

CSMC 417

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Set 5

The Medium Access Control Sublayer

The Channel Allocation Problem

- Static Channel Allocation in LANs and MANs
- Dynamic Channel Allocation in LANs and MANs

Dynamic Channel Allocation in LANs and MANs

1. Station Model.
2. Single Channel Assumption.
3. Collision Assumption.
4. (a) Continuous Time.
(b) Slotted Time.
5. (a) Carrier Sense.
(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

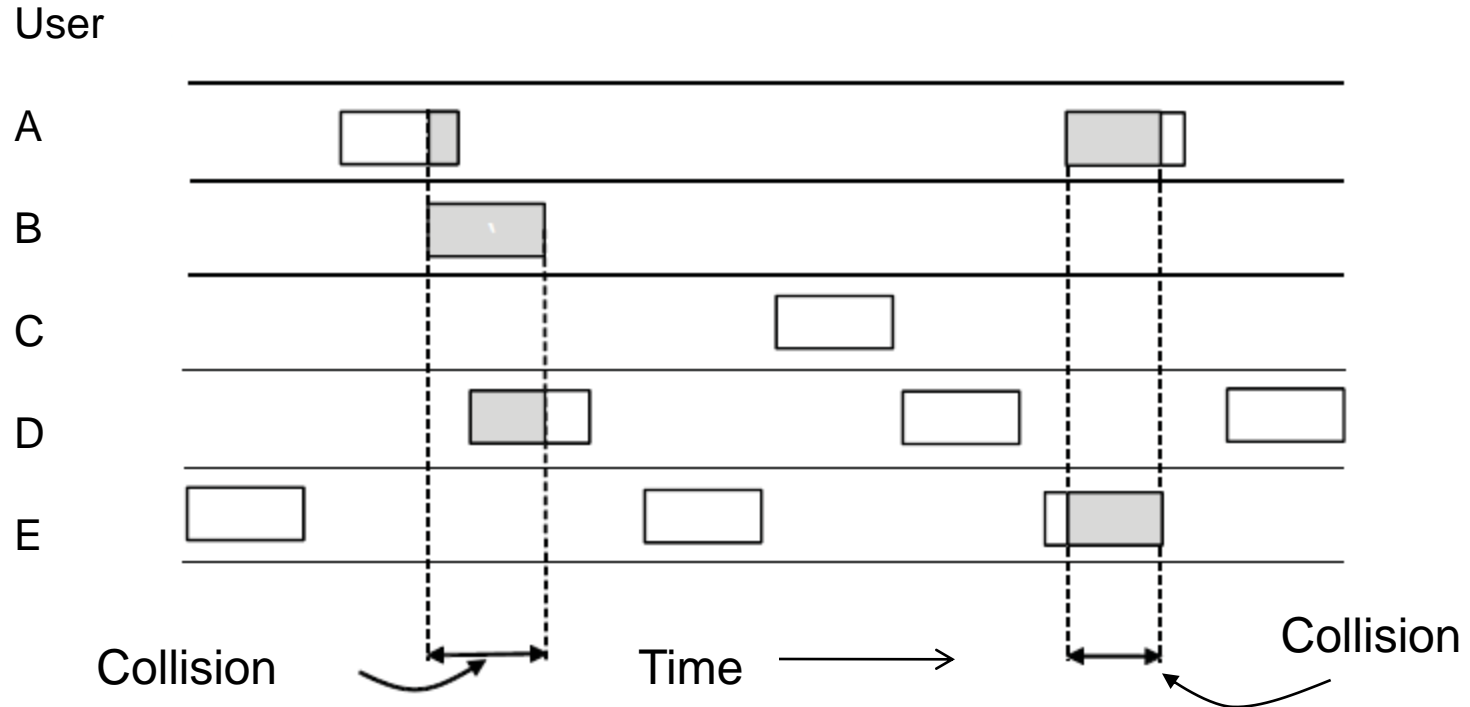
Random Access Protocols

- When node has packet to send
 - Transmit at full channel data rate R .
 - No a priori coordination among nodes
- Two or more transmitting nodes → “collision”,
- Random access MAC protocol specifies:
 - How to detect collisions
 - How to recover from collisions
- Examples
 - ALOHA and Slotted ALOHA
 - CSMA, CSMA/CD, CSMA/CA

Key Ideas of Random Access

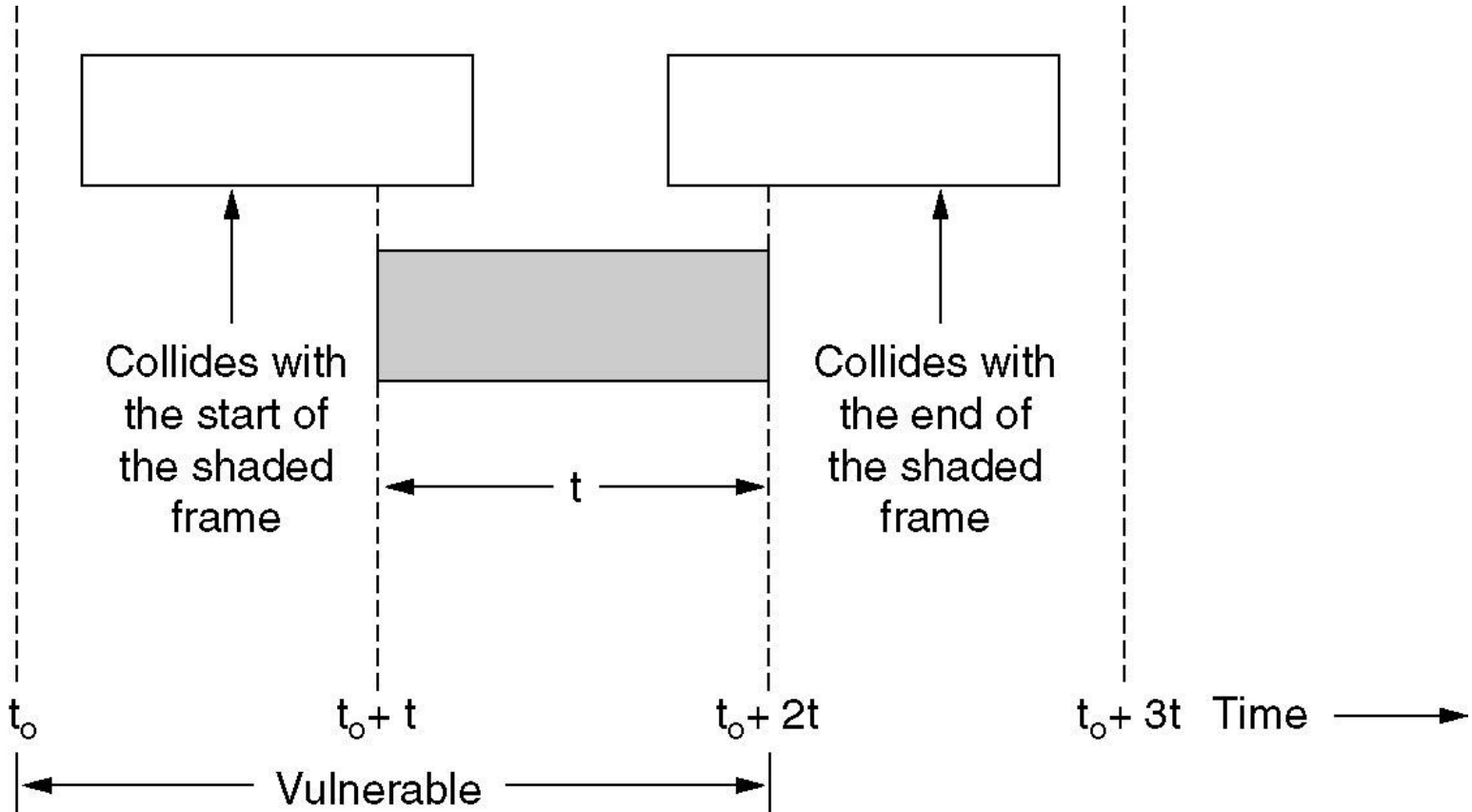
- Carrier sense
 - *Listen before speaking, and don't interrupt*
 - Checking if someone else is already sending data
 - ... and waiting till the other node is done
- Collision detection
 - *If someone else starts talking at the same time, stop*
 - Realizing when two nodes are transmitting at once
 - ...by detecting that the data on the wire is garbled
- Randomness
 - *Don't start talking again right away*
 - Waiting for a random time before trying again

ALOHA (1)

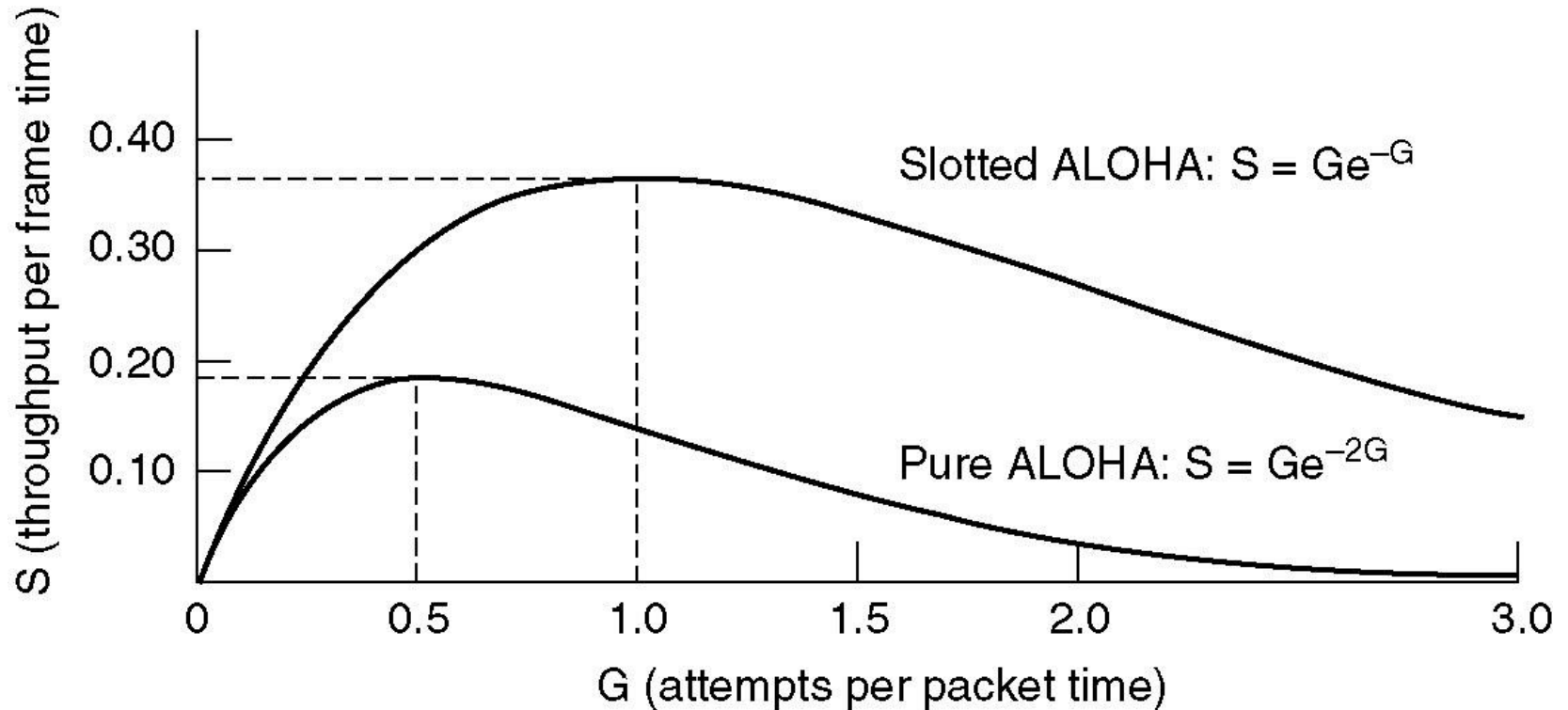


In pure ALOHA, frames are transmitted at completely arbitrary times

Pure ALOHA (2)



