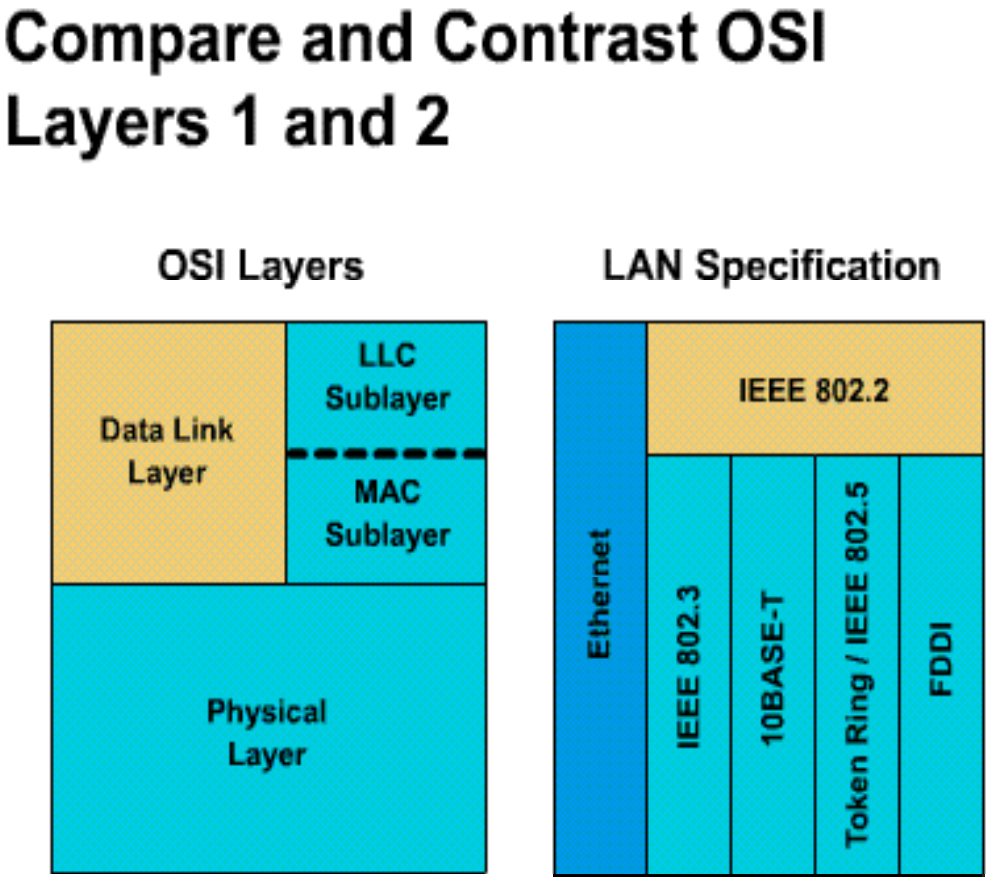
- Data link layer is broken into two parts by **IEEE** :
  - **Media Access Control *(MAC)*** (transitions down to media)
  - **Logical Link Control *(LLC)*** (transitions up to the network layer)

LAN Standards

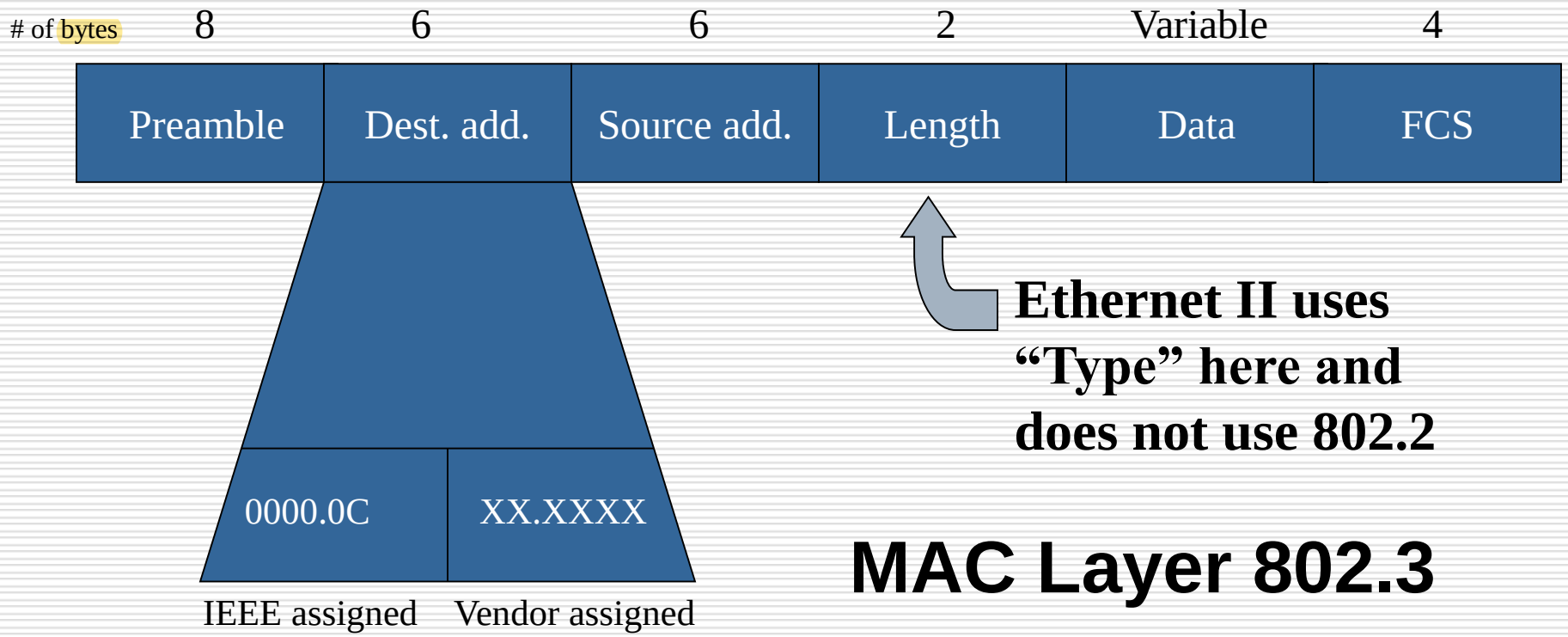
- The IEEE standard appears, at first glance, to violate the OSI model in two ways.
  - First, it defines its own layer (LLC), including its interfaces, etc.
  - Second, it appears that the MAC layer standards, 802.3 and 802.5, cross over the Layer 2/Layer 1 interface.
- However, 802.3 and 802.5 define the naming, framing, and Media Access Control rules around which specific technologies were built.

LAN Standards

- **MAC** sublayer (802.3)
  - Defines how to transmit frames on the physical wire
  - Handles physical addressing
  - Define network topology
  - Define line discipline.
- **LLC** sublayer (802.2)
  - logically identifies different protocol types and then encapsulates them.
  - Use SAP identifier to perform the logical identification
  - The type of LLC frame depends on what identifier the upper layer protocol expects.

