Chapter 4

The Medium Access Control Sublayer

4.1 The Channel Allocation Problem

- Sharing Broadcasting Medium
- Multiplexing
- Static Channel Allocation
- Dynamic Channel Allocation

4.1.1 Static Channel Allocation

- FDM/TDM
  - Constant number of users
  - Heavy and steady load of traffic
- Inefficient for burst data
- Queue theory
  - Mean time delay, T,
  - Channel capacity C bps,
  - Arrival rate of λframes/sec,
  - $1/\mu$ bits/frame
  - service rate is μC frames/sec.
  - Poisson arrival and service times
  - $T=1/(\mu C- \lambda)$
  - $T_{FDM}=1/(\mu C/N – \lambda/N) = NT$

4.1.2 Dynamic Channel Allocation in LANs and MANs

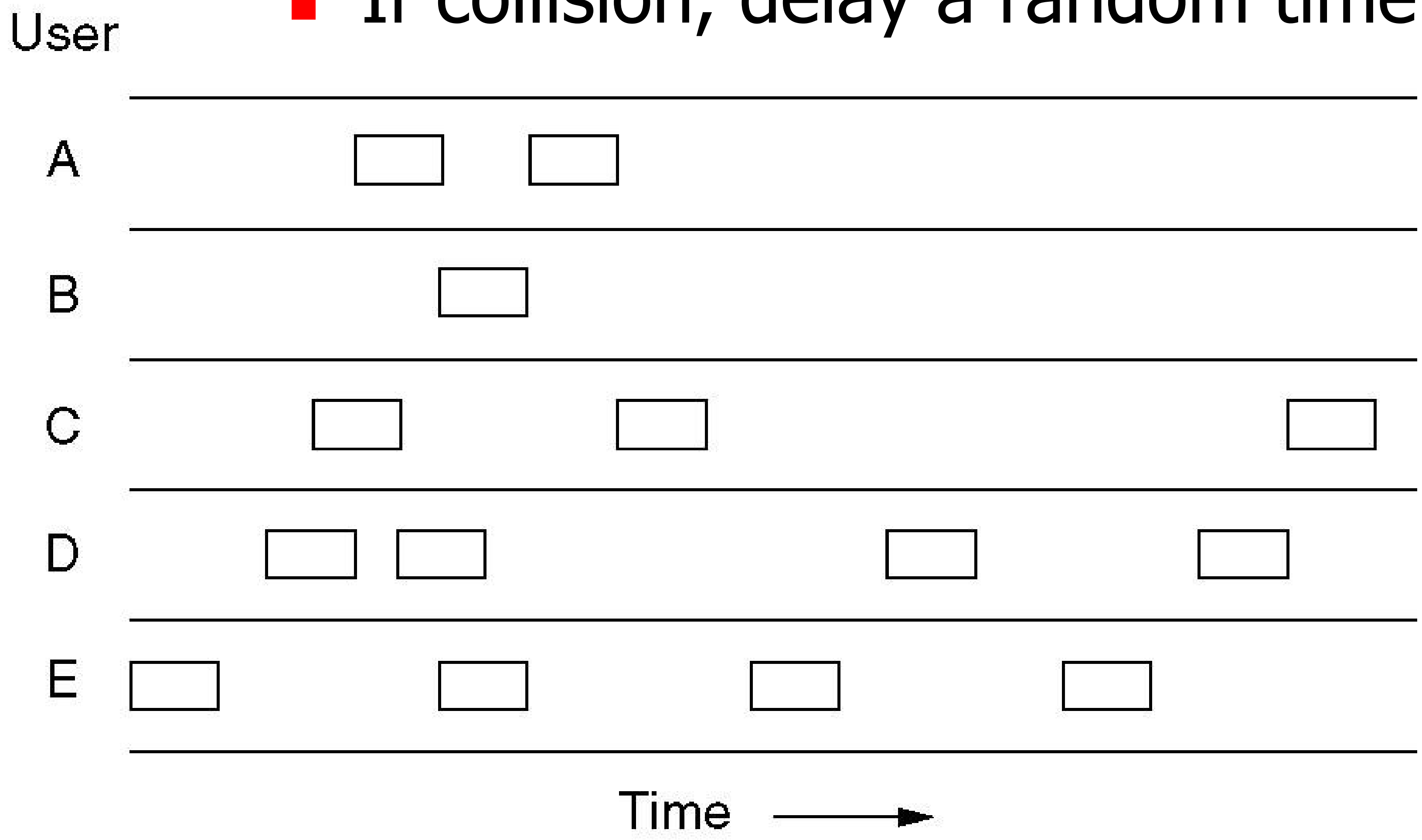
- Station Model.
  - The arrival rate of new frames is λ, a constant .
  - Once a frame has been generated, the station is blocked and does nothing until the frame has been successfully transmitted.
- Single Channel Assumption.
- Collision Assumption.
- (a) Continuous Time.
  (b) Slotted Time.
- (a) Carrier Sense.
  (b) No Carrier Sense.

4.2 Multiple Access Protocols

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

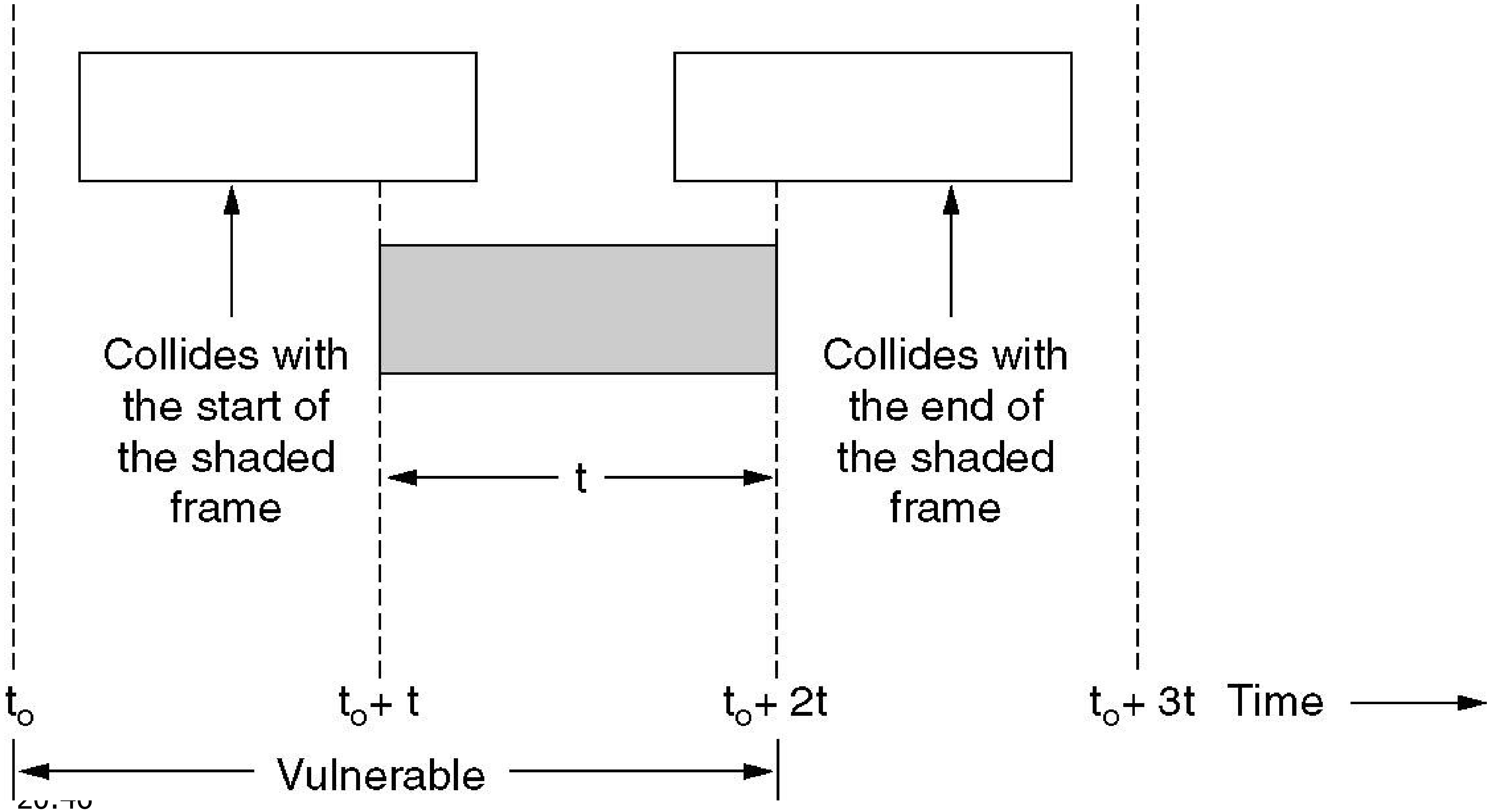
4.2.1 ALOHA(1)

- Pure ALOHA
  - Frames are transmitted at completely arbitrary times.
  - Listen when sending to detect collision
  - If collision, delay a random time and retransmit



4.2.1 ALOHA (2)

- Vulnerable period for the shaded frame.



4.2.1 ALOHA (3)

- Efficiency of pure ALOHA
  - Frame time:the amount of time needed to transmit a standard frame.
  - S: **throughput**, the number of new frames generated per frame time, $0<S<1$
  - G: the number of frames (new and old) waited for send per frame time $S<=G$
  - P_0: the probability that a frame does not suffer a collision
  - $S=GP_0$
  - The probability that k frames are generated during a given frame time according the Poisson distribution:$Pr[k] = G^k e^{-G}/k!$
  - When k=0 (no other frame to send), $P_0=e^{-G}$
  - In two frame time, the number of frames generated is 2G, $P_0=e^{-2G}$,$S=Ge^{-2G}$
  - When G = 0.5 , S=1/2e, a maximum throughput

4.2.1 ALOHA (4)*

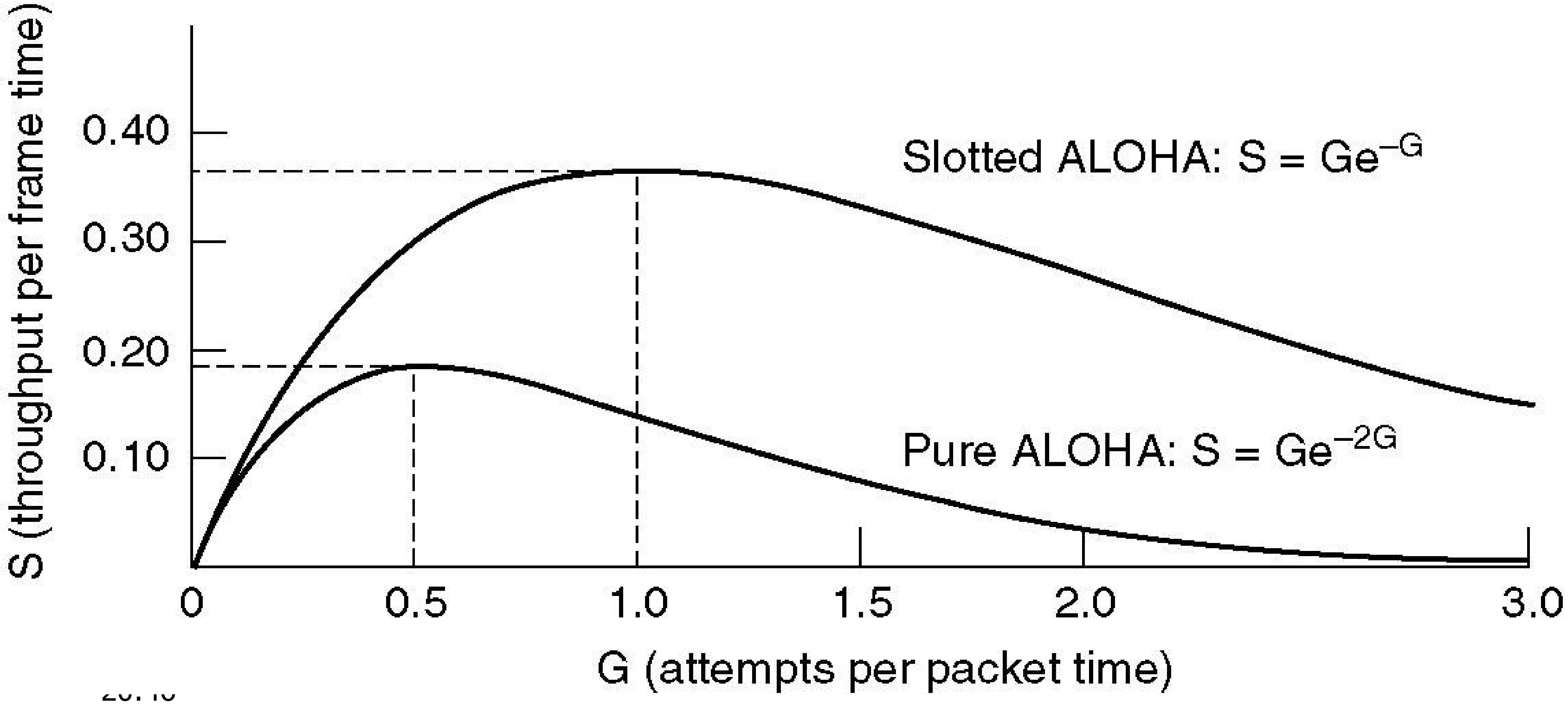
- Delay of pure ALOHA
  - Average **times** used to send one frame successfully is $G/S=e^{2G}$
  - Failed times is $G/S - 1=e^{2G} - 1$
  - B is a random backoff delay time
  - P is average time of sent a frame
  - Average time of successfully sending a frame is $P + (e^{2G} - 1)(P + B)$
  - If $B=0$, At $S = 0.184$, $T_{min} = Pe^{2G} = eP = 2.718P$

4.2.1 ALOHA (5)

- Slotted ALOHA
- Sending when the next slot begins
- Vulnerable period only at one slot time
  - $P_0=e^{-G}$,$S=Ge^{-G}$
  - When G = 1 , S=1/e, a maximum throughput

4.2.1 ALOHA (6)

- Throughput versus offered traffic for ALOHA systems.

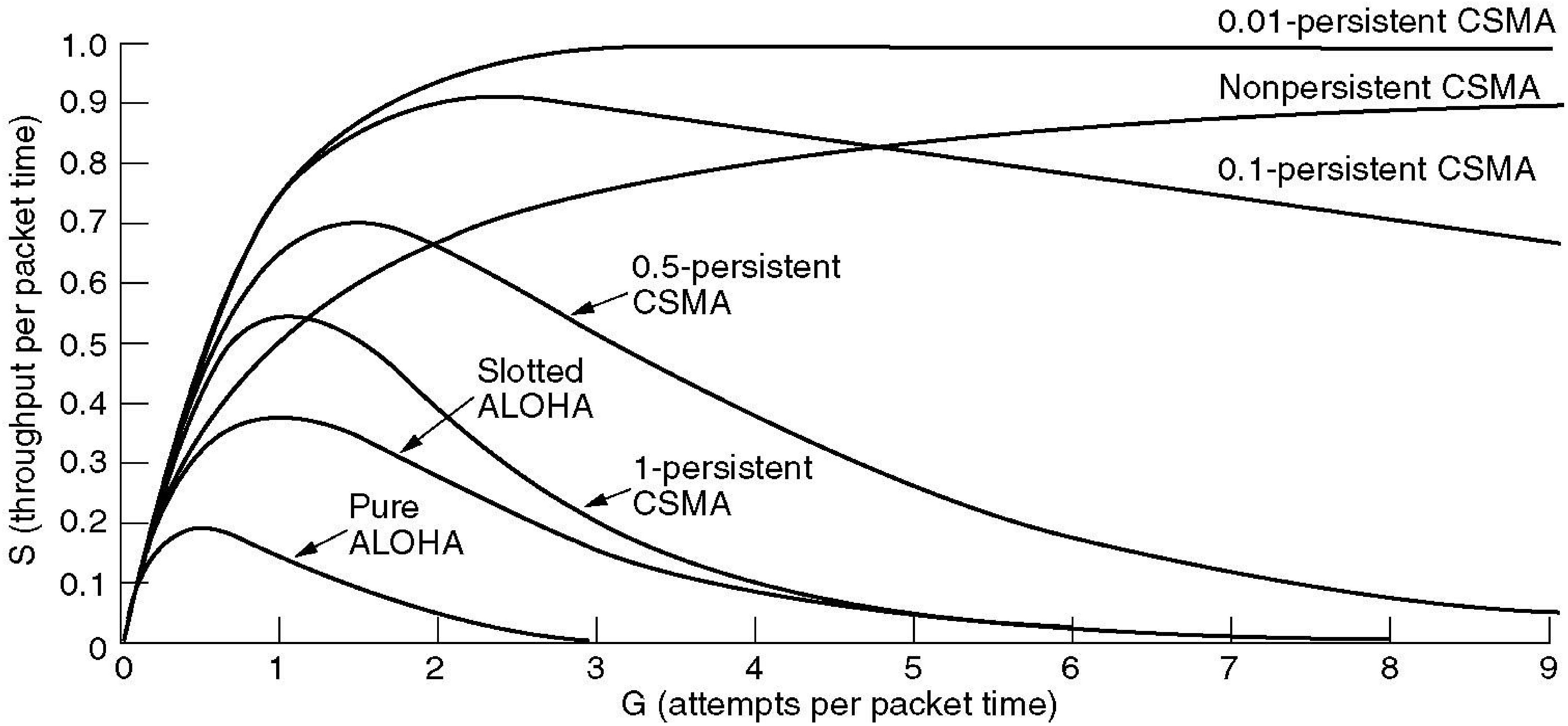


4.2.2 Carrier Sense Multiple Access Protocol (1)

- Persistent and Nonpersistent CSMA
  - 1-persistent CSMA
  - Nonpersistent CSMA
  - P-persistent CSMA