Pure ALOHA (3)



Slotted ALOHA

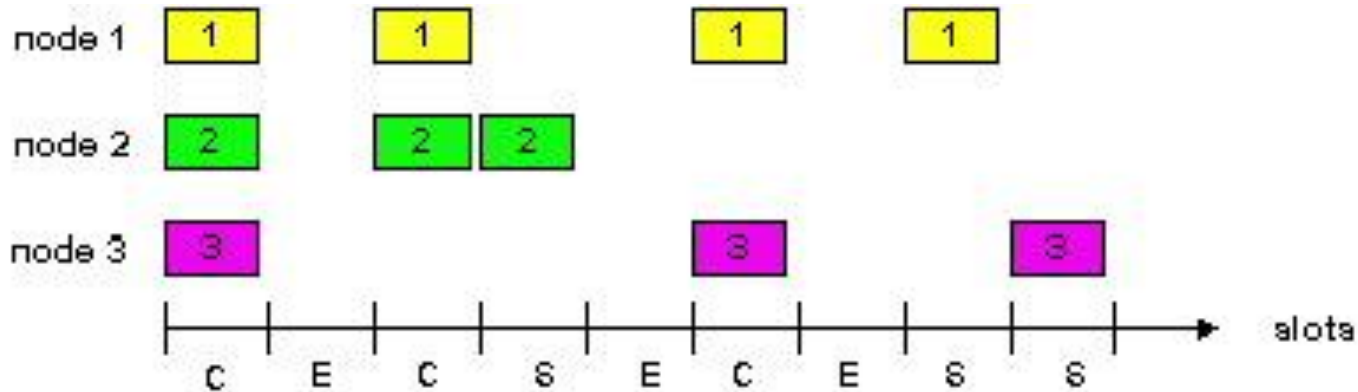
Assumptions

- All frames same size
- Time divided into equal slots (time to transmit a frame)
- Nodes start to transmit frames only at start of slots
- Nodes are synchronized
- If two or more nodes transmit, all nodes detect collision

Operation

- When node obtains fresh frame, transmits in next slot
- No collision: node can send new frame in next slot
- Collision: node retransmits frame in each subsequent slot with probability p until success

Slotted ALOHA



Pros

- Single active node can continuously transmit at full rate of channel
- Highly decentralized: only slots in nodes need to be in sync
- Simple

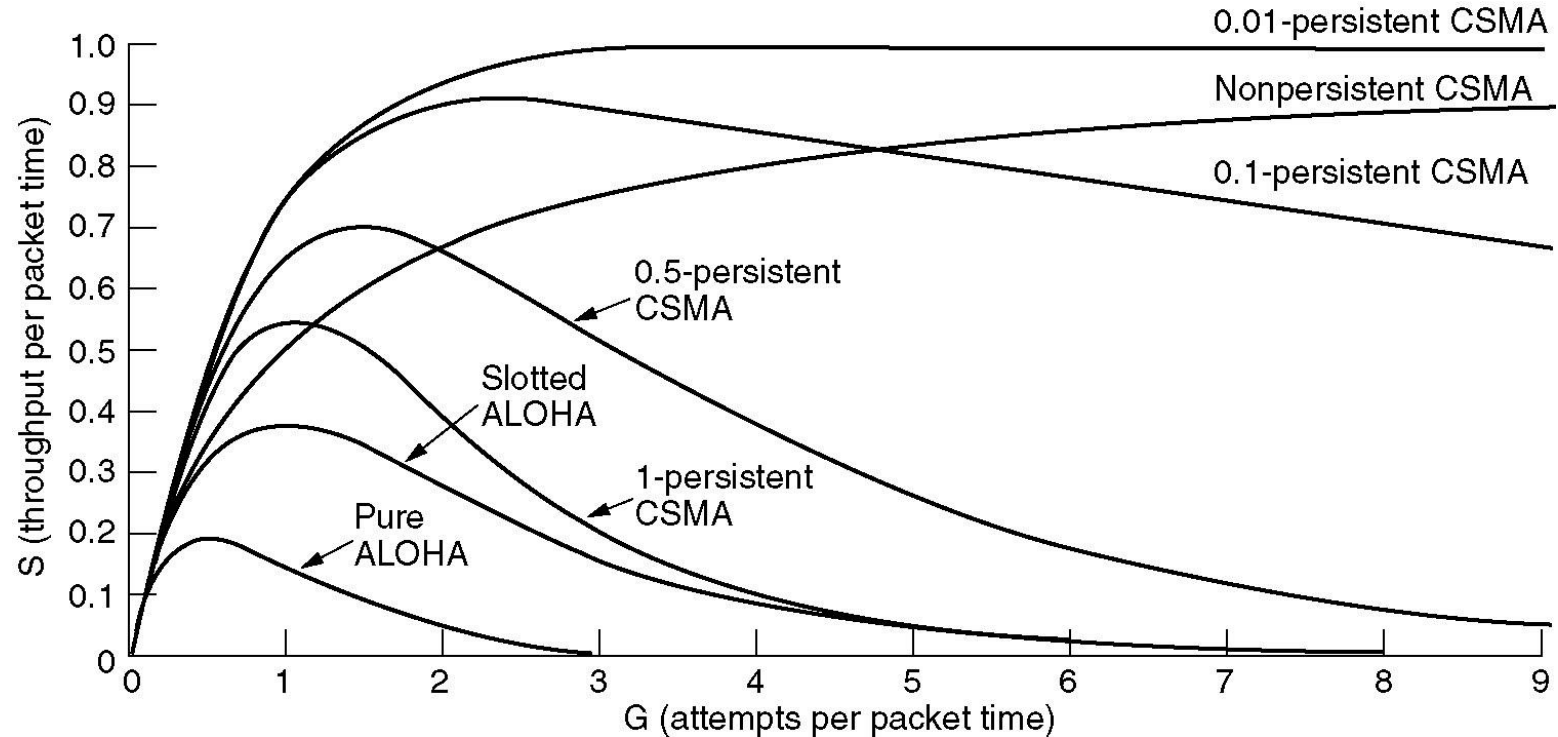
Cons

- Collisions, wasting slots
- Idle slots
- Nodes may be able to detect collision in less than time to transmit packet
- Clock synchronization

CSMA (Carrier Sense Multiple Access)

- Collisions hurt the efficiency of ALOHA protocol
 - At best, channel is useful 37% of the time
- CSMA: listen before transmit
 - If channel sensed idle: transmit entire frame
 - If channel sensed busy, defer transmission
- Human analogy: don't interrupt others!

Persistent and Nonpersistent CSMA



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

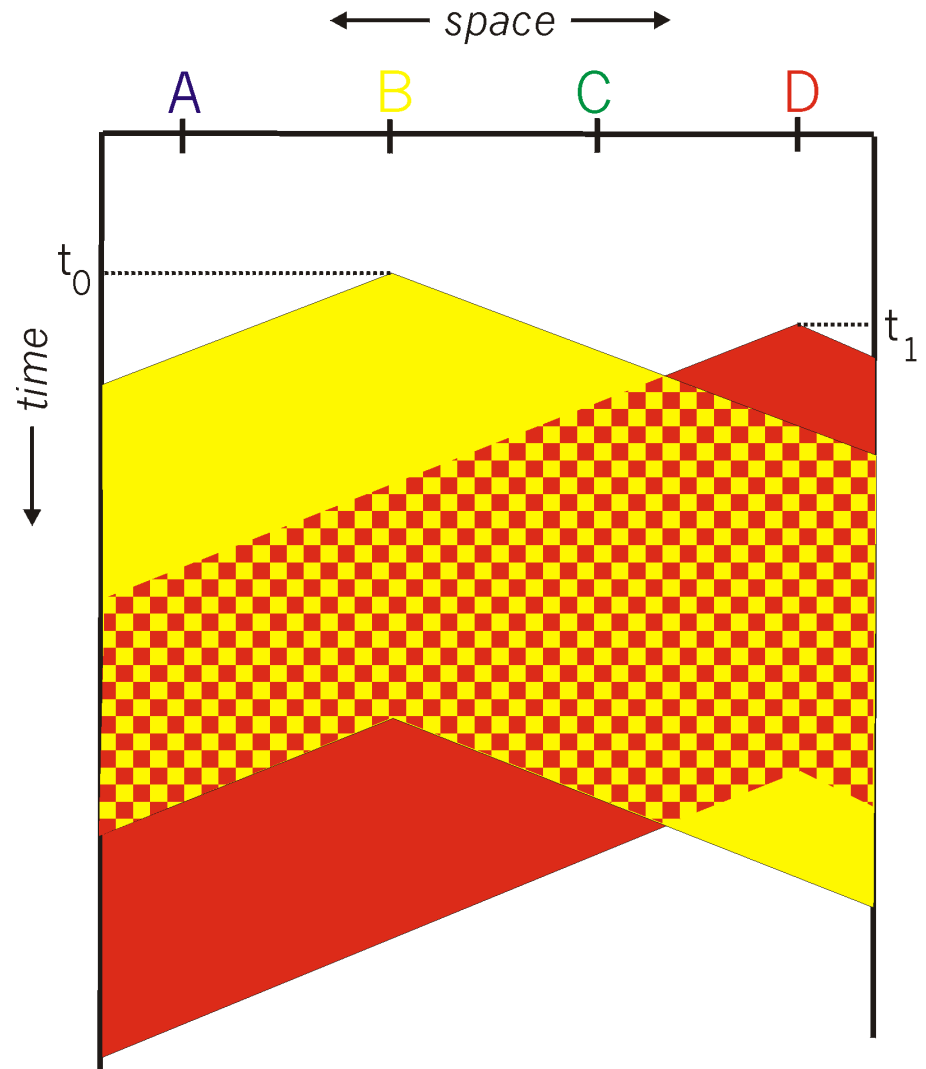
CSMA Collisions

Collisions *can* still occur:

propagation delay means
two nodes may not hear
each other's transmission

Collision:

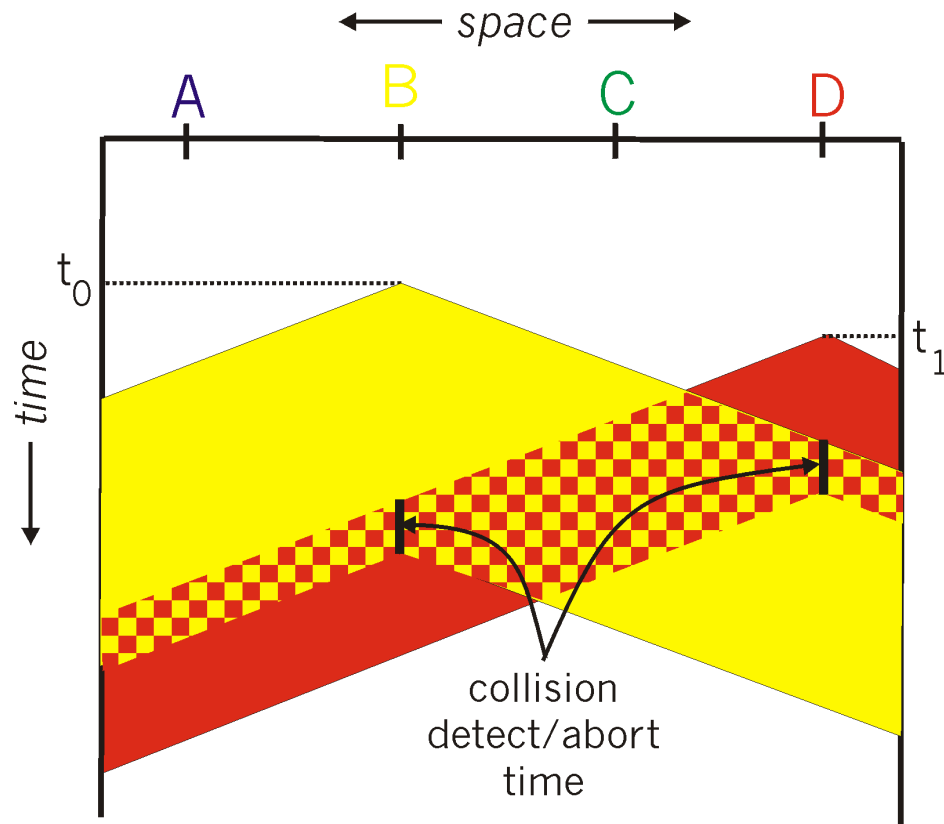
entire packet transmission
time wasted



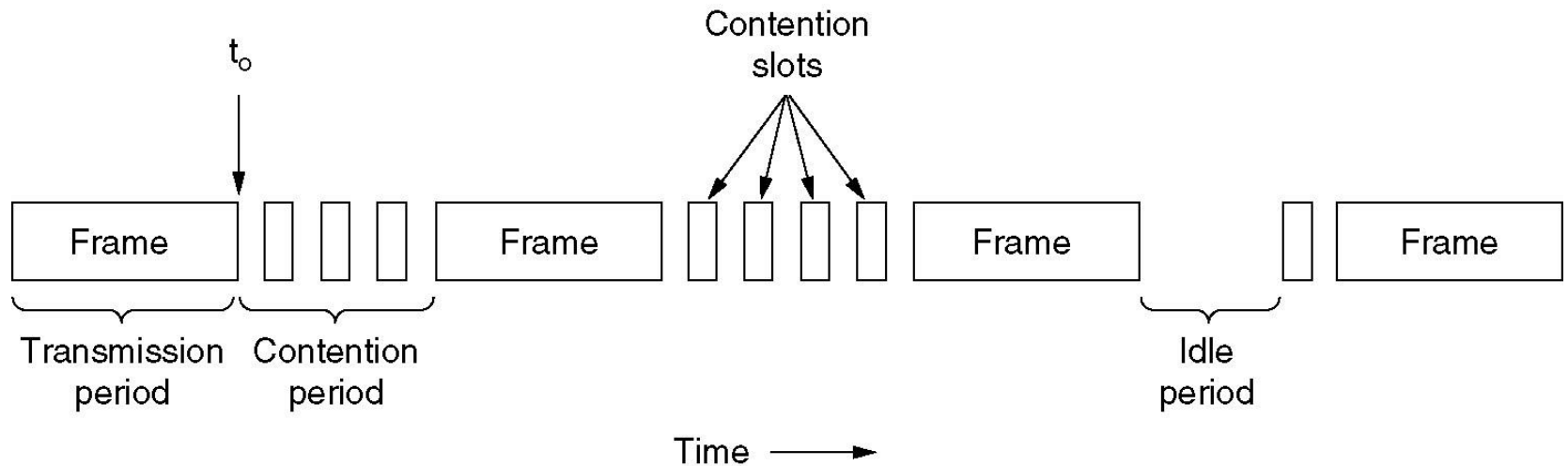
CSMA/CD (Collision Detection)

- CSMA/CD: carrier sensing, deferral as in CSMA
 - Collisions detected within short time
 - Colliding transmissions aborted, reducing wastage
- Collision detection
 - Easy in wired LANs: measure signal strengths, compare transmitted, received signals
 - Difficult in wireless LANs: receiver shut off while transmitting
- Human analogy: the polite conversationalist

CSMA/CD Collision Detection



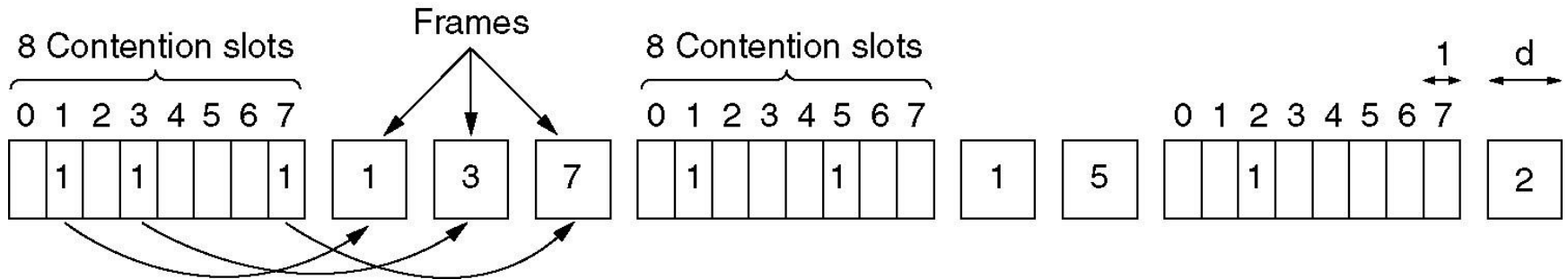
CSMA with Collision Detection



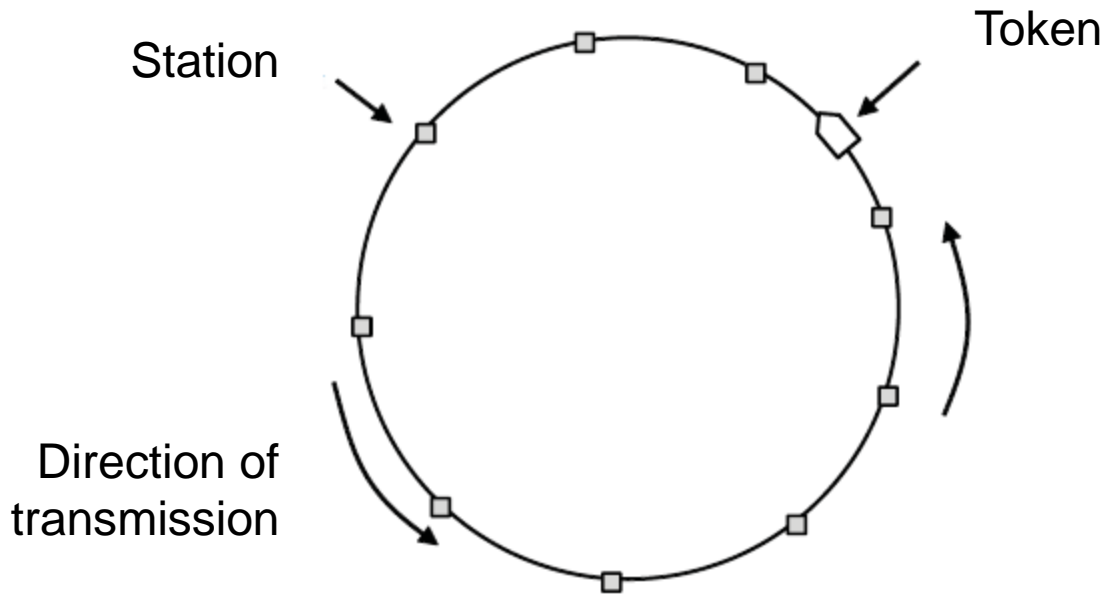
CSMA/CD can be in one of three states: contention, transmission, or idle.

Collision-Free Protocols

The basic bit-map protocol.

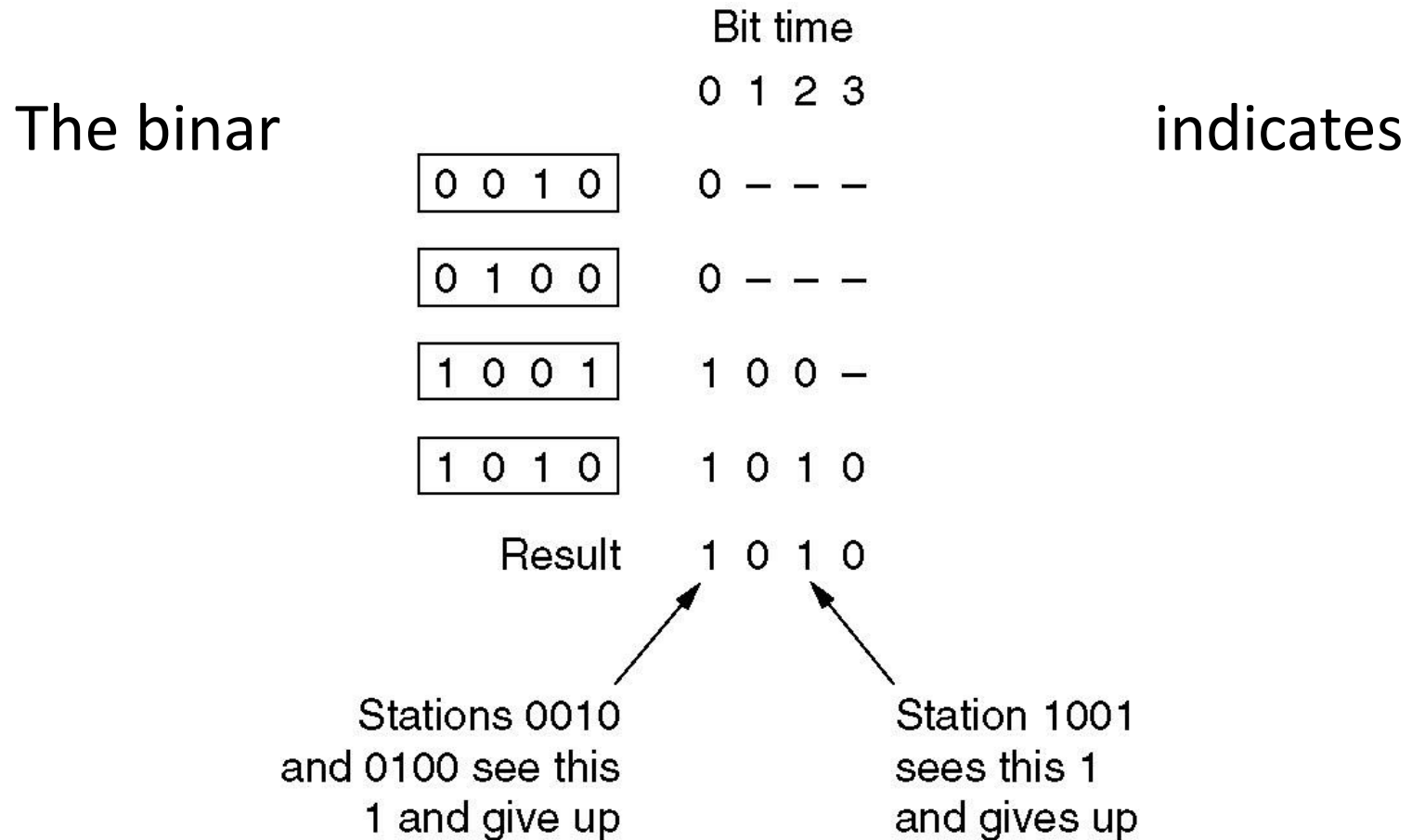


Collision-Free Protocols (2)