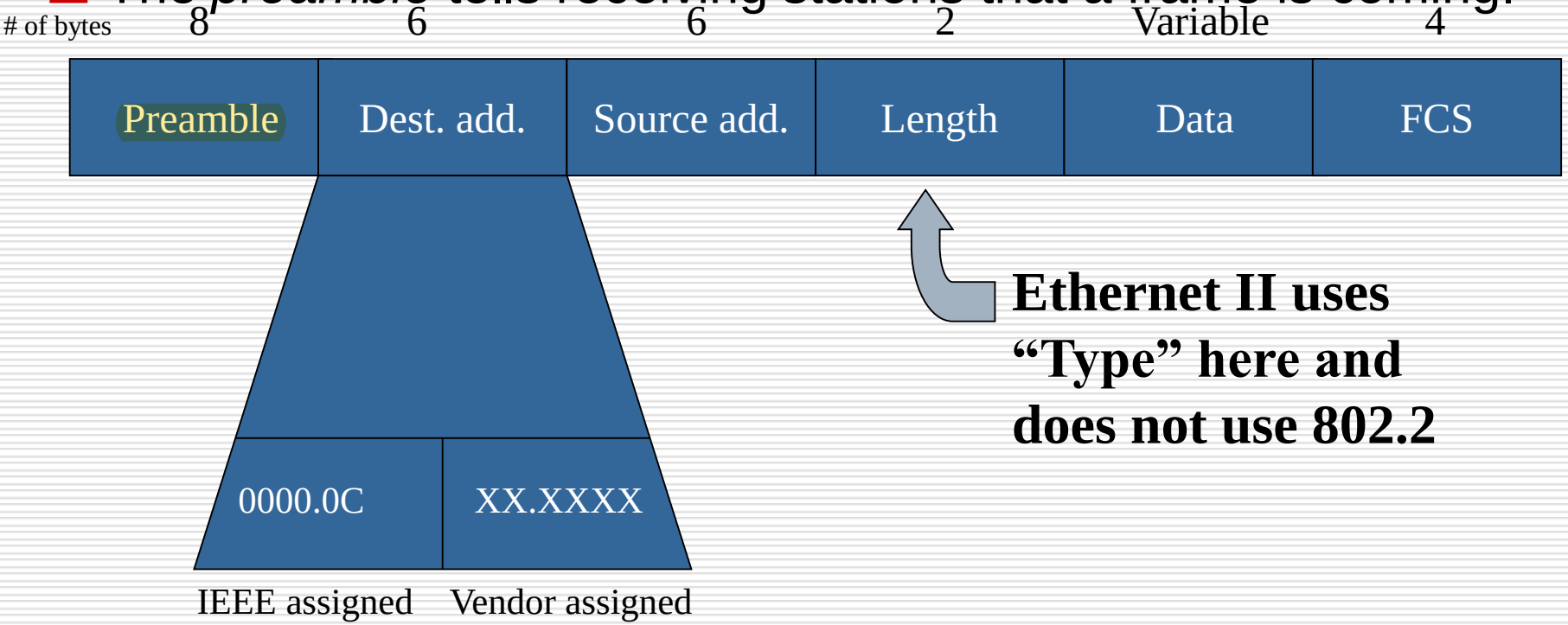


Media Access Control Sublayer



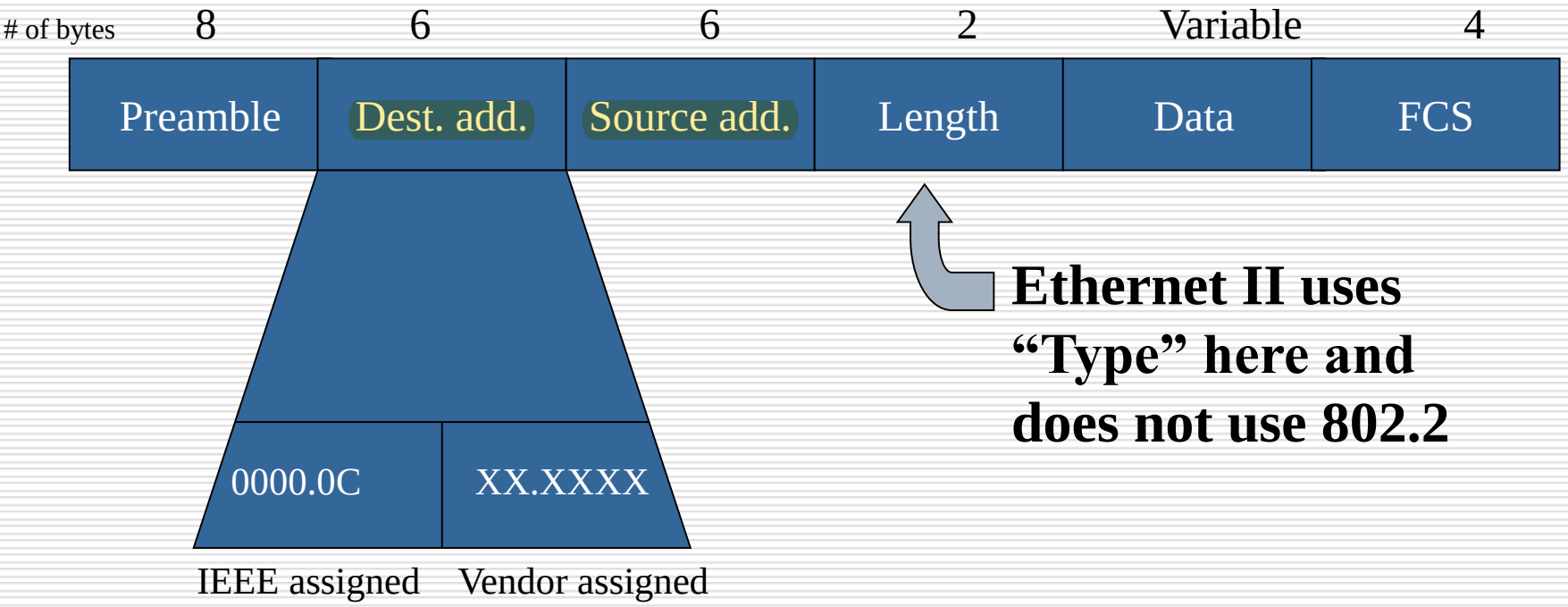
MAC Sub-layer: Fields in a Frame

- Begin with an alternating pattern of 1s and 0s called a *preamble*. (10101011)
- The *preamble* tells receiving stations that a frame is coming.



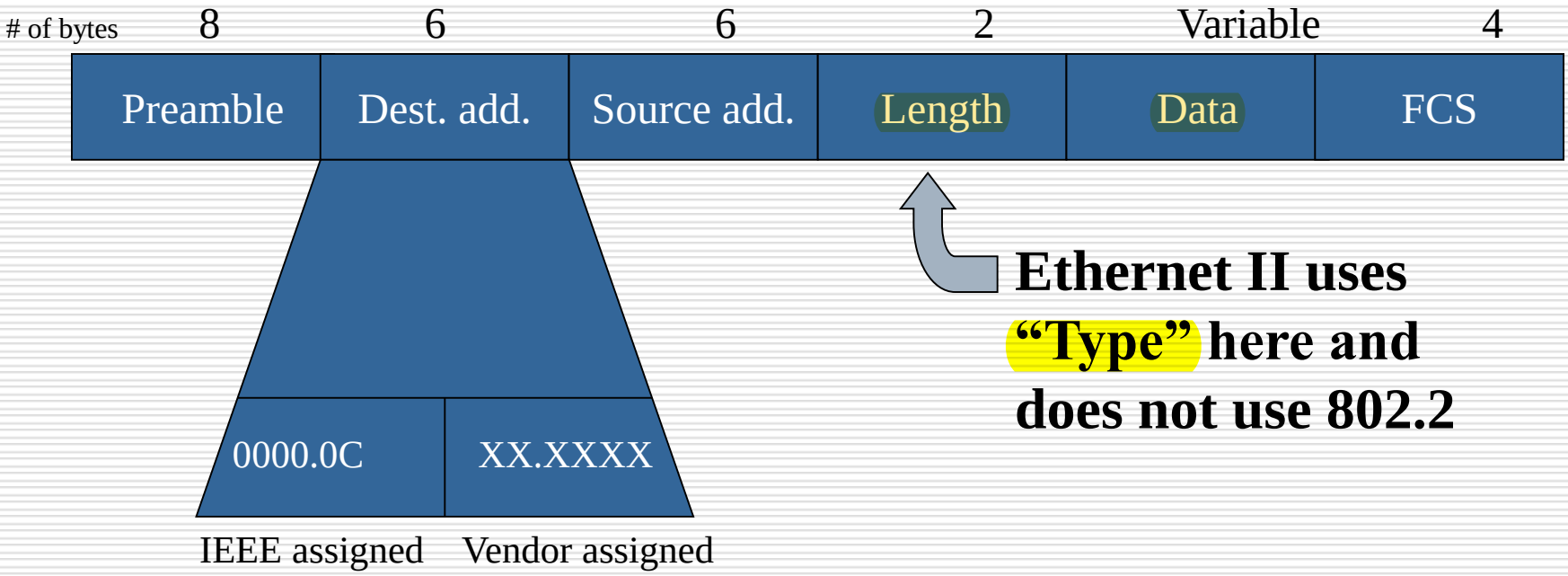
MAC Sub-layer: Fields in a Frame

- *Destination* and *source* physical address fields
  - *source address:* always a unicast address
  - destination address: unicast, multicast, or broadcast.