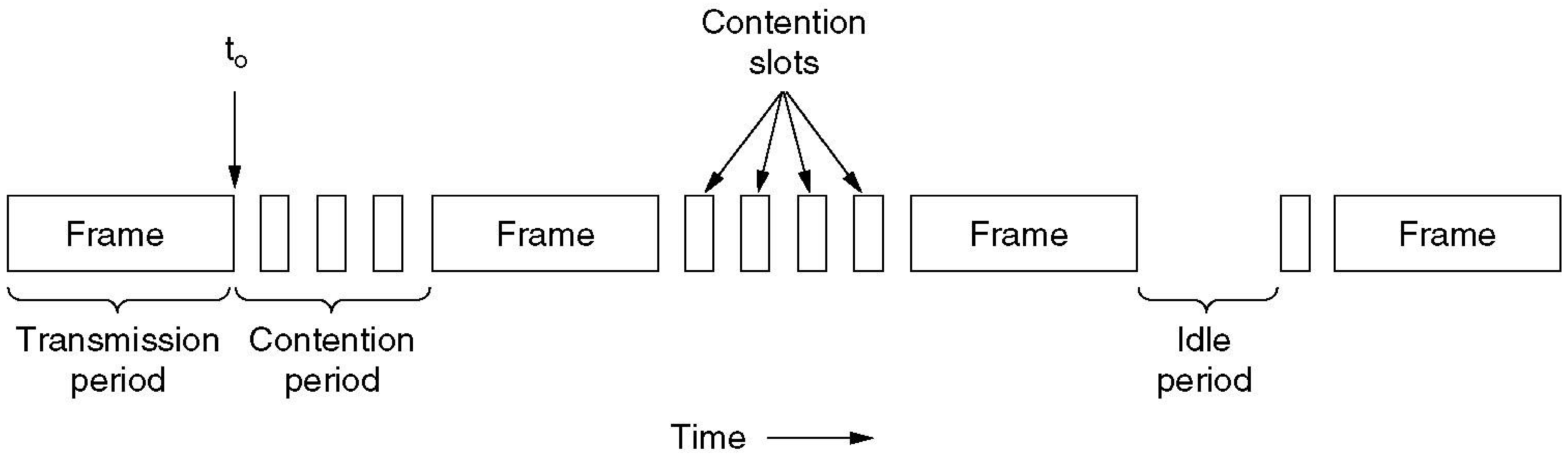
4.2.2 Carrier Sense Multiple Access Protocol (2)

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



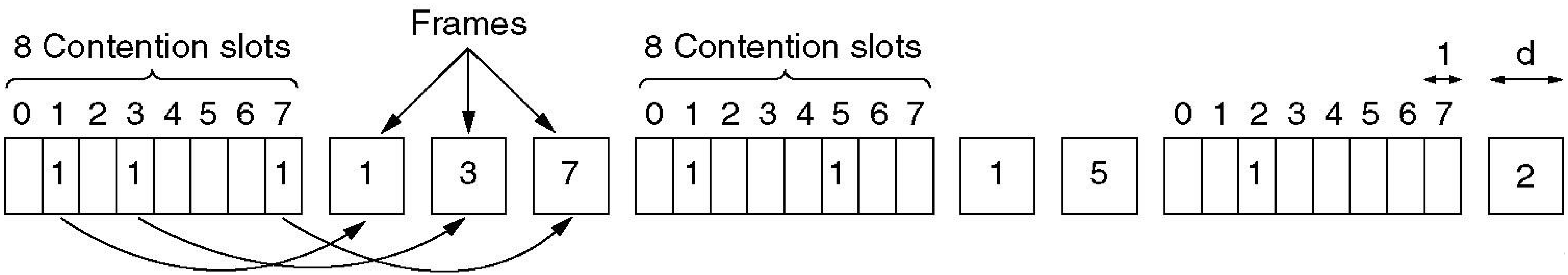
4.2.2 Carrier Sense Multiple Access Protocol (3)

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

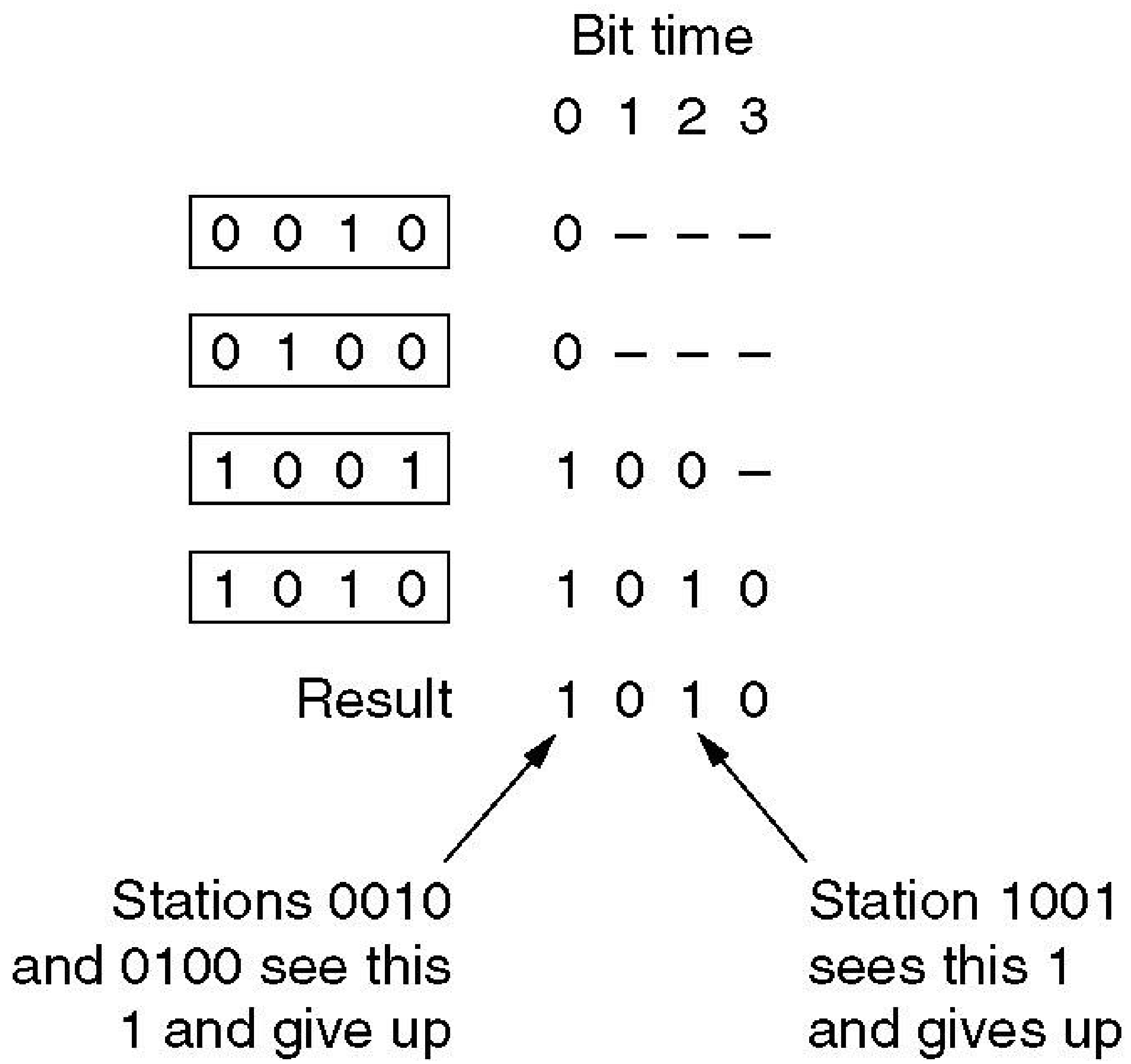


4.2.3 Collision-Free Protocols (1)

- The basic bit-map protocol.
- Efficiency of bit-map
  - Low load, the bit map repeated over and over.
    - Low-numbered station, On average, will wait N/2+N slots.
    - high-numbered station will wait N/2 slots
    - the mean for all stations is N slots
  - High load, the N bit contention period is prorated over N frames
    - an efficiency of d/(d + 1).
    - The mean delay for a frame is equal to N(d + 1)/2.



4.2.3 Collision-Free Protocols (2)



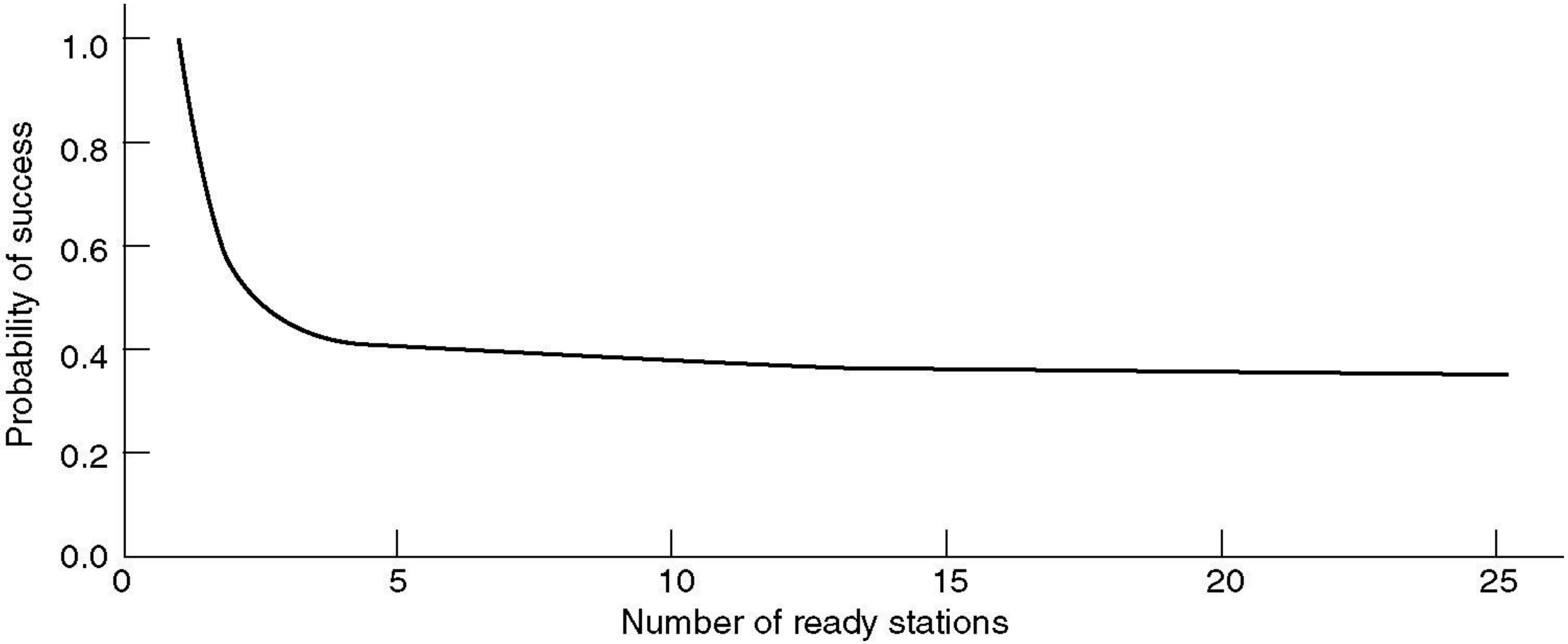
- The binary countdown protocol. (A dash indicates silence.)
  - The efficiency is $d/(d + \log_2 N)$.
  - If the sender's address is the first field in the frame, the efficiency is 100 percent.
  - No delay when low load
  - Problem: Priority

4.2.4 Limited-Contention Protocols(1)*

- Load, Delay, Efficiency
- Using contention at low load to provide low delay. Using collision-free at high load to provide good channel efficiency.
- Suppose that **k** stations are contending for channel access.
  - Each has a probability p of transmitting during each slot.
  - The probability that some station successfully acquires the channel during a given slot is $kp(1 - p)^{k - 1}$.
  - The optimal value of p is 1/k.
  - $Pr = (1-1/k)^{k-1}$
  - Less than 5 station is appropriate

4.2.4 Limited-Contention Protocols(2)

- Acquisition probability for a symmetric contention channel.

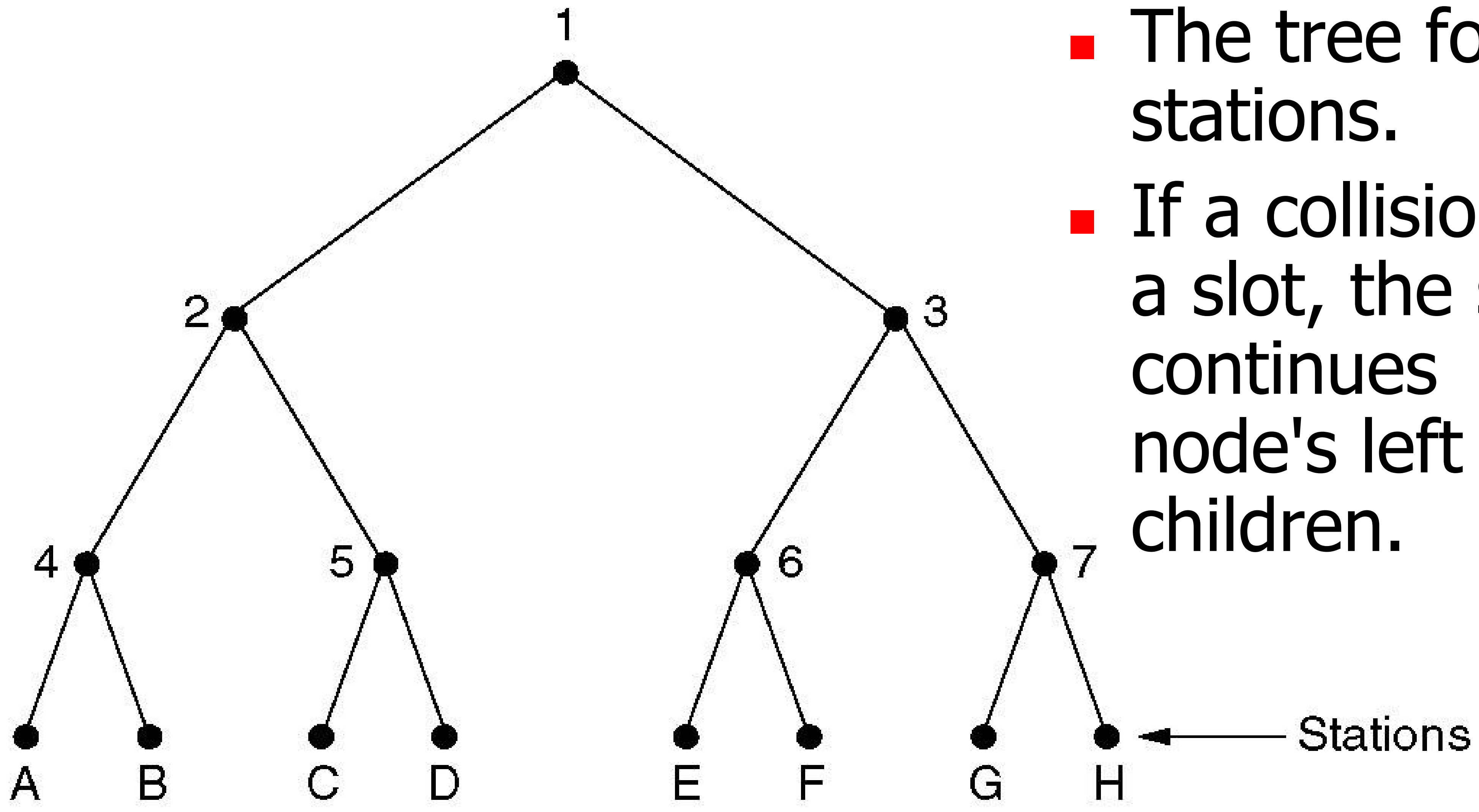


4.2.4 Limited-Contention Protocols(3)

- Divide the stations into groups
- Only the members of group N are permitted to compete for slot N.
- The amount of contention for each slot can be reduced.

