CPE 490: Information Systems Engineering I: Computer Networking

Chap. 4 - The Medium Access Control Sublayer

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The Channel Allocation Problem

- The Channel Allocation Problem - In broadcast networks, one key issue is to determine who gets to use the channel,
  - ✓ when there is competition for it.
  - ✓ A sublayer of the data link layer – Medium Access Control (MAC) sublayer.
- Static Channel Allocation in LANs and MANs
- Dynamic Channel Allocation in LANs and MANs

Static Channel Allocation in LANs and MANs

- FDM
  - ✓ What's the problem of using FDM?
  - ✓ When the number of sender is large and continuously varying or the traffic is bursty, FDM is not efficient.
- TDM
- CDMA

Dynamic Channel Allocation in LANs and MANs

Five key assumptions for Dynamic Channel Allocation:

1. Station Model.
   - N independent stations (computers, telephones, etc.) – terminals.
   - Each station generates a frame with probability $\lambda \Delta t$ for transmission.
   - Once a frame is generated, the station is blocked until the frame has been successfully transmitted.
2. Single Channel Assumption
   - ✓ A single channel is available for all communication.
   - ✓ All stations can transmit on it and receive from it.
3. Collision Assumption.
   - If two frames are transmitted simultaneously, they overlap in time and the resulting signal is garbled – collision.
4. (a) Continuous Time - Frame transmissions can begin at any time instant.
   (b) Slotted Time – Time is divided into discrete slots.
   - ✓ Frame transmissions always begin at the start of a slot.
5. (a) Carrier Sense – Stations can tell if the channel is in use before trying to use it.
   (b) No Carrier Sense.

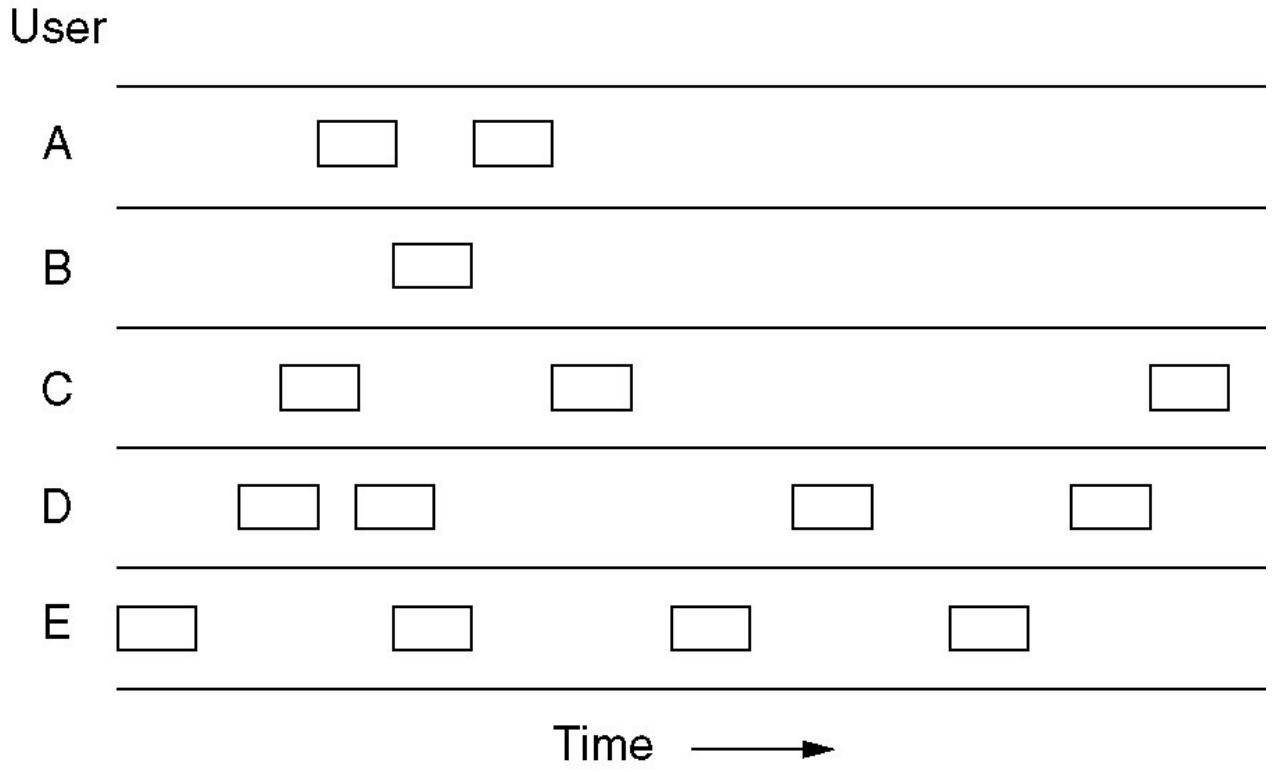
Multiple Access Protocols

- ALOHA
- Carrier Sense Multiple Access Protocols
- Collision-Free Protocols
- Limited-Contention Protocols
- Wavelength Division Multiple Access Protocols
- Wireless LAN Protocols

ALOHA

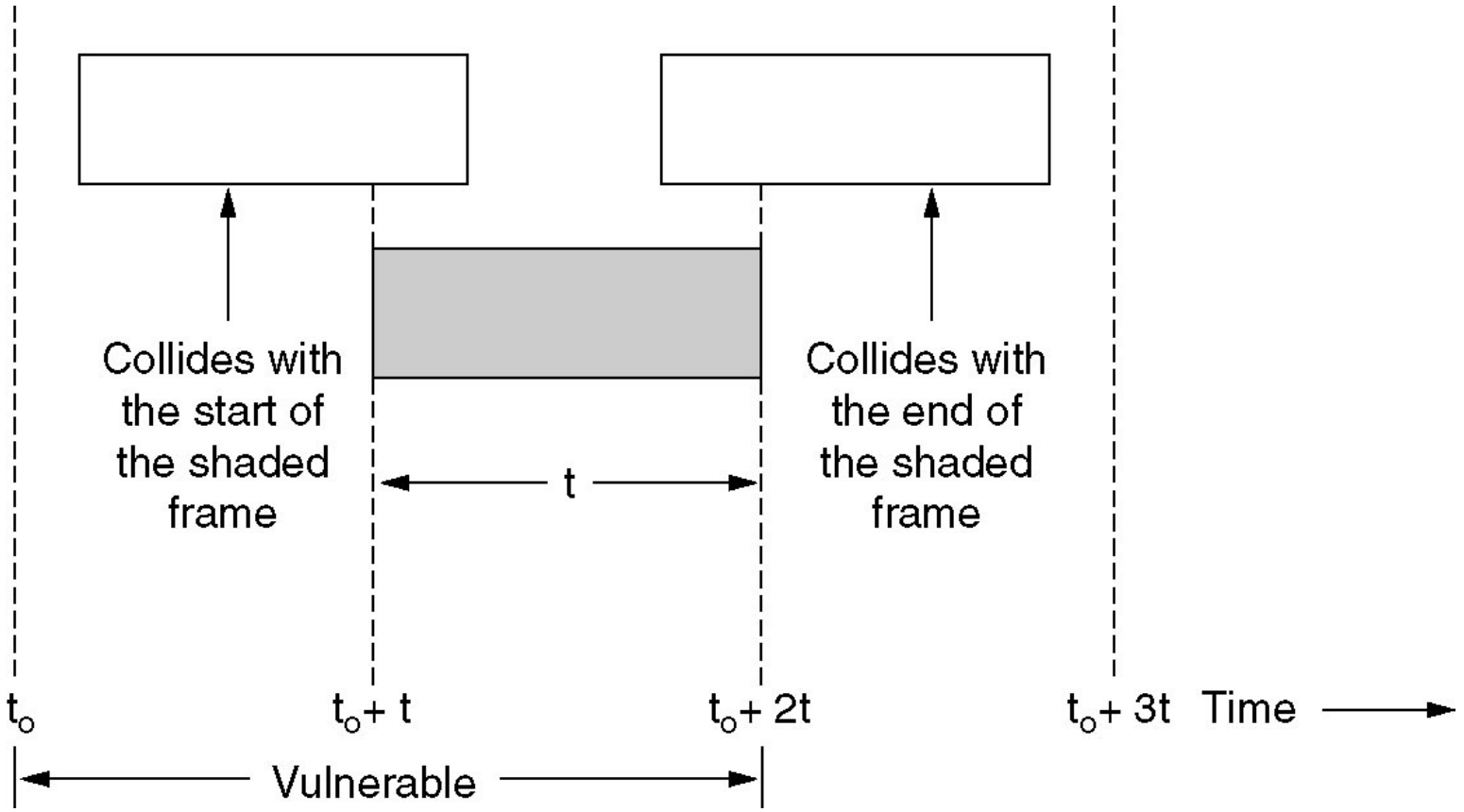
- ALOHA
  - ✓ In the 1970's, Norman Abramson at Univ. of Hawaii devised ALOHA to solve the channel allocation problem in ground-based radio broadcasting system.
  - ✓ The basic idea of ALOHA applies to all broadcast system.
  - ✓ Pure ALOHA and slotted ALOHA.
- Pure ALOHA
  - ✓ Let users transmit whenever they have data to be sent.
  - ✓ Due to the feedback property of broadcasting, a sender can always find out if its frame was destroyed
    - by listening to the channel.
  - ✓ If listening while transmitting is not possible, Ack is needed.
  - ✓ The throughput is max. by using a uniform frame size.
  - ✓ If the 1st bit of a new frame overlaps with just the last bit of a frame, both frames will be totally destroyed,
    - since the checksum can not distinguish between a total or partial loss.

Pure ALOHA



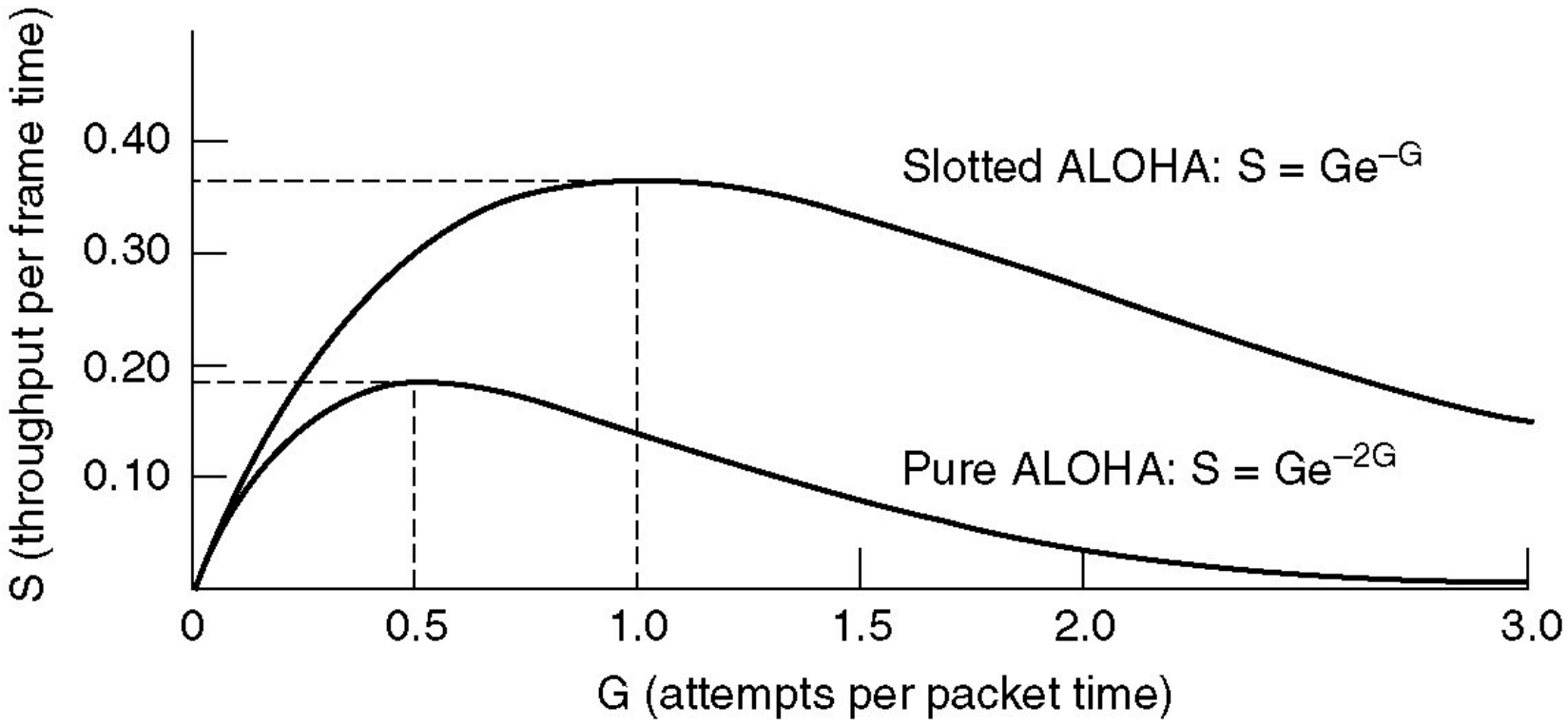
In pure ALOHA, frames are transmitted at completely arbitrary times.

Pure ALOHA (2)



Vulnerable period for the shaded frame.

Pure ALOHA (3)



Throughput versus offered traffic for ALOHA systems.

Slotted ALOHA – Transmitting only at the beginning of a time slot.

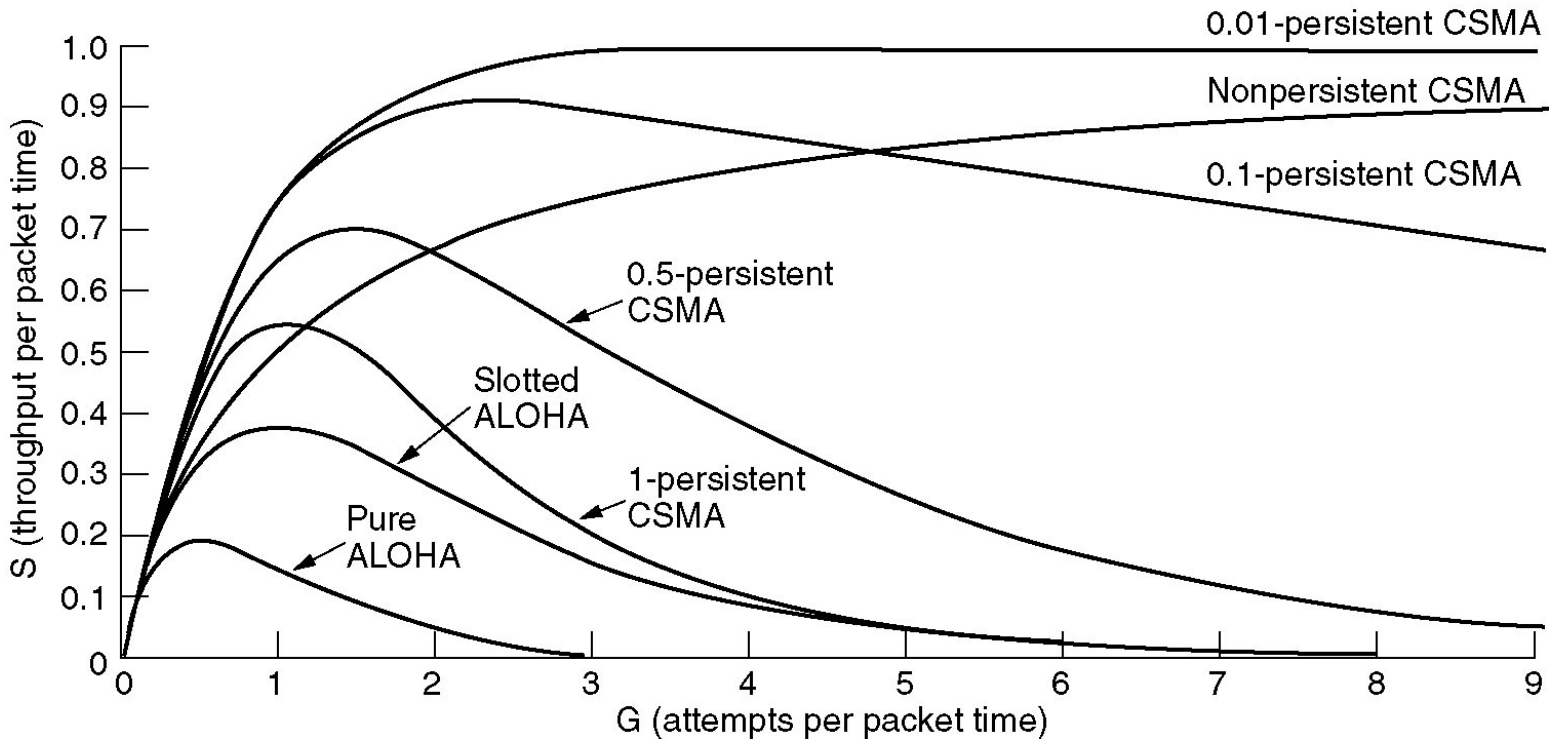
Carrier Sense Multiple Access Protocols

- In LANs, stations can detect what other stations are doing.
- Carrier sense protocols – Protocols in which stations listen for a carrier and act accordingly.
- Persistent and Non-persistent CSMA (Carrier Sense Multiple Access)
  - ✓ 1-persistent CSMA protocol
    - When a station has data to send, it first listen to the channel to see if anyone else is transmitting.
    - When the channel is idle, the station transmits a frame with prob. 1.
    - If a collision occurs, the station waits for a random time and resend.
    - The propagation delay affects the performance of the protocol. (Q)
  - ✓ Non-persistent CSMA protocol
    - A station senses the channel before transmission.
    - If the channel is busy, it does not continuously sense it.
    - It waits for a random time them starts sensing the channel.
    - Better channel utilization but longer delays than 1-persistent CSMA.