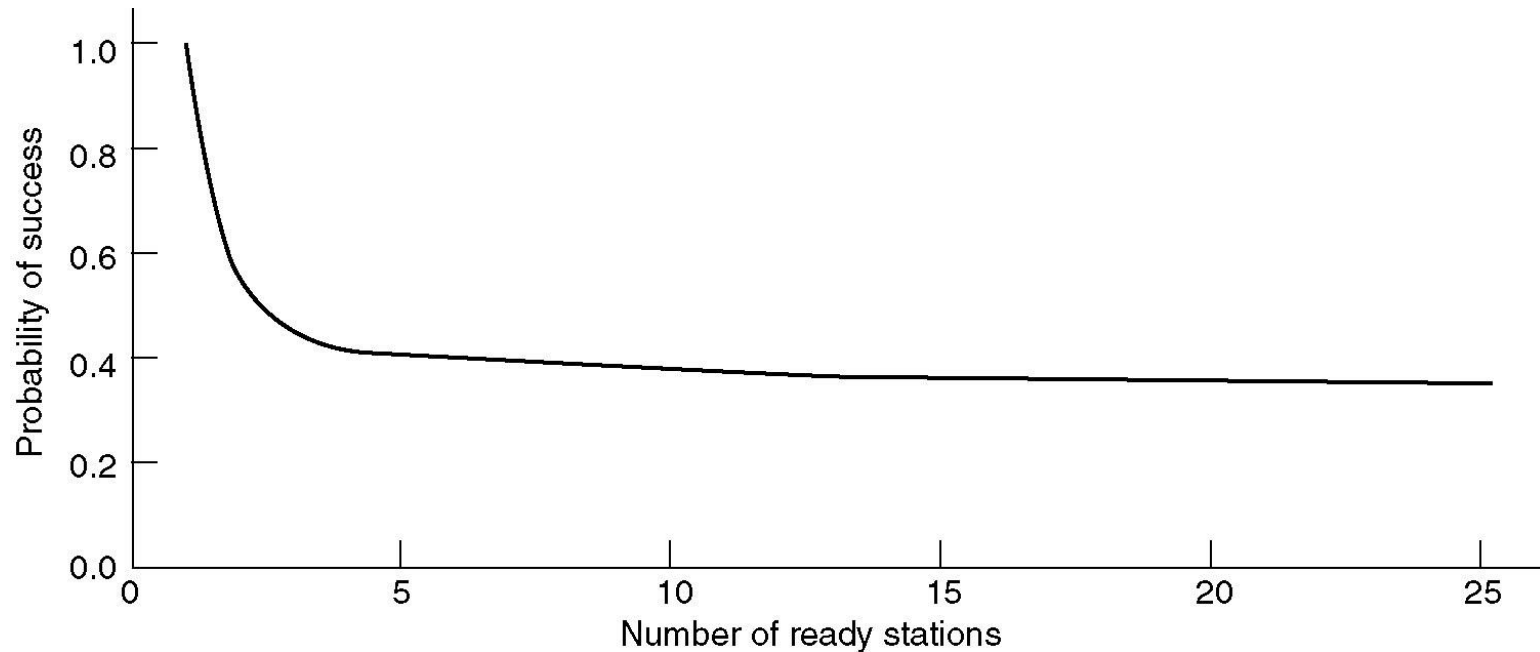
Token ring.

Collision-Free Protocols (2)

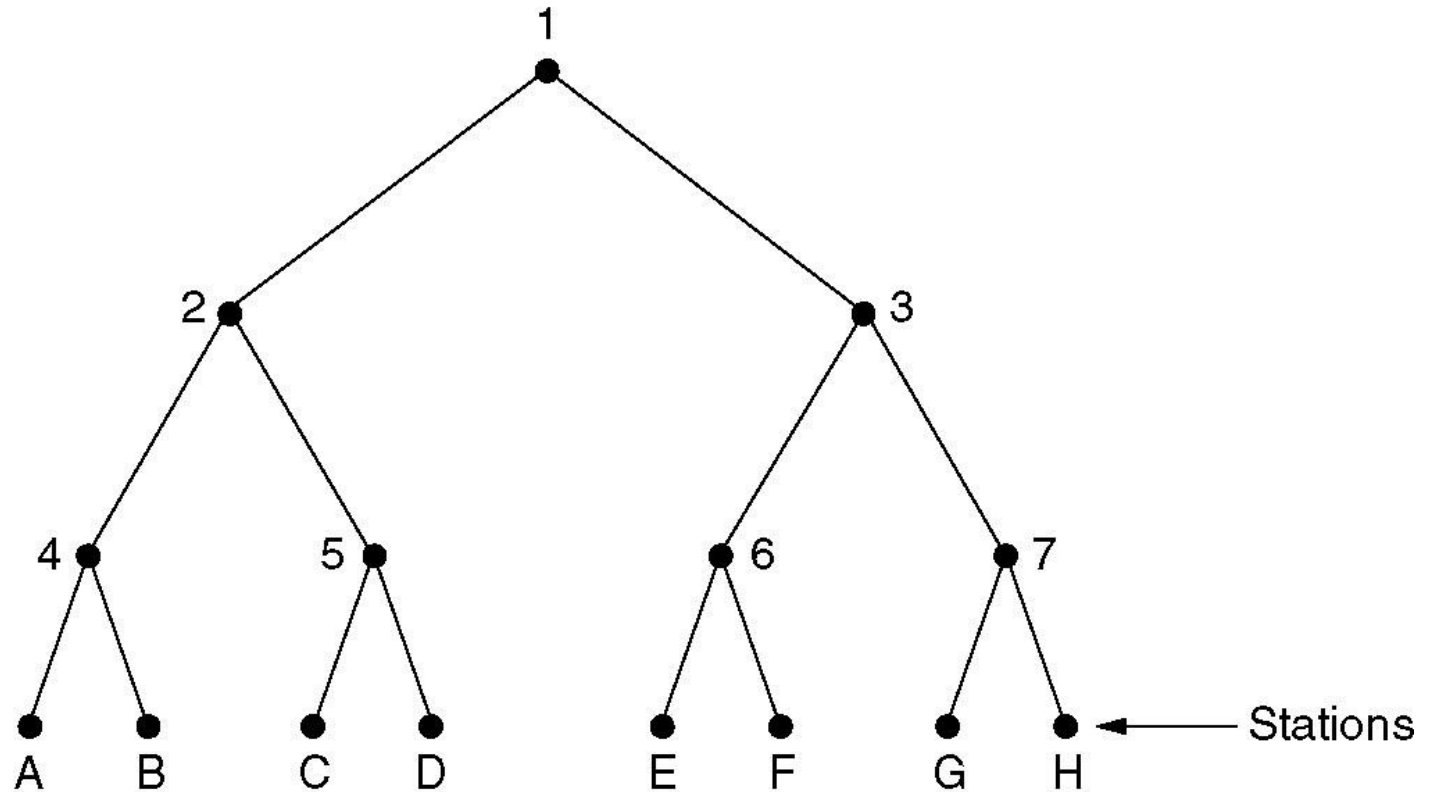


Limited-Contention Protocols

Acquisition probability for a symmetric contention channel.

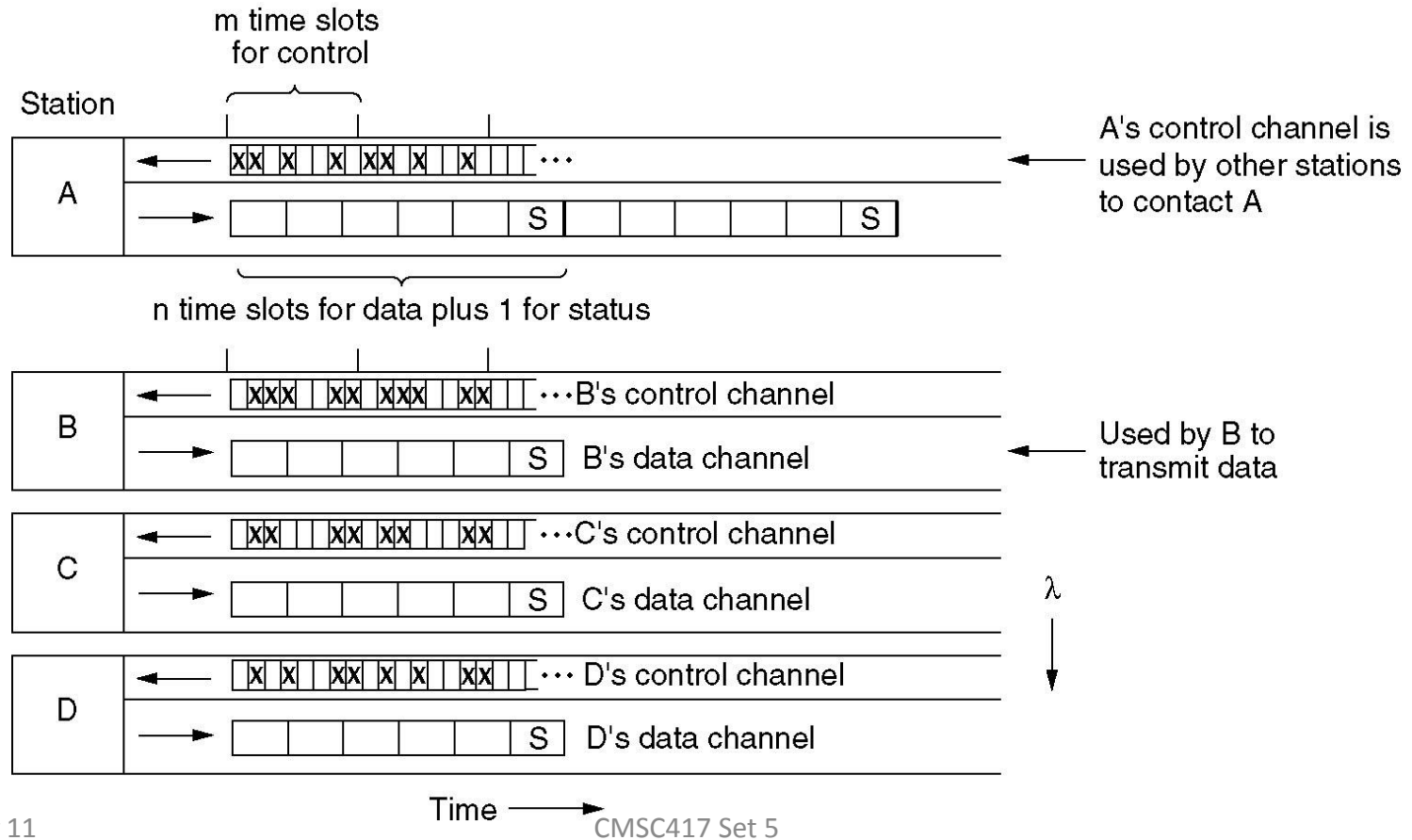


Adaptive Tree Walk Protocol



Wavelength Division Multiple Access Protocols

Wavelength division multiple access.