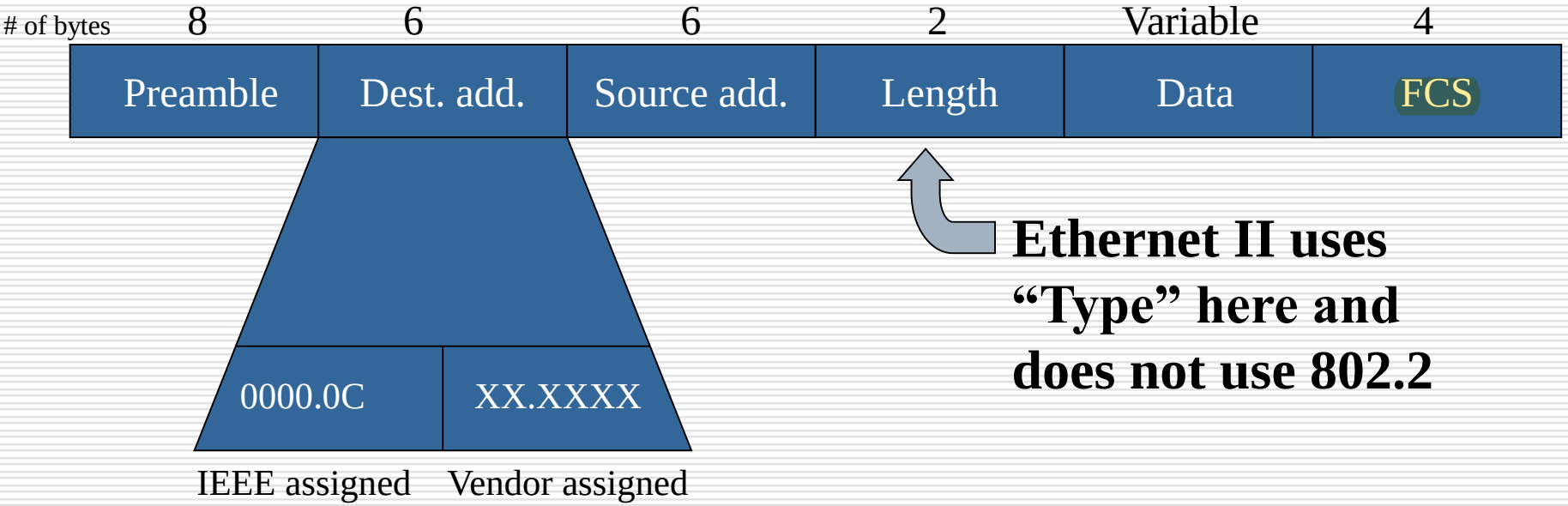
MAC Sub-layer: Fields in a Frame

- *length* field indicates the number of bytes of data that follow this field and precede the frame check sequence field.
- The *data* field contains the information you want to send.



MAC Sub-layer: Fields in a Frame

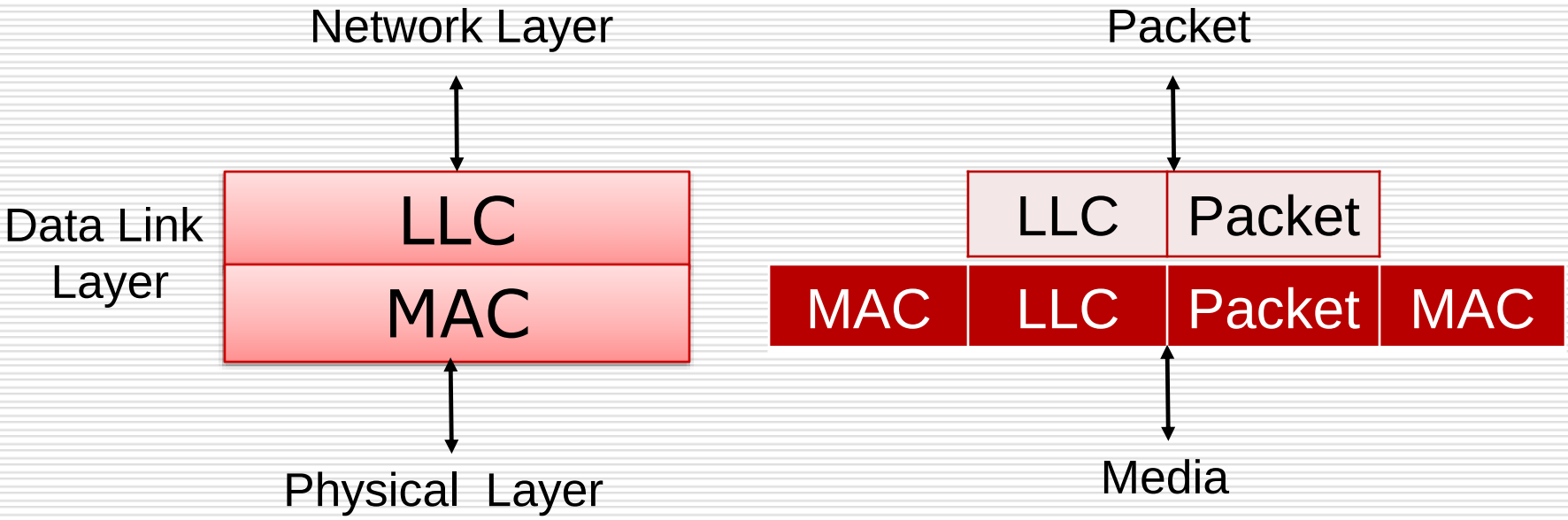
- FCS field (four bytes) contains a cyclic redundancy check value
  - The sending device creates the CRC
  - The receiving device recalculates the CRC to check for damage that might have occurred to the frame in transit.



Logical Link Control Sublayer

- The Logical Link Control (LLC) sublayer manages communication between devices over a single link
- LLC is defined in the IEEE 802.2 specification and supports both *connectionless* and *connect-oriented* services.
- LLC sublayer allows part of the DATA LINK LAYER to function independently from existing technologies.
  - A single LLC sub-layer can be compatible with different MAC sub-layers.

LLC Sub-layer: Encapsulation



(a) Position of LLC

(b) Encapsulation

LLC Sub-layer: Encapsulation

- The LLC takes the network protocol data (packet), and adds more control information to help deliver the packet to its destination.
- It adds two addressing components of the 802.2 specification to identify the upper layer protocol at each end :
  - The Destination Service Access Point (DSAP)
  - The Source Service Access Point (SSAP)
- This repackaged data then travels to the MAC for further encapsulation of the data.

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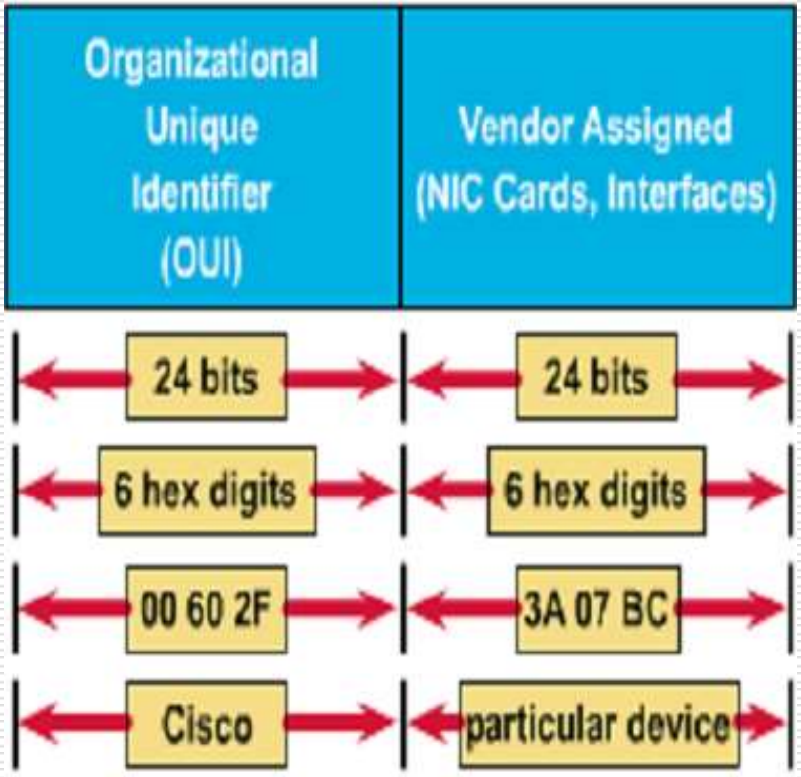
Hexadecimal Numbers as MAC Addresses

- MAC addresses are 48 bits and are always expressed as 12 hexadecimal digits.
- The first 6 hexadecimal digits (from left to right), which the IEEE administers, identify the **manufacturer** or **vendor** and comprise the *Organizational Unique Identifier* (OUI).
- The remaining 6 hex digits comprise the interface serial number, administered by specific vendor.