Carrier Sense Multiple Access Protocols

- Persistent and Non-persistent CSMA (Carrier Sense Multiple Access)
  - ✓ p-persistent CSMA protocol
    - It applies to slotted channels.
    - When a station has data to send, it first senses the channel.
    - When the channel is idle, the station transmits a frame with prob. p.
    - With prob. 1-p, it defers to the next slot (and runs the same algorithm).
  - ✓ Q: Drawback of using p-persistent CSMA.

Persistent and Nonpersistent CSMA



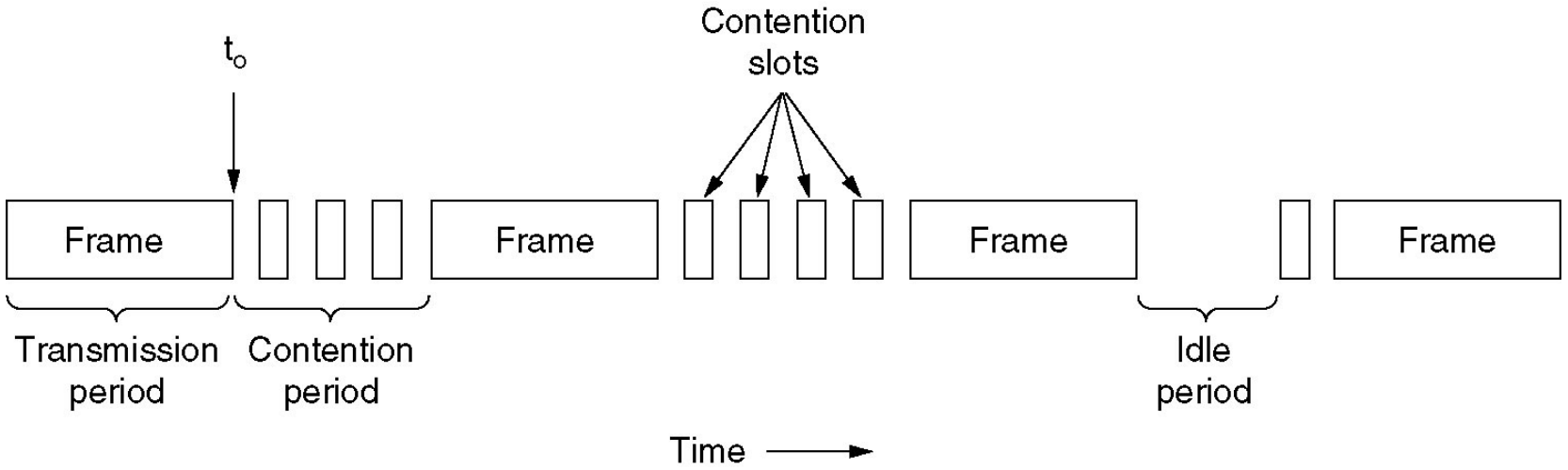
Comparison of the channel utilization versus load for various random access protocols.

CSMA with Collision Detection (CD)

- Persistent and Non-persistent CSMA protocols are better than ALOHA
  - ✓ because they ensure that no station begins to transmit when it senses the channel busy.
- Another improvement - Stations abort their transmission as soon as they detect a collision.
  - ✓ If two stations sense the channel to be idle and begin transmitting simultaneously, they will both detect the collision almost immediately.
  - ✓ They should abort the transmission as soon as the collision is detected.
  - ✓ The protocol – CSMA/CD is widely used on LANs.
    - E.g., Ethernet LANs.

CSMA/CD

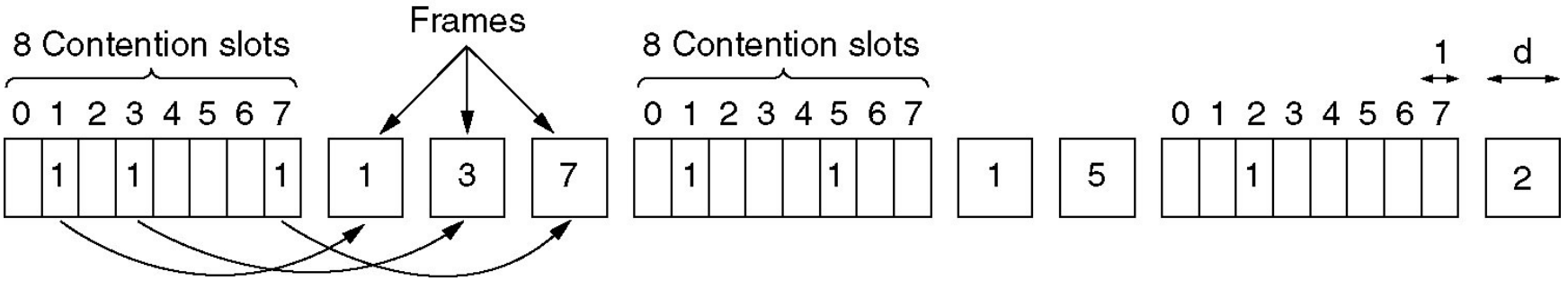
- ✓ At time t0, a station has finished transmitting its frame.
- ✓ During contention period, each possible sender transmits a short packet.
- ✓ Collisions can be detected by looking at the power or pulse width of the received signal and comparing it to the transmitted signal.
  - If what it reads back is different from what it is putting out, a station knows that a collision is occurring (with certain signal encoding).



CSMA/CD can be in one of three states: contention, transmission, or idle.

Collision-Free Protocols

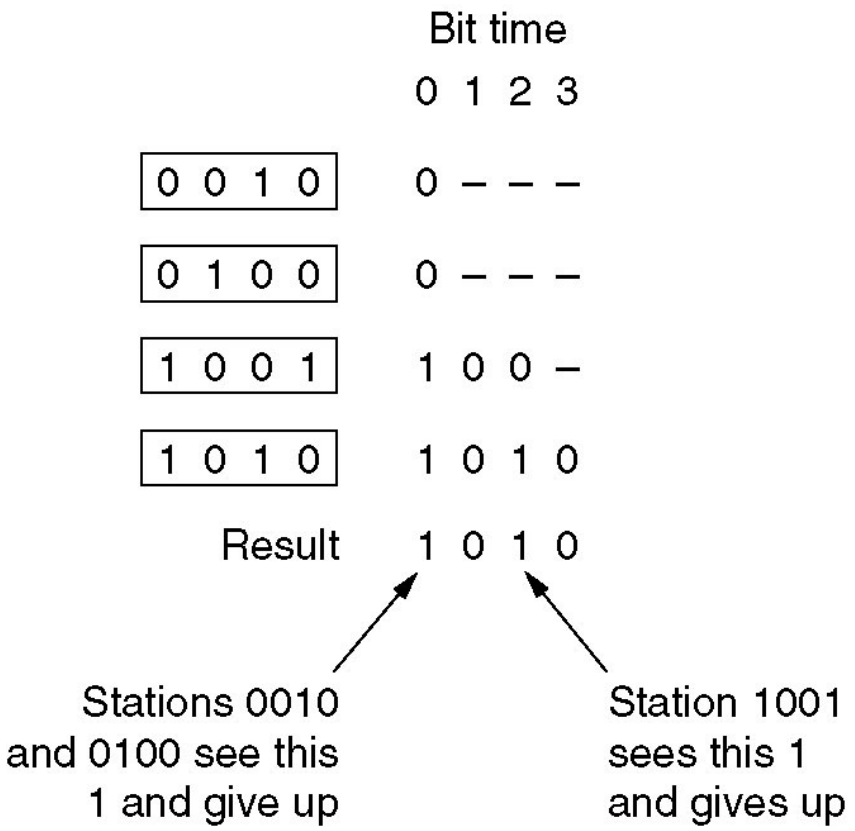
- ✓ For CSMA/CD, collision can still happen during contention period.
- ✓ The bit-map protocol
  - Assume N stations, each contention period consists of N slots.
  - If station 0 has a frame to transmit, it transmits a 1 bit during slot 0.
  - After N slots, each station has complete knowledge of which stations wish to transmit.
  - Then they begin transmitting in numerical order.
  - After the last station has transmitted its frame, another N-bit contention slot begins.
  - Q: Drawback?



The basic bit-map protocol.

Collision-Free Protocols (2)

- ✓ Binary station addresses are used.
- ✓ Each possible sender broadcasts its address, starting with the highest bit.
- ✓ The bits in each address are BOOLEAN ORed together – Binary countdown.
- ✓ As soon as a station sees that a high-order bit position of 0 has been overwritten with a 1, it gives up.

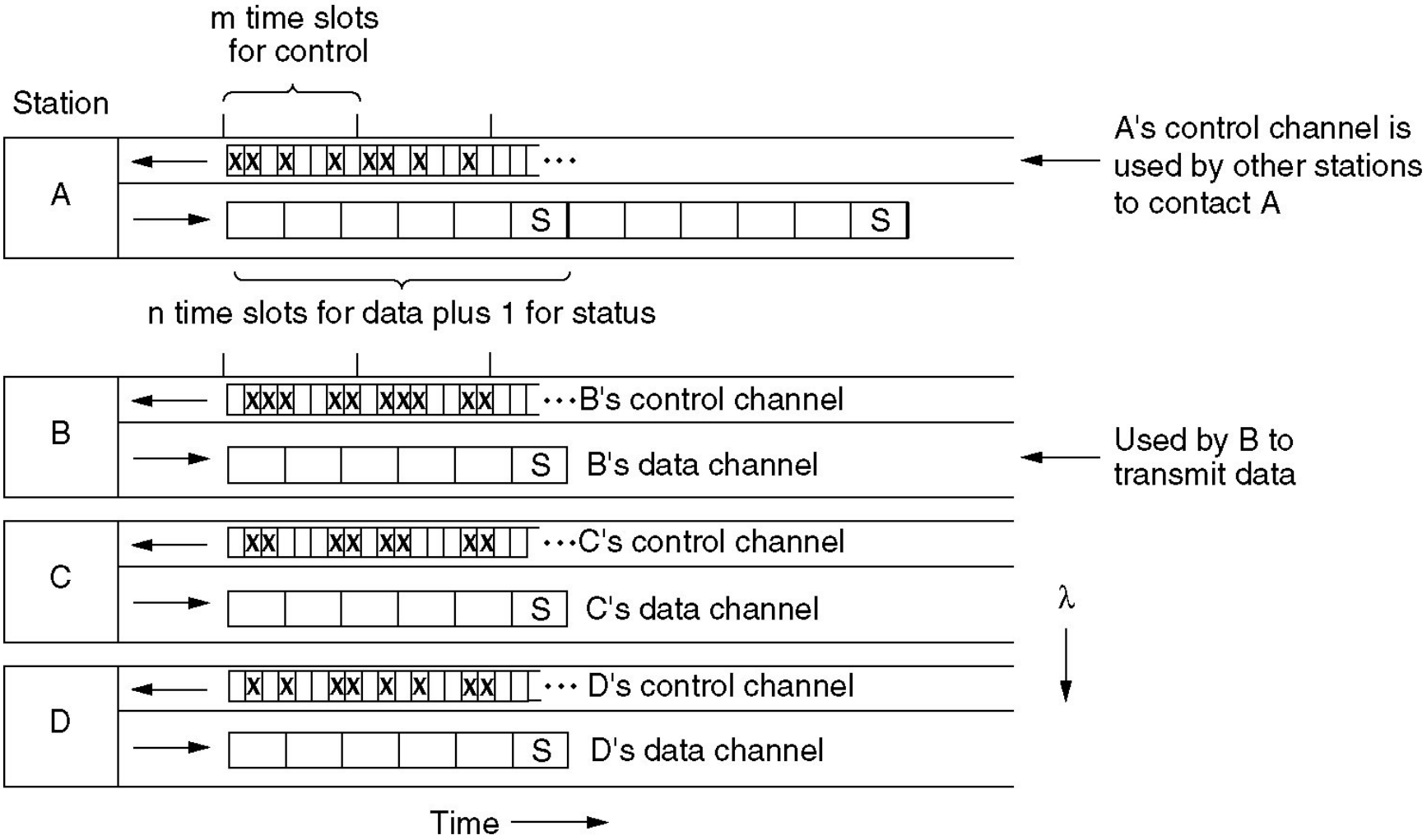


The binary countdown protocol. A dash indicates silence.

Wavelength Division Multiple Access Protocols

- ✓ A channel is divided into multiple sub-channels using FDM, TDM, and dynamically allocate them as needed.
  - Each station has two channels, two transmitters and two receivers.
  - A narrow channel is provided as a control channel to signal the station.
  - A wide channel is provided to transmit data frames.

Wavelength Division Multiple Access Protocols



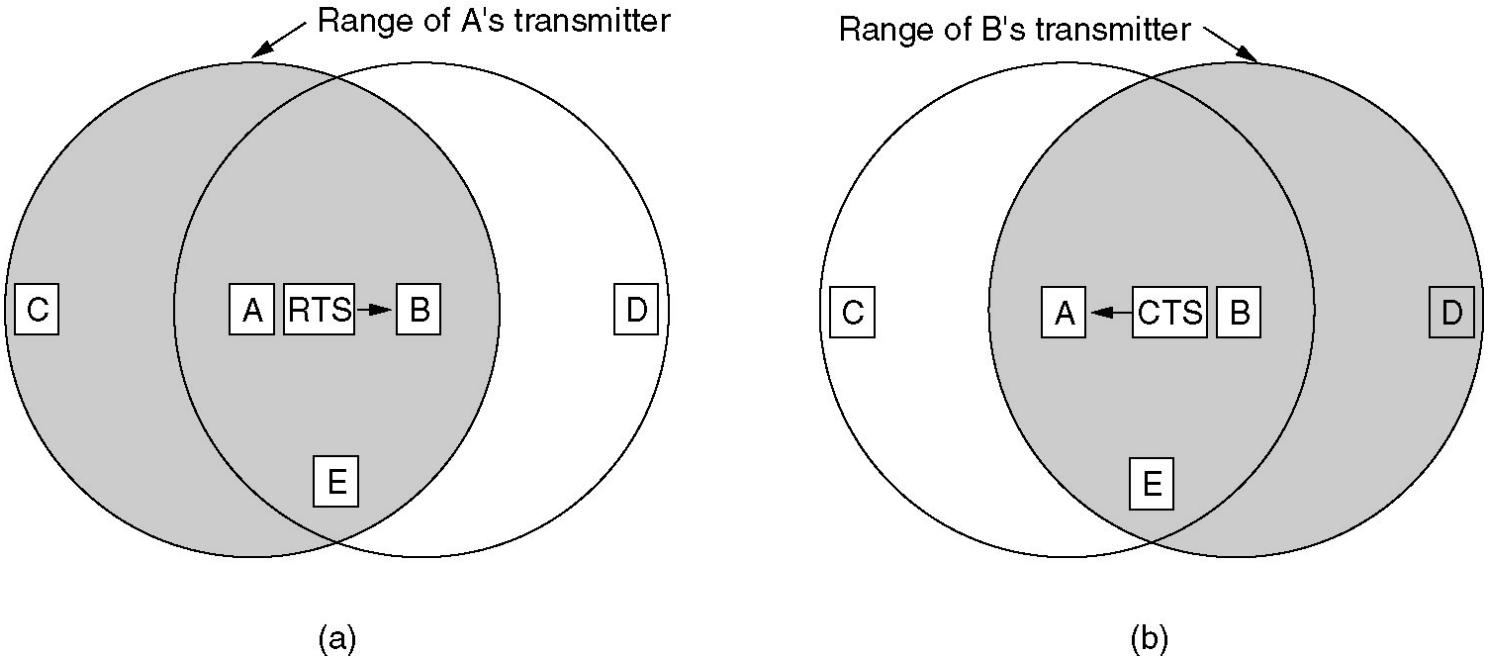
Wavelength division multiple access.

Wireless LAN Protocols

- Hidden station problem
- A → B.
- C can not hear the transmission of A.
- When C → B, collision happens at B.

A wireless LAN. (a) A transmitting. (b) B transmitting.

Wireless LAN Protocols (2)



The MACA (Multiple Access with Collision Avoidance) protocol – IEEE 802.11 Medium Access Control protocol is similar to MACA.

(a) A sending an RTS (Request To Send) to B.

(b) B responding with a CTS (Clear To Send) to A.