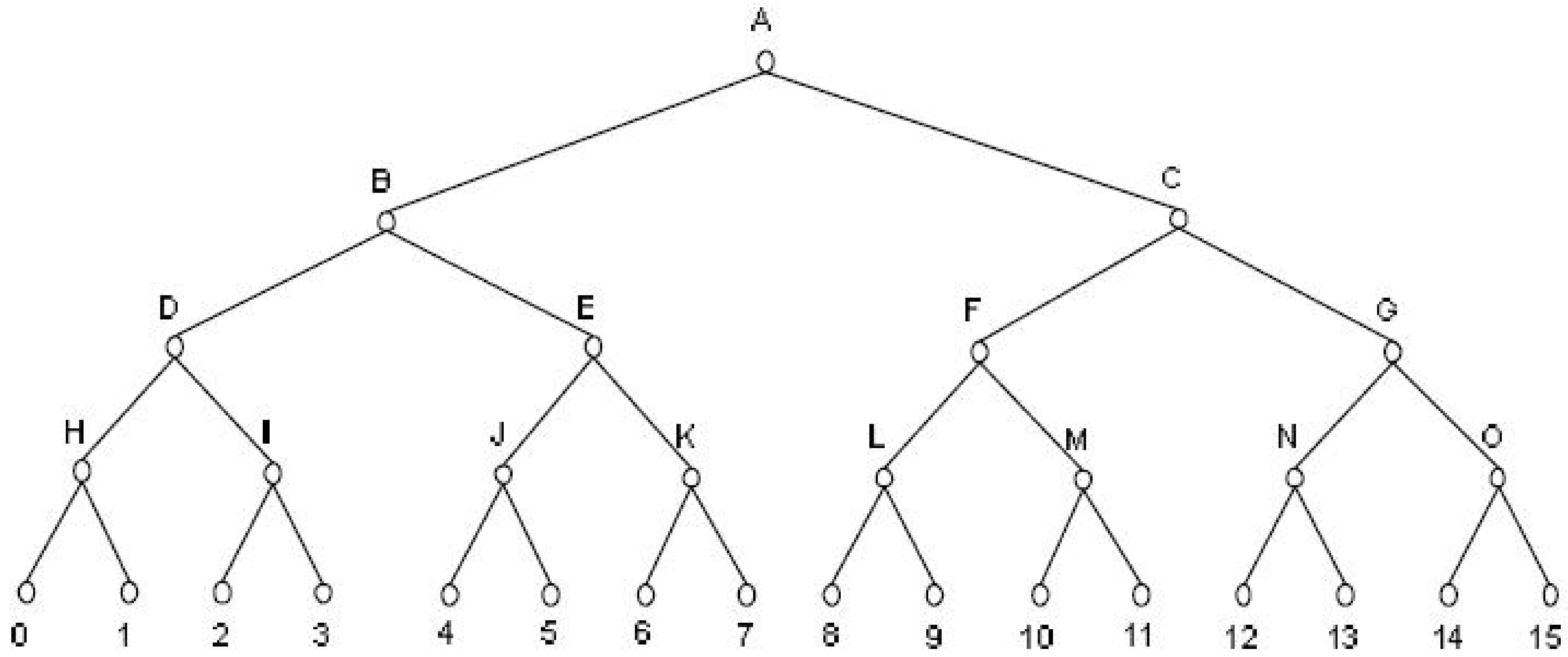
- Each group has but one member: Bit-map and Binary countdown.
- A single group containing all stations: Slotted ALOHA

4.2.4 Limited-Contention Protocols(4)



- Adaptive Tree Walk Protocol
  - The tree for eight stations.
  - If a collision occurs at a slot, the search continues with the node's left and right children.

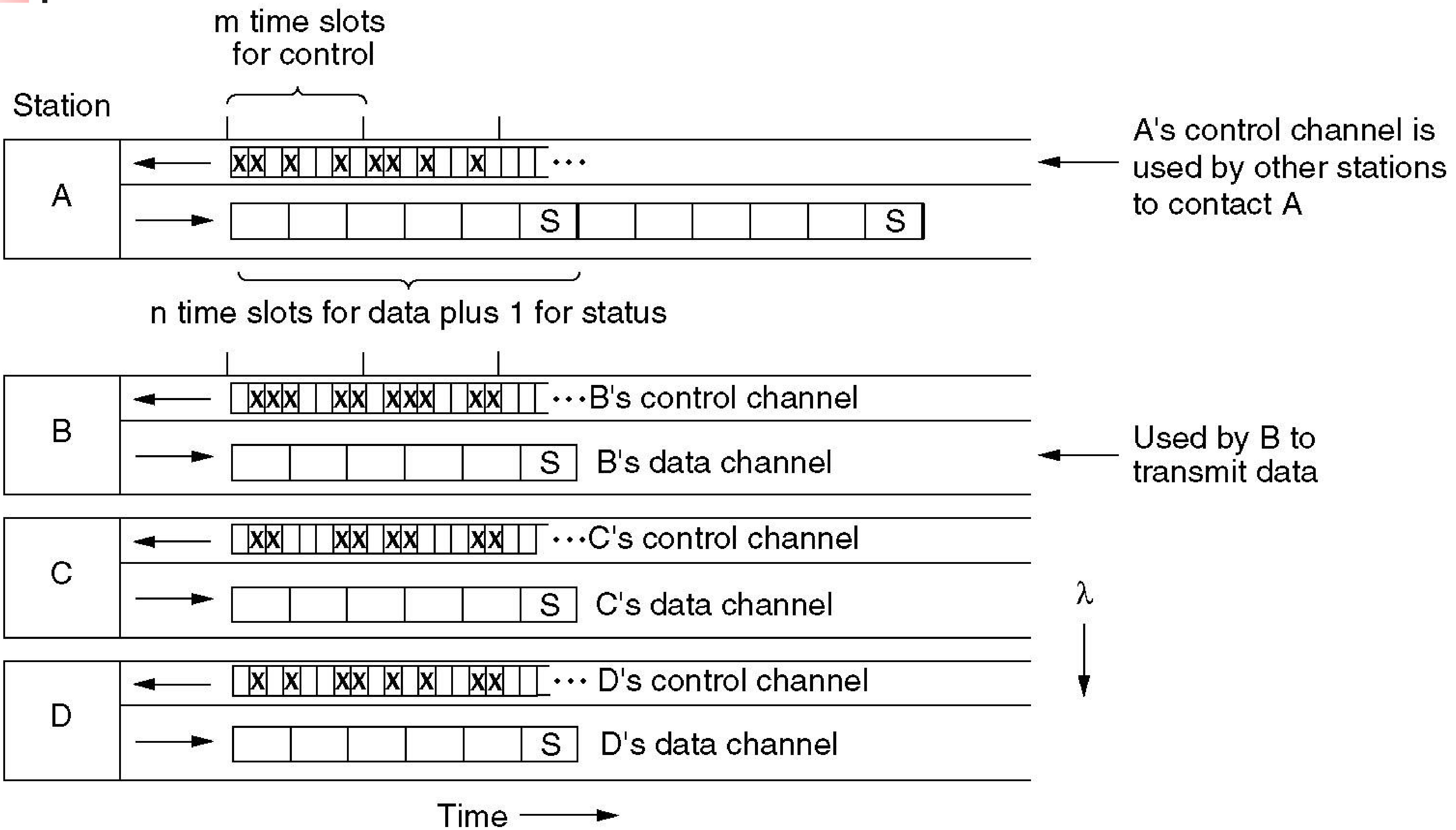
- Sixteen stations, numbered 1 through 16, are contending for the use of a shared channel by using the adaptive tree walk protocol. If all the stations whose addresses are prime numbers suddenly become ready at once, how many bit slots are needed to resolve the contention.



- **本题中，站2、3、5、7、11 和13 要发送**
- 第一时隙：2、3、5、7、11、13
- 第二时隙：2、3、5、7
- 第三时隙：2、3
- 第四时隙：空闲
- 第五时隙：2、3
- 第六时隙：2
- 第七时隙：3
- 第八时隙：5、7
- 第九时隙：5
- 第十时隙：7
- 第十一时隙：11、13
- 第十二时隙：11
- 第十三时隙：13

4.2.5 Wavelength Division Multiple Access Protocols*

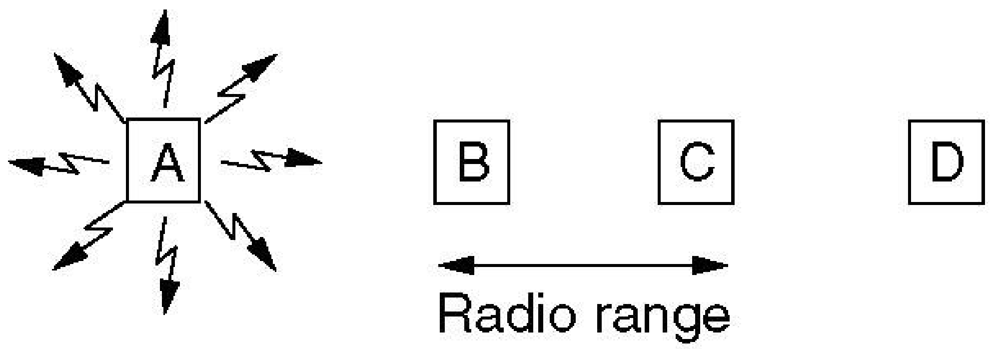
- Wavelength division multiple access.



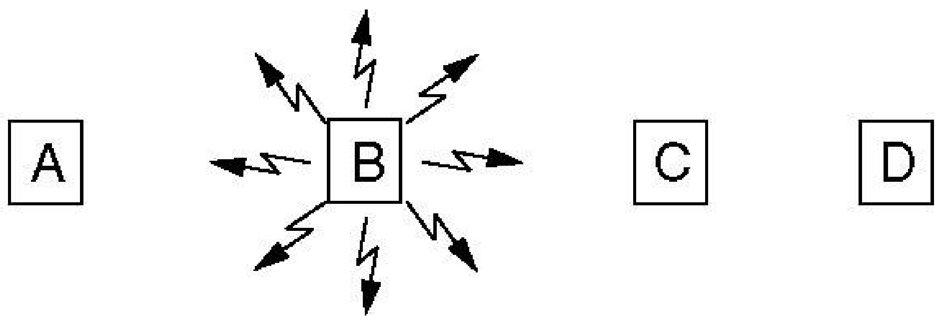
4.2.6 Wireless LAN Protocols (1)

WLAN

- Base stations - access points are wired together using copper or fiber.
- Each cell has only one channel, bandwidth is 11 to 54 Mbps.
- all radio transmitters have some fixed range.
- Hidden station problem (C's transmitting will interfere at B)
- Exposed station problem.



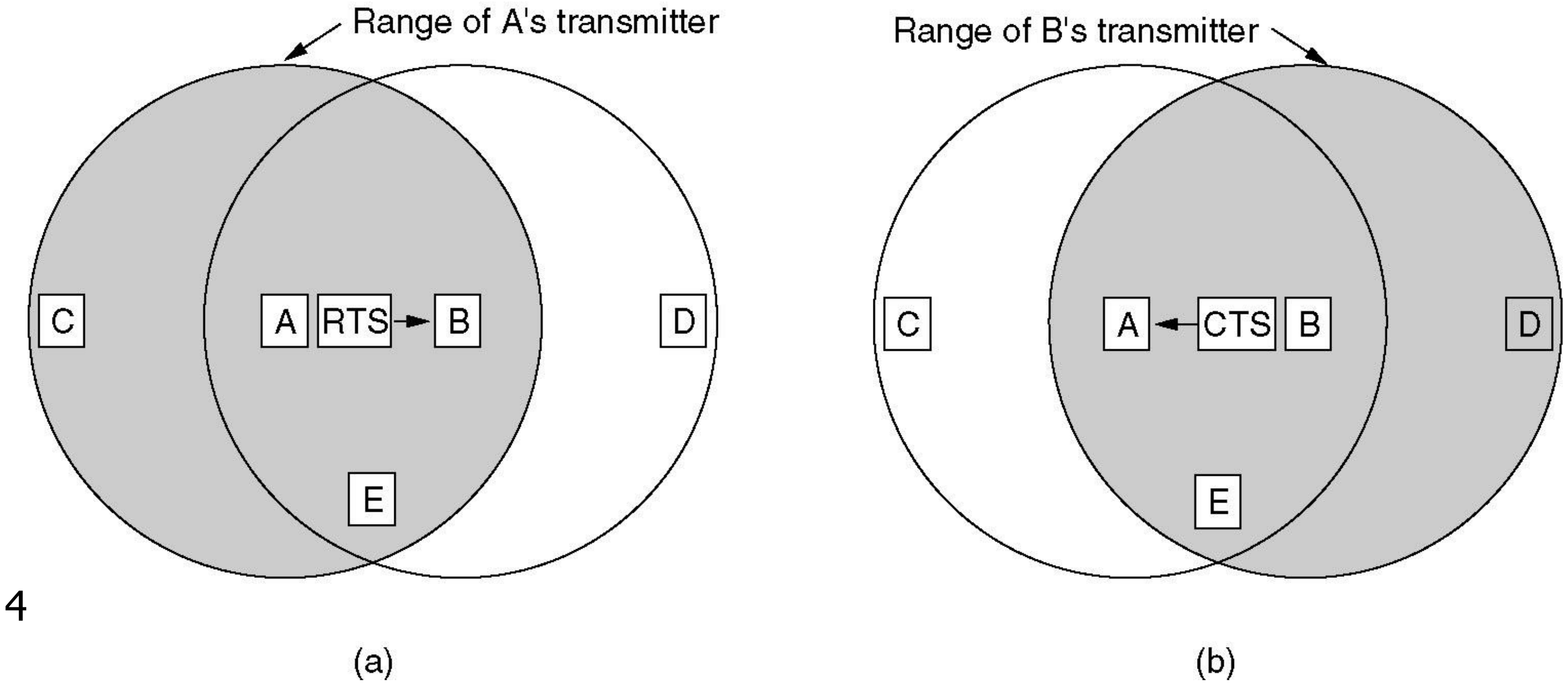
(a)



(b)

4.2.6 Wireless LAN Protocols (2)

- The MACA (Multiple Access with Collision Avoidance) protocol – 802.11.
- Sender output a short frame to stimulate the receiver and to get channel for sending data frame
  - A sending RTS to B, and send data frame when received CTS
  - B responding with a CTS to A, receive data frame from A
  - C hears the RTS , does not interfere with the CTS, free to transmit while the data frame is being sent.
  - D does not hear the RTS but does hear the CTS, silent until data frame is finished.
  - E hears RTS and CTS, like D, silent during A sending data frame.



4.3 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

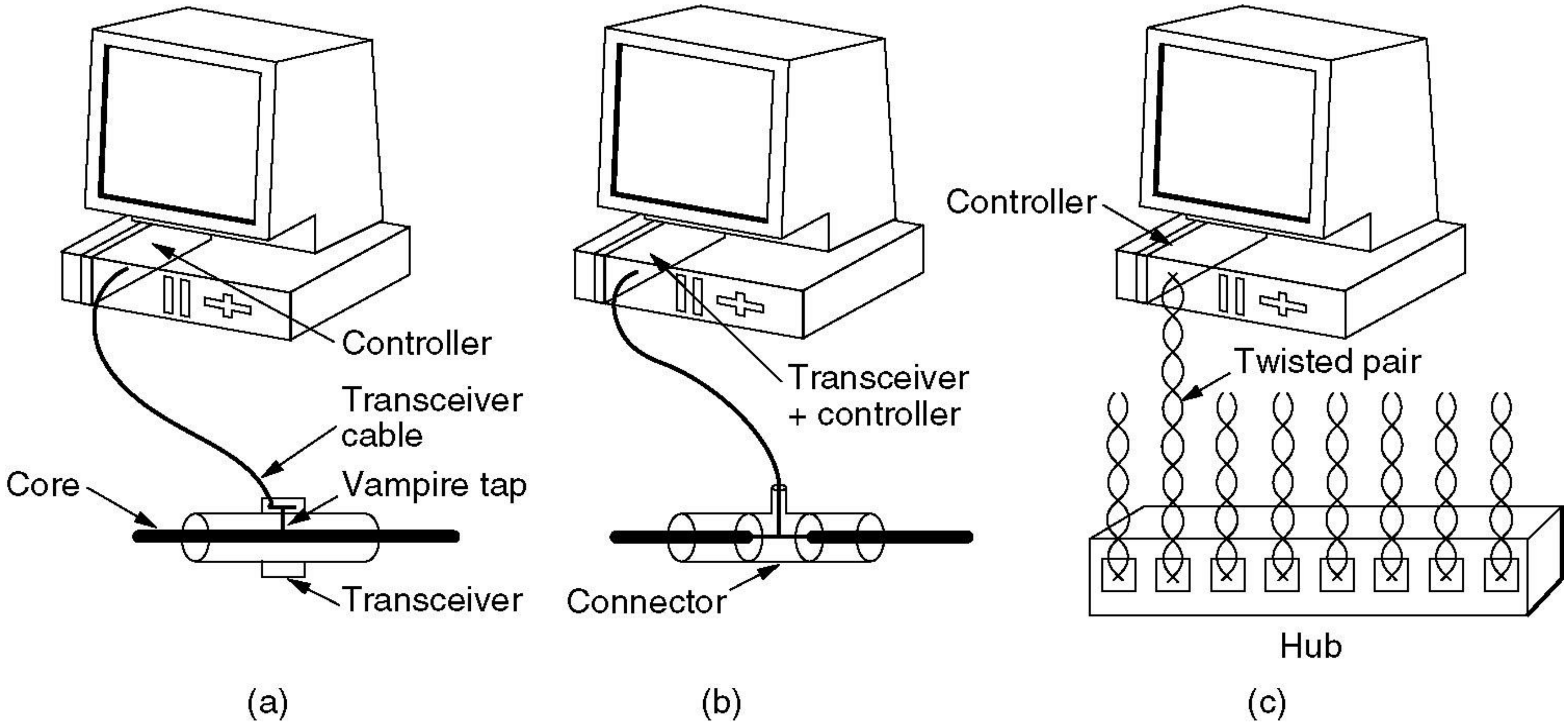
4.3.1 Ethernet Cabling (1)

- The most common kinds of 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

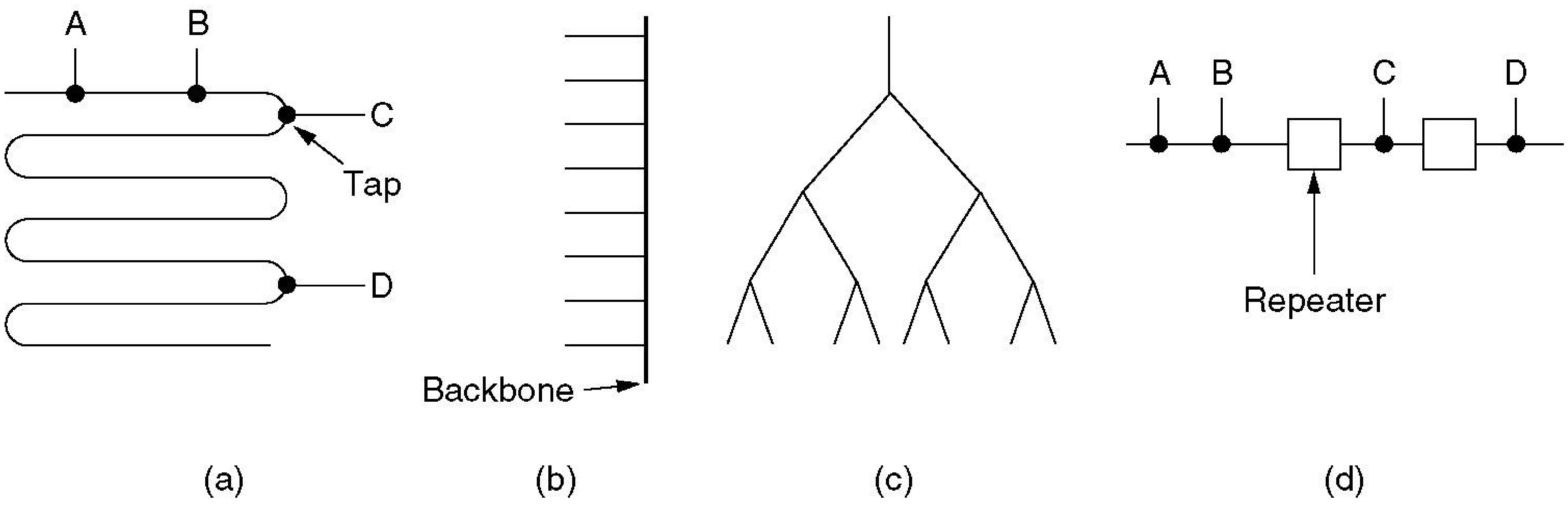
4.3.1 Ethernet Cabling (2)

- Three kinds of Ethernet cabling.
  - 10Base5, 10Base2, 10Base-T.