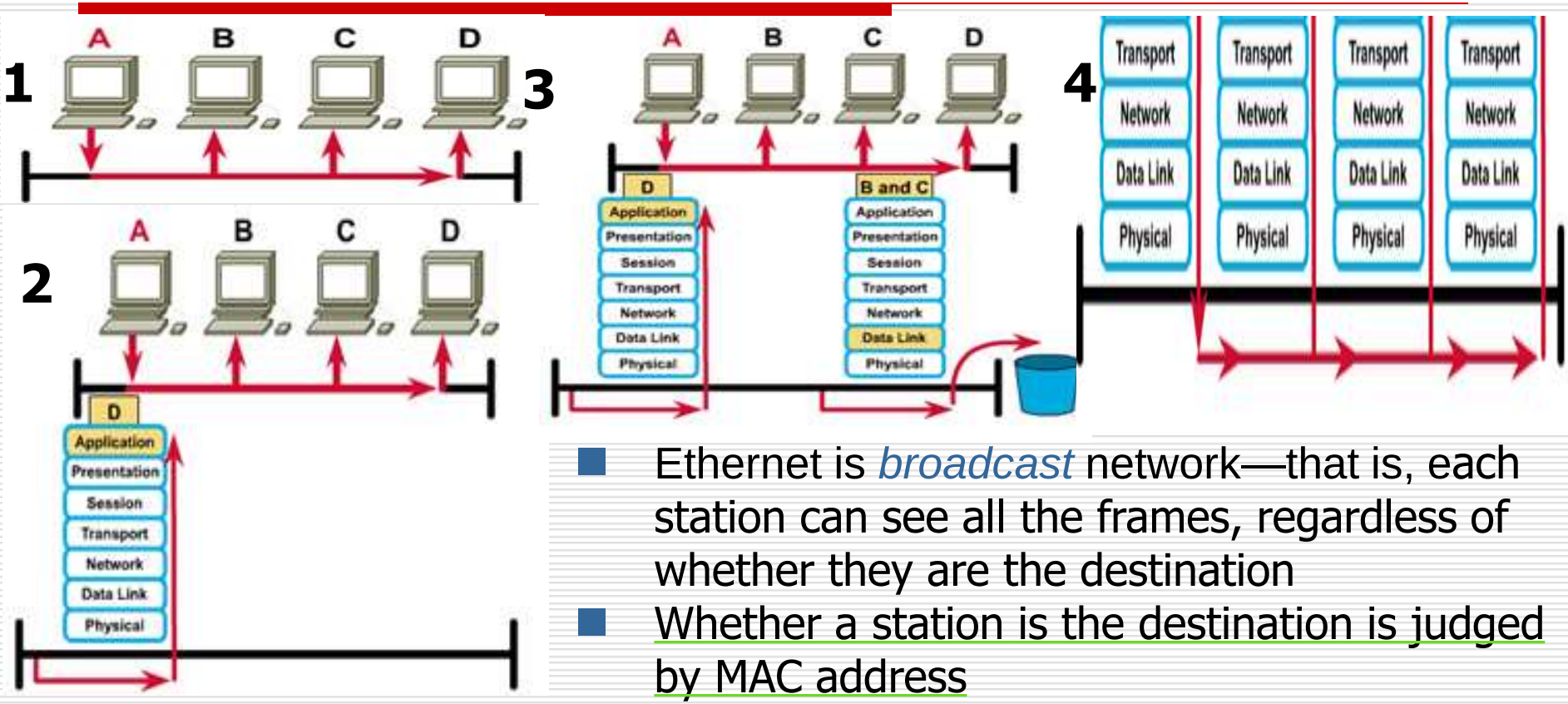


0000.0c12.3456 or 00-00-0c-12-34-56

Ethernet 802.3 Broadcast

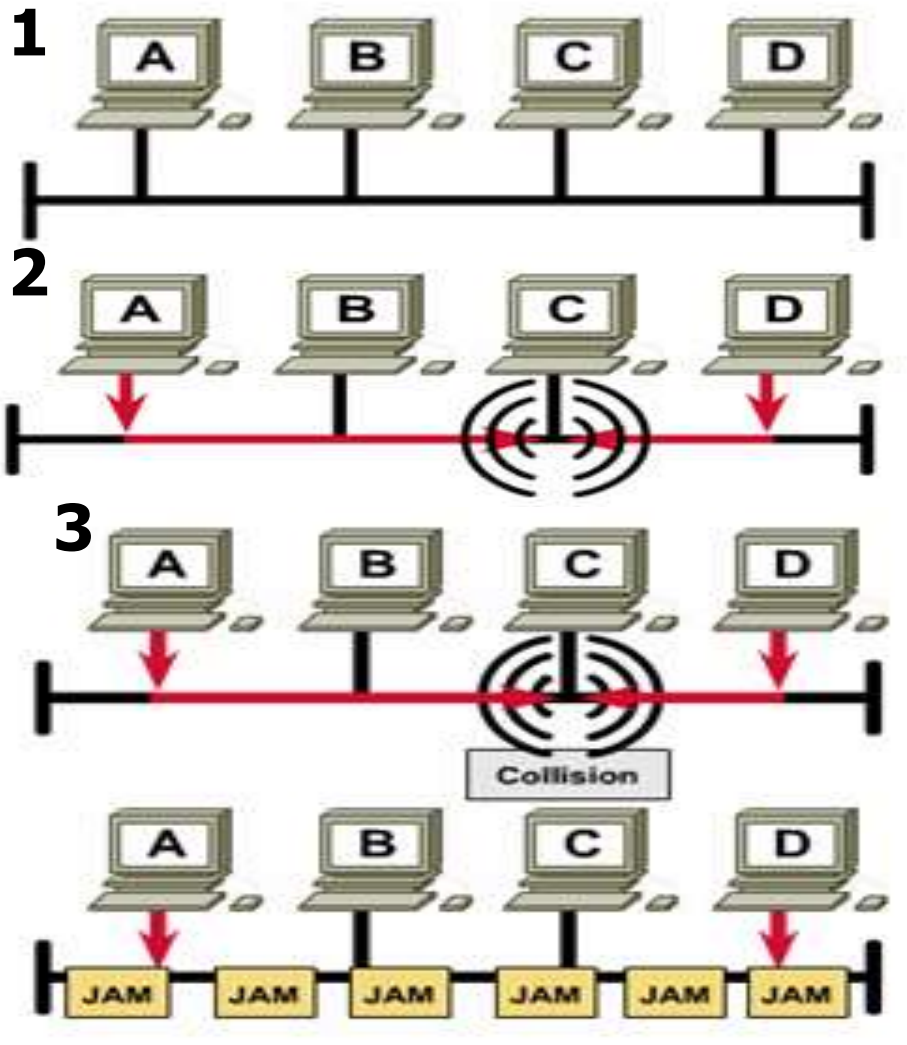
- Broadcast
  - The destination MAC: all 1s (FFFF.FFFF.FFFF)
- Broadcasting can seriously affect the performance of stations by interrupting them unnecessarily
- So broadcasts should be used only when:
  - The MAC address of the destination is unknown
  - The destination is all hosts

Ethernet Operation

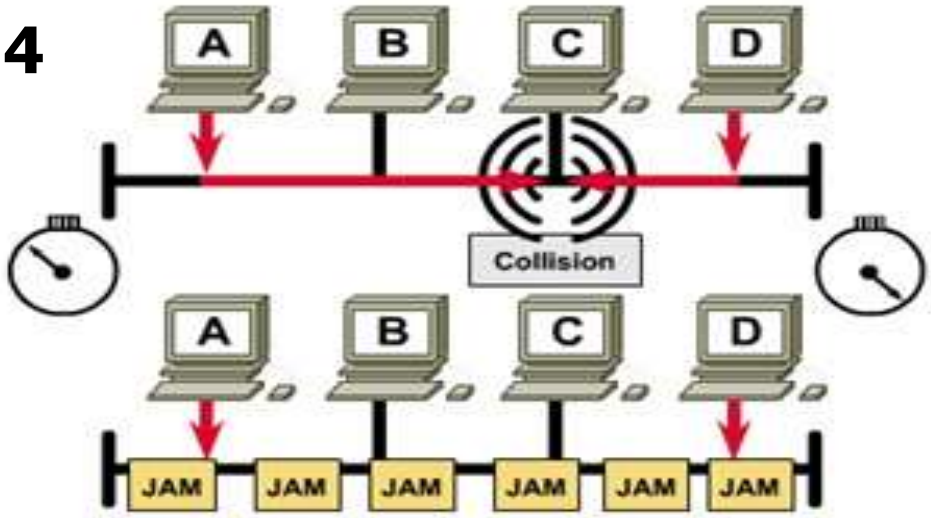


- Ethernet is *broadcast* network—that is, each station can see all the frames, regardless of whether they are the destination
- Whether a station is the destination is judged by MAC address
- Destination station sends data up OSI layers. Other nodes discard frame