Ethernet

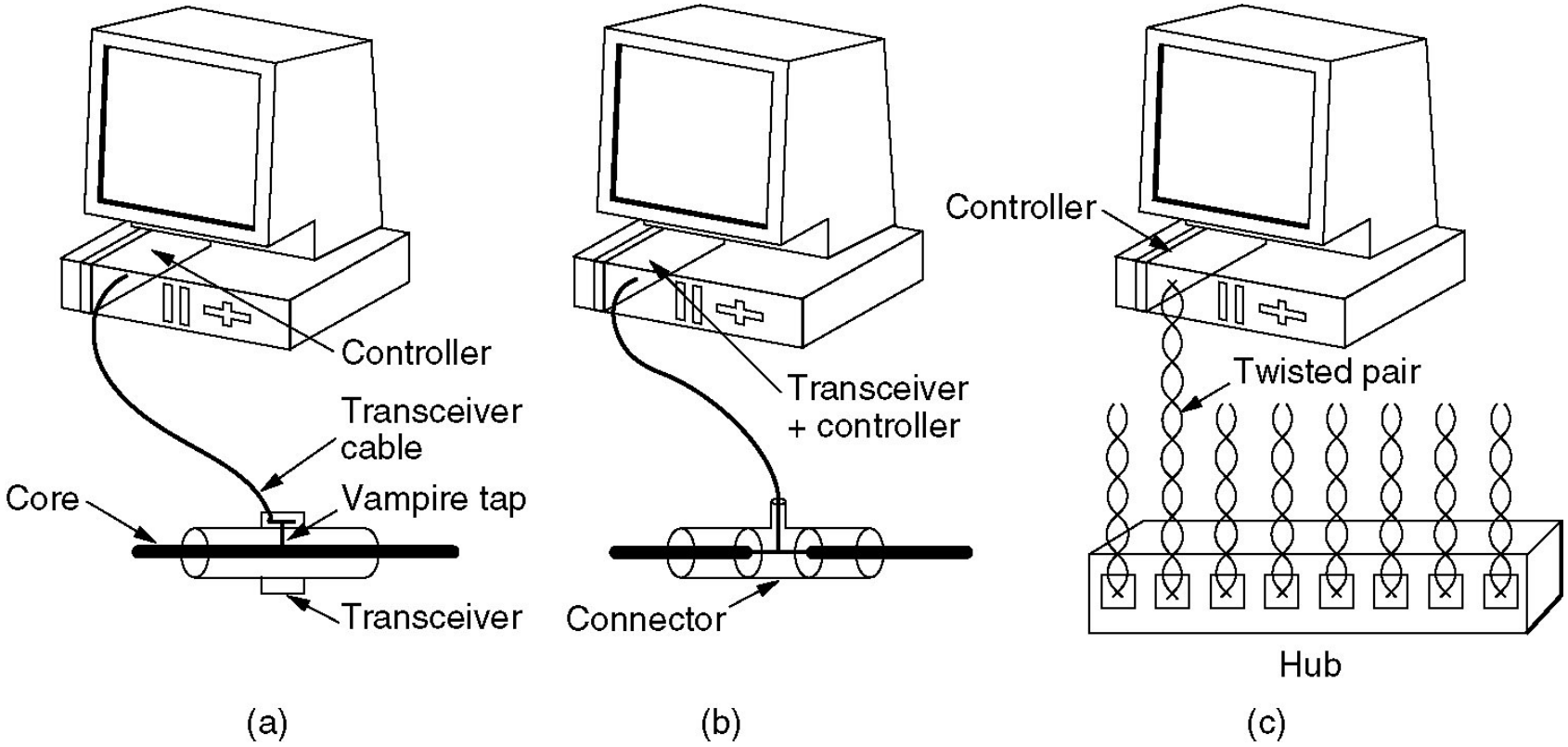
- Ethernet Cabling
- Manchester Encoding
- The Ethernet MAC Sublayer Protocol
- The Binary Exponential Backoff Algorithm
- Ethernet Performance
- Switched Ethernet
- Fast Ethernet
- Gigabit Ethernet
- IEEE 802.2: Logical Link Control
- Retrospective on Ethernet

Ethernet Cabling

Name	Cable	Max. seg.	Nodes/seg.	Advantages
10Base5	Thick coax	500 m	100	Original cable; now obsolete
10Base2	Thin coax	185 m	30	No hub needed
10Base-T	Twisted pair	100 m	1024	Cheapest system
10Base-F	Fiber optics	2000 m	1024	Best between buildings

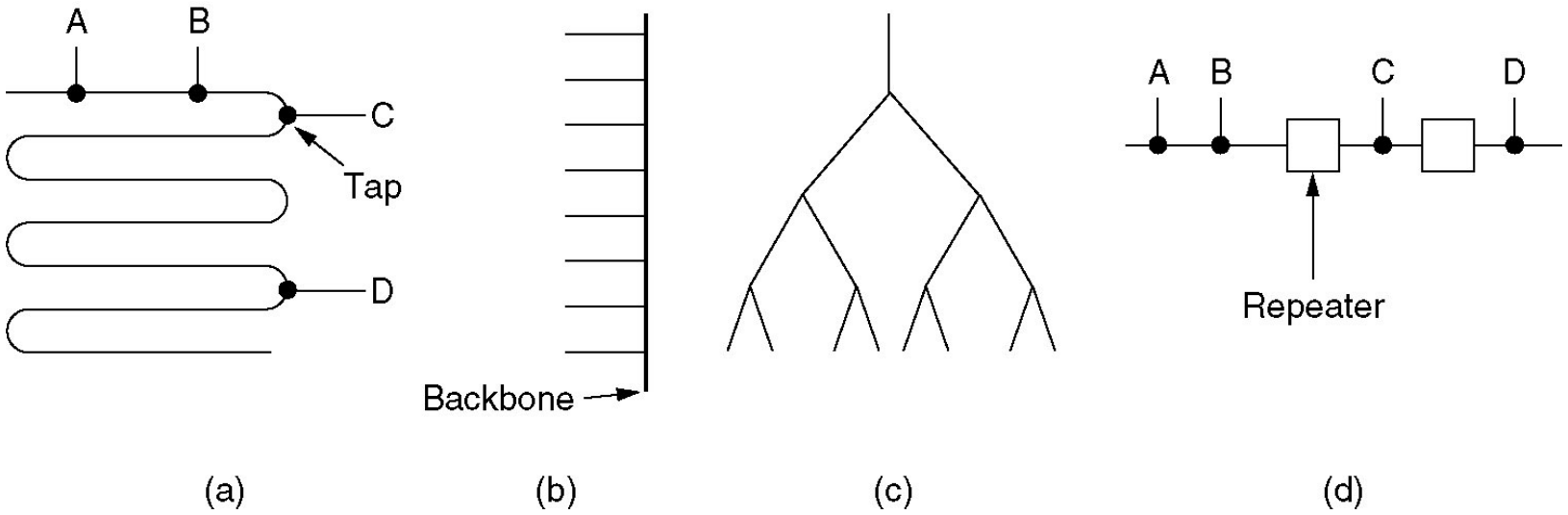
The most common kinds of Ethernet cabling.

Ethernet Cabling (2)



Three kinds of Ethernet cabling.
(a) 10Base5, (b) 10Base2, (c) 10Base-T.

Ethernet Cabling (3)



Cable topologies: (a) Linear – A single cable is used.

(b) Spine – A backbone cable runs from the basement to the roof, with horizontal cables on each floor.

(c) Tree – The most general topology.

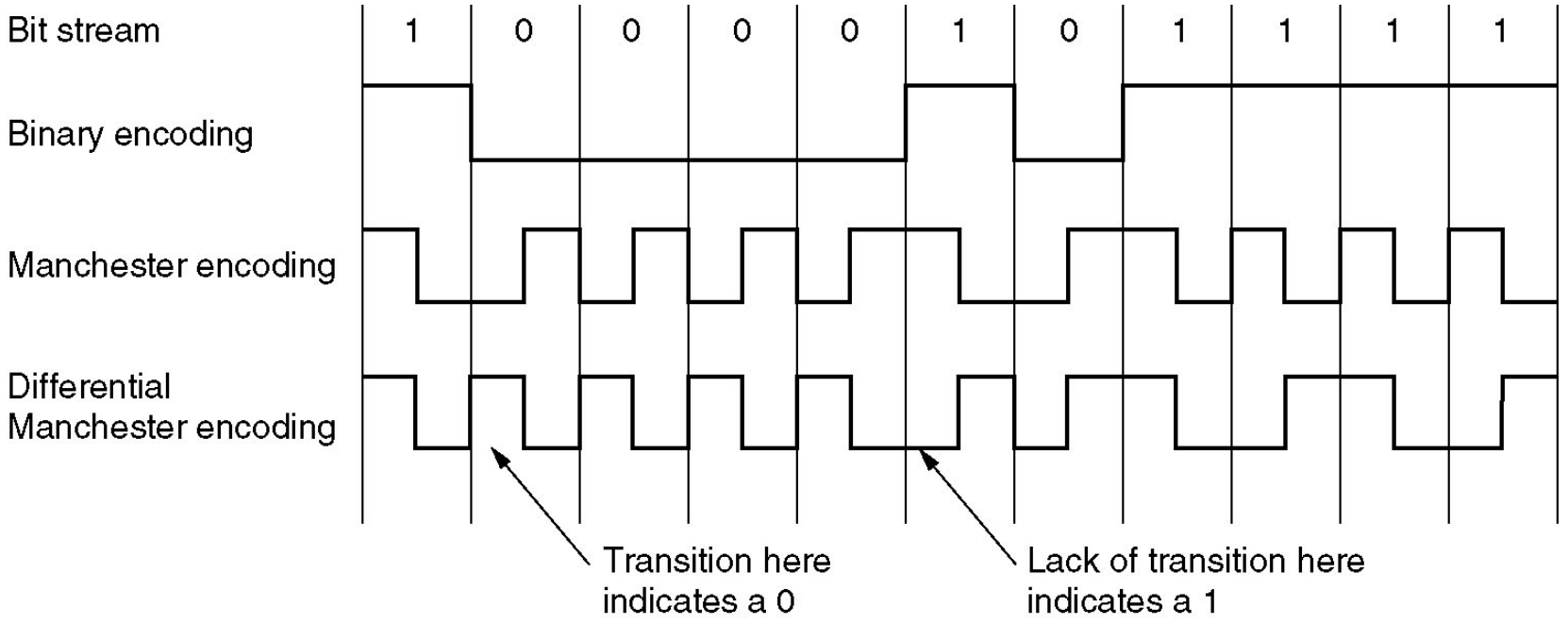
(d) Segmented- Multiple cables can be connected together by repeaters to form larger networks.

Repeater: A physical layer device. It receives, amplifies and retransmits signals in both directions.

Ethernet Cabling (4)

- Problems with binary encoding
  - ✓ Cannot tell the difference between an idle sender (0 volt) and a 0 bit (0 volt).
  - ✓ Even if +1 volts and -1 volts are used to represent 1 and 0, the receiver and the sender can be out of synchronization.
- Manchester encoding
  - ✓ Each bit period is divided into two equal intervals.
  - ✓ A binary 1 bit – high voltage (the 1st interval) + low voltage (the 2nd interval).
  - ✓ A binary 0 bit – low voltage + high voltage.
  - ✓ This scheme ensures that every bit period has a transition in the middle, making it easy for the receiver to synchronize with the sender.
- Differential Manchester encoding.
  - ✓ A binary 1 bit is indicated by the absence of a transition at the start of the interval.
  - ✓ A binary 0 bit is indicated by the presence of a transition at the start of the interval.

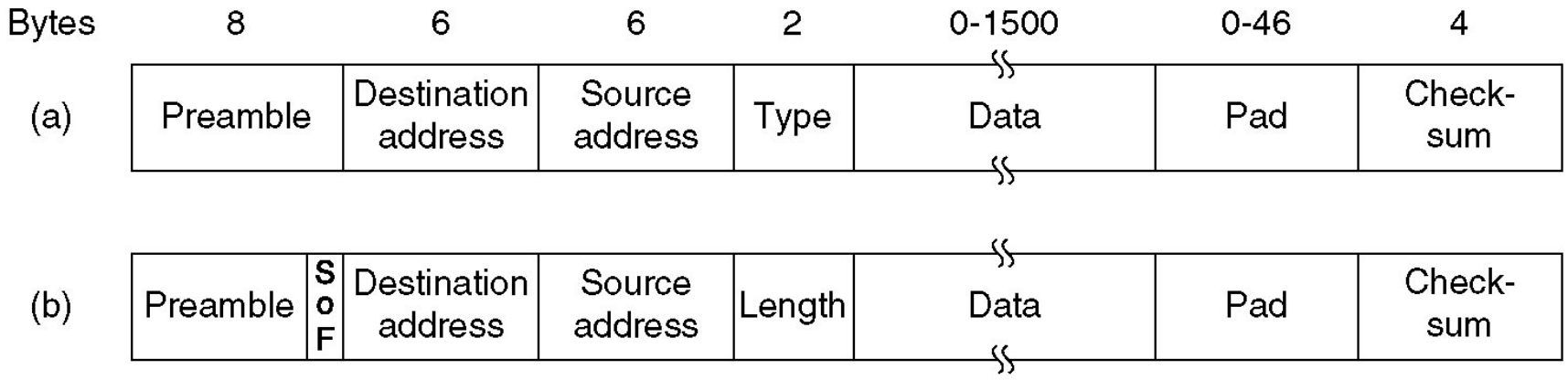
Ethernet Cabling (5)



(a) Binary encoding, (b) Manchester encoding, (c) Differential Manchester encoding.

Ethernet MAC Sublayer Protocol

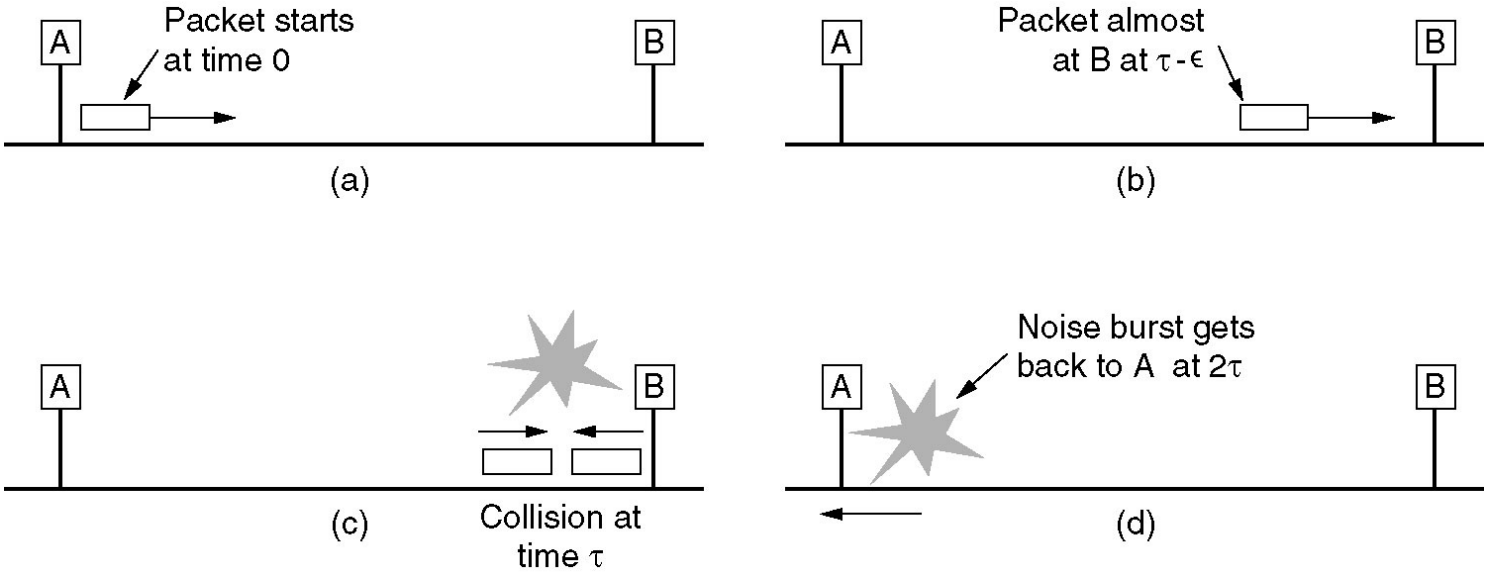
- Type
  - ✓ Multiple network-layer protocols may be in use at the same machine.
  - ✓ The type field specifies which process to give the frame to.
- IEEE Ethernet Frame Format:
  - ✓ 7-byte Preamble + 1 byte Start of Frame (SoF)
  - ✓ Type field → Length field (type is handled by a small header in the Data field)



Frame formats. (a) DIX (DEC, Intel, Xerox) Ethernet, (b) IEEE 802.3.