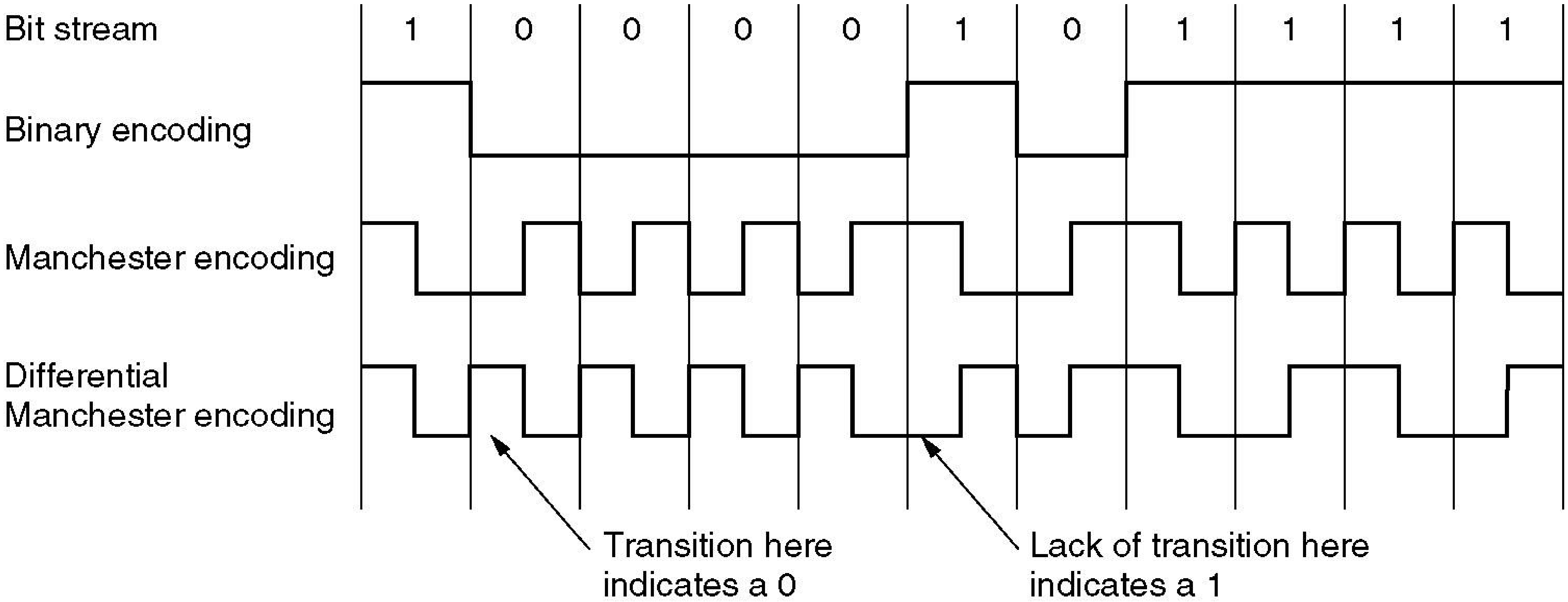
4.3.1 Ethernet Cabling (3)

- Cable topologies.
  - Linear, Spine, Tree, Segmented.



4.3.2 Manchester encoding

- Manchester encoding,
- Differential Manchester encoding.
- Bit Synchronize



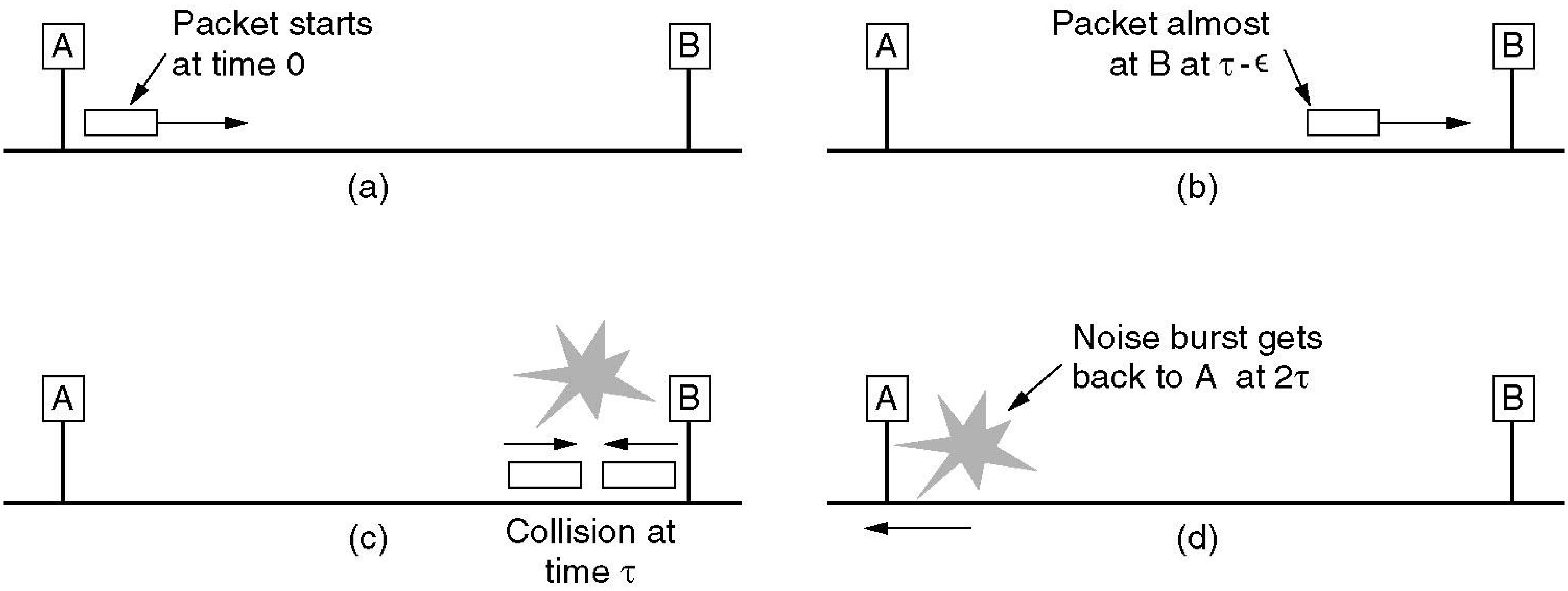
4.3.3 Ethernet MAC Sublayer Protocol(1)

- Frame formats.
  - (a) DIX Ethernet,
  - (b) IEEE 802.3.

Bytes	8		6	6	2	0-1500	0-46	4
(a)	Preamble		Destination address	Source address	Type	Data	Pad	Check-sum
(b)	Preamble	SOF	Destination address	Source address	Length	Data	Pad	Check-sum

4.3.3 Ethernet MAC Sublayer Protocol (2)

- 1-persistent CSMA/CD
- Collision Detection can take as long as **2τ**(contention slot)



4.3.4 The Binary Exponential Backoff Algorithm

- to dynamically adapt to the number of stations trying to send.
- After i collisions, a random number between 0 and 2^i - 1 is chosen , and that number of contention slots is skipped before trying again.

4.3.5 Ethernet Performance (1)

- k stations always ready to transmit (heavy and constant load).
- Assume a constant retransmission probability in each slot.
- Each station transmits during a contention slot with probability p
- Some station acquires the channel in that slot is

$$A = k\,p\,(1-p)^{k-1}$$

- A is maximized when p = 1/k, with A->1/e as k->∞.
- The probability that the contention interval has exactly j slots in it is $A(1 - A)^{j-1}$
- The mean number of slots per contention is given by

$$\sum_{j=0}^{\infty} jA(1-A)^{j-1} = \frac{1}{A}$$

4.3.5 Ethernet Performance (2)

- Each slot has a duration 2τ, the mean contention interval $w = 2\tau/A$.
- Assuming optimal p, so $w = 2\tau e = 5.4\tau$.
- If the mean frame takes P sec to transmit, when many stations have frames to send,
- Channel efficiency $= P/ (P+2\tau/A)$

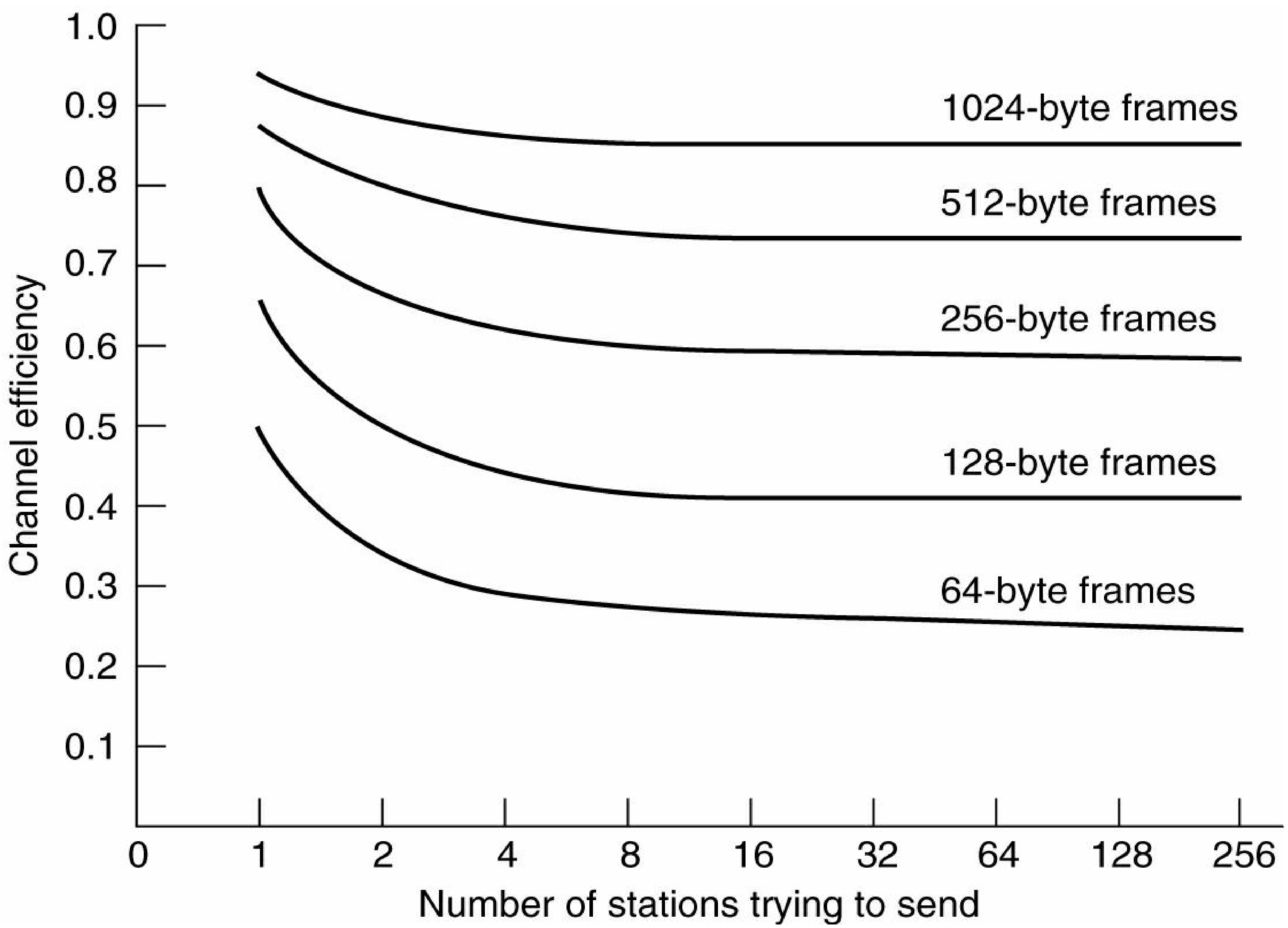
$$= 1/(1+2\tau e/P)$$

$$= 1/(1+2BLe/cF)$$

  - Frame length F
  - Network bandwidth B
  - $P = F/B$.
  - Cable length L
  - Speed of signal propagation c

4.3.5 Ethernet Performance (3)

- Efficiency of Ethernet at 10 Mbps with 512-bit slot times.

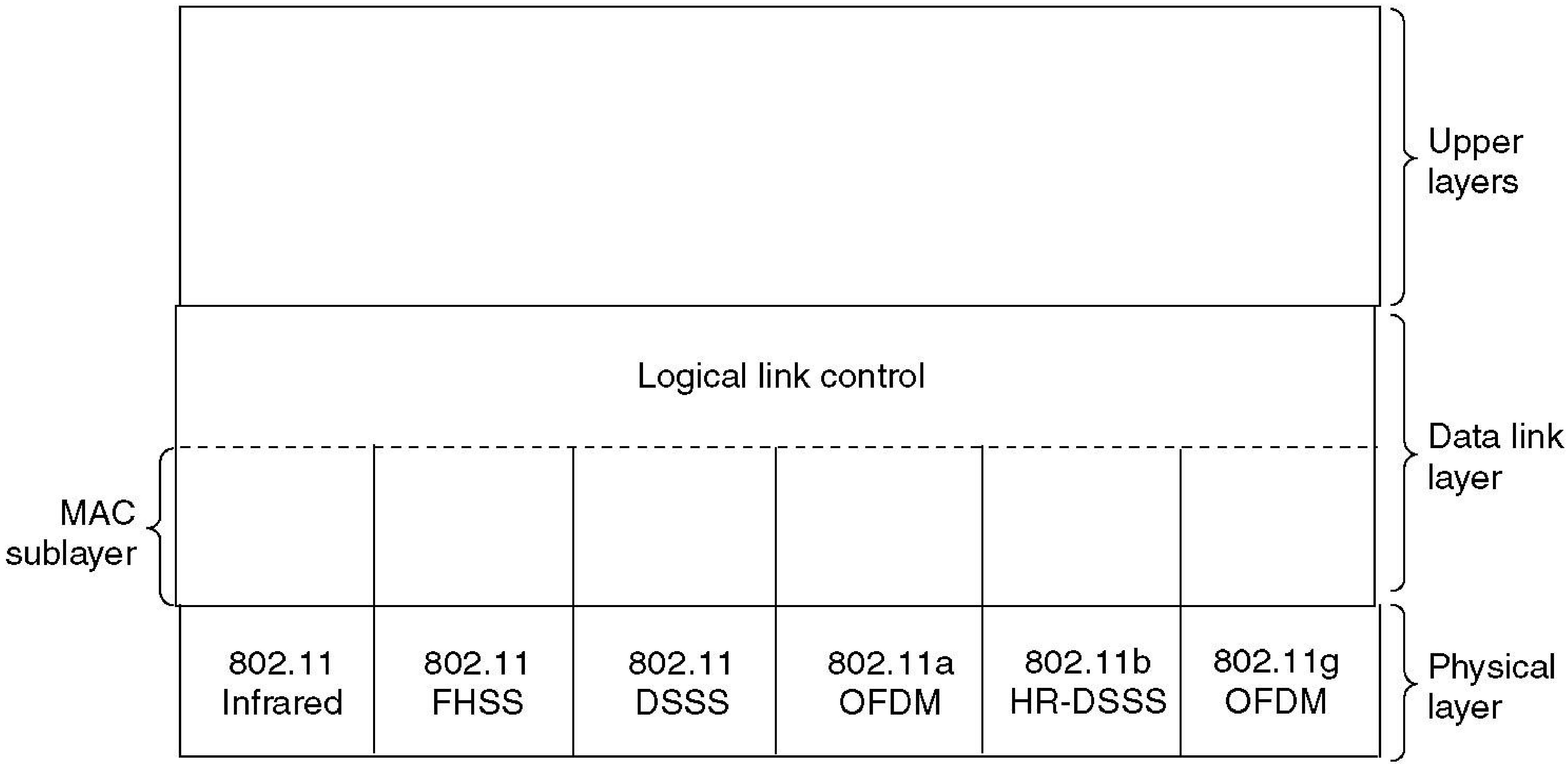


4.4 Wireless LANs*

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

4.4.1 The 802.11 Protocol Stack

- Part of the 802.11 protocol stack.