Ethernet Operation

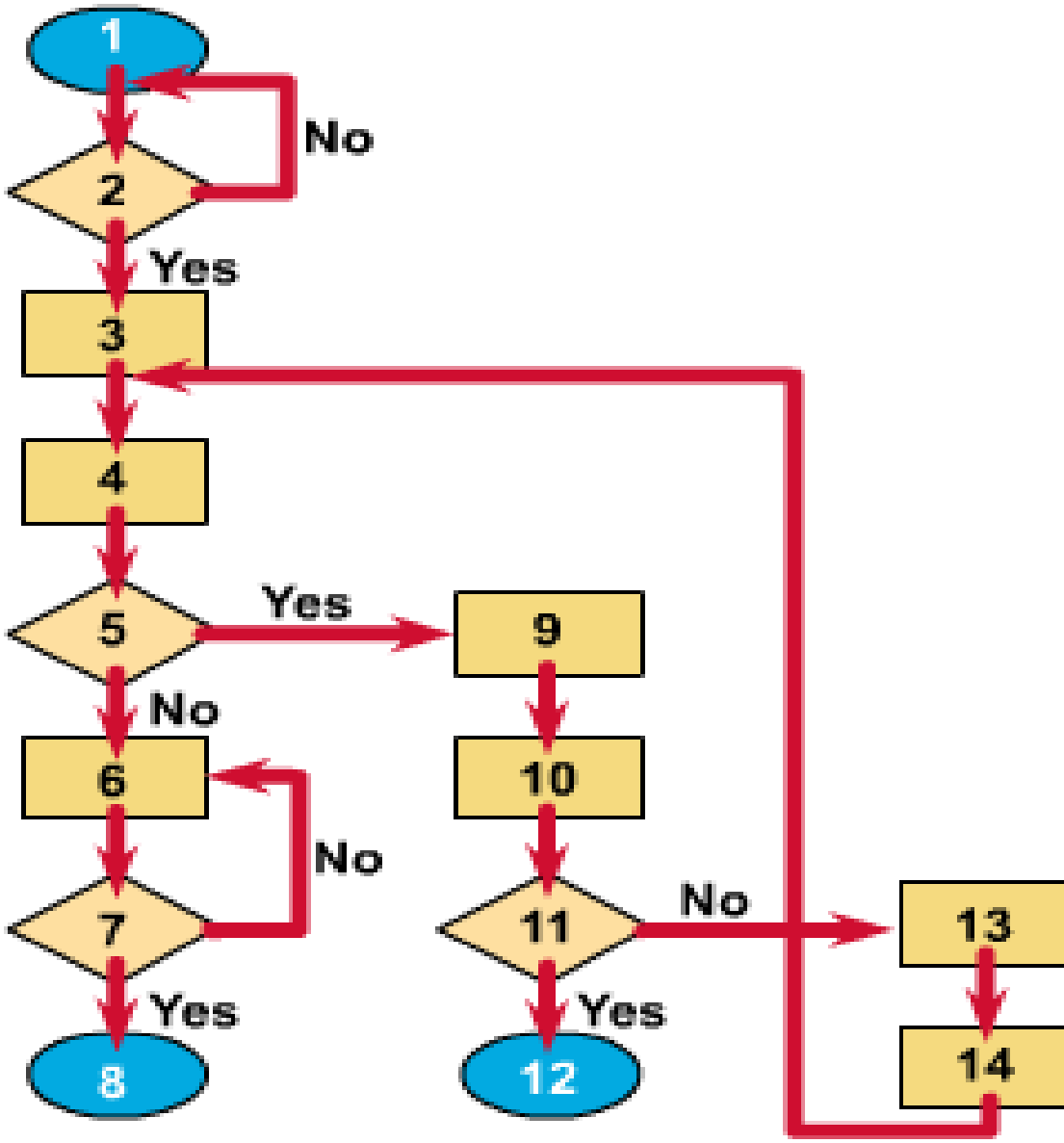


1. Listen then transmit
2. Broadcast jam signal
3. Collision occurs
4. Devices back off appropriate amount of time and then retransmit



Ethernet CSMA / CD

1. Host wants to transmit
2. Is carrier sensed?
3. Assemble frame
4. Start transmitting
5. Is a collision detected?
6. Keep transmitting
7. Is the transmission done?
8. Transmission completed
9. Broadcast jam signal
10. attempts = attempts + 1
11. attempts > too many?
12. Too many collisions; abort transmission
13. Algorithm calculates backoff
14. Wait for t seconds



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Wireless LAN

- Wireless LAN
  - Communications based on cells
  - The signals sent by a station can only be received by the stations nearby
  - Short-distance transmission
- Wireless LAN Standard
  - IEEE 802.11
  - IEEE 802.11b
  - IEEE 802.11a
  - IEEE 802.11g
  - IEEE 802.11n

Wireless LAN Standard

- IEEE 802.11
  - A key technology: Direct Sequence Spread Spectrum (DSSS)
  - DSSS applies to wireless devices operating within a 1 to 2 Mbps range.
  - DSSS may operate at up to 11 Mbps but will not be considered compliant above 2 Mbps
  - Also called Wi-Fi™
- IEEE 802.11b
  - It increased transmission capabilities to 11 Mbps
  - All 802.11b systems are backward compliant in that they also support 802.11 for 1 and 2 Mbps data rates for DSSS only
  - Achieves higher data throughput rate by using a different coding technique from 802.11
  - Operate within 2.4 GHz

Wireless LAN Standard

- IEEE 802.11a
  - Covers WLAN devices operating in the 5 GHz transmission band.
  - Using the 5 GHz
  - 802.11a is capable of supplying data throughput of 54 Mbps and with proprietary technology known as "rate doubling" has achieved 108 Mbps.
  - In practice, a more standard rating is 20-26 Mbps.

Wireless LAN Standard

- IEEE 802.11g
  - provides the same throughout as 802.11a (54Mbps) but with backwards compatibility for 802.11b
  - using Orthogonal Frequency Division Multiplexing (OFDM) technology.
- IEEE 802.11n: next generation WLAN
  - provide double bandwidth than 802.11g, that is, 108Mbps, and theoretically up to 500-600Mbps