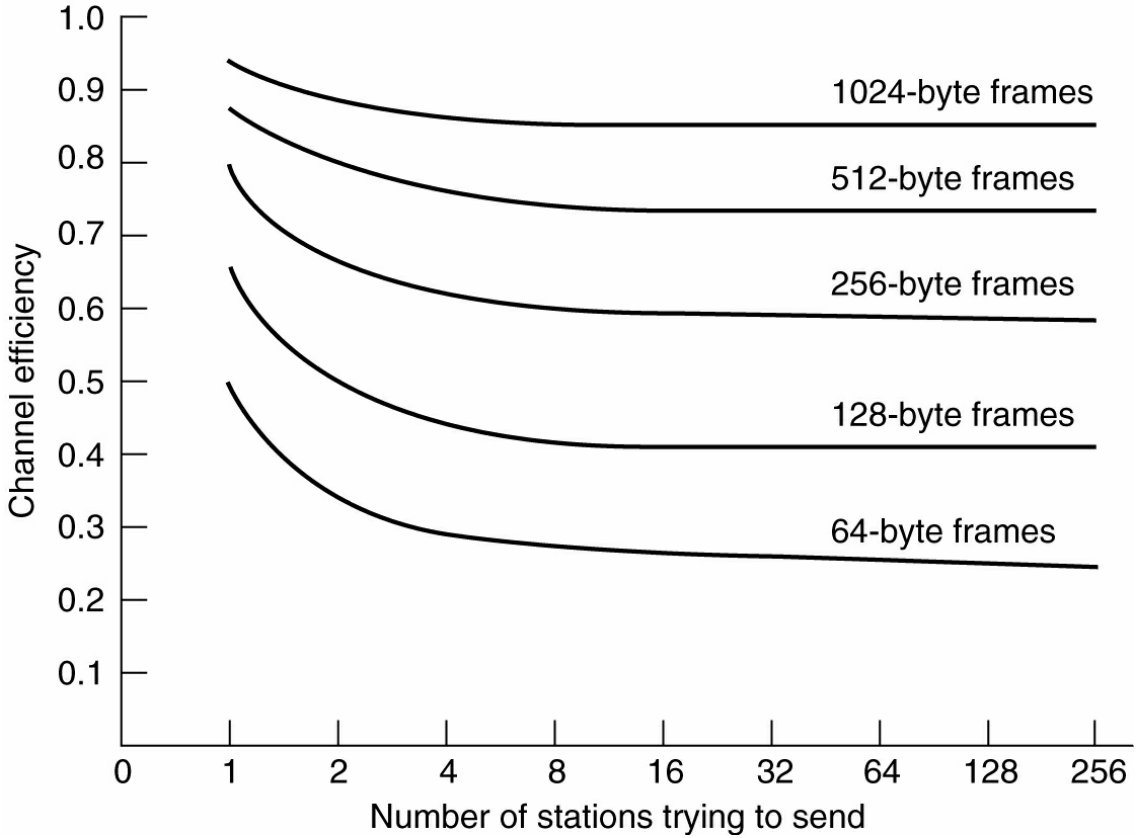
Ethernet MAC Sublayer Protocol (2)

- Pad is used to ensure the min. frame length.
  - ✓ A minimum frame length (64 bytes) is needed to distinguish valid frames from pieces of frames – A transceiver truncates the frame when a collision is detected.
  - ✓ Pad To prevent the completion of frame transmission before the first bit has reached the far end of the cable.
  - ✓ For a short frame, the transmission completes before the noise burst gets back, then the sender will incorrectly conclude the transmission was ok.



Collision detection can take as long as 2τ.

Ethernet Performance



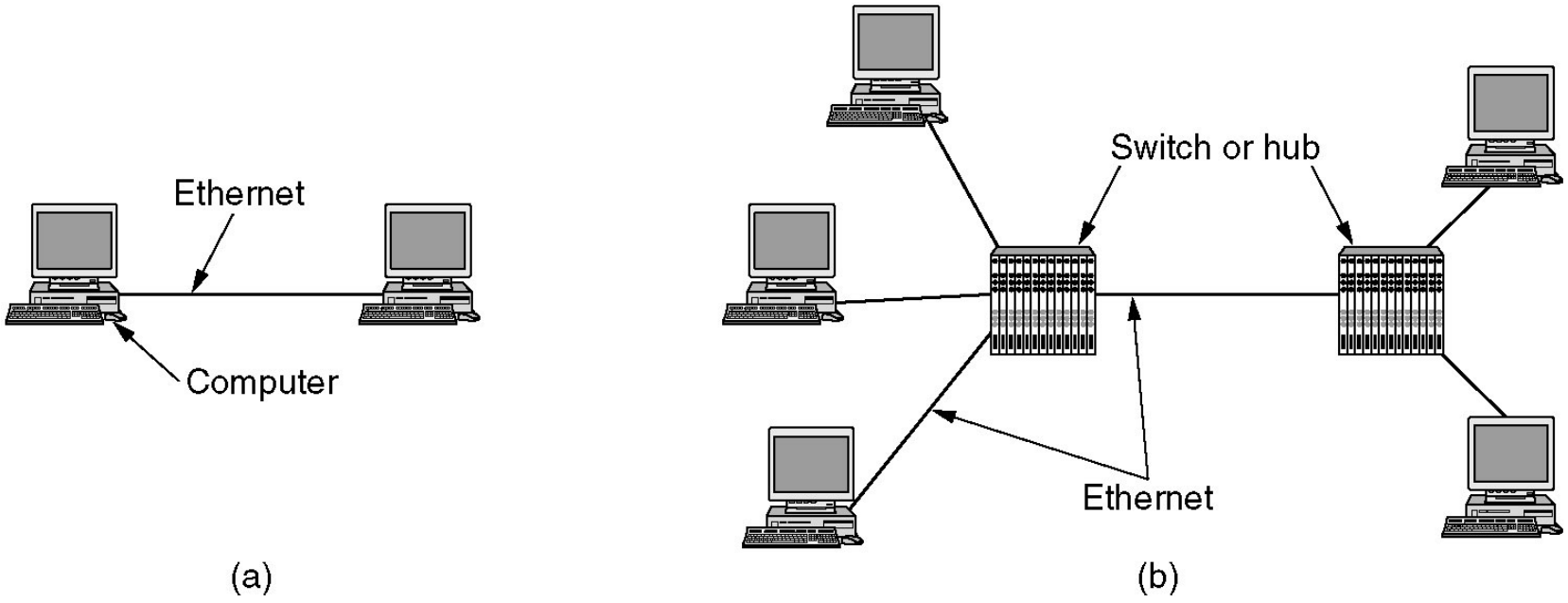
Efficiency of Ethernet at 10 Mbps with 512-bit slot times (2τ)

Fast Ethernet

Name	Cable	Max. segment	Advantages
100Base-T4	Twisted pair	100 m	Uses category 3 UTP
100Base-TX	Twisted pair	100 m	Full duplex at 100 Mbps
100Base-FX	Fiber optics	2000 m	Full duplex at 100 Mbps; long runs

The original fast Ethernet cabling.

Gigabit Ethernet



(a) A two-station Ethernet. (b) A multi-station Ethernet.

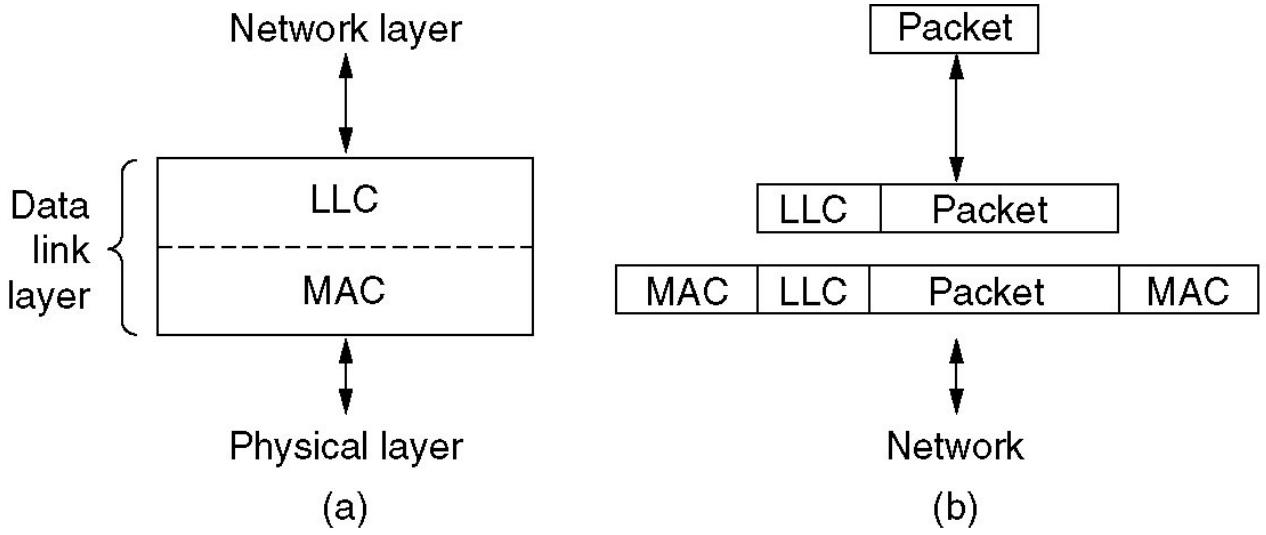
Gigabit Ethernet (2)

Name	Cable	Max. segment	Advantages
1000Base-SX	Fiber optics	550 m	Multimode fiber (50, 62.5 microns)
1000Base-LX	Fiber optics	5000 m	Single (10 μ) or multimode (50, 62.5 μ)
1000Base-CX	2 Pairs of STP	25 m	Shielded twisted pair
1000Base-T	4 Pairs of UTP	100 m	Standard category 5 UTP

Gigabit Ethernet cabling.

IEEE 802.2: Logical Link Control

- Logical Link Control (LLC) sublayer
  - ✓ Handles error control, flow control.
  - ✓ Provides a single format and interface to the network layer.
  - ✓ The protocol is closely based on the HDLC protocol (Chap. 3).
  - ✓ LLC header:
    - A destination access point (the process associated with the frame);
    - A source access point;
    - A control field: sequence # and Ack #.

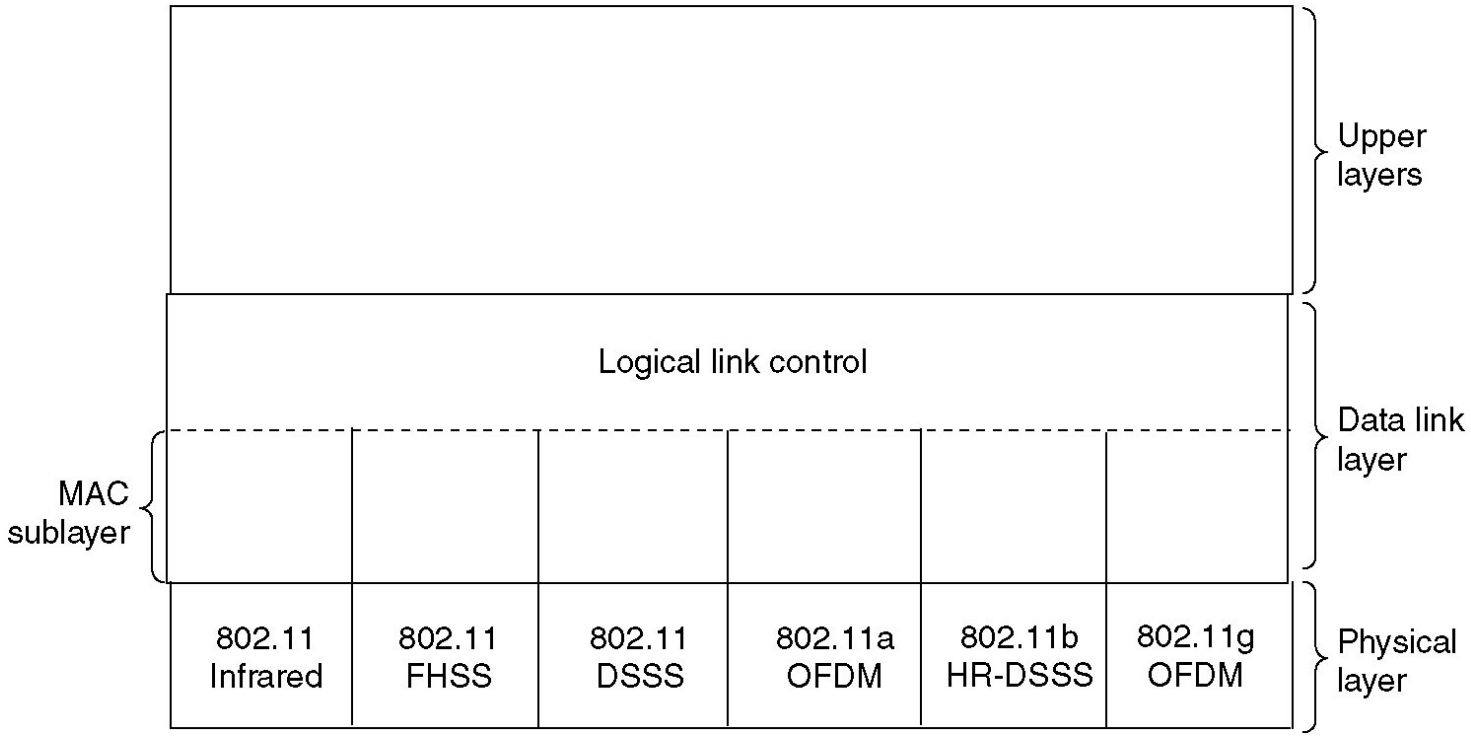


(a) Position of LLC. (b) Protocol formats.

Wireless LANs

- The 802.11 Protocol Stack
- The 802.11 Physical Layer
- The 802.11 MAC Sublayer Protocol
- The 802.11 Frame Structure
- Services

The 802.11 Protocol Stack

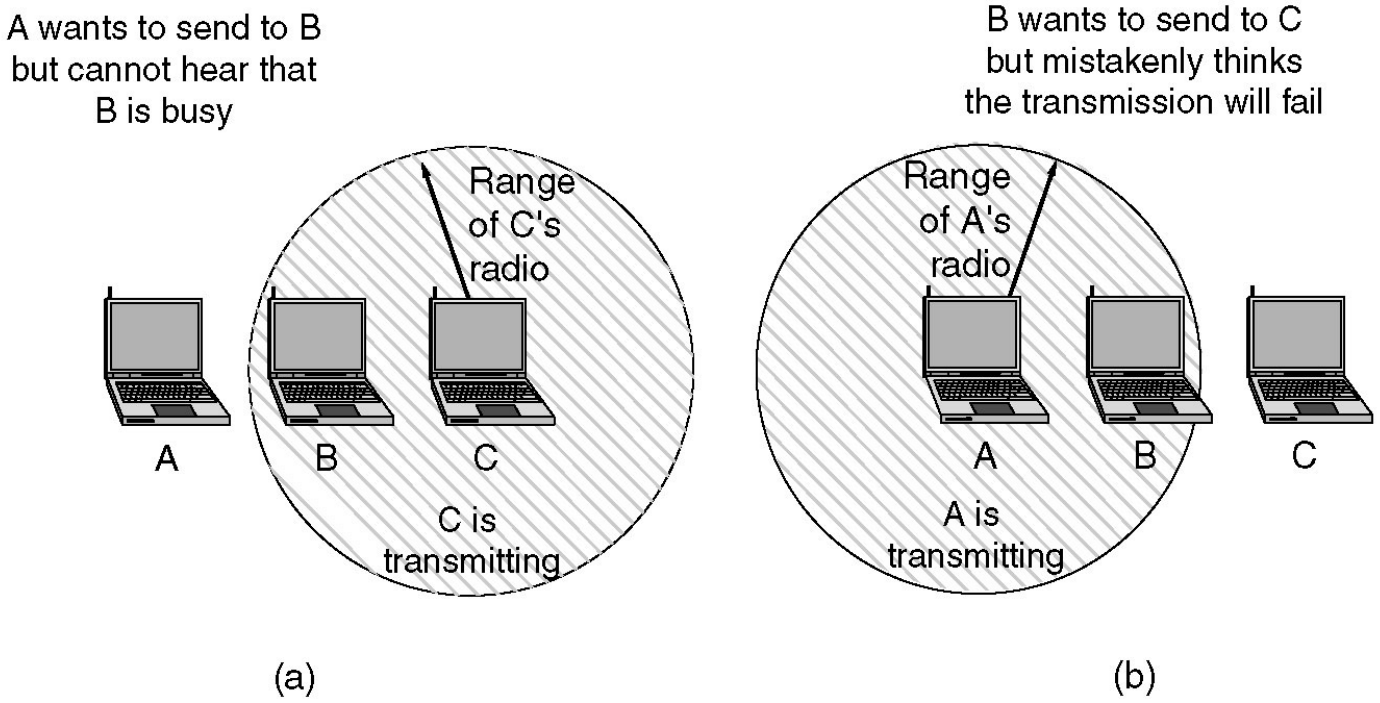


Part of the 802.11 protocol stack.

FHSS – Frequency Hopping Spread Spectrum (HR – High Rate)
DSSS – Direct Sequence Spread Spectrum
OFDM – Orthogonal Frequency Division Multiplexing

The 802.11 MAC Sublayer Protocol

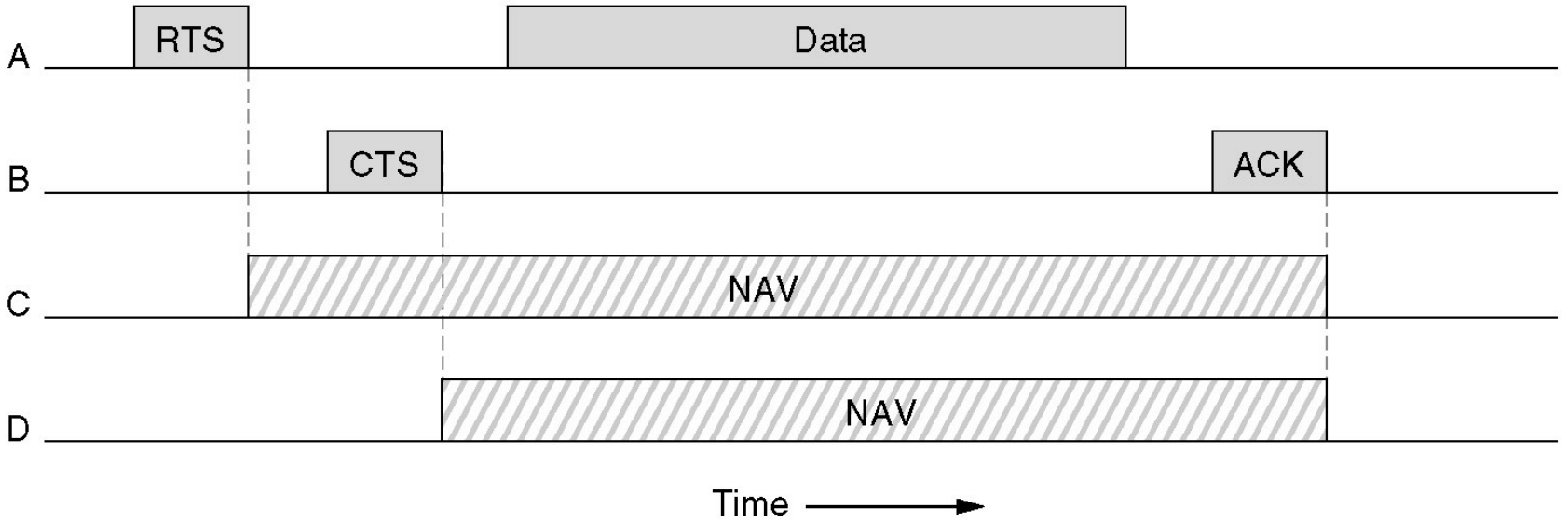
- Most radios are half duplex – they can not transmit and listen for noise bursts at the same time on a single freq.
- 802.11 does not use CSMA/CD.
- 802.11 supports
  - ✓ DCF (Distributed Coordination Function) – no central control.
  - ✓ PCF (Point Coordination Function) – uses base stations to control all activity.