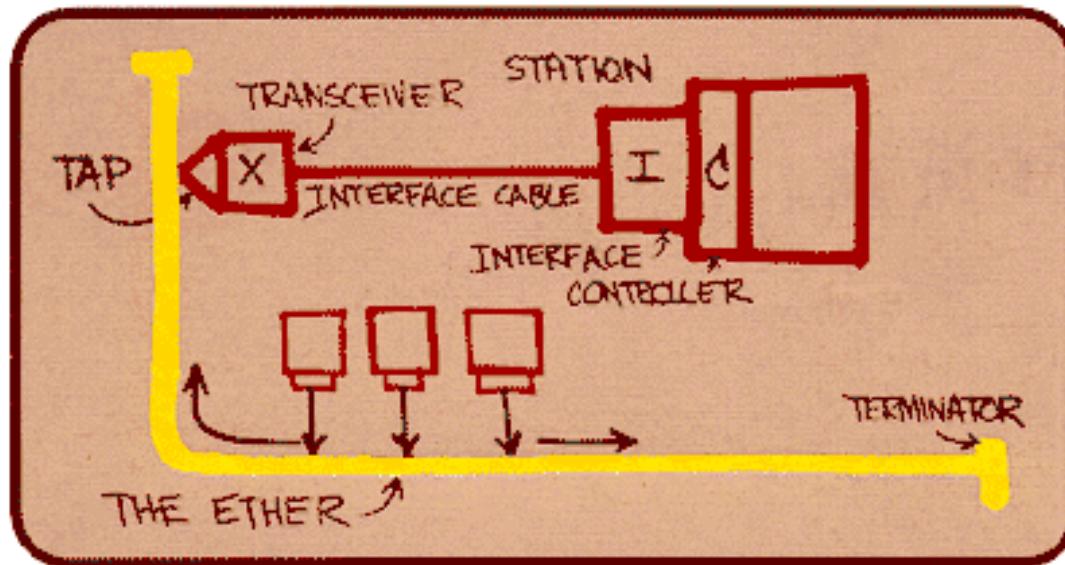


Ethernet

- 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

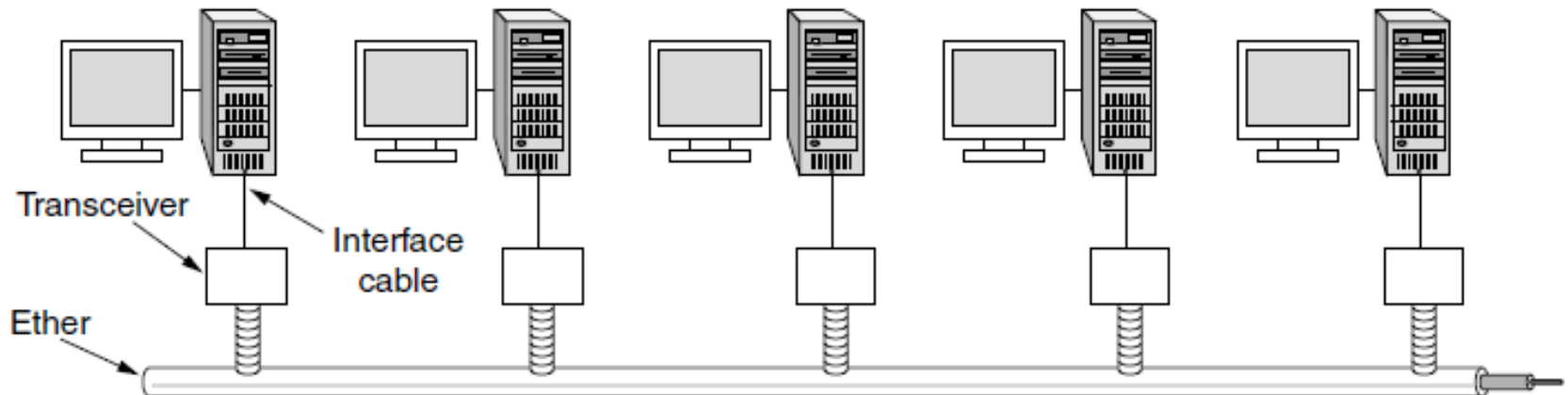
Ethernet

- Dominant wired LAN technology:
- First widely used LAN technology
- Simpler, cheaper than token LANs and ATM
- Kept up with speed race: 10 Mbps – 10 Gbps



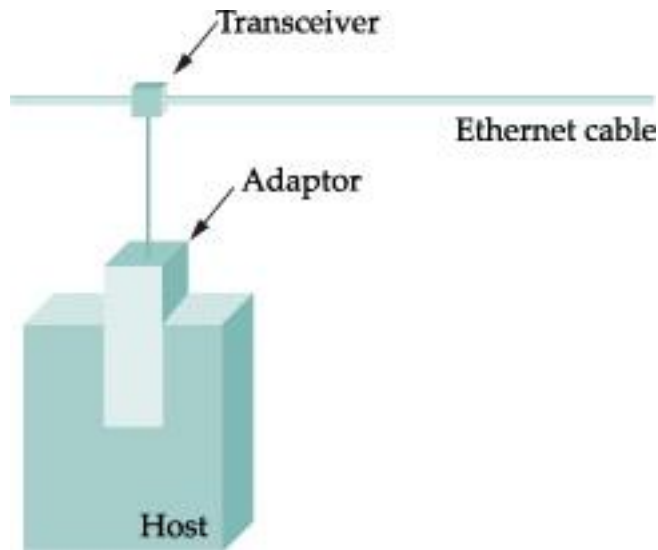
Metcalfe's
Ethernet
sketch

Classic Ethernet Physical Layer



Architecture of classic Ethernet

Ethernet Transceiver and Adapter



- Medium – 50 ohm cable
- Taps 2.5 m apart
- Transceiver – can send and receive
- Multiple segments can be joined by repeaters – no more than 4
- Max end-to-end distance – 2500 m

Ethernet Uses CSMA/CD

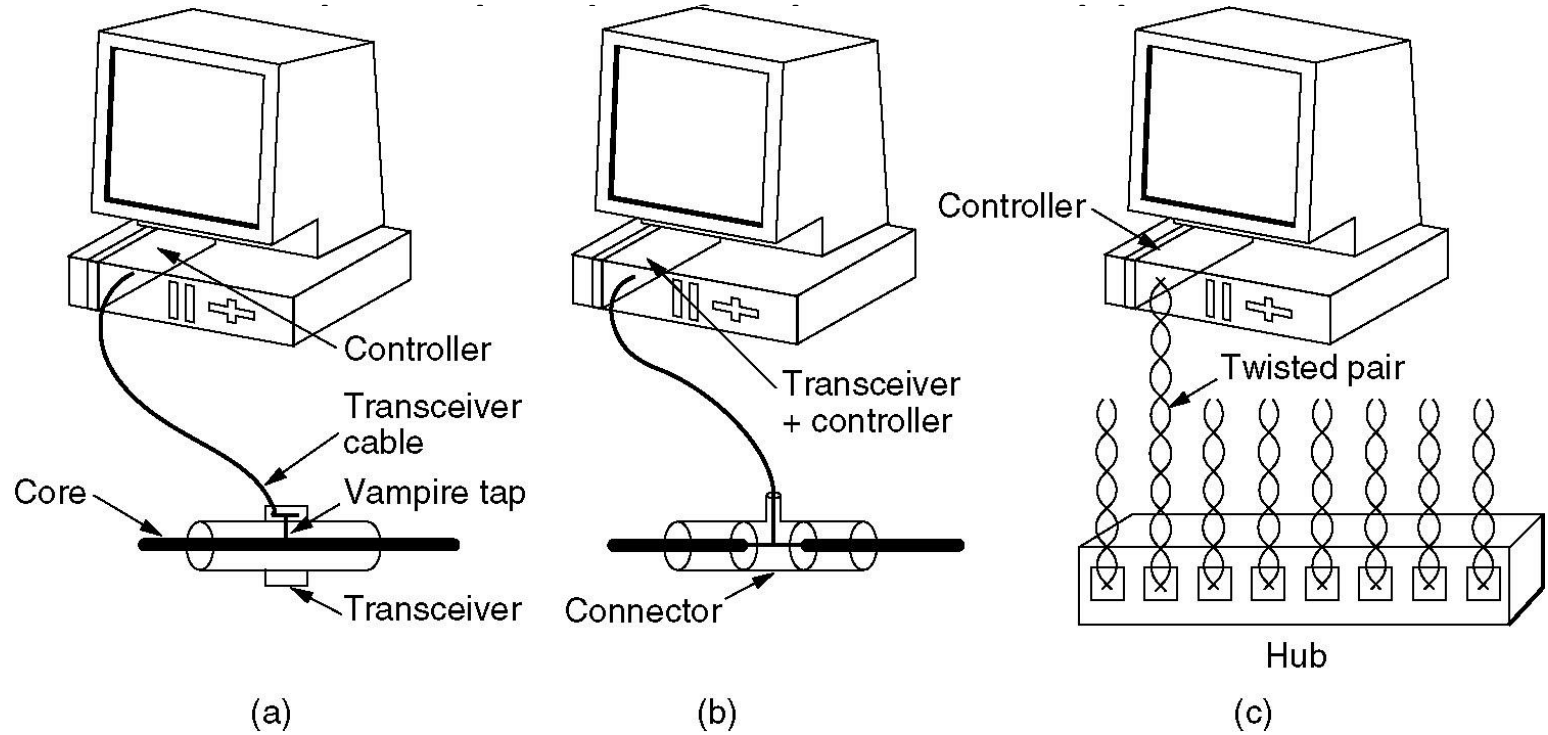
- Carrier sense: wait for link to be idle
 - Channel idle: start transmitting
 - Channel busy: wait until idle
- Collision detection: listen while transmitting
 - No collision: transmission is complete
 - Collision: abort transmission, and send jam signal
- Random access: exponential back-off
 - After collision, wait a random time before trying again
 - After m^{th} collision, choose K randomly from $\{0, \dots, 2^m-1\}$
 - ... and wait for $K*512$ bit times before trying again

Ethernet Cabling

The most common kinds of Ethernet cabling.

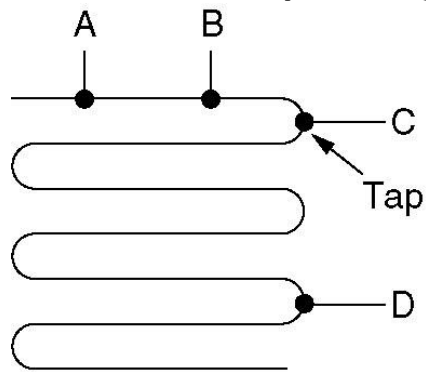
Name	Cable	Max. seg.	Nodes/seg.	Advantages
10Base5	Thick coax	500 m	100	Original cable; now obsolete
10Base2	Thin coax	185 m	30	No hub needed
10Base-T	Twisted pair	100 m	1024	Cheapest system
10Base-F	Fiber optics	2000 m	1024	Best between buildings

Ethernet Cabling (2)

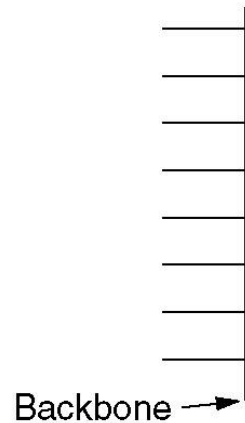


Ethernet Cabling (3)

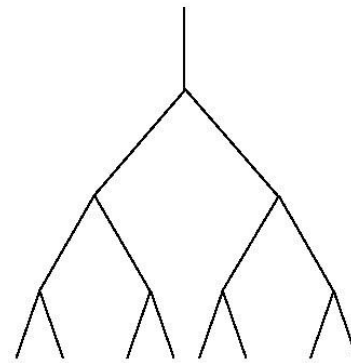
Cable topologies. (a) Linear, (b) Spine, (c) Tree, (d)



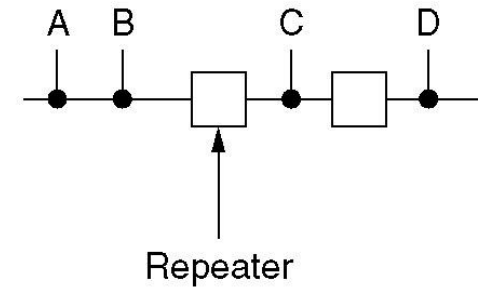
(a)



(b)

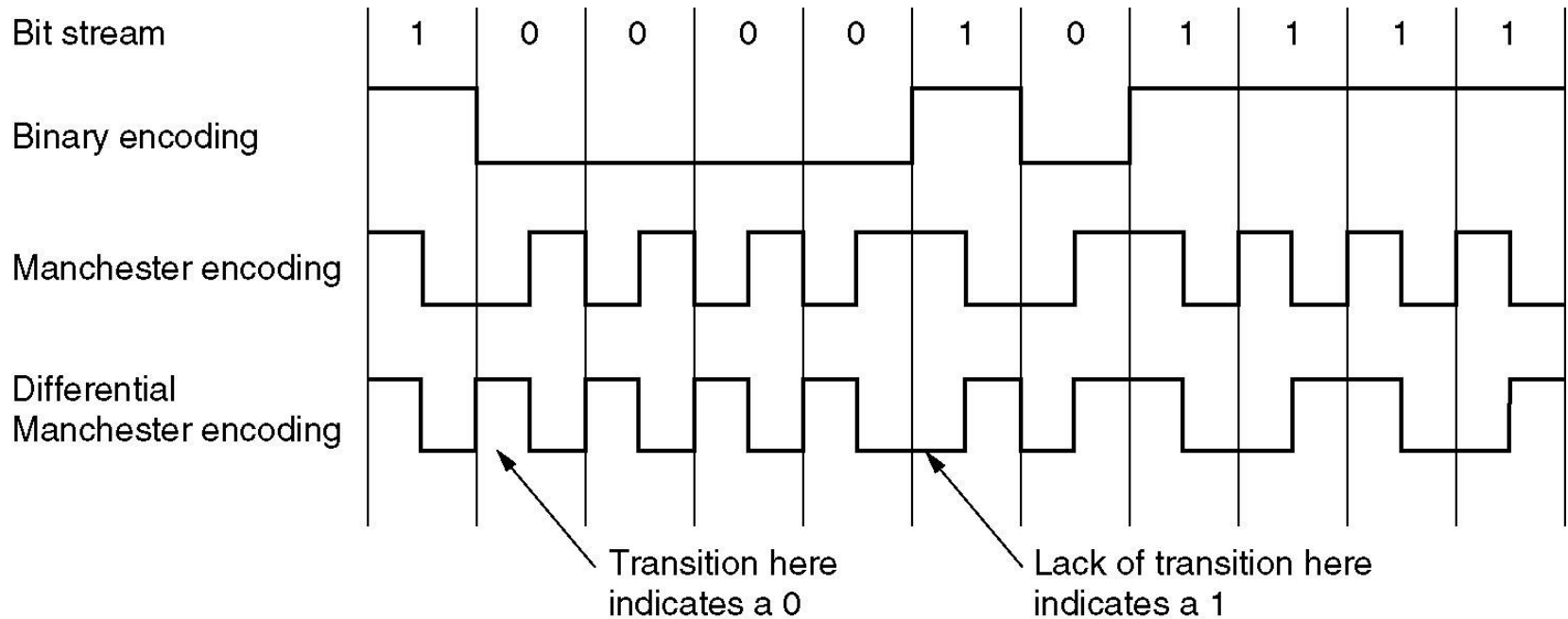


(c)