Wireless LAN Topology

- **Infrastructure mode** and **ad-hoc mode**

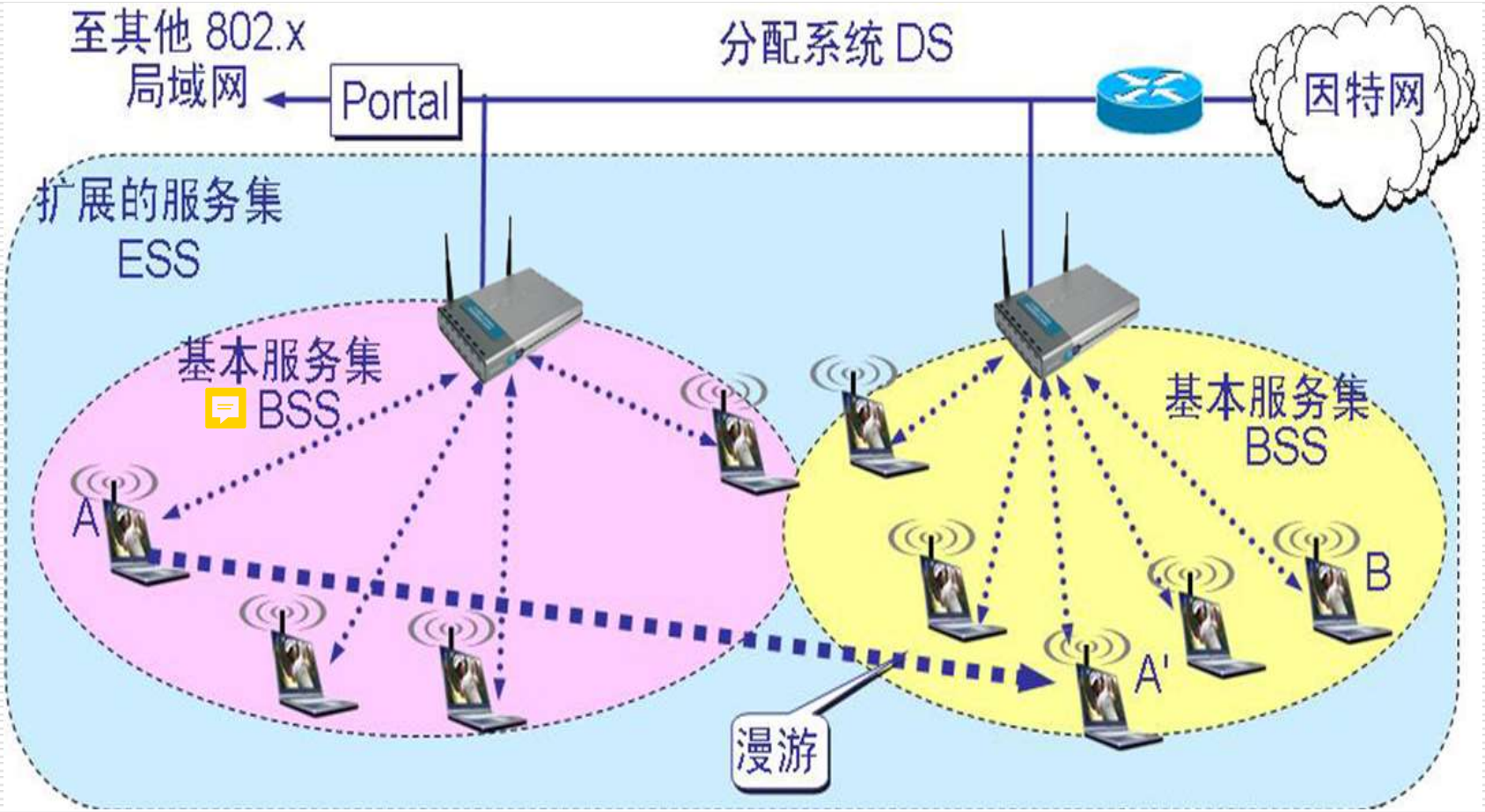


Fig. Infrastructure Mode

Wireless LAN: Infrastructure Mode

- A Basic Service Set(BSS) includes a Base Station(BS) and several wireless hosts
  - All hosts can communicate with each other directly in local BSS
- Access Point (AP) acts as a Base Station(BS) for infrastructure mode
  - AP is hard wired to the cabled LAN to provide Internet access and connectivity to the wired network
  - When an AP is installed, a Service Set Identifier(SSID) and a channel are assigned
  - The range of the cell will be from 91.44 to 152.4 meters (300 to 500 feet)
- A BSS can connect to another BSS via a Distribution System(DS), and constructs an Extended Service Set (ESS)

Accessing Procedure

- When a client is activated within the WLAN
  - it will start "listening" for a compatible device with which to "associate“
- This is referred to as "scanning"
  - Active scanning
  - Passive scanning

Active scanning

- Cause a probe request to be sent from the wireless node seeking to join the network.
- The probe request will contain the Service Set Identifier (SSID) of the network it wishes to join
- When an AP with the same SSID is found, the AP will issue a probe response
- The authentication and association steps are completed.

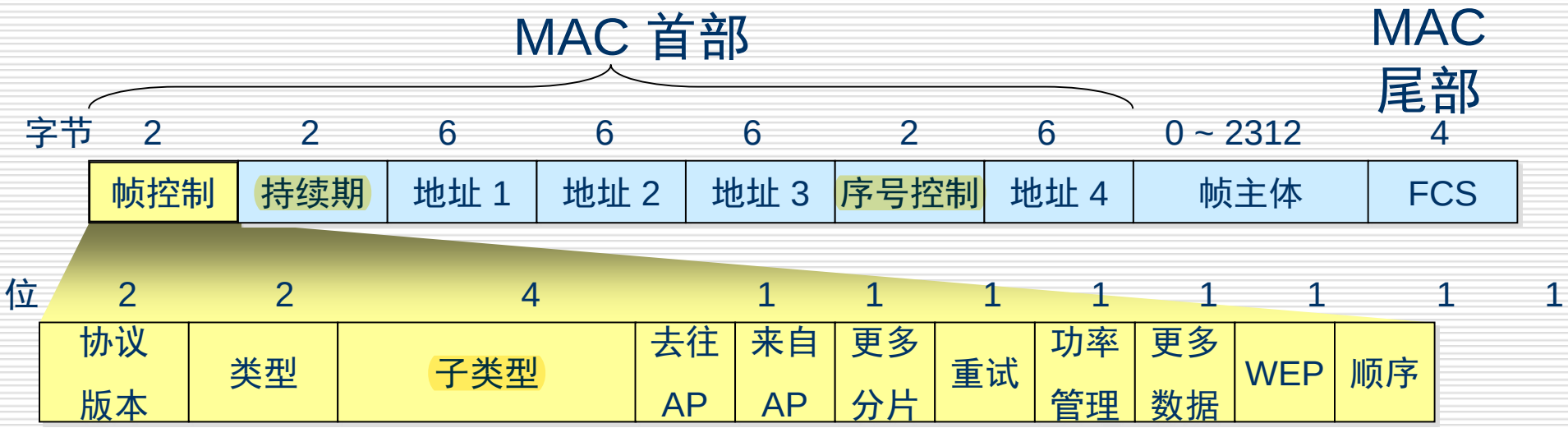
Passive scanning

- Listen for beacon management frames (beacons), which are transmitted by the AP (infrastructure mode) or peer nodes (ad hoc)
- When a node receives a beacon that contains the SSID of the network it is trying to join, an attempt is made to join the network.
- Passive scanning is a continuous process and nodes may associate or disassociate with APs as signal strength changes.

Frames in WLAN

- WLANs do not use a standard 802.3 frame.
- There are three types of frames
  - Control Frames
  - Management frames
  - Data frames(Only data frames are similar to 802.3 frames)
- The payload of wireless data frames and 802.3 frames is 1500 bytes
  - However, an Ether frame may not exceed 1518 bytes whereas a wireless frame could be as large as 2346 bytes.
  - Usually the WLAN frame size will be limited to 1518 bytes as it is most commonly connected to a wired Ethernet network.

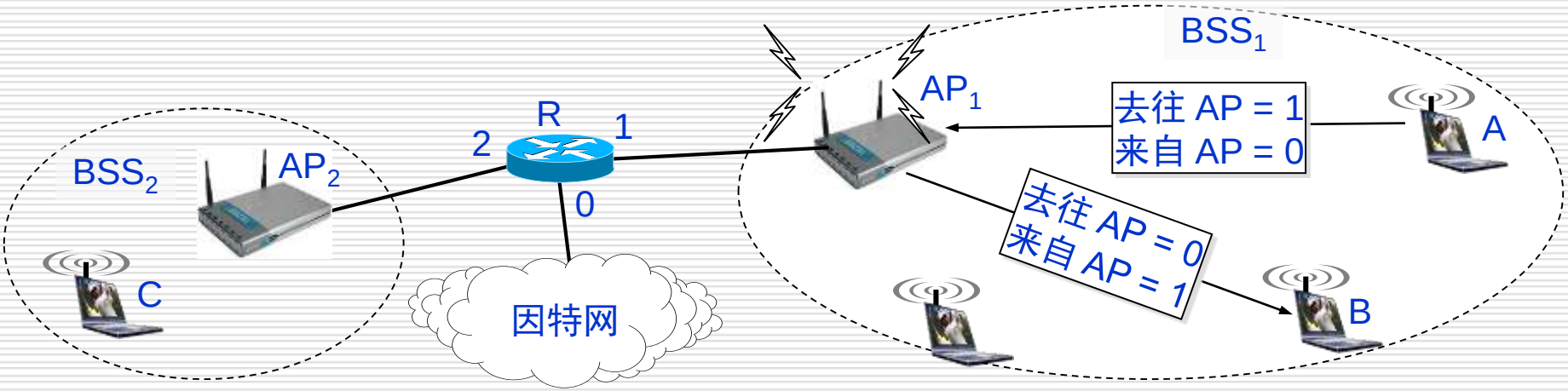
Data Frames in 802.11 WLAN



Addresses in 802.11 Data Frames

802.11 数据帧有四个地址字段。地址 4 用于自组网络

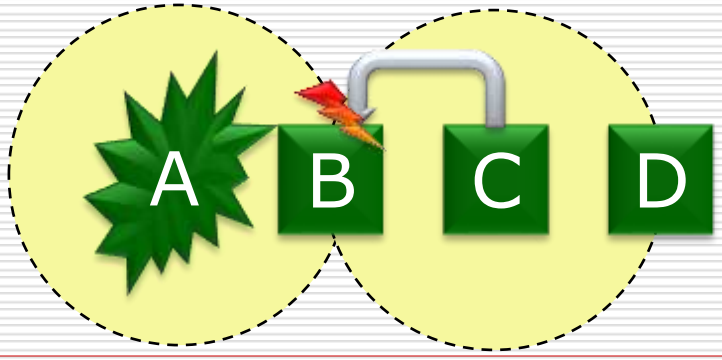
去往 AP	来自 AP	地址 1	地址 2	地址 3	地址 4
0	1	目的地址	AP 地址	源地址	——
1	0	AP 地址	源地址	目的地址	——

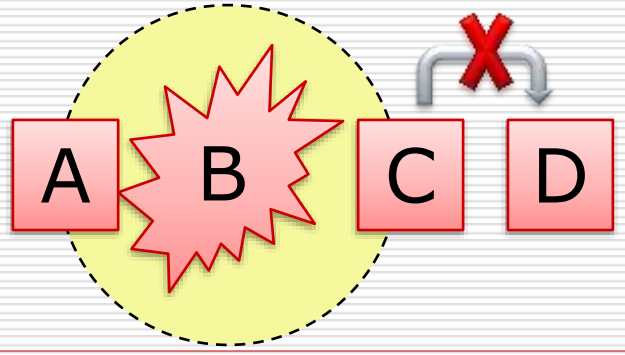


站点 A 向 B 发送数据帧。数据帧必须经过 AP 转发

Why We Need CSMA/CA?