(a) The hidden station problem. (b) The exposed station problem.

The 802.11 MAC Sublayer Protocol (2)

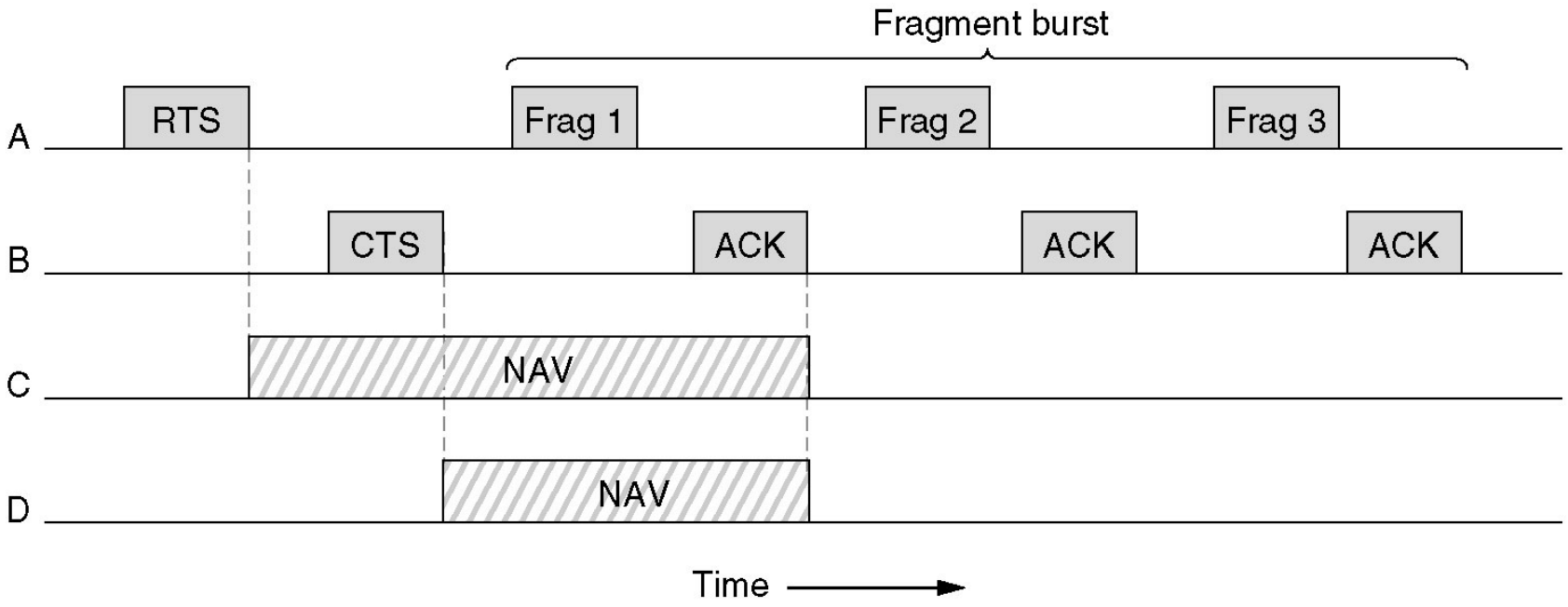
- 802.11 DCF
  - ✓ Uses CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance)
  - ✓ Both physical channel sensing and virtual channel sensing.
  - ✓ C -- A → B -- D
  - ✓ Node C and D insert NAV (Network Allocation Vector)
    - indicating virtual channel busy.
    - not really signal.



The use of virtual channel sensing using CSMA/CA.

The 802.11 MAC Sublayer Protocol (3)

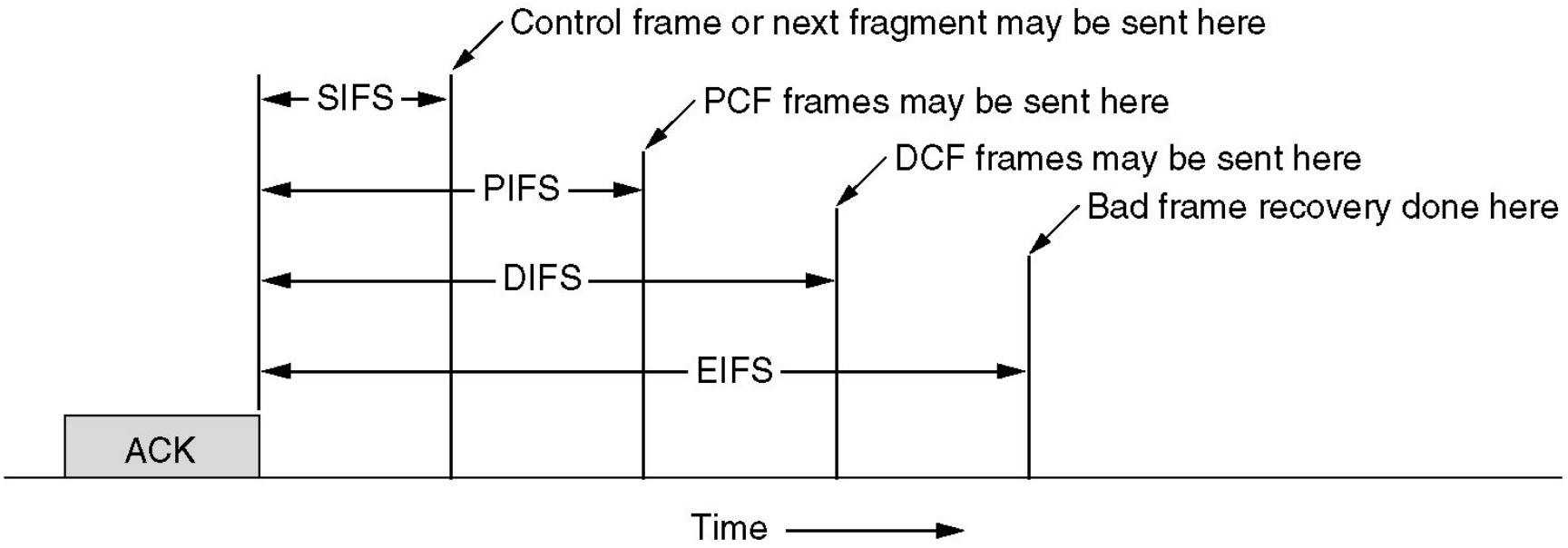
- To deal with noise, frames are fragmented into smaller pieces.
  - ✓ The fragments are numbered and Ack. Using a stop-and-wait protocol.
  - ✓ How to increase NAV?



A fragment burst.

The 802.11 MAC Sublayer Protocol (4)

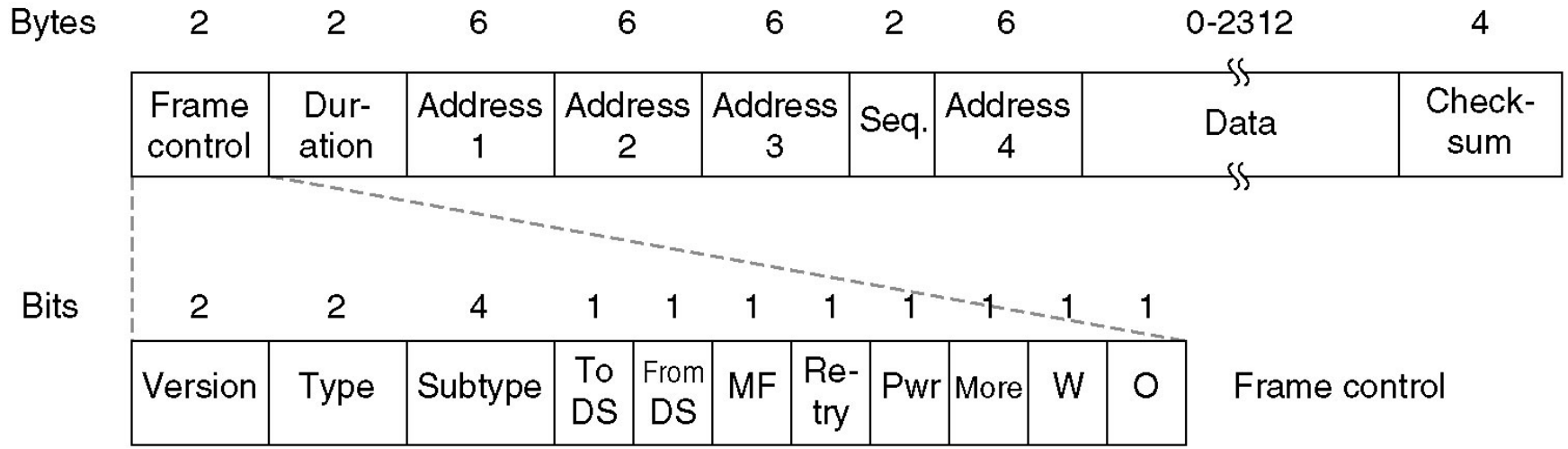
- After a frame has been sent, a certain amount of idle time is needed before any station may send a (control or data) frame.
  - ✓ SIFS – Short InterFrame Spacing; PIFS – PCF InterFrame Spacing;
  - ✓ DIFS - DCF InterFrame Spacing; EIFS - Extended InterFrame Spacing.



Interframe spacing in 802.11.

The 802.11 Frame Structure

- ✓ Frame control (11 subfields): Protocol version; Type (data or control); Subtype (RTS/CTS); To DS and From DS (frame ←→ intercell distribution system); MF (more fragments); Retry (retransmission); Power mgmt (sleep state); More (additional frames); W (frame is encrypted using WEP (Wired Equivalent Privacy); O (frames must be processed strictly in order).
- ✓ Duration – how long the frame and its Ack. will occupy the channel.
- ✓ 4 addresses – source, destination, and source & destination base stations.
- ✓ Sequence - fragment #



The 802.11 data frame.

802.11 Services

Distribution Services

- Association
  - Used by mobile stations to connect to Access Points (APs) or base stations.
- Disassociation
  - Either a station or a AP may disassociate to break the relationship.
- Re-association
  - A station may change its preferred AP .
- Distribution
  - How to route frames to AP?
- Integration
  - Translation from the 802.11 frame to other frame.

802.11 Services

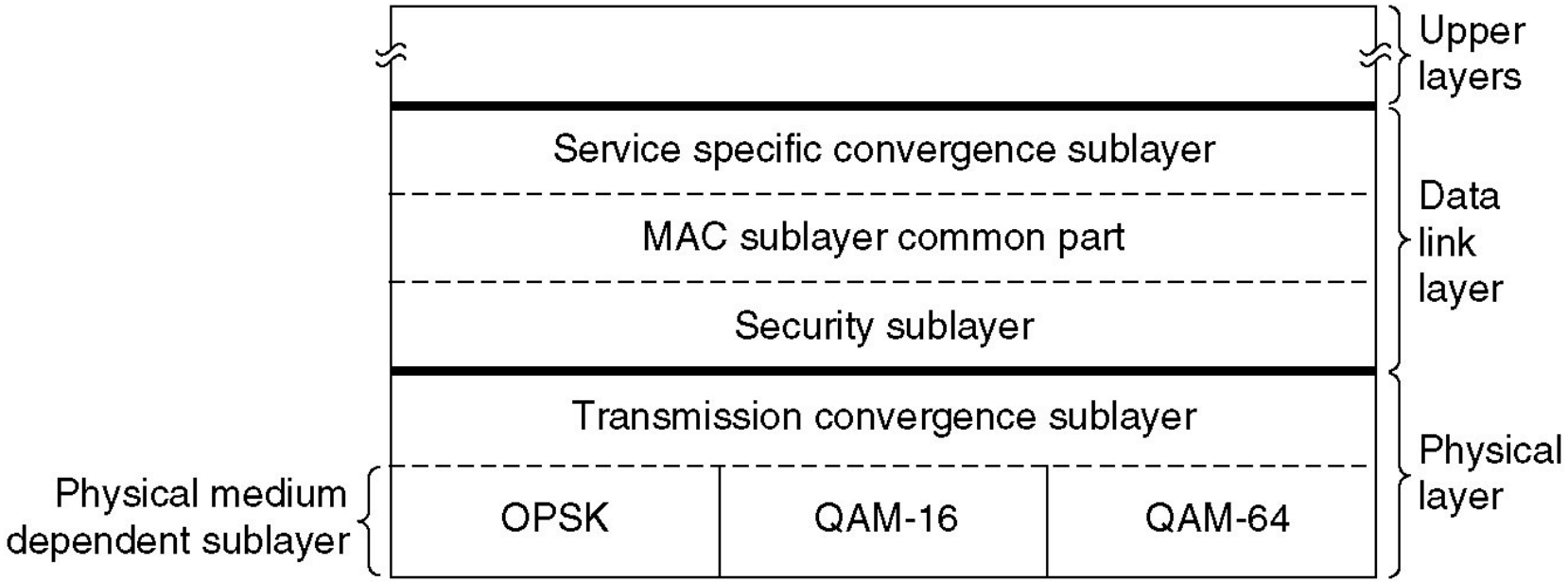
Intracell (within one cell) Services after association

- Authentication
  - Only authorized stations can send data.
- De-authentication
  - when a station leaves the network.
- Privacy
  - For confidentiality, information needs to be encrypted.
- Data Delivery
  - Transmitting and receiving data.

Broadband Wireless – IEEE 802.16

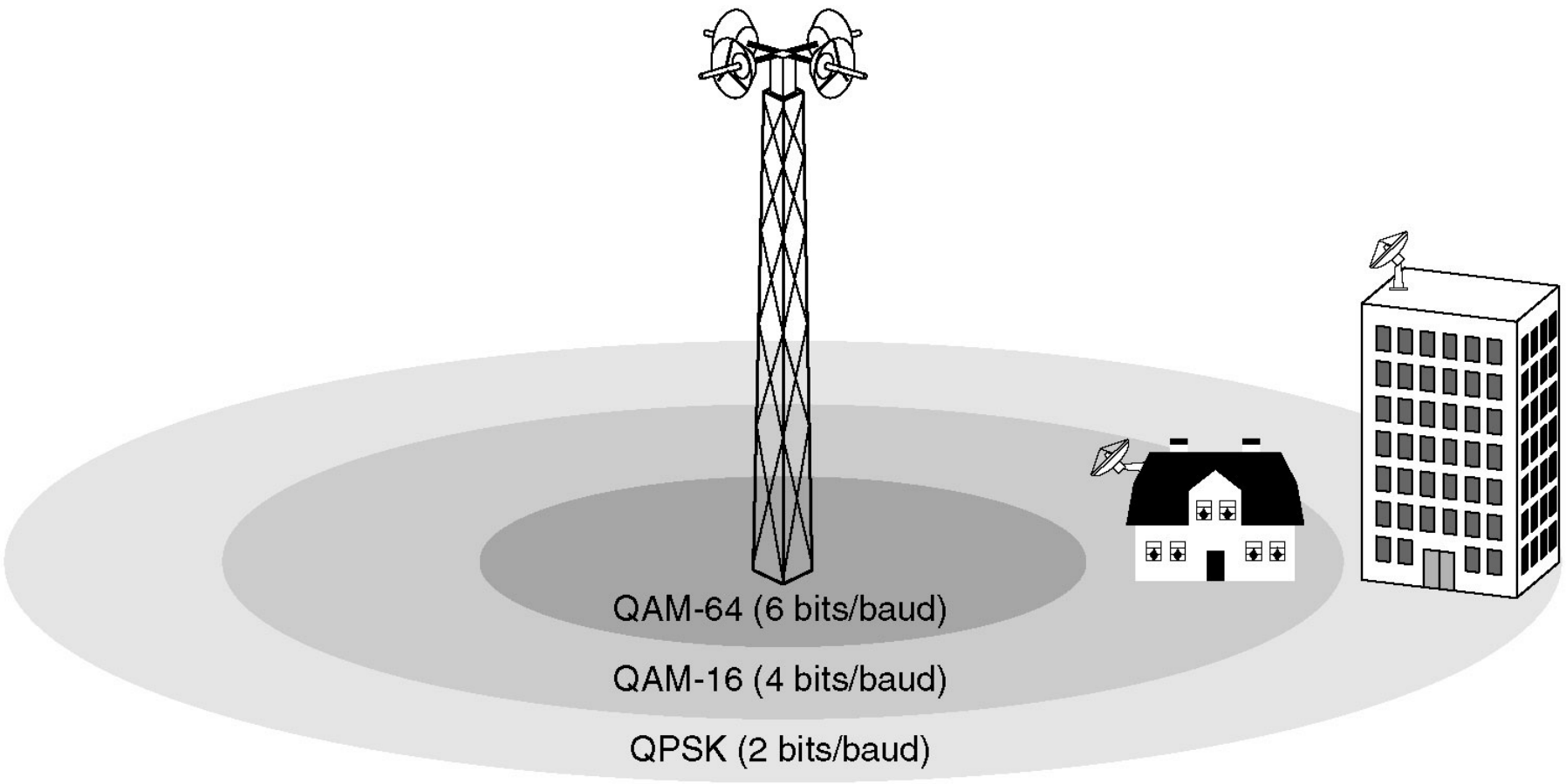
- Comparison of 802.11 and 802.16
  - ✓ 802.16d provides services to building (fixed).
    - Fixed Broadband Wireless Access System
  - ✓ 802.16e provides services to mobile users.
    - Mobile Broadband Wireless Access System
  - ✓ 802.11 provides services to mobile users.
- The 802.16 Protocol Stack
- The 802.16 Physical Layer
- The 802.16 MAC Sublayer Protocol
- The 802.16 Frame Structure