4.4.2 The 802.11 Physical Layer

- Different transmission techniques
- Speed

- 802.11n
  - >108Mbps
  - 2.4Ghz & 5.8Ghz
  - MIMO + OFDM
  - >1Km

4.4.3 The 802.11 MAC Sublayer Protocol (1)

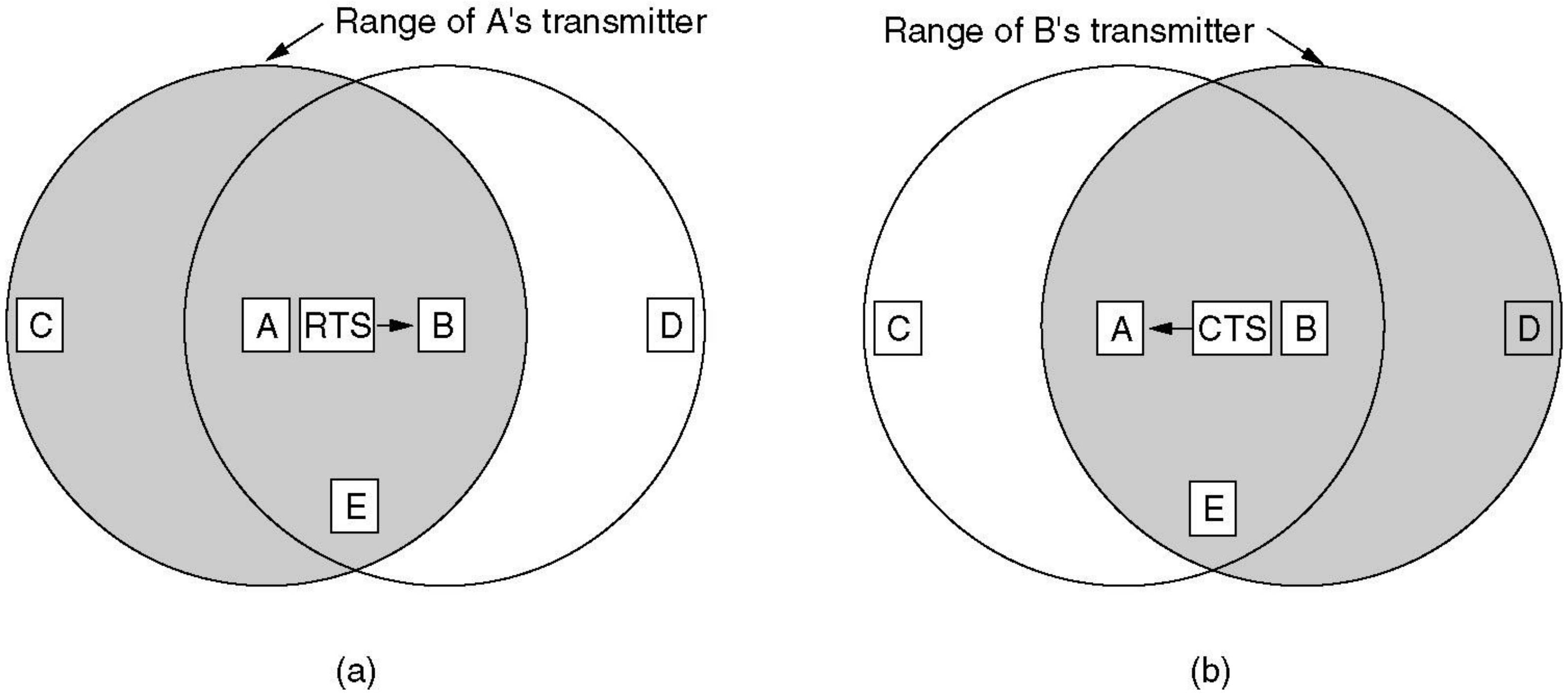
- Single MAC to support multiple PHYs
  - Single and multiple channel PHYs
  - PHYs with different "Medium Sense" characteristics
- Hidden station problem and exposed station problem.
- DCF (Distributed Coordination Function). No central controller (similar to Ethernet).
- PCF (Point Coordination Function). The base station controls all activity in its cell.

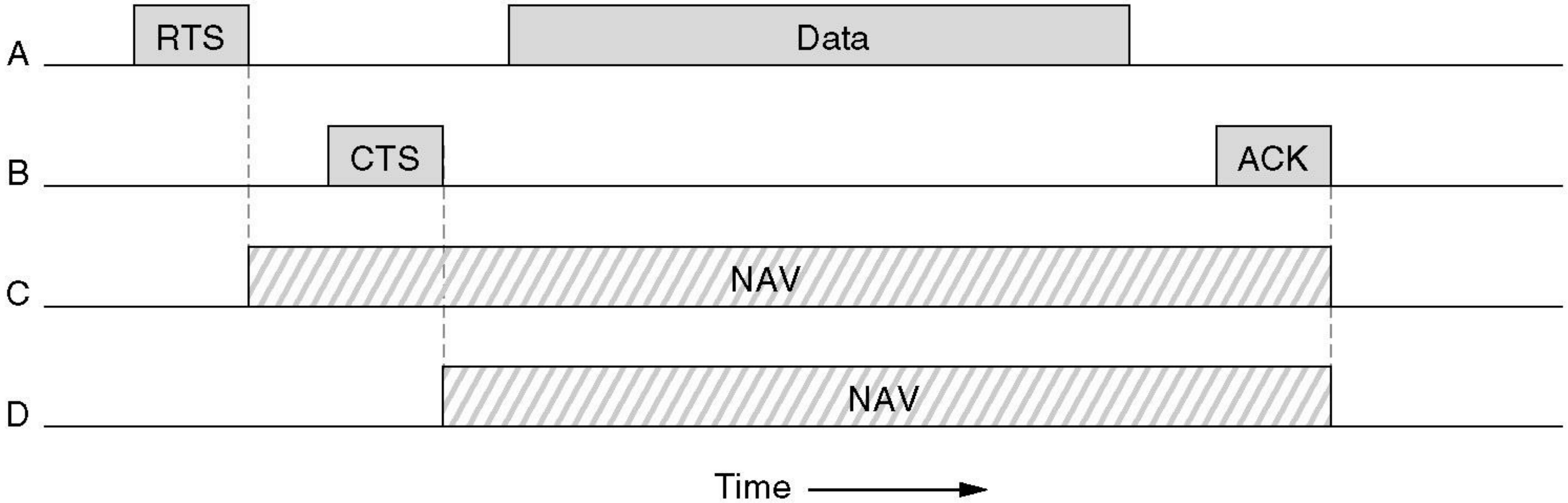
4.4.3 The 802.11 MAC Sublayer Protocol (2)

- DCF uses CSMA/CA (CSMA with Collision Avoidance) protocol.
- Physical channel sensing:
  - when a station wants to transmit, it senses the channel.
  - If it is idle, it just starts transmitting.
  - If the channel is busy, the sender defers until it goes idle and then starts transmitting.
  - If a collision occurs, wait a random time, using binary exponential backoff algorithm, and then try again later.
- Virtual channel sensing, based on MACAW
  - (example) A wants to send to B.
  - C is a station within range of A.
  - D is a station within range of B but not within range of A.
  - NAV (Network Allocation Vector) , not transmitted

4.4.3 The 802.11 MAC Sublayer Protocol (3)

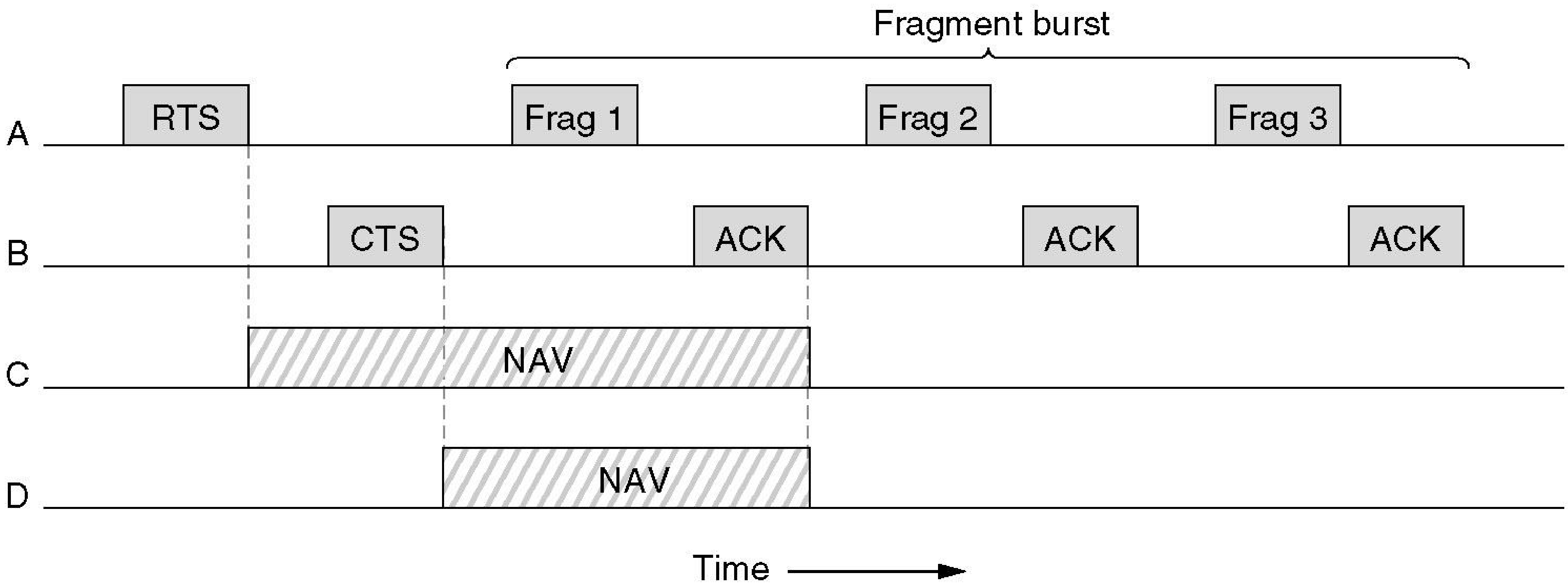
- The use of virtual channel sensing using CSMA/CA.





4.4.3 The 802.11 MAC Sublayer Protocol (4)

- Noisy channel, fragment
- A fragment burst.

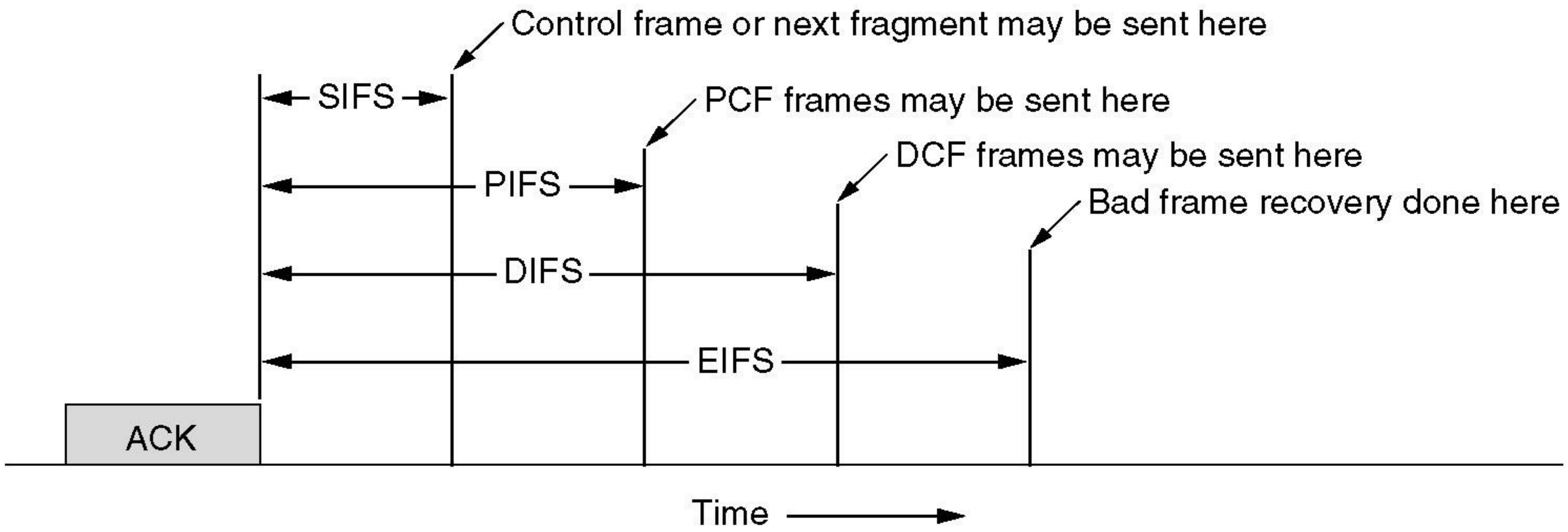


4.4.3 The 802.11 MAC Sublayer Protocol (5)

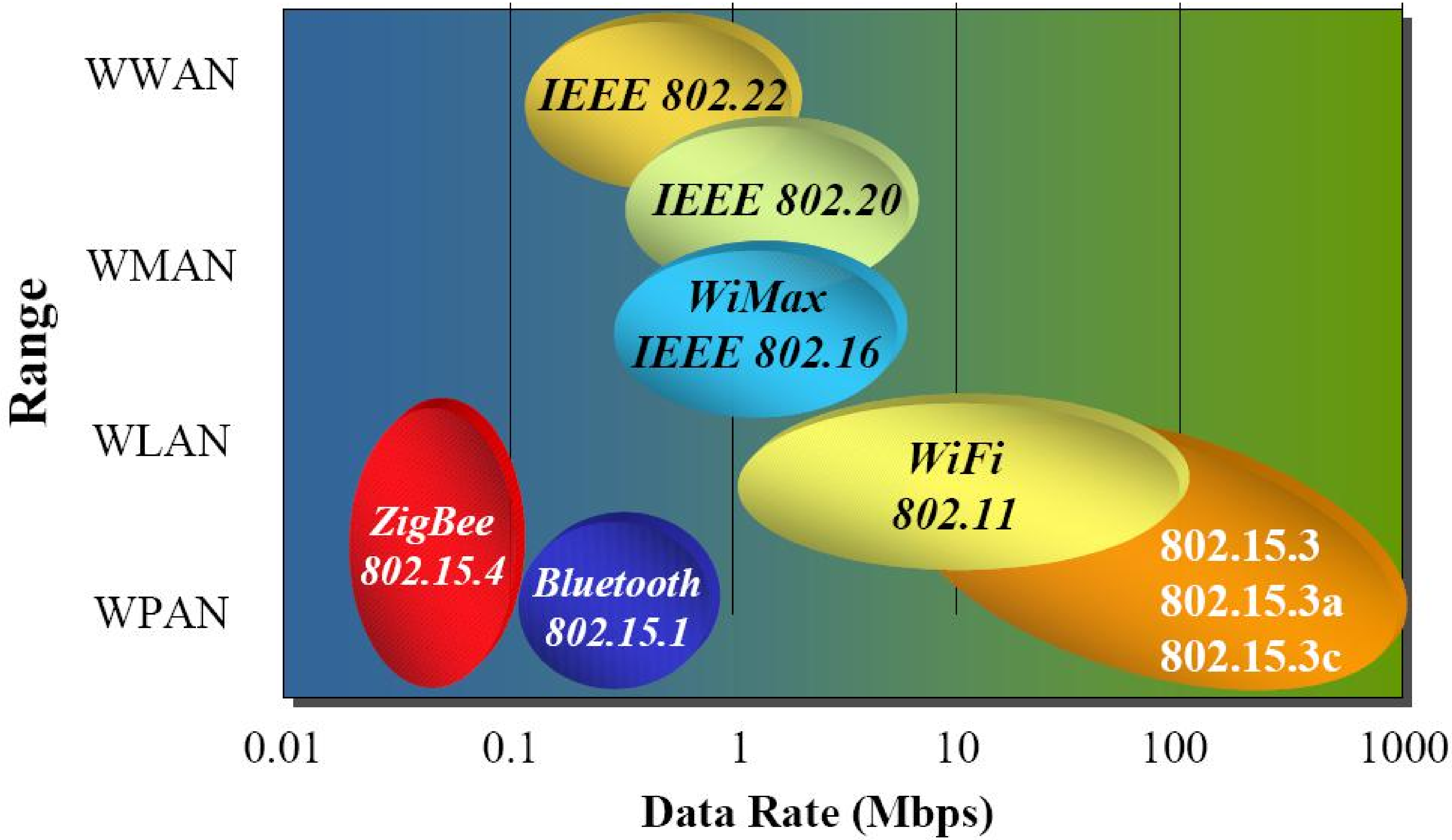
- PCF
  - Base station polls the other stations, asking them if they have any frames to send.
  - no collisions ever occur.
  - Base station to broadcast a **beacon frame** periodically (10 to 100 times per second), contains system parameters, also invites new stations to sign up for polling service.
- PCF and DCF can coexist within one cell, by carefully defining the interframe time interval.