(d)

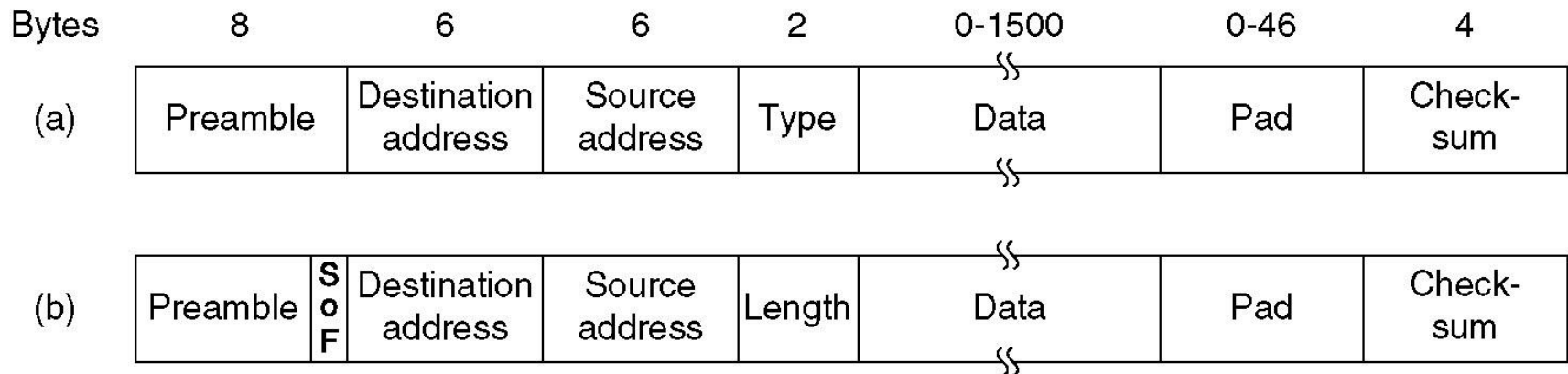
Ethernet Signalling



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

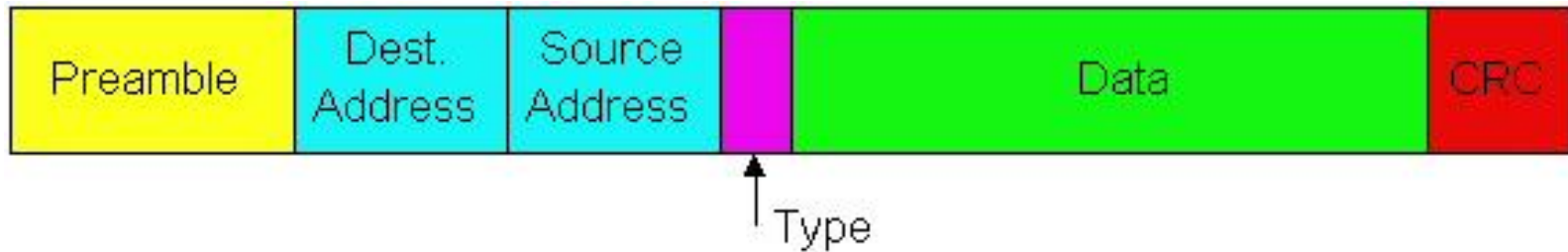
Ethernet MAC Sublayer Protocol

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



Ethernet Frame Structure

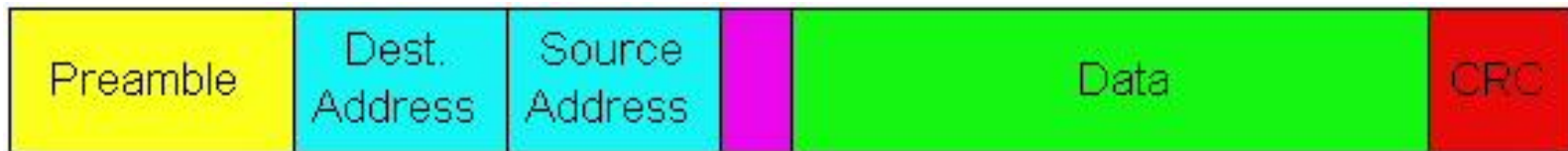
- Sending adapter encapsulates packet in frame



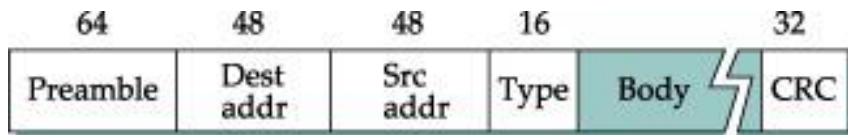
- **Preamble:** synchronization
 - Seven bytes with pattern 10101010, followed by one byte with pattern 10101011
 - Used to synchronize receiver, sender clock rates

Ethernet Frame Structure (Continued)

- **Addresses:** source and destination MAC addresses
 - Adaptor passes frame to network-level protocol
 - If destination address matches the adaptor
 - Or the destination address is the broadcast address
 - Otherwise, adapter discards frame
- **Type:** indicates the higher layer protocol
 - Usually IP
 - But also Novell IPX, AppleTalk, ...
- **CRC:** cyclic redundancy check
 - Checked at receiver
 - If error is detected, the frame is simply dropped



Ethernet Frame Format

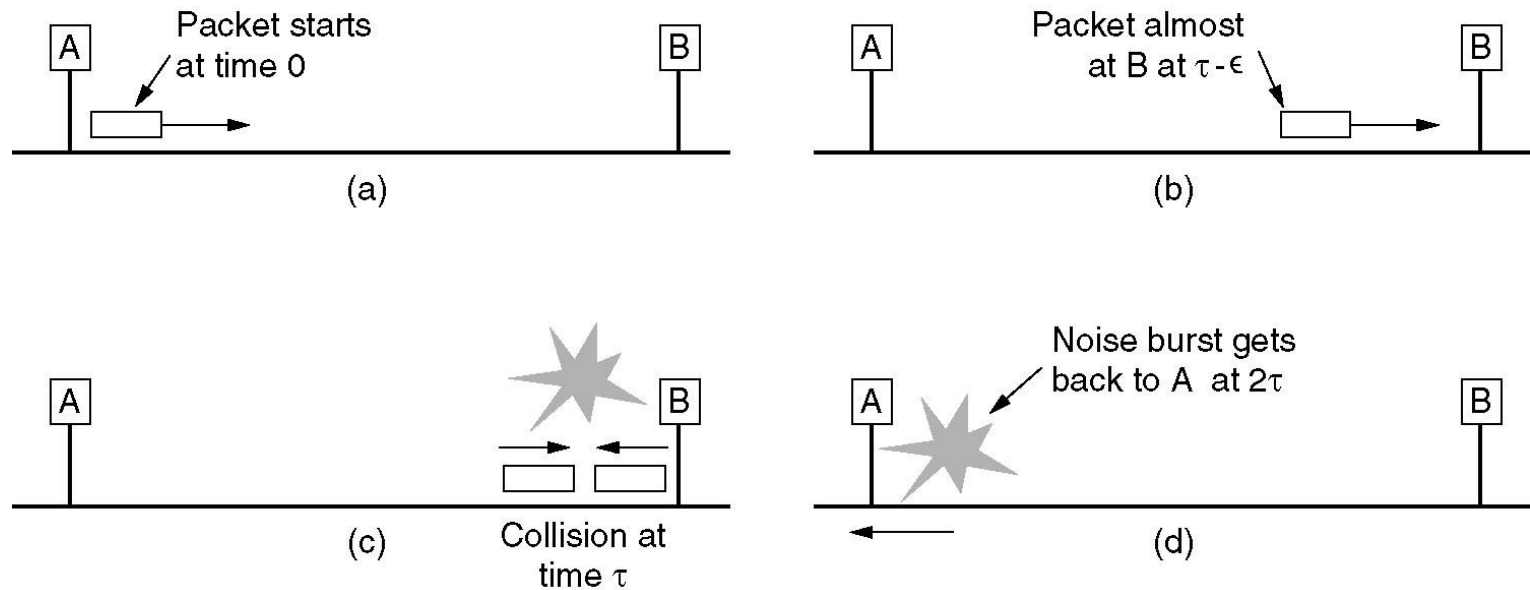


- Preamble –
 - For synchronizing
 - Alternate 0 and 1
- Address – 48 bit MAC
- Type – Id for higher level protocol
- Length – up to 1500 bytes, with minimum of 46 bytes, of data
- 802.3 – Length for Type field.

Ethernet Transmitter Algorithm

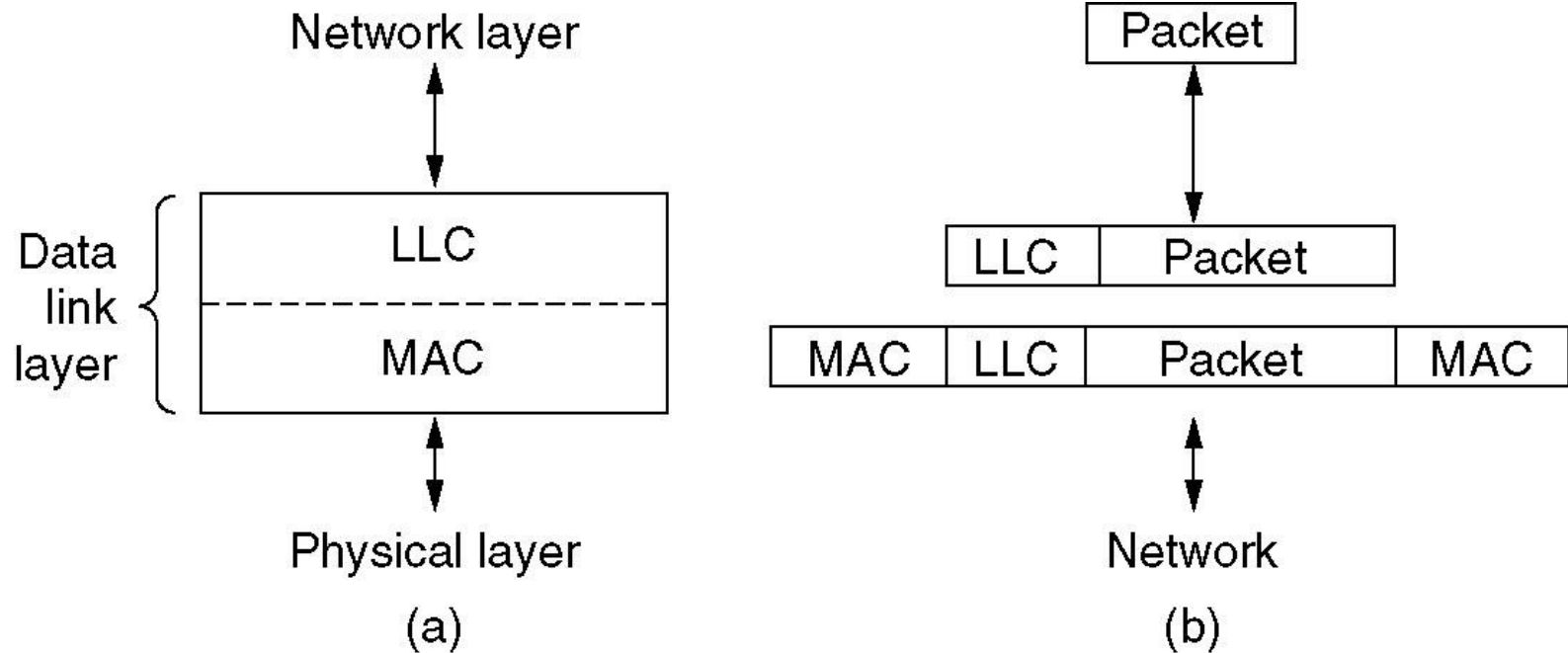
- P-persistent
 - Transmit with prob p when line goes idle
- Ethernet uses 1-persistent algorithm
- On Collision-
 - 32 bit jamming sequence
 - Stops transmitting
 - Runt frame – 64 synch + 32 bit jamming sequence
- Min frame size – 64 bytes – 46 + 14 + 4
- For 2500 m line with up to 4 repeaters max round trip delay – 51.2 μ s
- Exponential Backoff
 - In steps of 51.2 μ s
 - Wait $k^* \text{ rand}(0, .. 2^k - 1)$