The 802.16 Protocol Stack



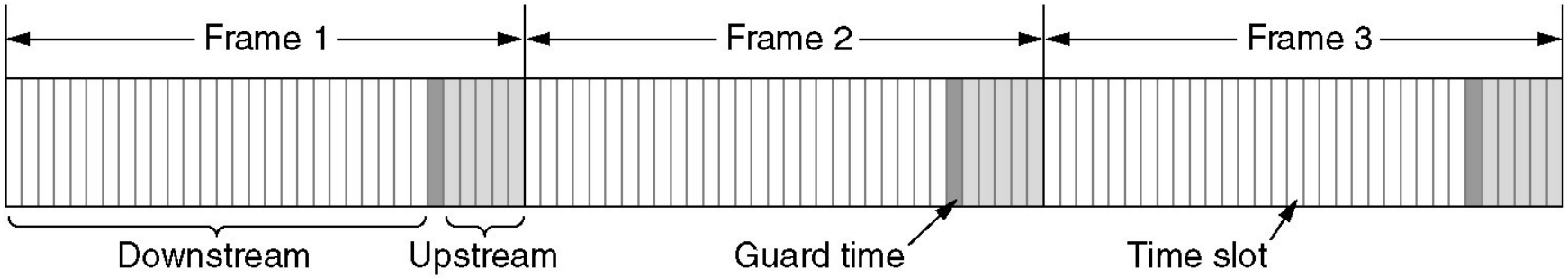
The 802.16 Protocol Stack.

The 802.16 Physical Layer



The 802.16 transmission environment.

The 802.16 Physical Layer (2)



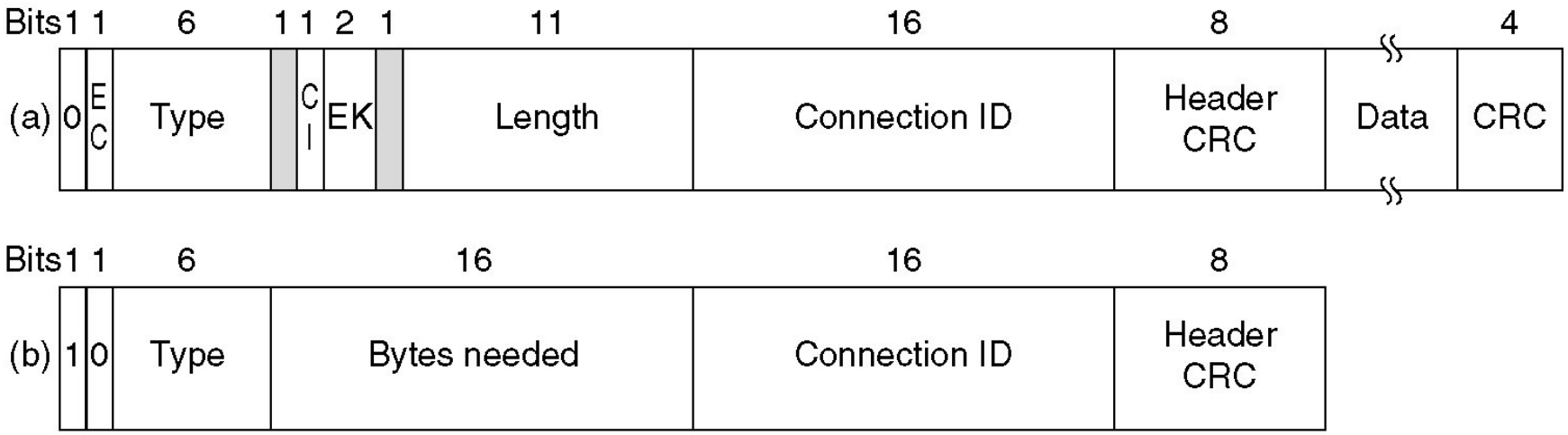
Frames and time slots for time division duplexing.

The 802.16 MAC Sublayer Protocol

Service Classes

- Constant bit rate service
- Real-time variable bit rate service
- Non-real-time variable bit rate service
- Best efforts service

The 802.16 Frame Structure



- EC – Is payload encrypted?
- Type – Frame type.
- CI – Has final CRC checksum?
- EK – Which encryption key is used?

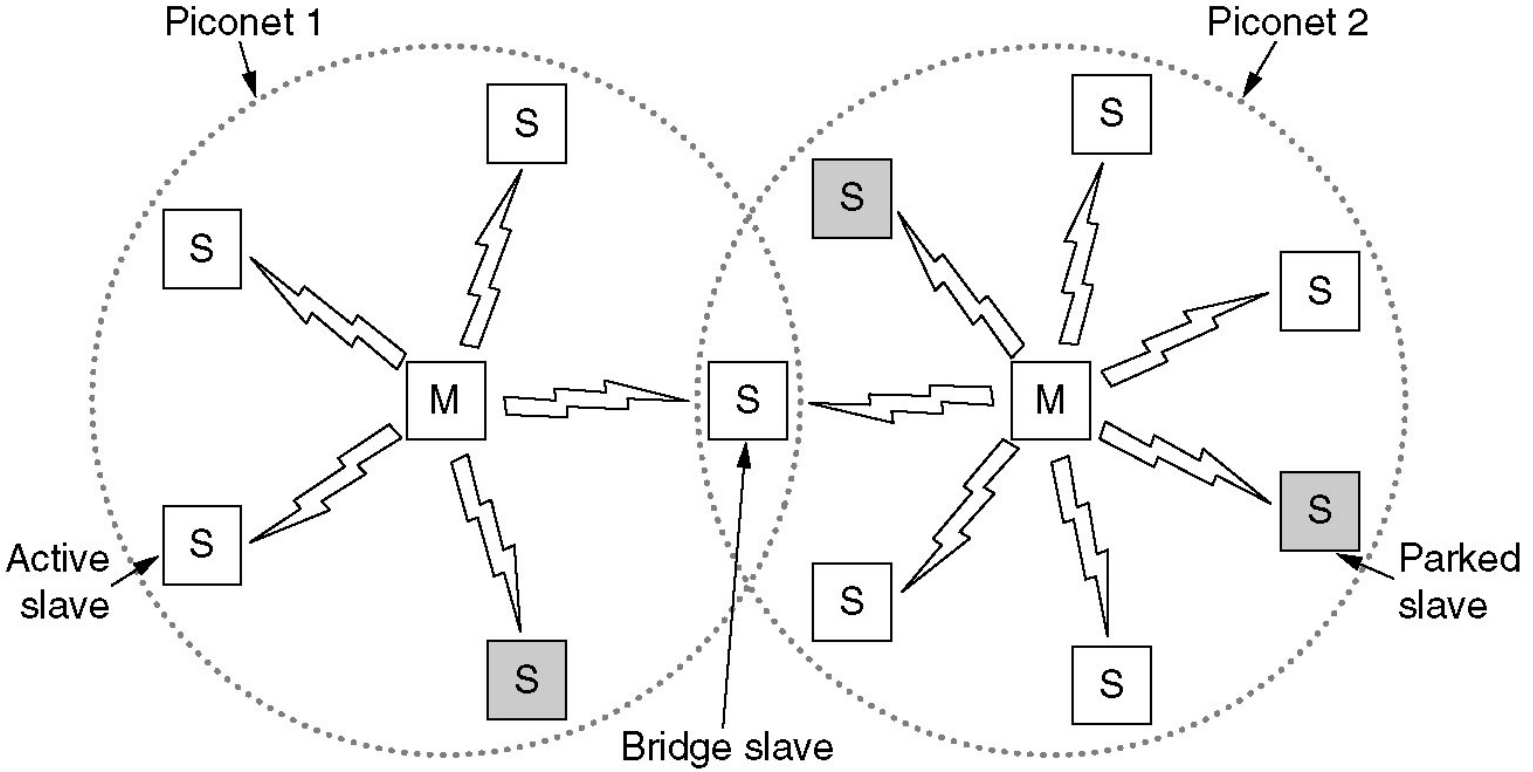
(a) A generic frame. (b) A bandwidth request frame.

Bluetooth (IEEE 802.15)

- Bluetooth Architecture
- Bluetooth Applications
- The Bluetooth Protocol Stack
- The Bluetooth Frame Structure

Bluetooth Architecture

- The basic unit of a Bluetooth system is a piconet
  - ✓ A master node and up to seven active slave nodes within 10 meters.
  - ✓ Two or more piconets can be connected to form a scatternet.
  - ✓ Bluetooth system is a low-cost, short-range wireless system.



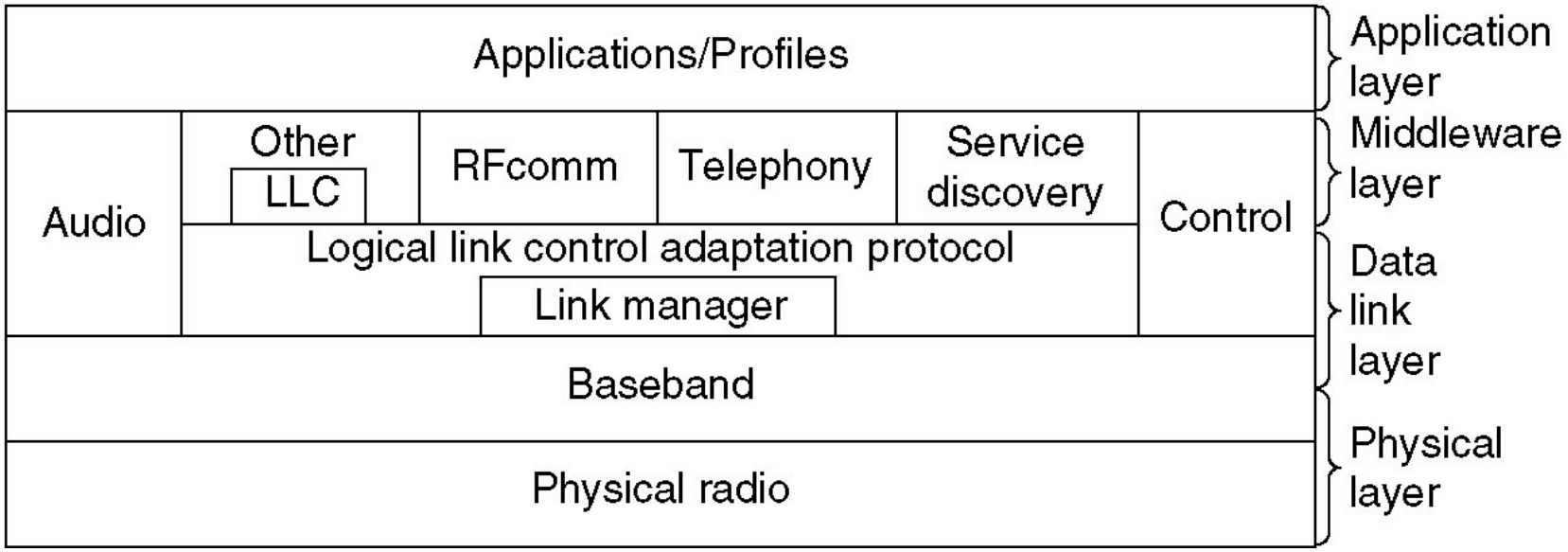
Two piconets can be connected to form a scatternet.

Bluetooth Applications

Name	Description
Generic access	Procedures for link management
Service discovery	Protocol for discovering offered services
Serial port	Replacement for a serial port cable
Generic object exchange	Defines client-server relationship for object movement
LAN access	Protocol between a mobile computer and a fixed LAN
Dial-up networking	Allows a notebook computer to call via a mobile phone
Fax	Allows a mobile fax machine to talk to a mobile phone
Cordless telephony	Connects a handset and its local base station
Intercom	Digital walkie-talkie
Headset	Intended for hands-free voice communication
Object push	Provides a way to exchange simple objects
File transfer	Provides a more general file transfer facility
Synchronization	Permits a PDA to synchronize with another computer

The Bluetooth profiles.

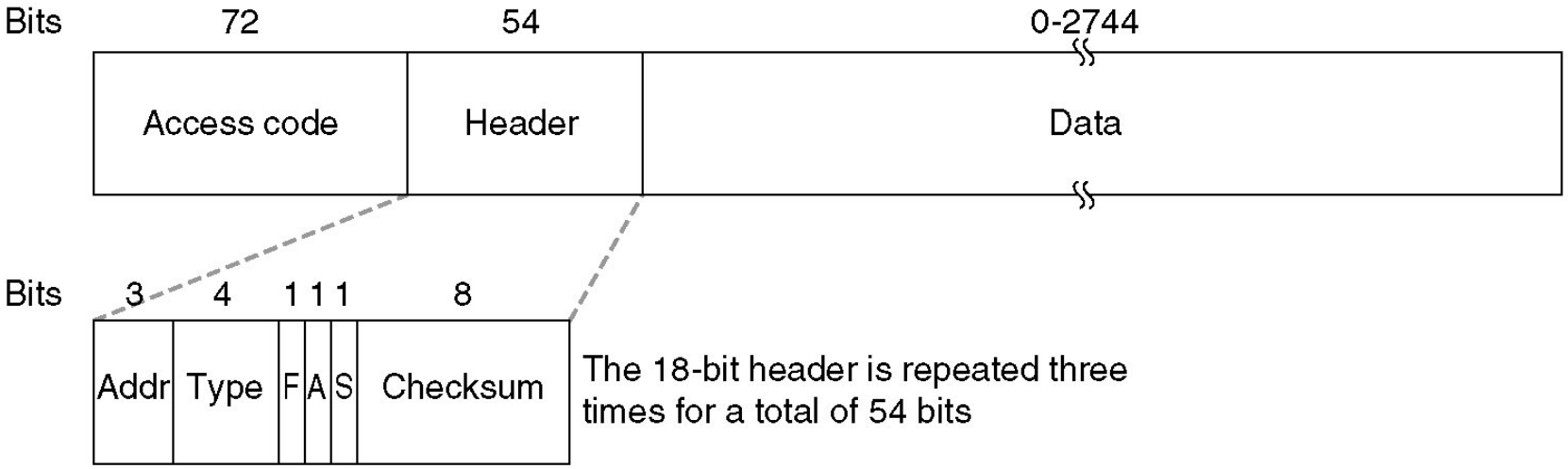
The Bluetooth Protocol Stack



The 802.15 version of the Bluetooth protocol architecture.

The Bluetooth Frame Structure

- ✓ Access code – identify the master node
- ✓ Header – typical MAC sublayer fields.
- ✓ F – Flow bit: 1 means that a slave's buffer is full and cannot receive any more data.
- ✓ A – Ack. Bit: used to piggyback an ACK.
- ✓ S – Sequence #: used to number the frames.