- Collisions can occur in WLAN, but the stations can only know the transmission nearby, so CSMA/CD is not a good choice.
  - **Hidden Station Problem**
    - When A is transmitting data to B, C can't detect the transmission between A and B, so perhaps C will decide to transmit data to B and result in a collision at B.
  - **Exposed Station Problem**
    - When B is transmitting data to A, C can detect the transmission, so C will not transmit data to D. But that is a mistake.





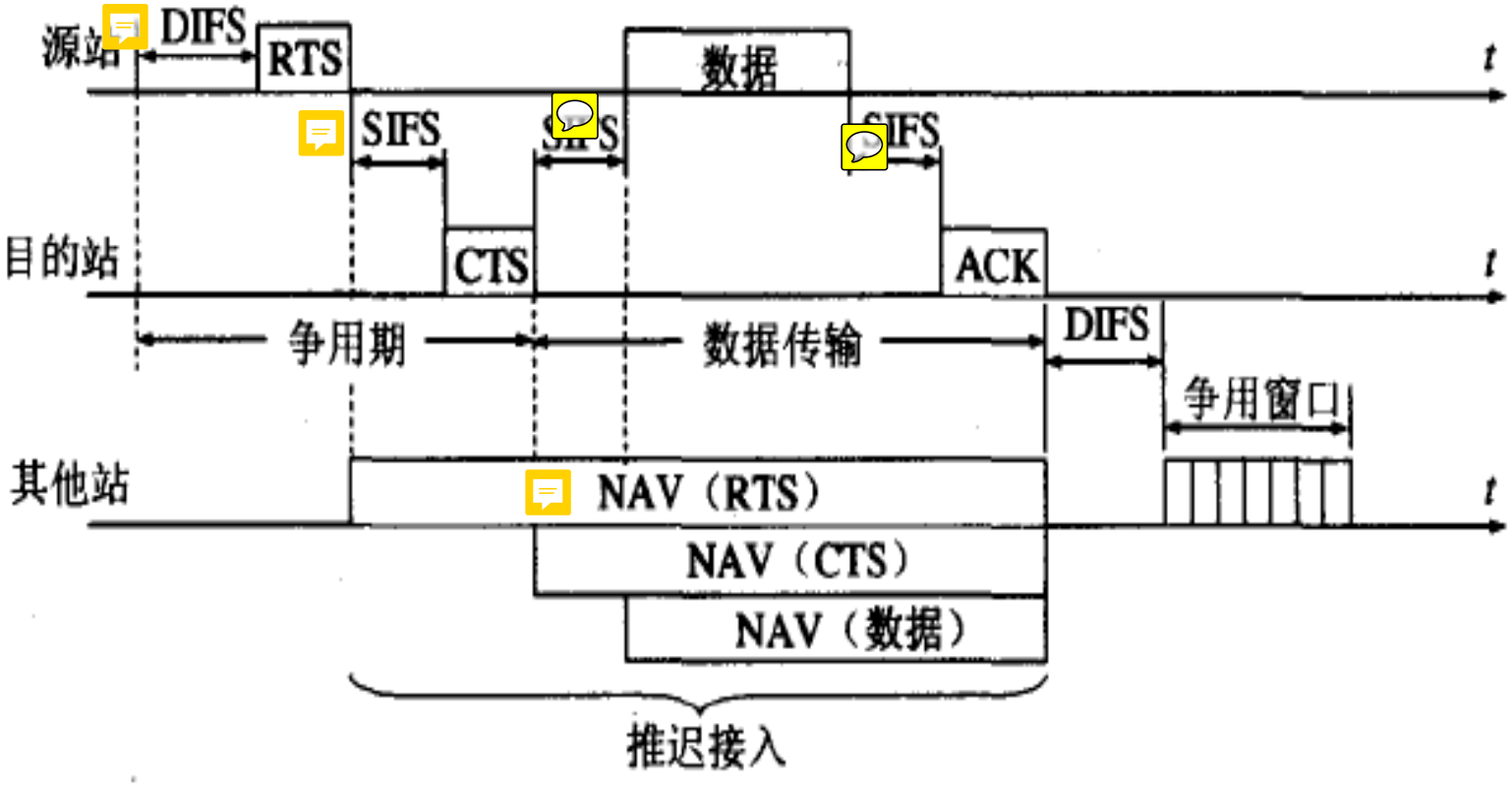
Multiple Accessing Mechanism

- Ethernet
  - Signals is transmitted to all stations on the cable.
  - The sending station detects the collisions.
  - At a time, only an effective frame can be transmitted on the channel.
- WLAN
  - Signals is transmitted to stations near to the sending station on the cable
  - The MAC protocol must try it best to ensure only a sending station near to the receiving station
  - The receiving station detects the collisions.
  - At a time, multiple effective frames can be transmitted on the channel.

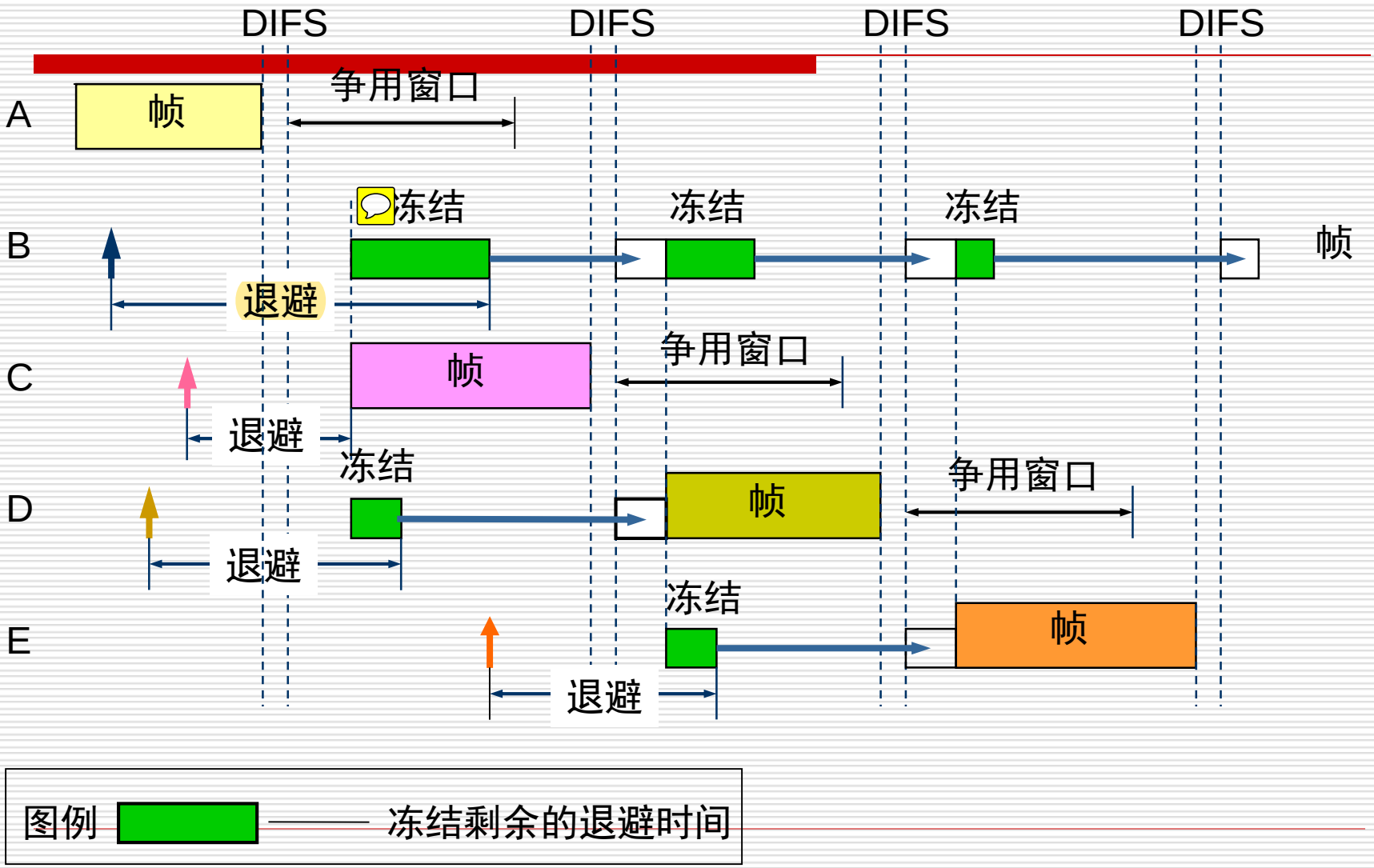
CSMA/CA

- CSMA/CA（Carrier Sense Multiple Access with Collision Avoidance）
  - 发送站点在发送数据前，以控制短帧刺激接收站点发送应答短帧，使接收站点周围的站点监听到该帧，从而在一定时间内避免数据发送
  - 基本过程
    - A向B发送RTS（Request To Send）帧，A周围的站点在一定时间内不发送数据，以保证CTS帧返回给A；
    - B向A回答CTS（Clear To Send）帧，B周围的站点在一定时间内不发送数据，以保证A发送完数据；
    - A开始发送
    - 若控制帧RTS或CTS发生冲突，采用二进制指数后退算法等待随机时间，再重新开始。