Ethernet MAC Sublayer Protocol (2)



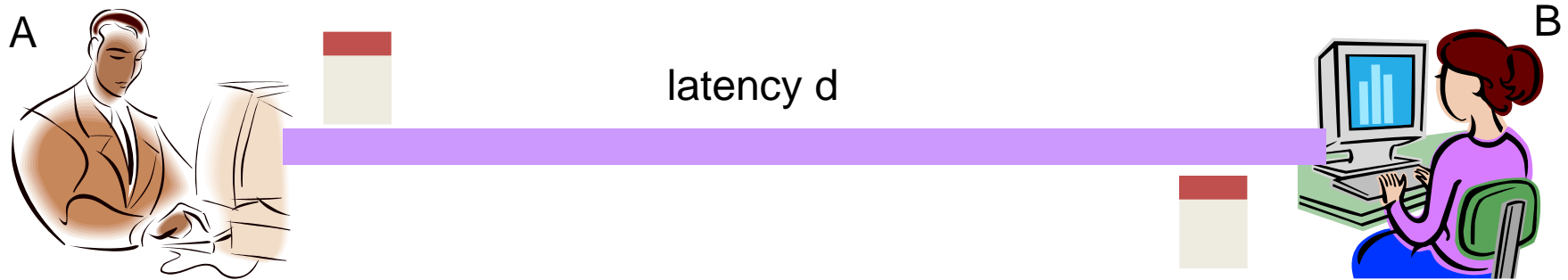
Collision detection can take as long as 2τ .

IEEE 802.2: Logical Link Control



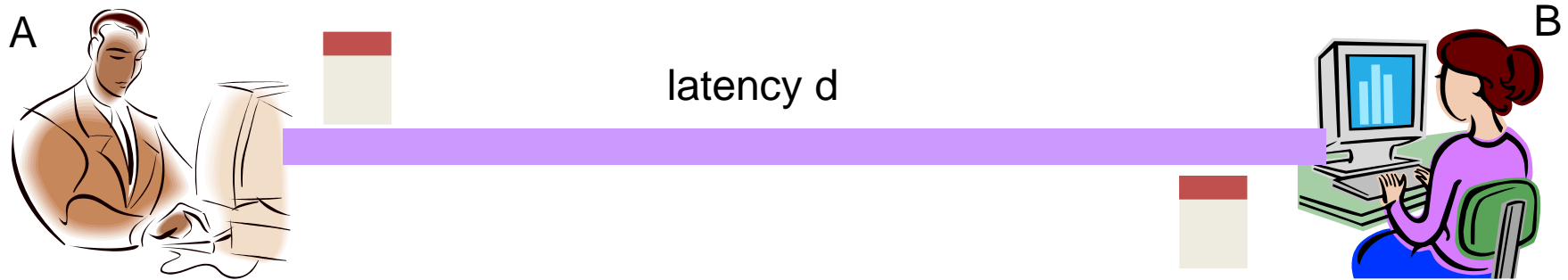
(a) Position of LLC. (b) Protocol formats.

Limitations on Ethernet Length



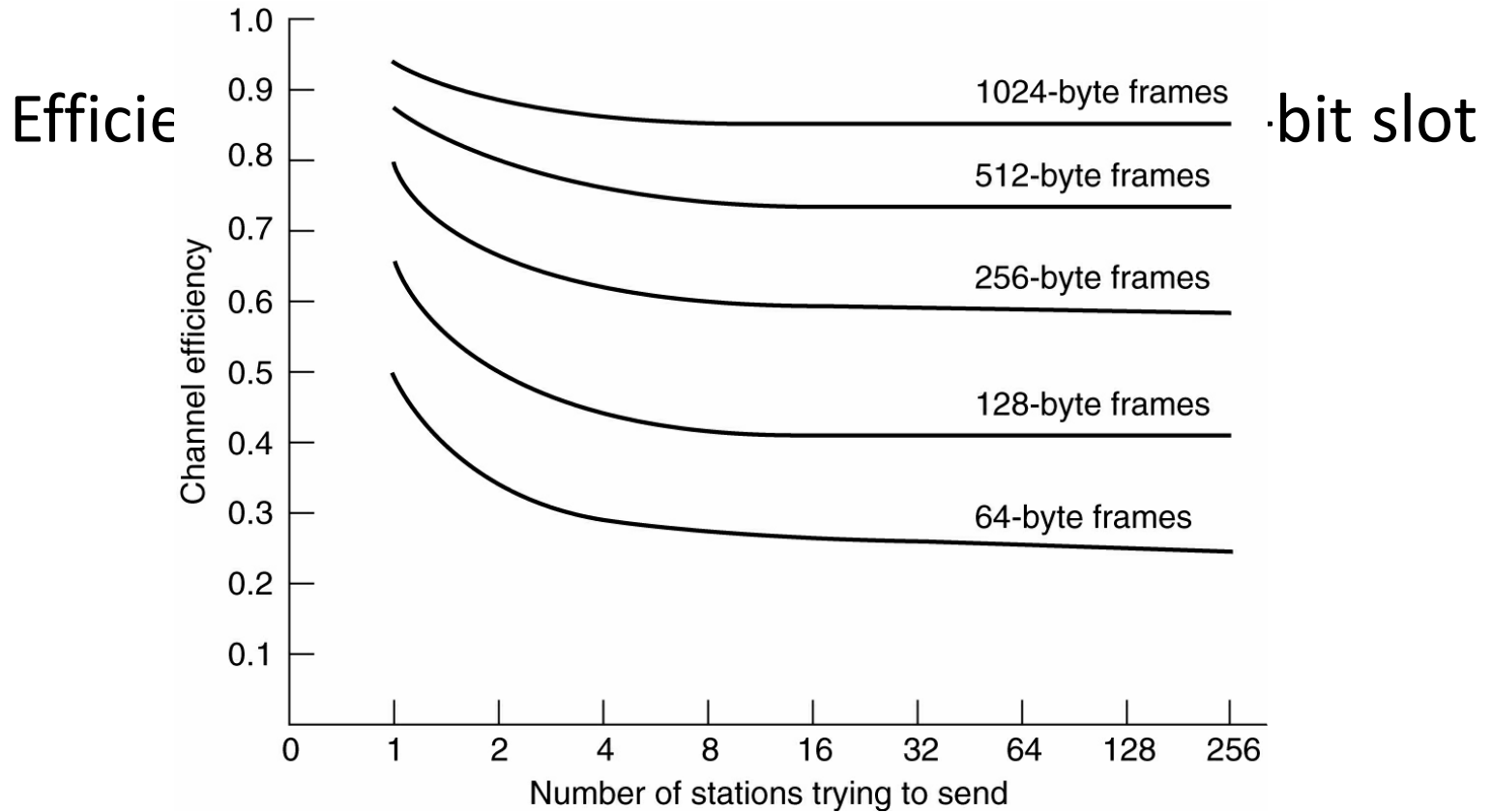
- Latency depends on physical length of link
 - Time to propagate a packet from one end to the other
- Suppose A sends a packet at time t
 - And B sees an idle line at a time just before $t+d$
 - ... so B happily starts transmitting a packet
- B detects a collision, and sends jamming signal
 - But A doesn't see collision till $t+2d$

Limitations on Ethernet Length

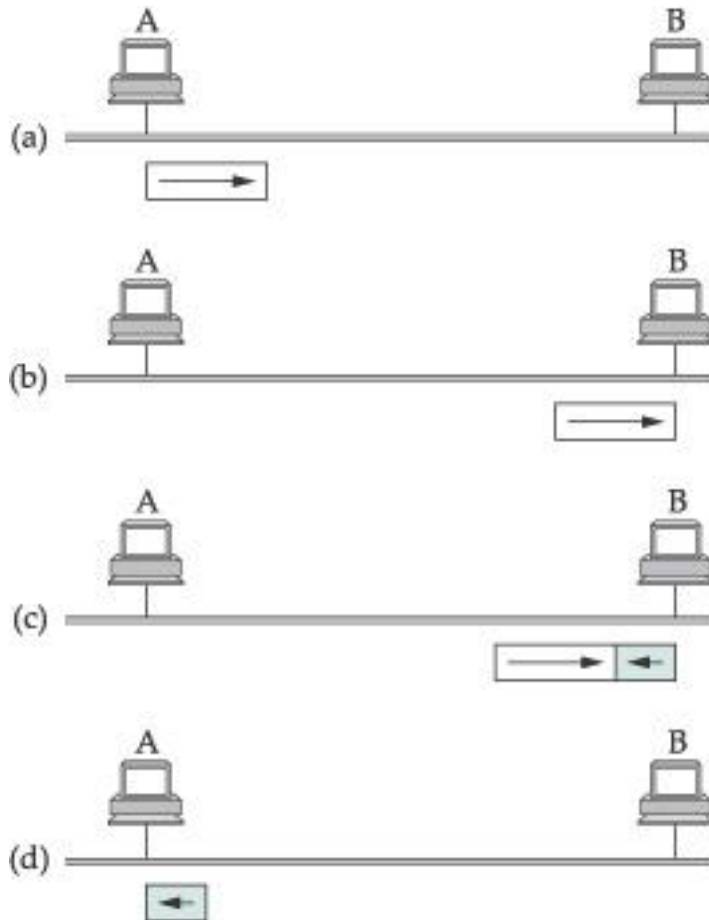


- A needs to wait for time $2d$ to detect collision
 - So, A should keep transmitting during this period
 - ... and keep an eye out for a possible collision
- Imposes restrictions on Ethernet
 - Maximum length of the wire: 2500 meters
 - Minimum length of the packet: 512 bits (64 bytes)