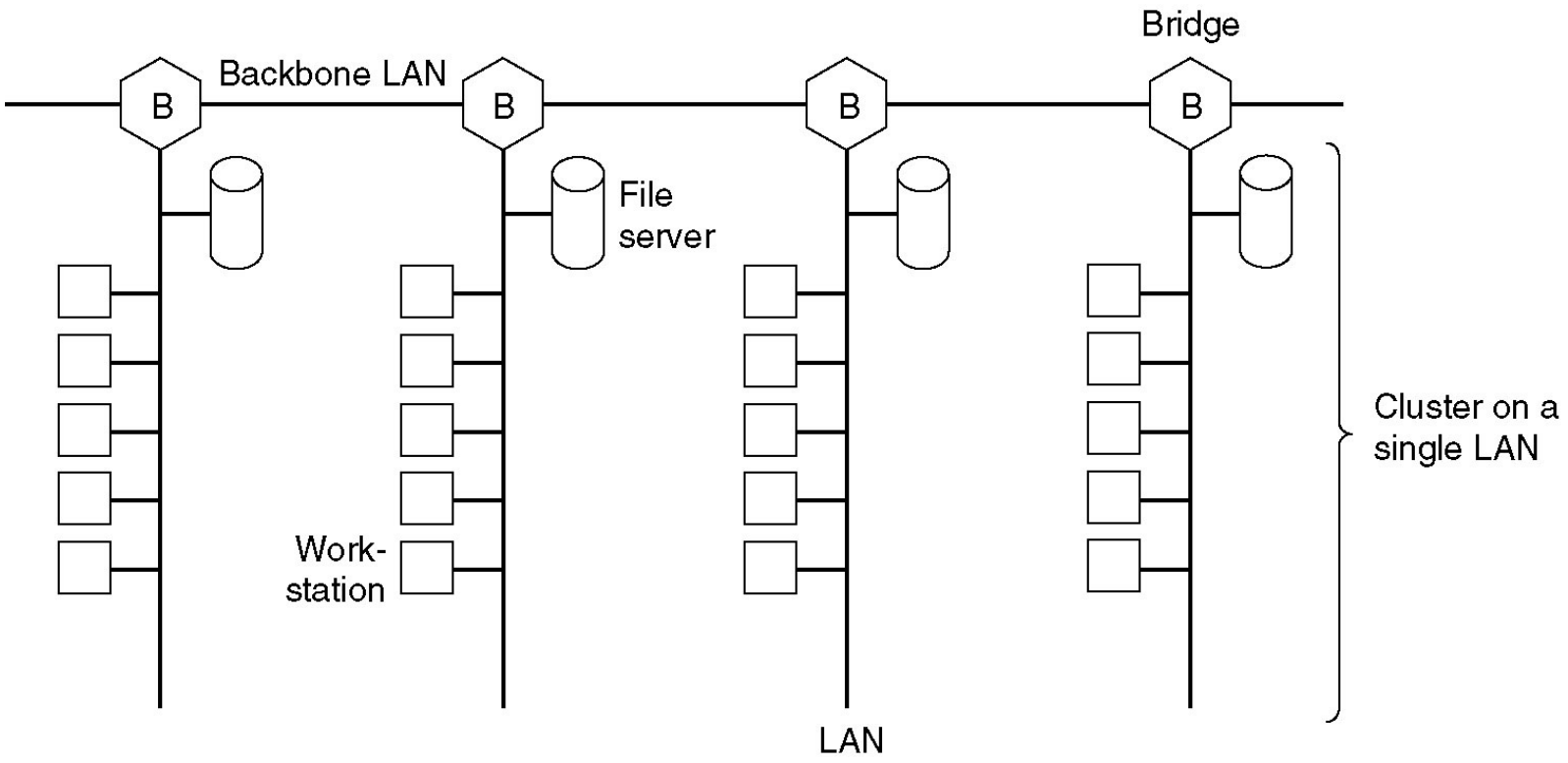


A typical Bluetooth data frame.

Data Link Layer Switching

- Bridges from 802.x to 802.y
  - ✓ Different LANs can be connected by bridges.
  - ✓ Bridges operate in the data link layer and use data link layer address to do routing.
  - ✓ Since bridges do not examine the payload field, they can transport IPv4, IPv6, ATM, OSI, or any other kinds of packets.
  - ✓ Routers examine the payload field (IP address in the network layer).
- Local Internetworking
- Spanning Tree Bridges
- Remote Bridges
- Repeaters, Hubs, Bridges, Switches, Routers, Gateways
- Virtual LANs

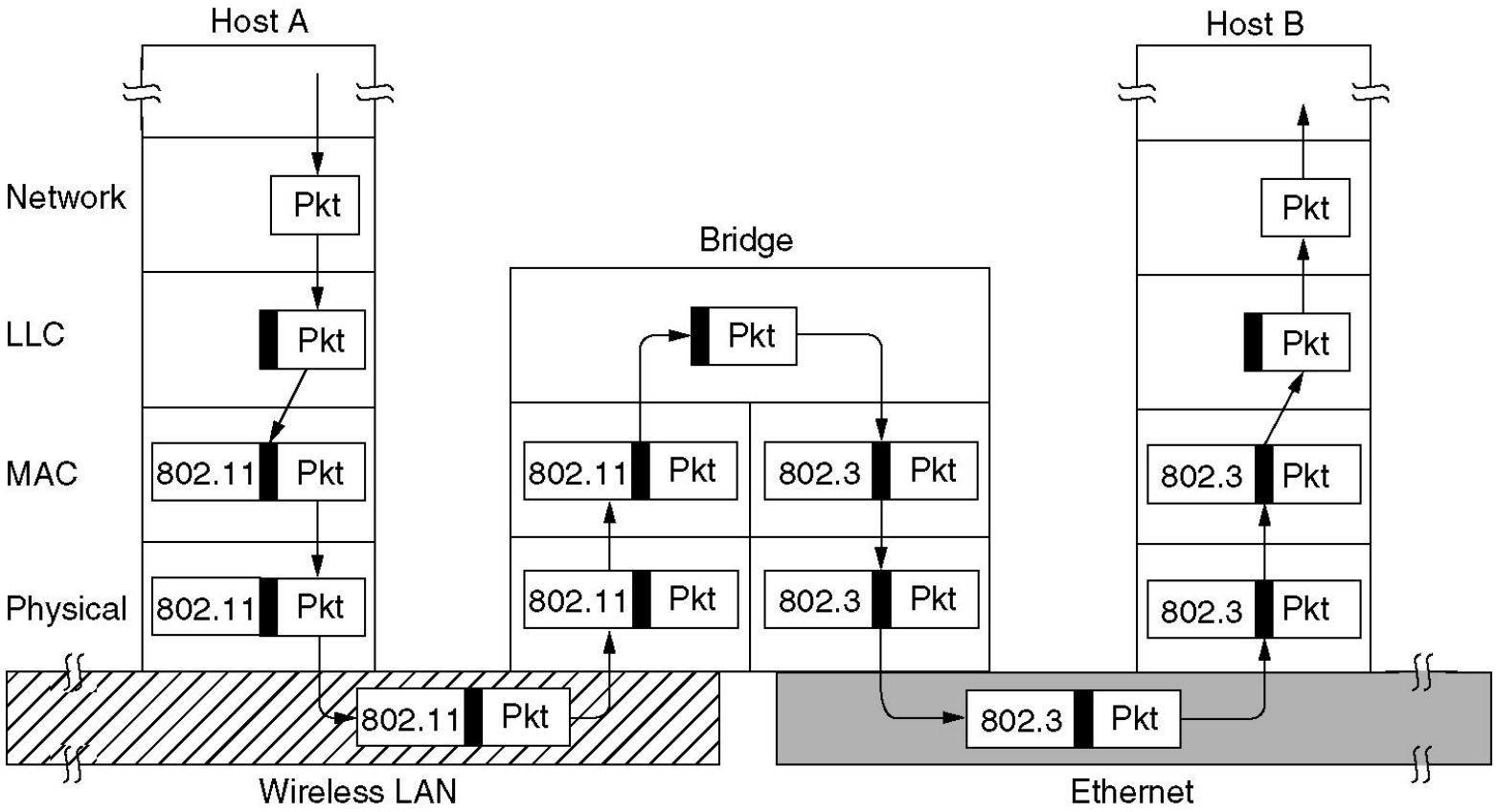
Data Link Layer Switching



Multiple LANs connected by a backbone to handle a total load higher than the capacity of a single LAN.

Bridges from 802.x to 802.y

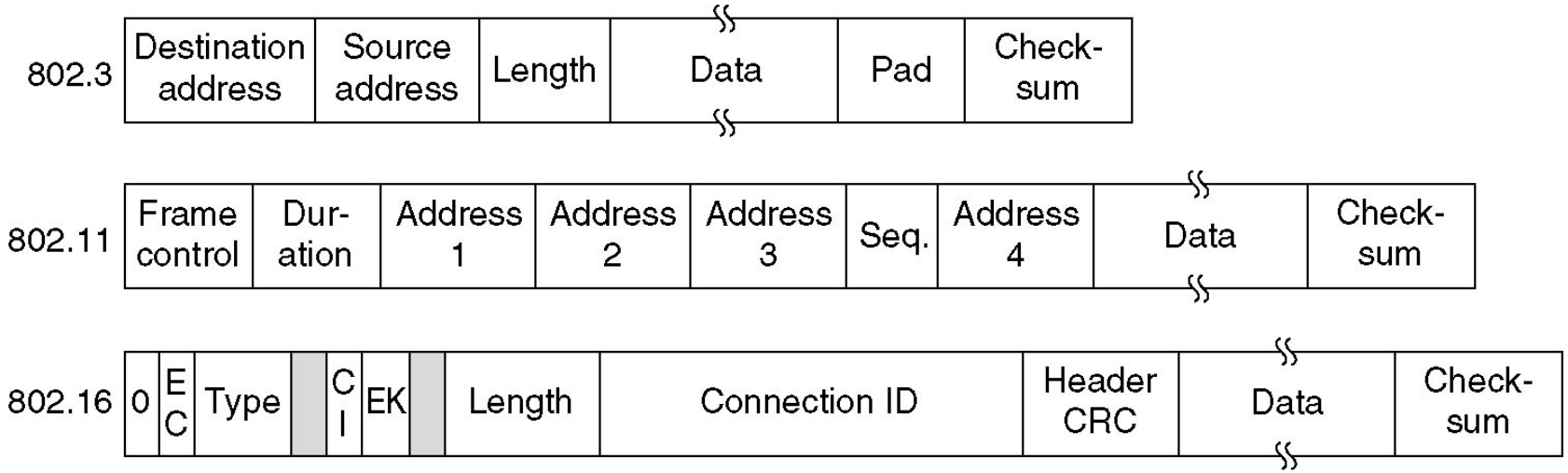
- An example: Communication from a Wireless LAN to an Ethernet



Operation of a LAN bridge from 802.11 to 802.3.

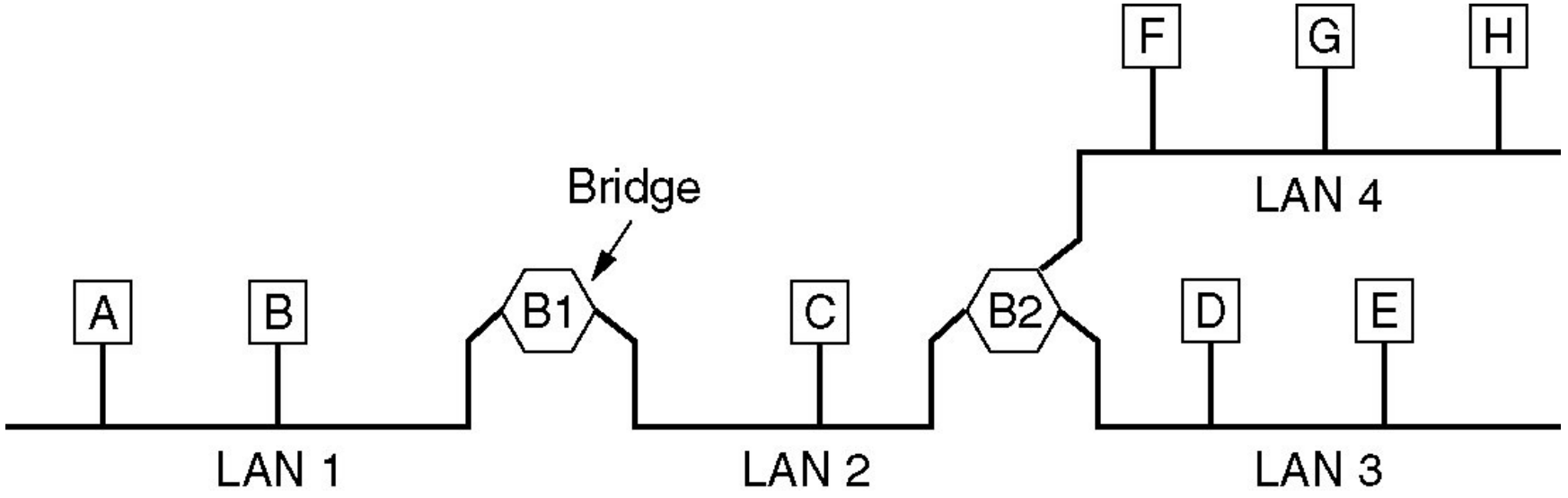
Bridges from 802.x to 802.y (2)

- ✓ Connecting two different LANs is not easy as it seems.



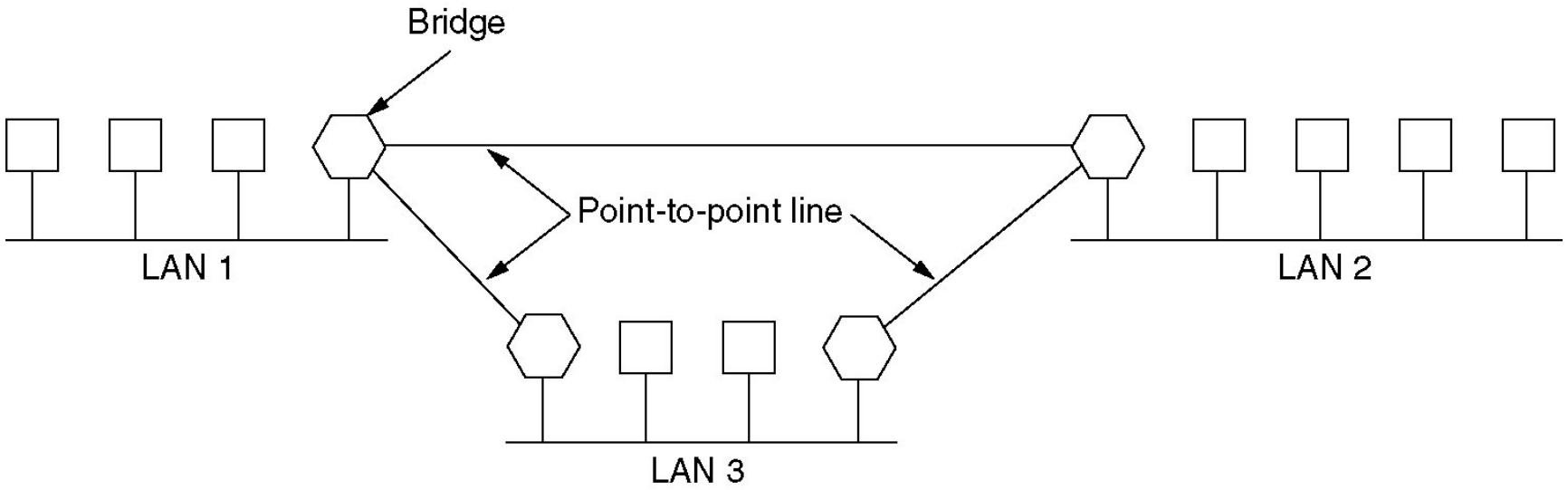
The IEEE 802 frame formats. The drawing is not to scale.

Local Internetworking



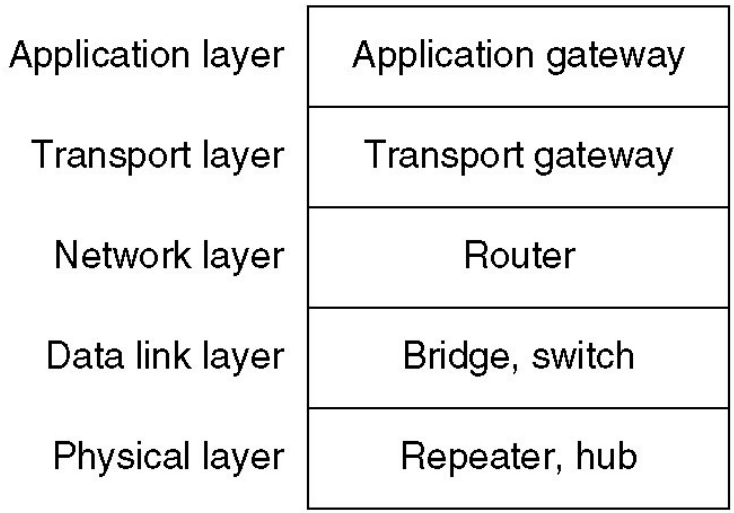
A configuration with four LANs and two bridges.

Remote Bridges

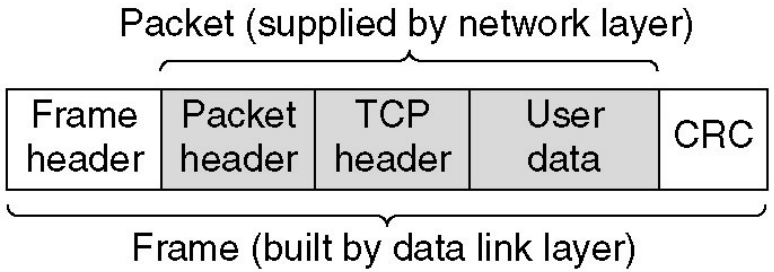


Remote bridges can be used to interconnect distant LANs.