4.4.3 The 802.11 MAC Sublayer Protocol (6)

- Interframe spacing in 802.11.
  - SIFS (Short InterFrame Spacing). To allow the parties in a single dialog the chance to go first.
    - the receiver send a CTS to respond to an RTS
    - the receiver send an ACK for a fragment or full data frame
    - the sender of a fragment burst transmit the next fragment
  - PIFS (PCF InterFrame Spacing).
    - The base station send a beacon frame or poll frame.
  - DIFS (DCF InterFrame Spacing), any station may attempt to acquire the channel to send a new frame. The usual contention rules apply.
  - EIFS (Extended InterFrame Spacing)
    - a station that has just received a bad or unknown frame to report the bad frame.



The 802 Wireless Space



4.5 Broadband Wireless*

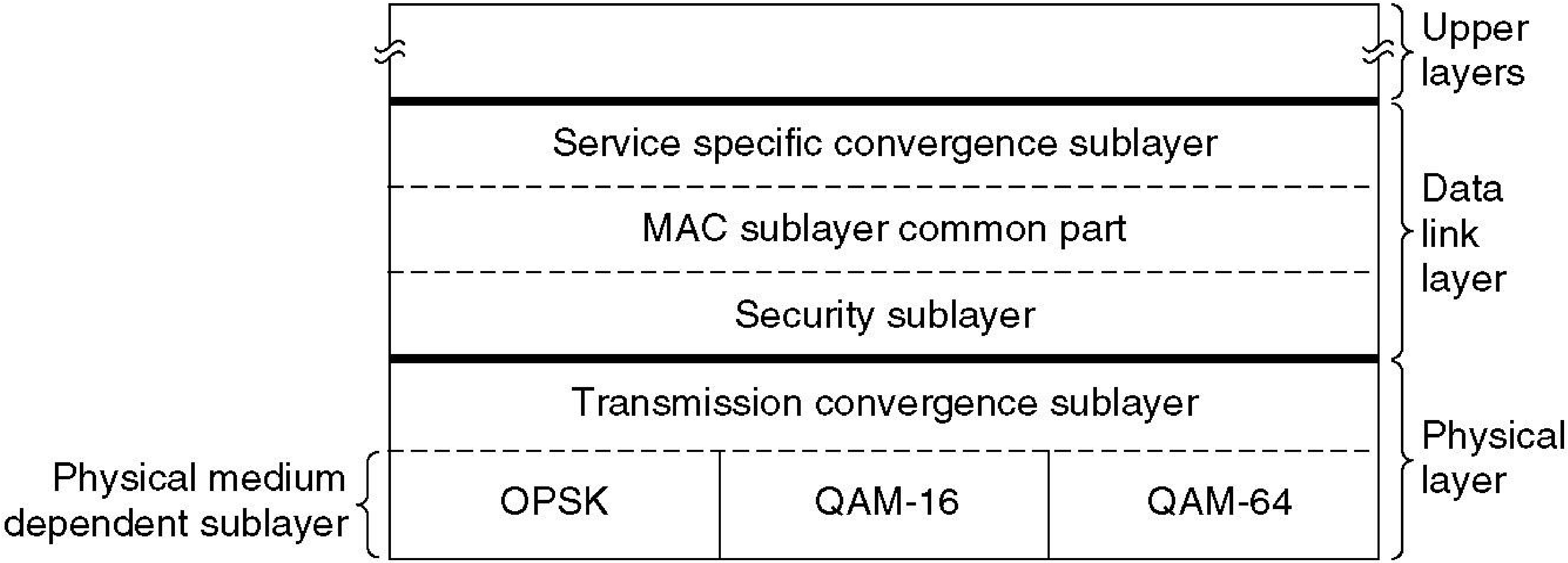
- 802.16, approved in April 2002. (WiMax)
  - Air Interface for Fixed Broadband Wireless Access Systems, Officially
  - Wireless MAN (Metropolitan Area Network)
  - Wireless local loop
- Comparison of 802.11 and 802.16
- The 802.16 Protocol Stack
- The 802.16 Physical Layer
- The 802.16 MAC Sublayer Protocol
- The 802.16 Frame Structure

4.5.1 Comparison of 802.11 and 802.16

- Wireless, Not mobile
- Distances can be several kilometers
- Each cell have many more users
- More spectrum is needed
- 10-to-66 GHz frequency range, directional beams ,802.16
  - 2-to-11GHz,802.16a
- 802.22, Wireless Regional Area Networks ("WRANs")
  - using the "white space" between TV channels.

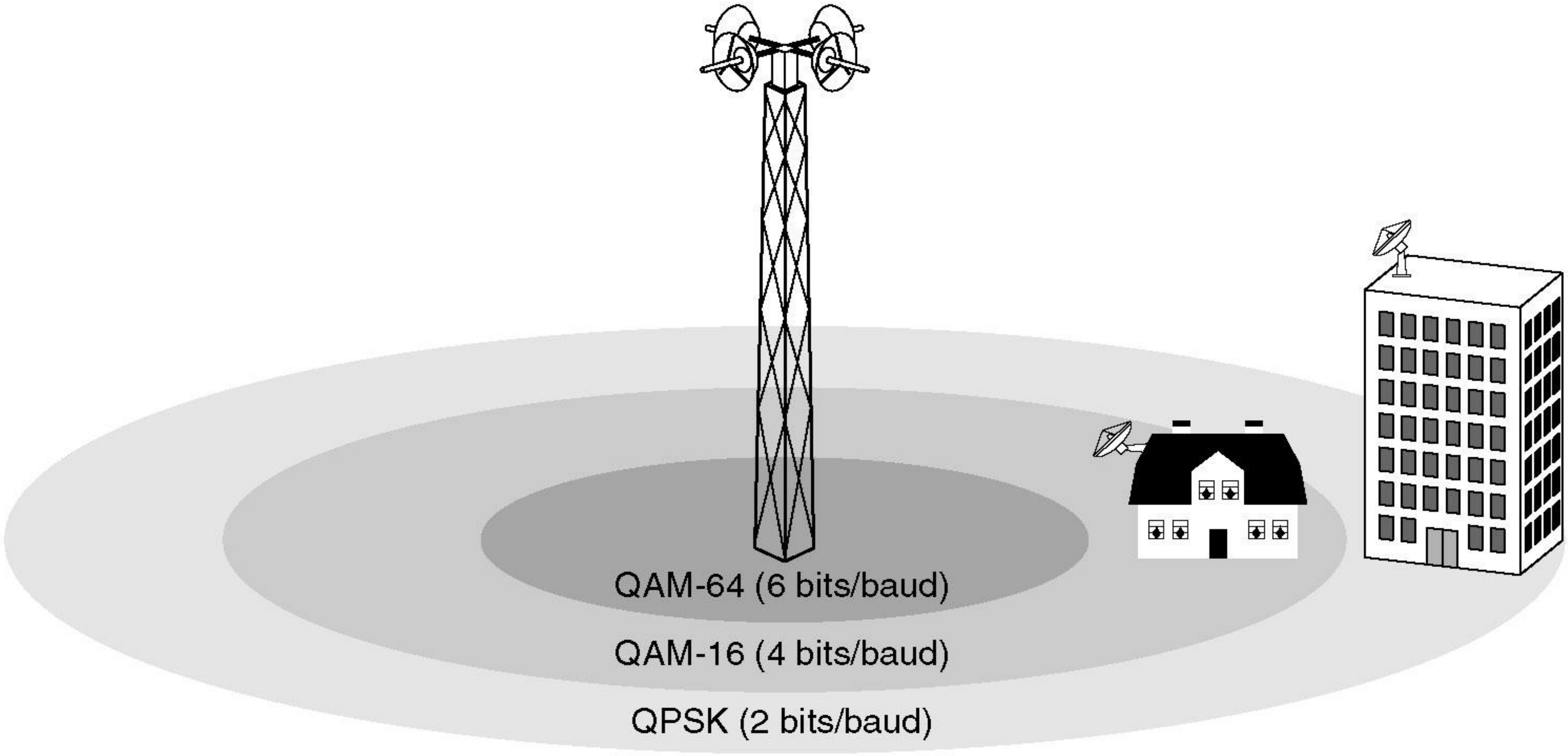
4.5.2 The 802.16 Protocol Stack

- The 802.16 Protocol Stack.
  - Transmission convergence sublayer to hide the different from the data link layer. (ATM service or Packet service)
  - MAC sublayer common part, allocate and manage channel, to provide QoS
  - Security sublayer, authentication, connection establishment, key exchange and encryption.
  - Service-specific convergence sublayer takes place of LLC, to interface to the network layer.



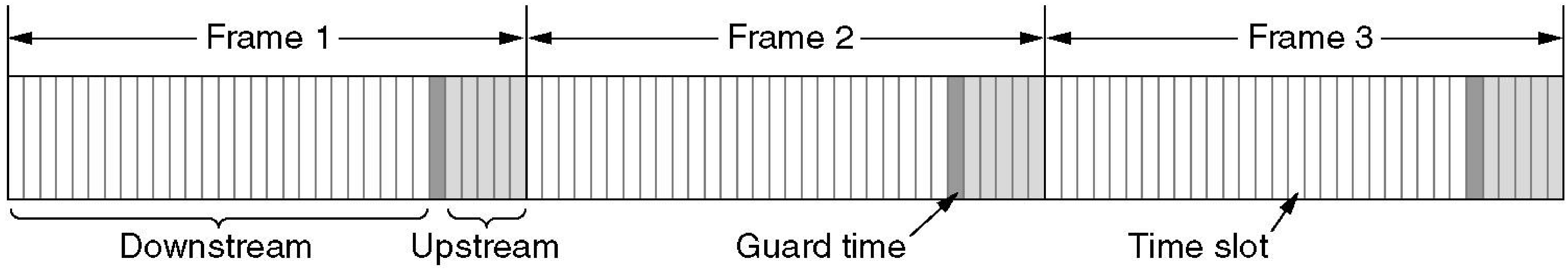
4.5.3 The 802.16 Physical Layer (1)

- The 802.16 transmission environment.
  - multiple antennas
  - three different modulation schemes,
  - flexible way to allocate the bandwidth. FDD & TDD



4.5.3 The 802.16 Physical Layer (2)

- TDD(time division duplexing), frames and time slots.



4.5.4 The 802.16 MAC Sublayer Protocol

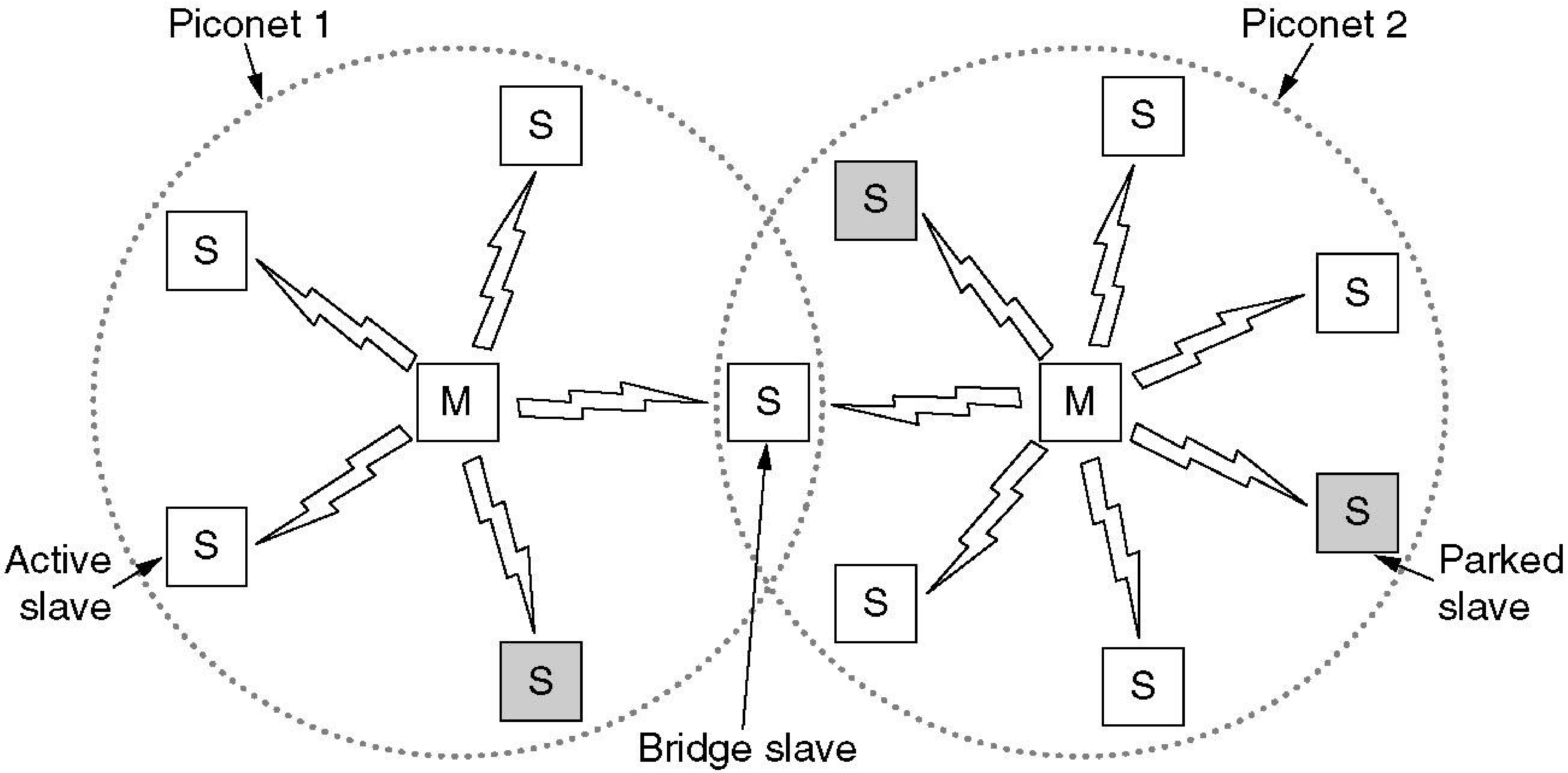
- Connection oriented
- MAC frames occupy an integral number of physical layer time slots.
- Each frame is composed of sub-frames, the first two of which are the downstream and upstream maps, tell what is in which time slot and which time slots are free.
- Service Classes
  - Constant bit rate service
  - Real-time variable bit rate service
  - Non-real-time variable bit rate service
  - Best efforts service

4.6 Bluetooth*

- 802.15
- Bluetooth Architecture
- Bluetooth Applications
- The Bluetooth Protocol Stack
- The Bluetooth Radio Layer
- The Bluetooth Baseband Layer
- The Bluetooth L2CAP Layer
- The Bluetooth Frame Structure

4.6.1 Bluetooth Architecture

- A master node and up to seven active slave nodes
- All communication is between the master and a slave
- Two piconets can be connected to form a scatternet.



4.6.2 Bluetooth Applications

- The Bluetooth profiles.
  - the basis upon which the real applications are built
  - 13 applications supported and different protocol stacks provided for each one.

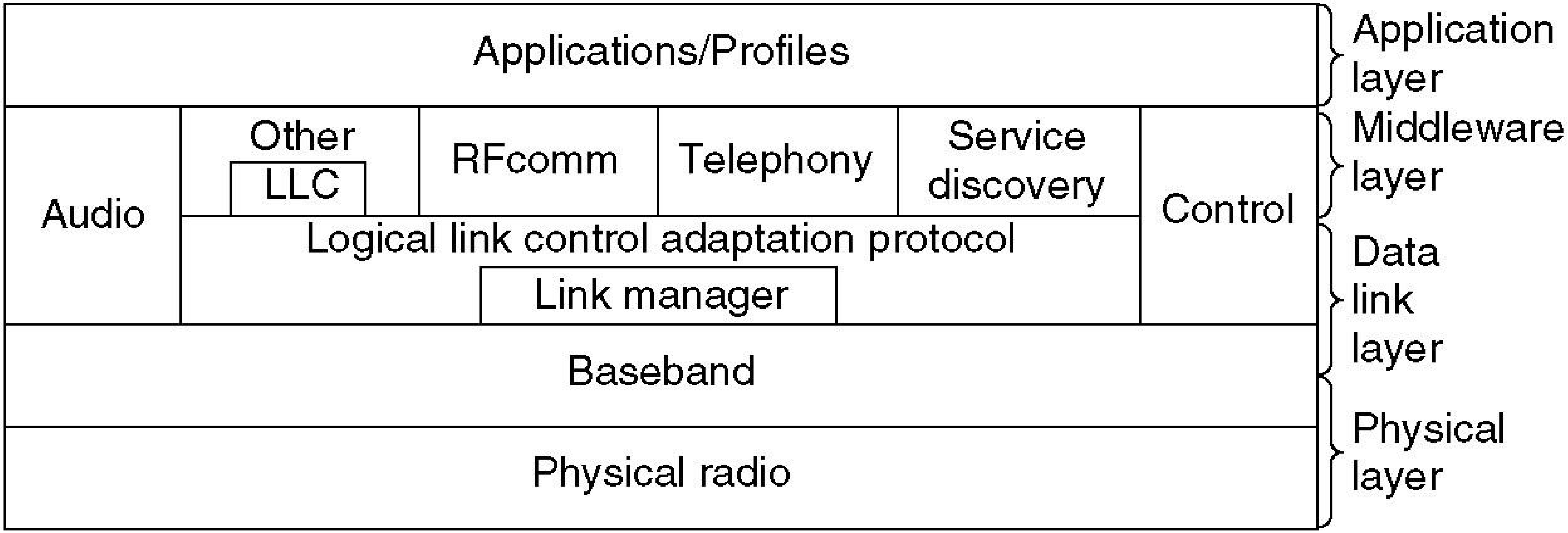
Generic

Optional

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

4.6.3 The Bluetooth Protocol Stack(1)

- The 802.15 version of the Bluetooth protocol architecture.