CSMA/CA


源站
DIFS
RTS
数据
t
SIFS
SIFS
目的站
CTS
ACK
t
争用期
数据传输
DIFS
争用窗口
其他站
NAV（RTS）
t
NAV（CTS）
NAV（数据）
推迟接入

CSMA/CA


DIFS
DIFS
DIFS
DIFS
A
帧
争用窗口
B
冻结
冻结
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退避
C
帧
争用窗口
退避
冻结
D
帧
争用窗口
退避
冻结
E
帧
退避
图例
冻结剩余的退避时间

The Actual Throughput

- When a source node sends a frame, the receiving node returns a positive acknowledgment (ACK).
  - This can cause consumption of 50% of the available bandwidth.
  - This reduces the actual data throughput to a maximum of 5.0 to 5.5 Mbps on an 802.11b wireless LAN rated at 11 Mbps.
- Performance of the network will also be affected by signal strength
  - As the signal becomes weaker, Adaptive Rate Selection (ARS) may be invoked
  - The transmitting unit will drop the data rate from 11 Mbps to 5.5 Mbps, from 5.5 Mbps to 2 Mbps or 2 Mbps to 1 Mbps.

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Layer 2 Devices—NICs

- NICs perform important Layer 2 data link layer functions:
  - Logical Link Control - communicates with upper layers in the computer
  - Media Access Control - provides structured access to shared access media
  - naming - provides a unique MAC address identifier
  - framing - part of the encapsulation process, packaging the bits for transport
  - signaling - creates signals and interface with the media by using built-in transceivers

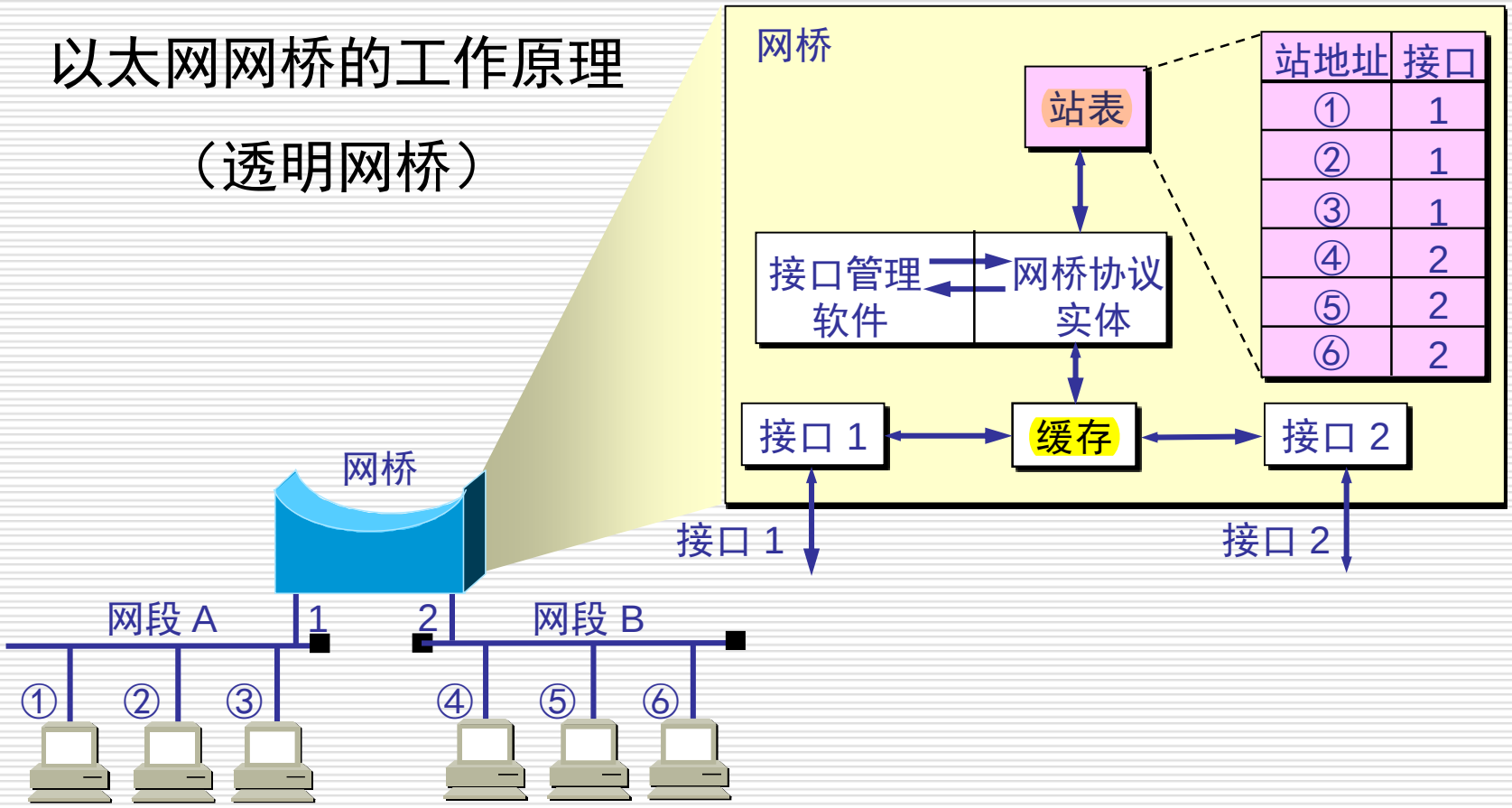
Layer 2 Devices—Bridges

- Bridges divide traffic into segments and filters traffic based on the MAC address, not based on protocols.
- Bridges can improve network performance by *reducing large collision domains*.
- Bridges work best where traffic is low from one segment of a network to other segments.
  - When traffic between network segments becomes heavy, bridges can become a bottleneck and slow down communication.

Layer 2 Devices—Bridges

以太网网桥的工作原理

（透明网桥）



Transparent Bridge

- Problem: When a device on a network wants to send data, but does not know the destination address.
  - Send out a broadcast to all devices on a network.
  - Since every device on the network has to pay attention to such broadcasts, bridges always forward them.
- Too many broadcasts can result in a broadcast storm, and it can cause:
  - network time-outs
  - traffic slowdowns
  - less than acceptable performance.

Layer 2 Devices—Switches

- Perform two basic operations:
  - switching data frames: a frame is received on an input medium and then transmitted to an output medium
  - maintenance of switching operations: Switches build and maintain switching tables and search for loops. Routers build and maintain both routing tables and switching tables.

Layer 2 Devices—Switches

- Switching is a technology that alleviates congestion in Ethernet LANs by *reducing traffic* and *increasing bandwidth*.
  - Switches create dedicated network segments, or point-to-point connections, and connecting these segments in a virtual network within the switch.
  - This is called a virtual circuit because it exists only when two nodes need to communicate and is established within the switch
  - You can think of each switch port as a micro-bridge; this process is called microsegmentation.
  - Each switch port gives the full bandwidth of the medium to each host

Layer 2 Devices—Switches

- LAN switch reduces the size of collision domains
- However, All hosts connected to the switch are still in the same broadcast domain.
  - That is, a broadcast from one node will still be seen by all other nodes connected through the LAN switch.

Switch Segmentation of a Collision Domain

- Switches are significantly faster because they switch in *hardware*, while bridges switch in *software*.
- A 10 Mbps Ethernet LAN and a 100 Mbps Ethernet LAN can be connected by using a switch.
- In a switched Ethernet implementation, the available bandwidth can reach close to 100 percent.
- Shared Ethernet networks perform best when kept to less than 30 to 40 percent of full capacity because of CSMA/CD.
- Some switches support cut-through switching, which reduces latency and delays, while bridges only support store-and-forward switching.

Router Segmentation of a Collision Domain

- Router can create the highest level of segmentation:
  - Create smaller collision domains
  - Create smaller broadcast domains: routers do not forward broadcasts unless programmed to do so.
- Routers accomplish forwarding of packets by examining the destination logical address on the data packet and then looking in its routing table for forwarding instructions
- Because routers perform more functions than bridges, they operate with a higher rate of latency.
- Routers can work as gateway:
  - be used to connect different networking media and different LAN technologies

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