Repeaters, Hubs, Bridges, Switches, Routers and Gateways



(a)

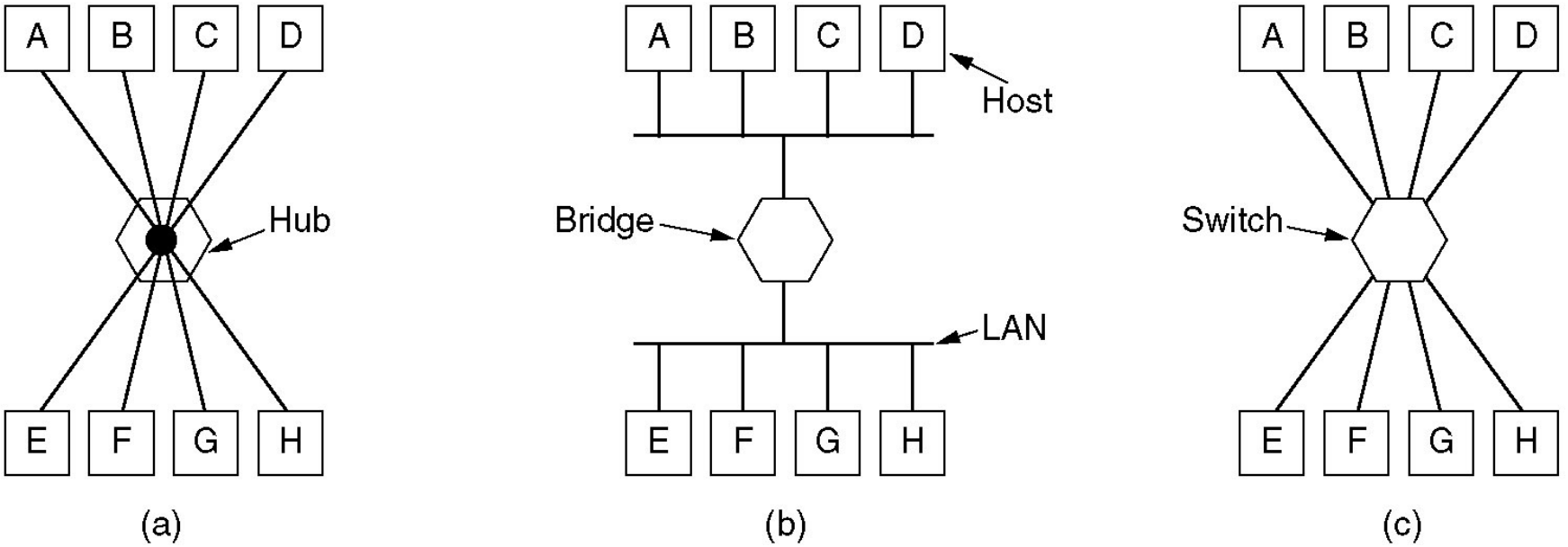


(b)

(a) Which device is in which layer.

(b) Frames, packets, and headers.

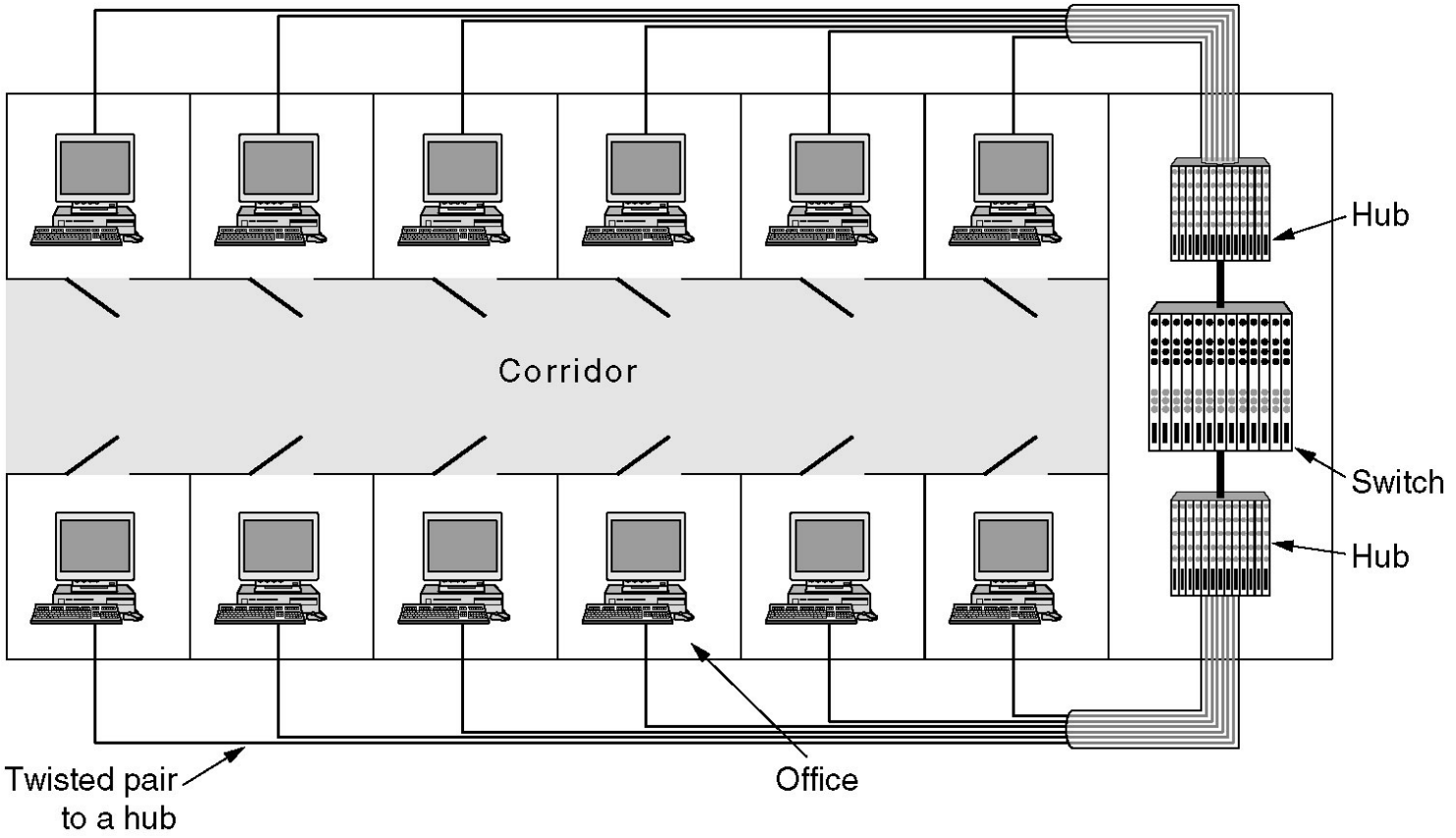
Repeaters, Hubs, Bridges, Switches, Routers and Gateways



(a) A hub. (b) A bridge. (c) a switch.

Virtual LANs

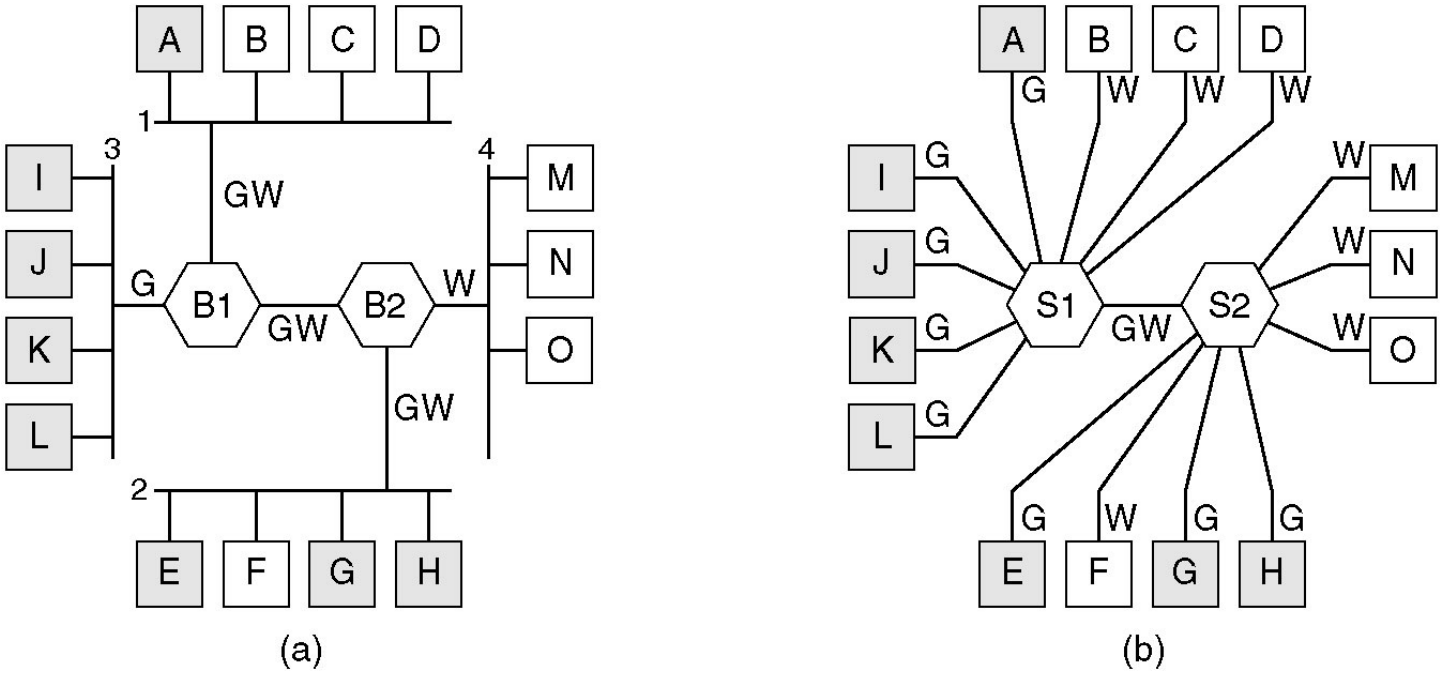
- ✓ Before having hubs and switches, LANs are formed based one physical locations of computers.
- ✓ Virtual LANs – LANs are formed based on organization, etc.



A building with centralized wiring using hubs and a switch.

Virtual LANs (2)

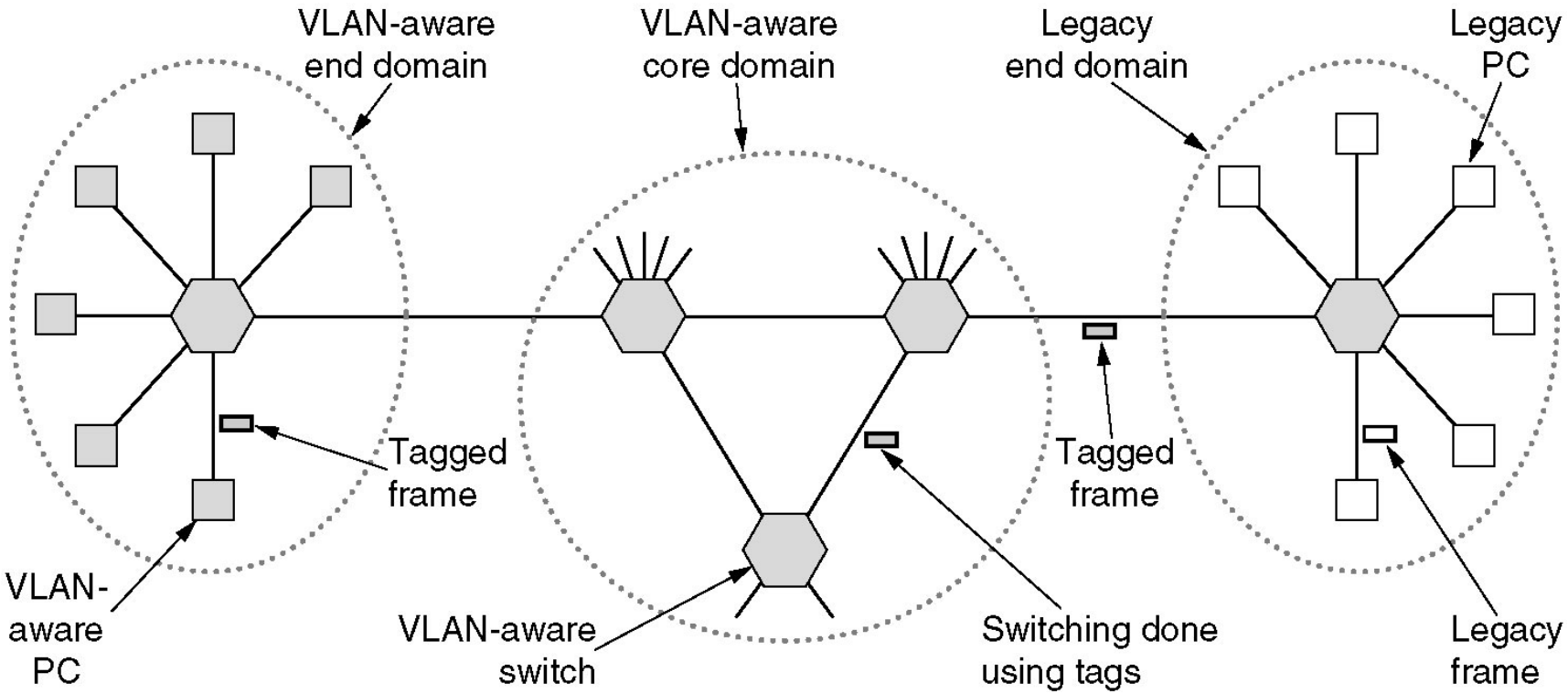
- ✓ Virtual LANs (VLANs) – Security; Load; Broadcasting (spam).
- ✓ VLANs are based on specially-designed VLAN-aware switches (installed special software)
- ✓ Configurable tables have to be set up in the bridges and switches.
  - The tables tell which VLANs are accessible via which ports (lines).



(a) Four physical LANs organized into two VLANs, gray and white, by two bridges.

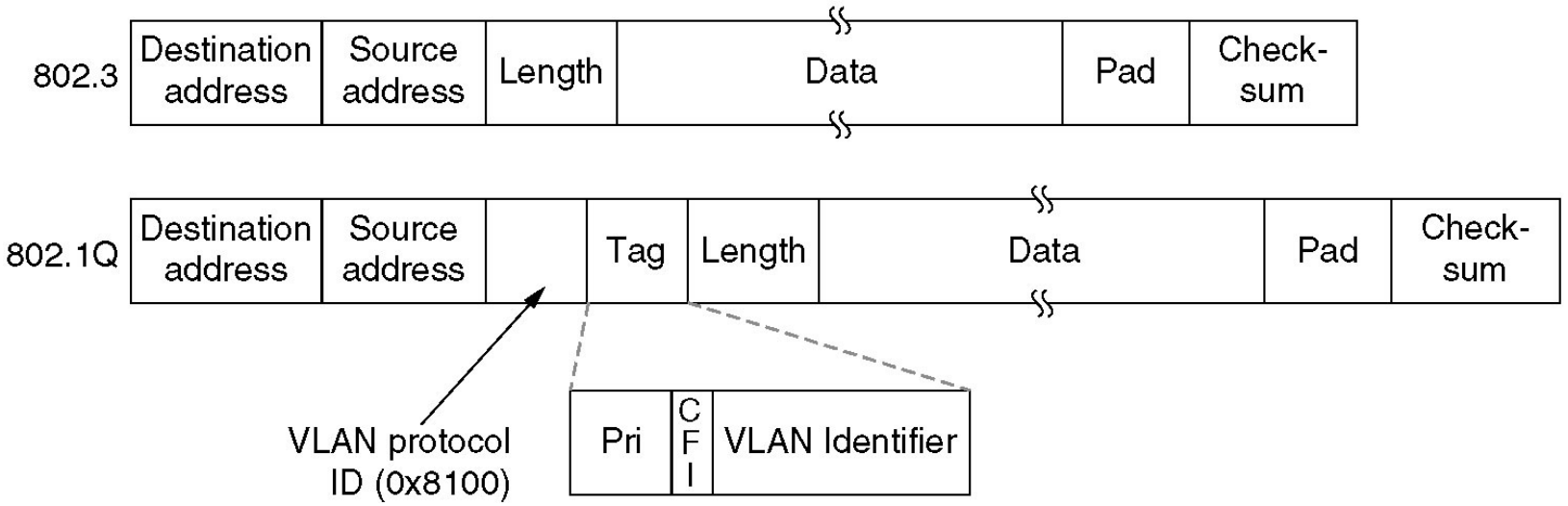
(b) The same 15 machines organized into two VLANs by switches.

The IEEE 802.1Q Standard



Transition from legacy Ethernet to VLAN-aware Ethernet. The shaded symbols are VLAN aware. The empty ones are not.

The IEEE 802.1Q Standard (2)



- Pri – 3-bit Priority field: real-time traffic?
- CFI – Canonical Format Indicator: Used to indicate if little (or big) endian MAC address. Now refers to a 802.5 frame.

The 802.3 (legacy) and 802.1Q Ethernet frame formats.

Summary

Method	Description
FDM	Dedicate a frequency band to each station
WDM	A dynamic FDM scheme for fiber
TDM	Dedicate a time slot to each station
Pure ALOHA	Unsynchronized transmission at any instant
Slotted ALOHA	Random transmission in well-defined time slots
1-persistent CSMA	Standard carrier sense multiple access
Nonpersistent CSMA	Random delay when channel is sensed busy
P-persistent CSMA	CSMA, but with a probability of p of persisting
CSMA/CD	CSMA, but abort on detecting a collision
Bit map	Round robin scheduling using a bit map
Binary countdown	Highest numbered ready station goes next
Tree walk	Reduced contention by selective enabling
MACA, MACAW	Wireless LAN protocols
Ethernet	CSMA/CD with binary exponential backoff
FHSS	Frequency hopping spread spectrum
DSSS	Direct sequence spread spectrum
CSMA/CA	Carrier sense multiple access with collision avoidance

Channel allocation methods and systems for a common channel.