4.6.3 The Bluetooth Protocol Stack(2)

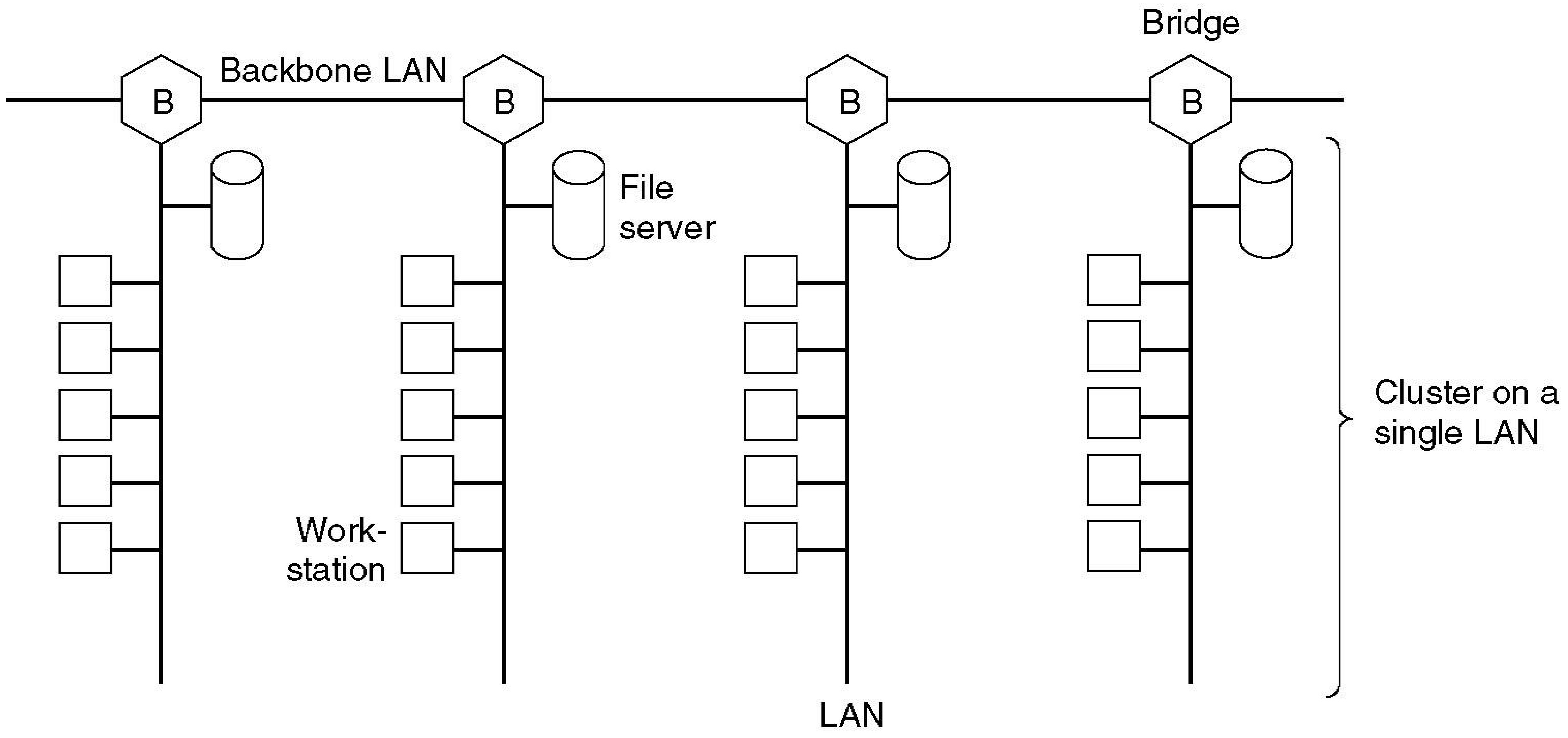
- Physical radio layer, radio transmission and modulation.
- Baseband layer, master controls time slots and slots are grouped into frames.
- Link manager, establishment of logical channels, power management, authentication, and quality of service.
- Logical link control adaptation protocol, analogous to the standard 802 LLC sublayer
- Middleware layer, a mix of different protocols.
  - 802 LLC
  - Rfcomm, emulates the standard serial port
  - Telephony protocol, for the three speech-oriented profiles, manages call setup and termination.
  - Service discovery protocol, to locate services within the network.
- Applications and profiles.

4.7 Data Link Layer Switching(1)

- Bridges from 802.x to 802.y
- Local Internetworking
- Spanning Tree Bridges
- Remote Bridges
- Repeaters, Hubs, Bridges, Switches, Routers, Gateways
- Virtual LANs

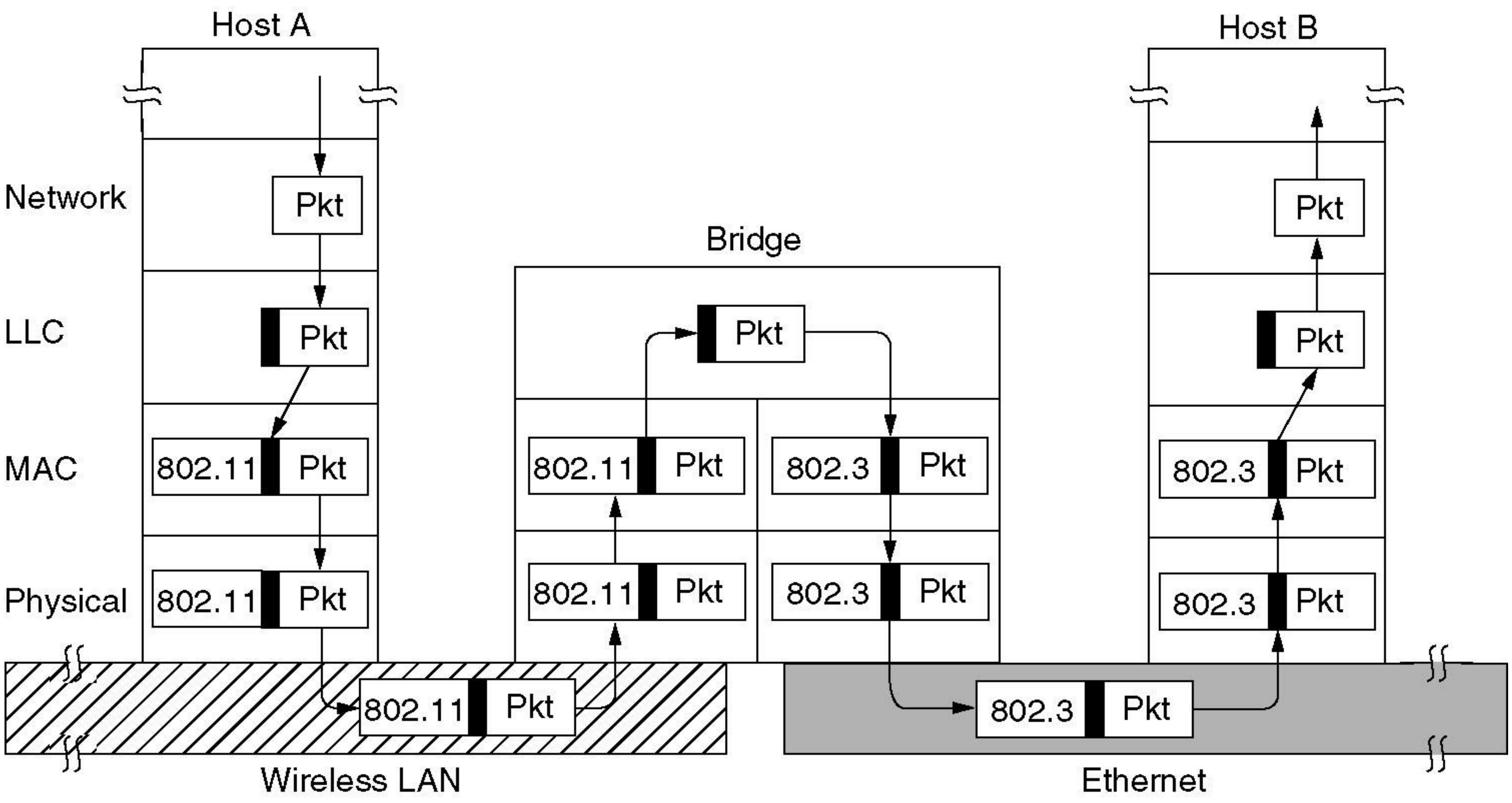
4.7 Data Link Layer Switching(2)

- Multiple reasons why a single organization end up with multiple LANs
- Multiple LANs connected by a backbone



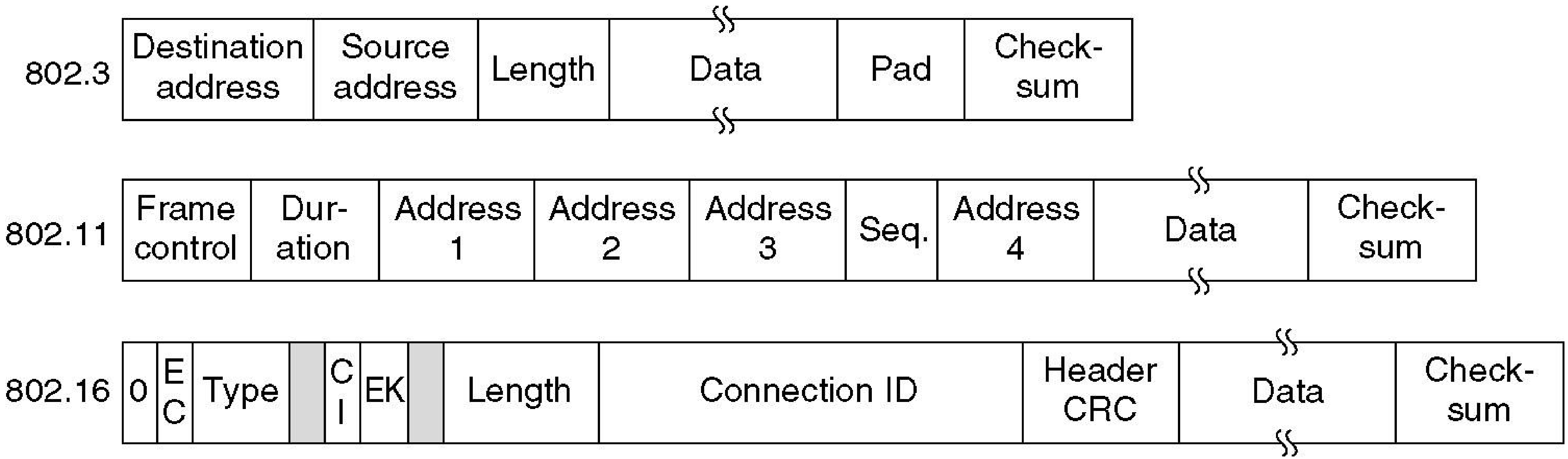
4.7.1 Bridges from 802.x to 802.y(1)

- Operation of a LAN bridge from 802.11 to 802.3.



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

- The difficulties when trying to build a bridge
  - A different frame format.
  - A different data rate.
  - A different maximum frame length
  - Security, 802.11 to 802.3
  - Quality of service

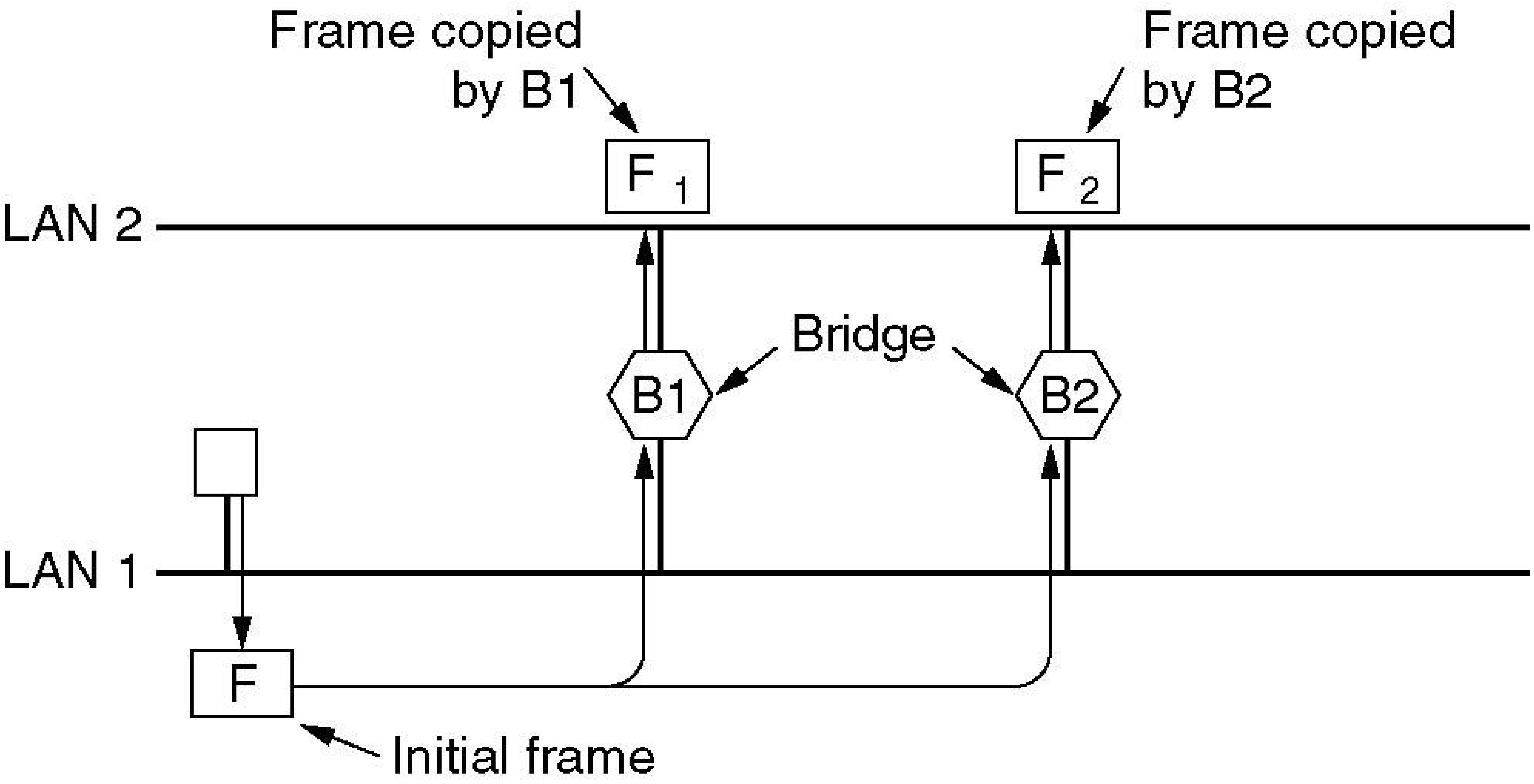


4.7.2 Local Internetworking(1)

- Transparent bridge
- The routing procedure for an incoming frame
  - If destination and source LANs are the same, discard the frame
  - If the destination and source LANs are different, forward the frame
  - If the destination LAN is unknown, use flooding
- A hash table lists each possible destination and tell which output line (LAN) it belongs on
- Backward learning

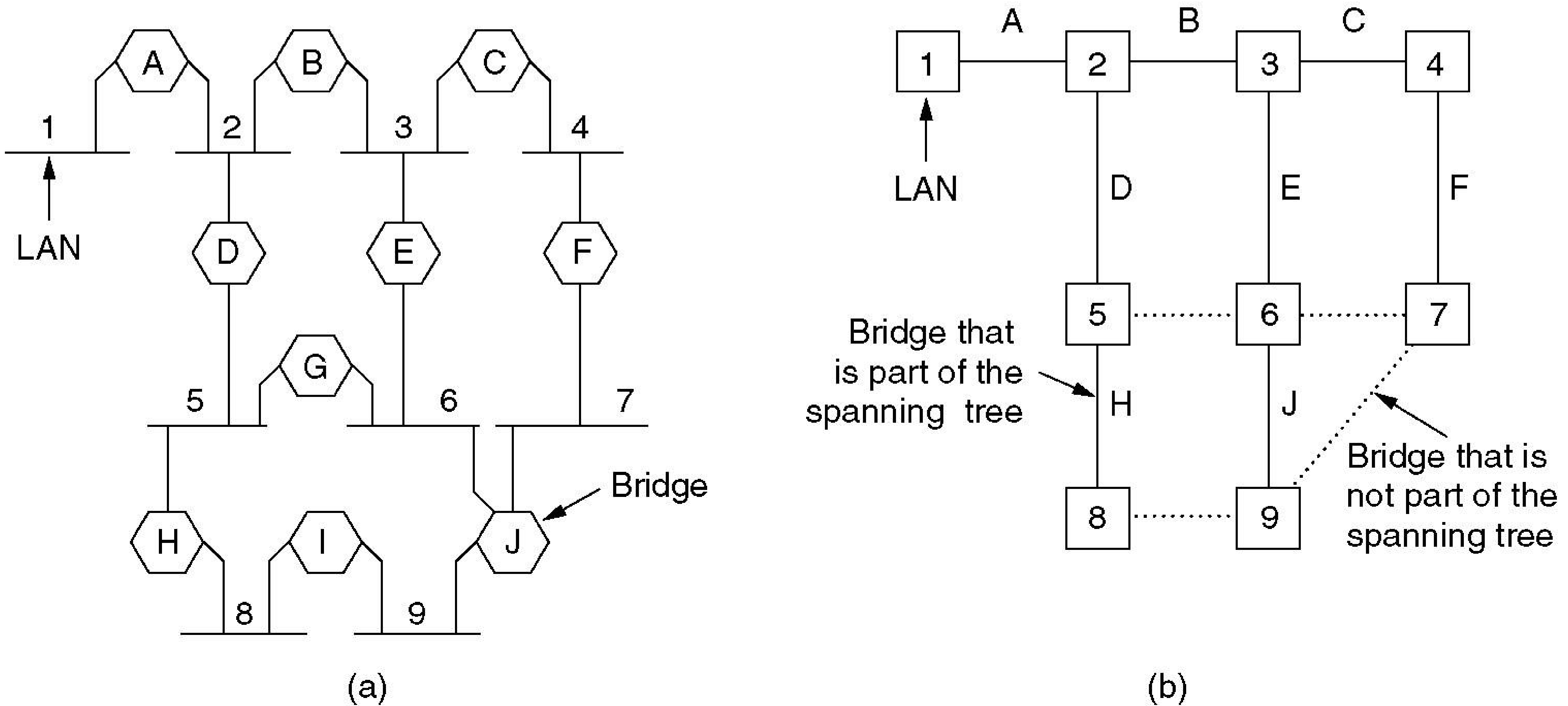
4.7.3 Spanning Tree Bridges (1)

- Two parallel transparent bridges.
- Cycle goes on forever for unknown destination frame.



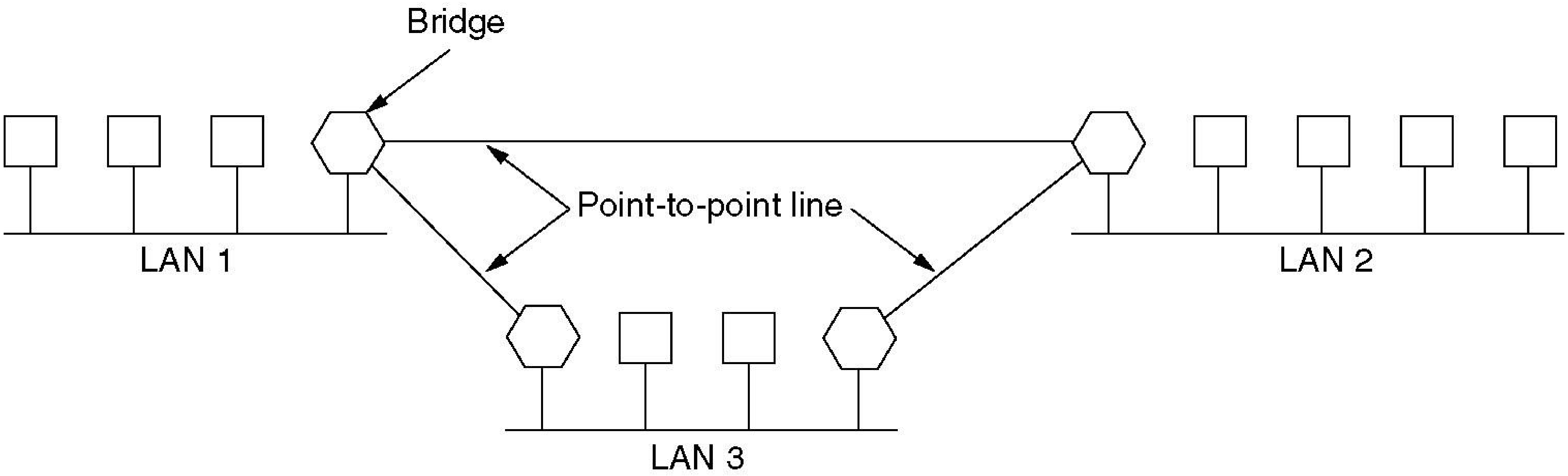
4.7.3 Spanning Tree Bridges (2)

- Interconnected LANs.
- A spanning tree covering the LANs.
- There is exactly one path from every LAN to every other LAN.

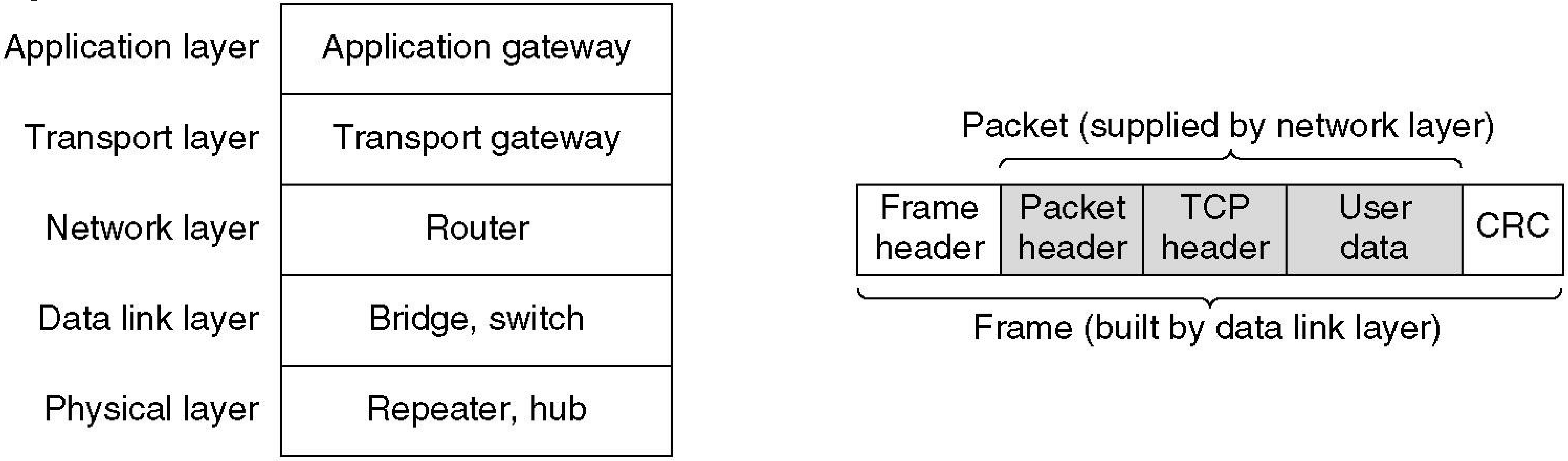


4.7.4 Remote Bridges

- Remote bridges can be used to interconnect distant LANs.
- Various point-to-point protocols can be used on the point-to-point lines such as PPP.



4.7.5 Repeaters, Hubs, Bridges, Switches, Routers and Gateways(1)

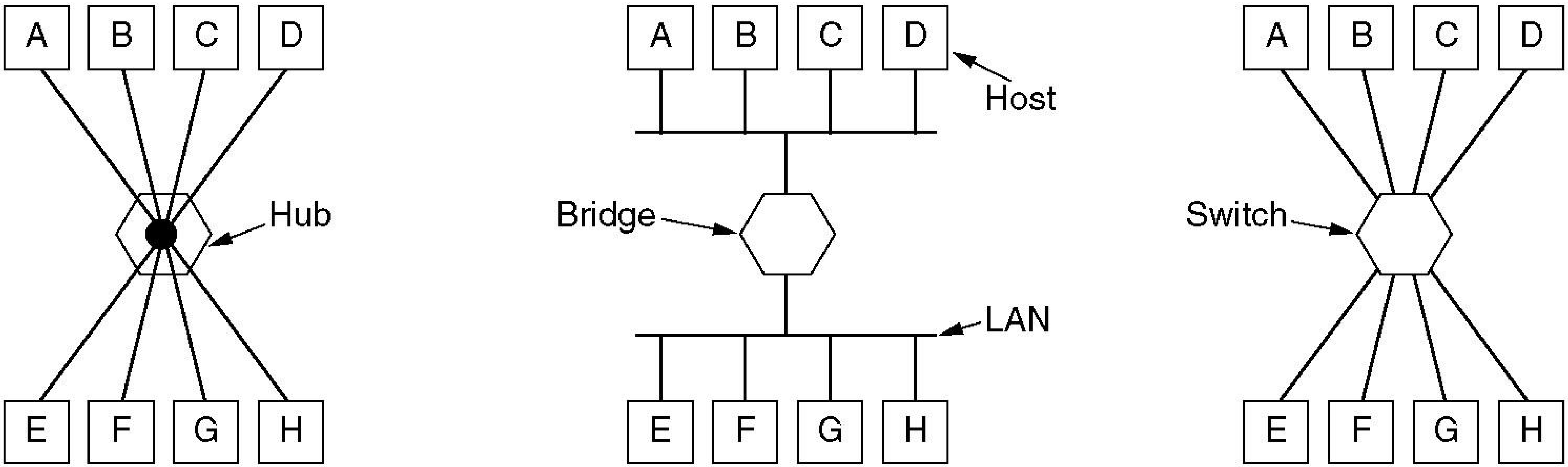


(a) (b)

- (a) Which device is in which layer.
- (b) Frames, packets, and headers.

4.7.5 Repeaters, Hubs, Bridges, Switches, Routers and Gateways (2)

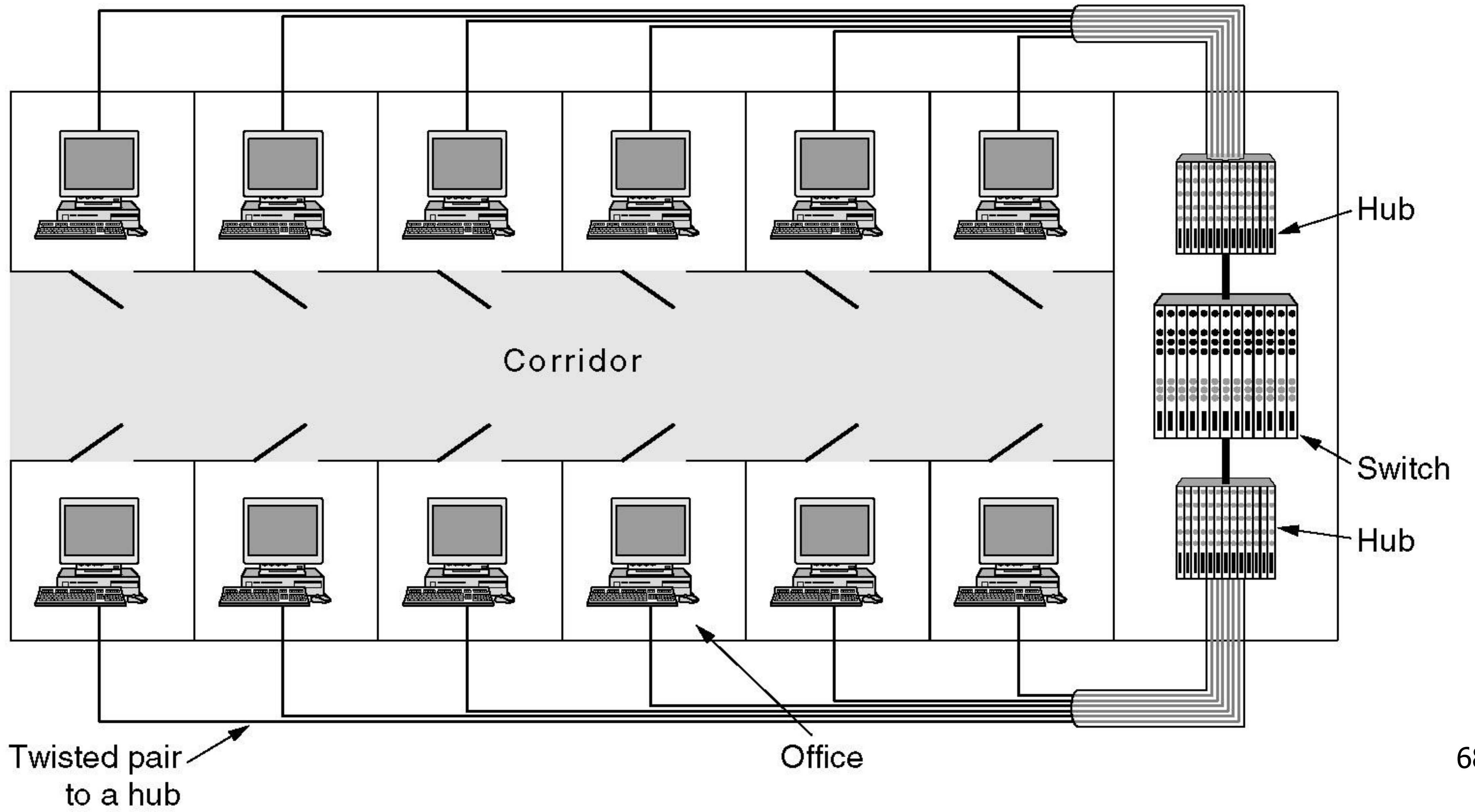
- (a) A hub.
- (b) A bridge.
- (c) a switch.



(a) (b) (c)

4.7.6 Virtual LANs (1)

- A building with centralized wiring using hubs and a switch.

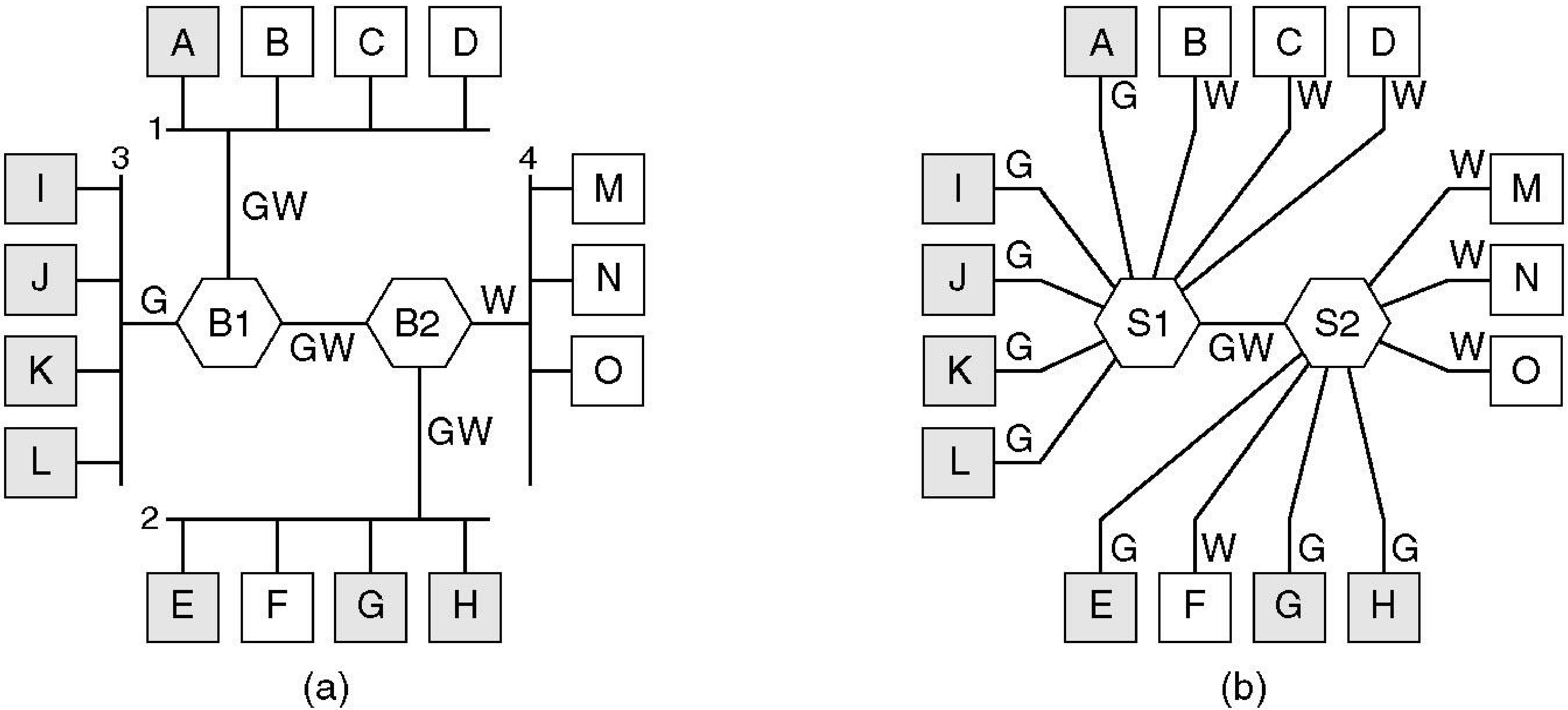


4.7.6 Virtual LANs (2)

- Security
- Load
- Broadcast
- Moving

4.7.6 Virtual LANs (3)

- (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.



4.7.6 Virtual LANs (4)

- Identify the VLAN
  - Port, all machines on a port belong to the same VLAN
  - MAC address
  - Layer 3 protocol or IP address, examine the payload field of the frame

4.7.6 VLAN, IEEE 802.1Q Standard

- Frame itself, not sending machine to identify the VLAN
- Add a field in the header
- The first VLAN-aware bridge or switch to touch a frame adds them and the last one down the road removes them

4.8 Summary

- Channel allocation methods and systems for a common channel.

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