Ethernet Performance



Worst Case Scenario



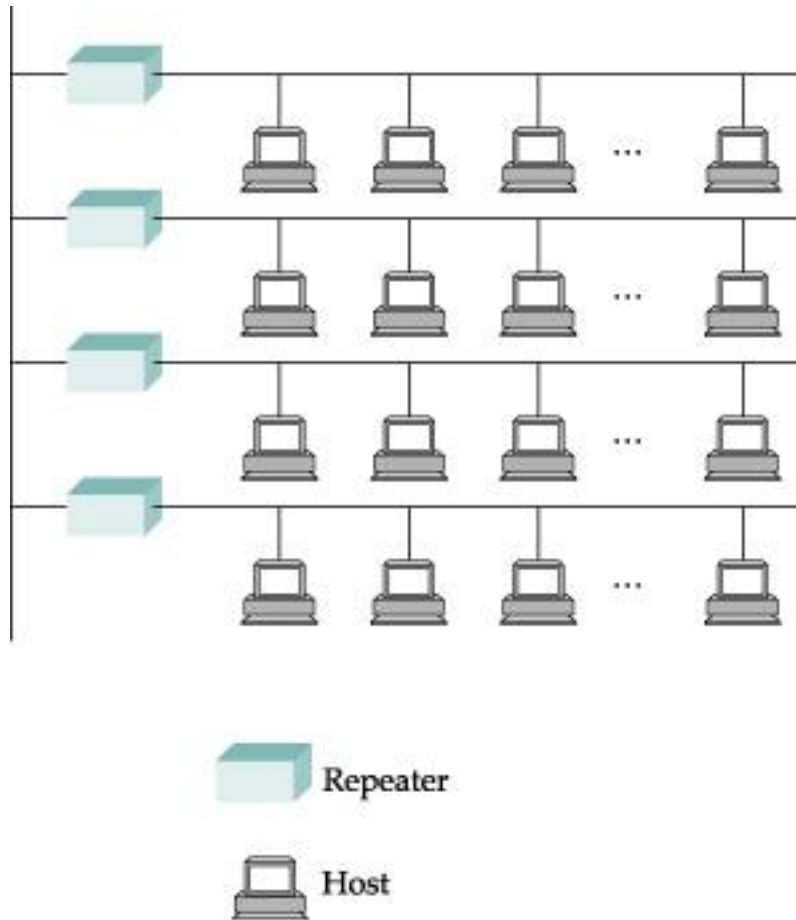
A sends a frame at time t

Frame arrives at B at $t+d$

B begins transmitting at $t+d$ and collides with A's Frame

B's 32 bit frame arrives at A at $t+2d$

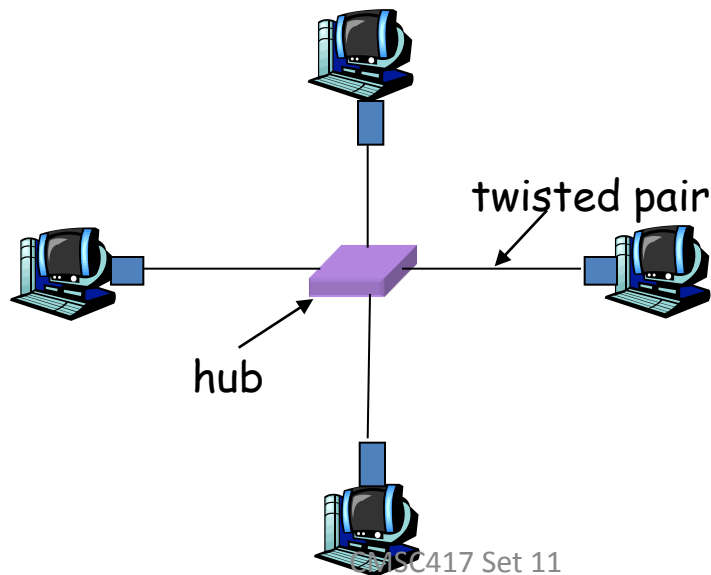
Ethernet Repeaters



- Up to 4 Repeaters
- Cables
 - 10Base 5
 - 10Mbps
 - Baseband
 - 500 Meters
 - 10Base2
 - 10BaseT
 - Twisted Pair 100 M
 - Category 5 (Cat 5)
 - 10 M and 100 M
 - Twisted Pair

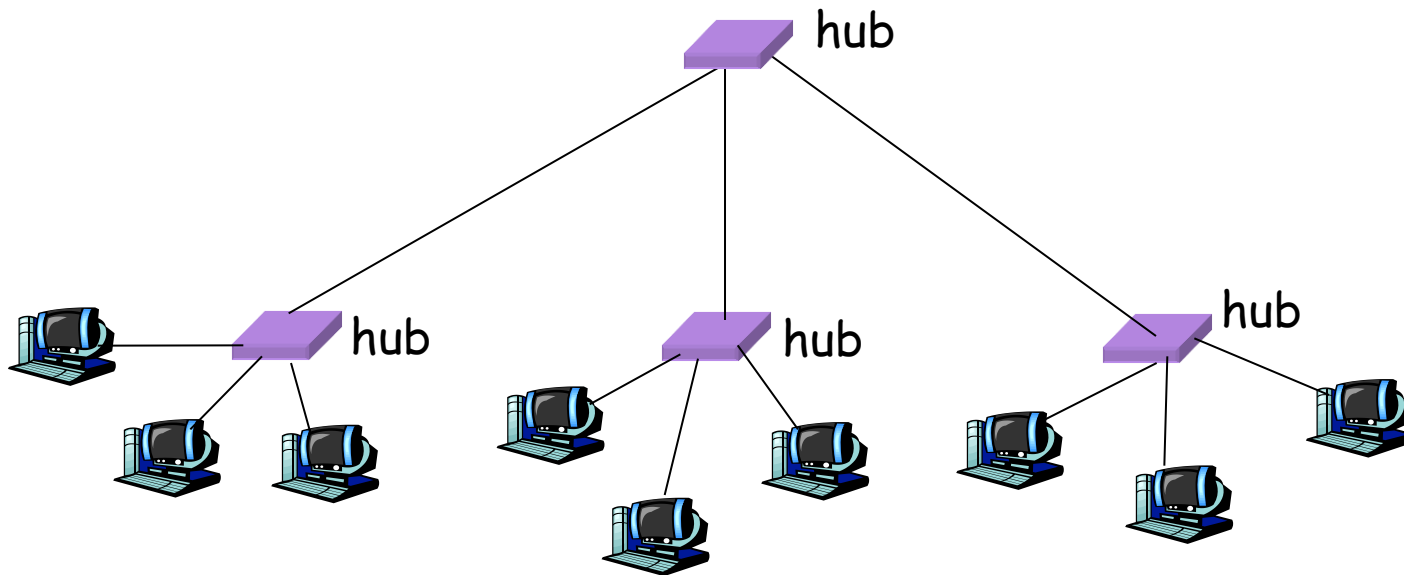
Hubs: Physical-Layer Repeaters

- Hubs are physical-layer repeaters
 - Bits coming from one link go out all other links
 - At the same rate, with no frame buffering
 - No CSMA/CD at hub: adapters detect collisions



Interconnecting with Hubs

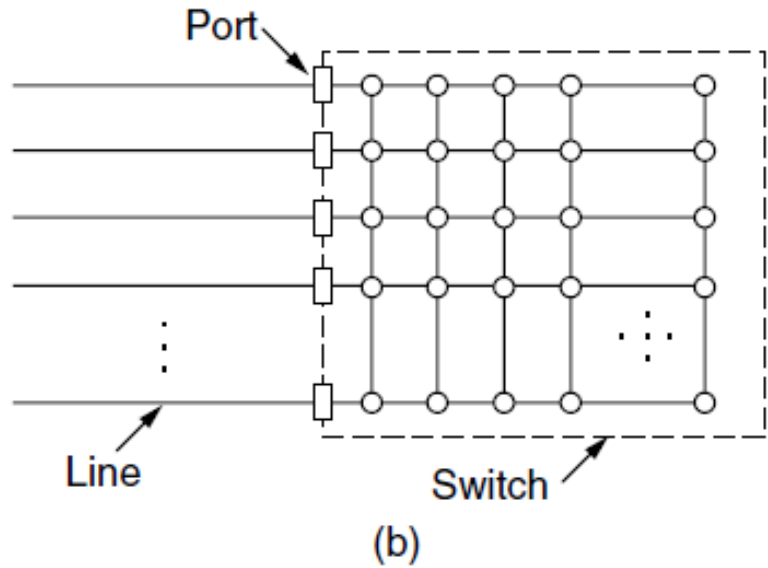
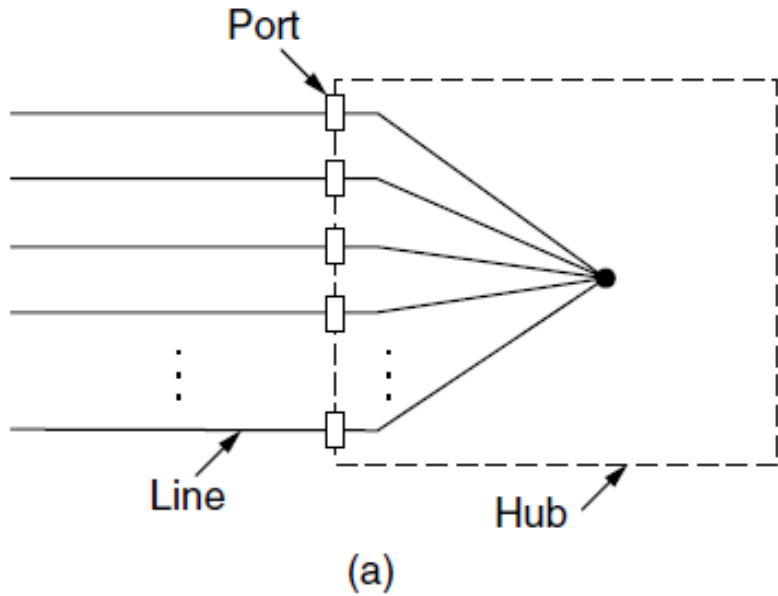
- Backbone hub interconnects LAN segments
- All packets seen everywhere, forming one large collision domain
- Can't interconnect Ethernets of different speeds



Switch

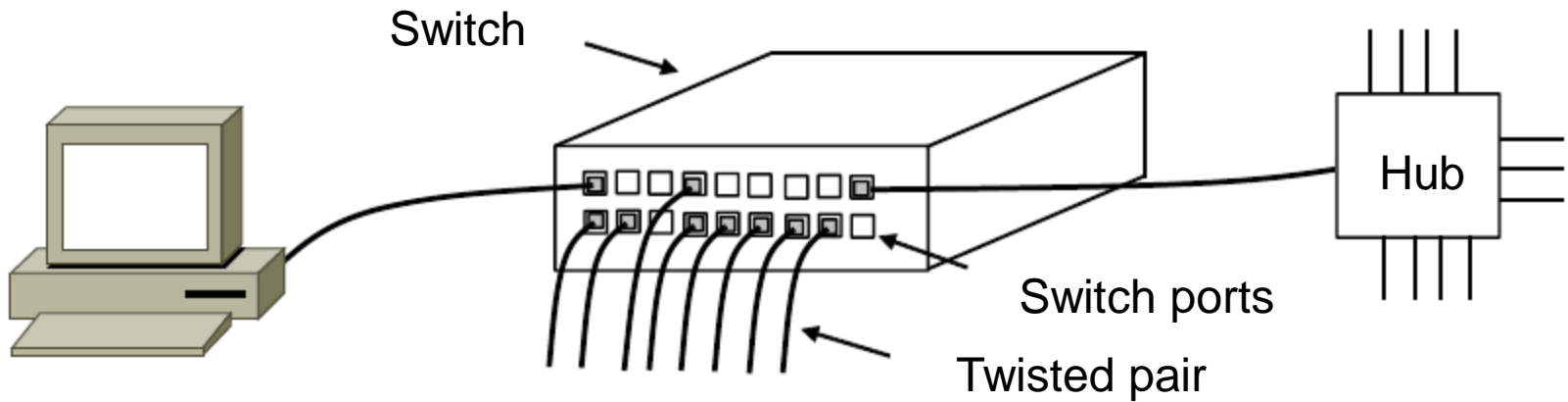
- Link layer device
 - Stores and forwards Ethernet frames
 - Examines frame header and selectively forwards frame based on MAC dest address
 - When frame is to be forwarded on segment, uses CSMA/CD to access segment
- Transparent
 - Hosts are unaware of presence of switches
- Plug-and-play, self-learning
 - Switches do not need to be configured

Switched Ethernet (1)



(a) Hub. (b) Switch.

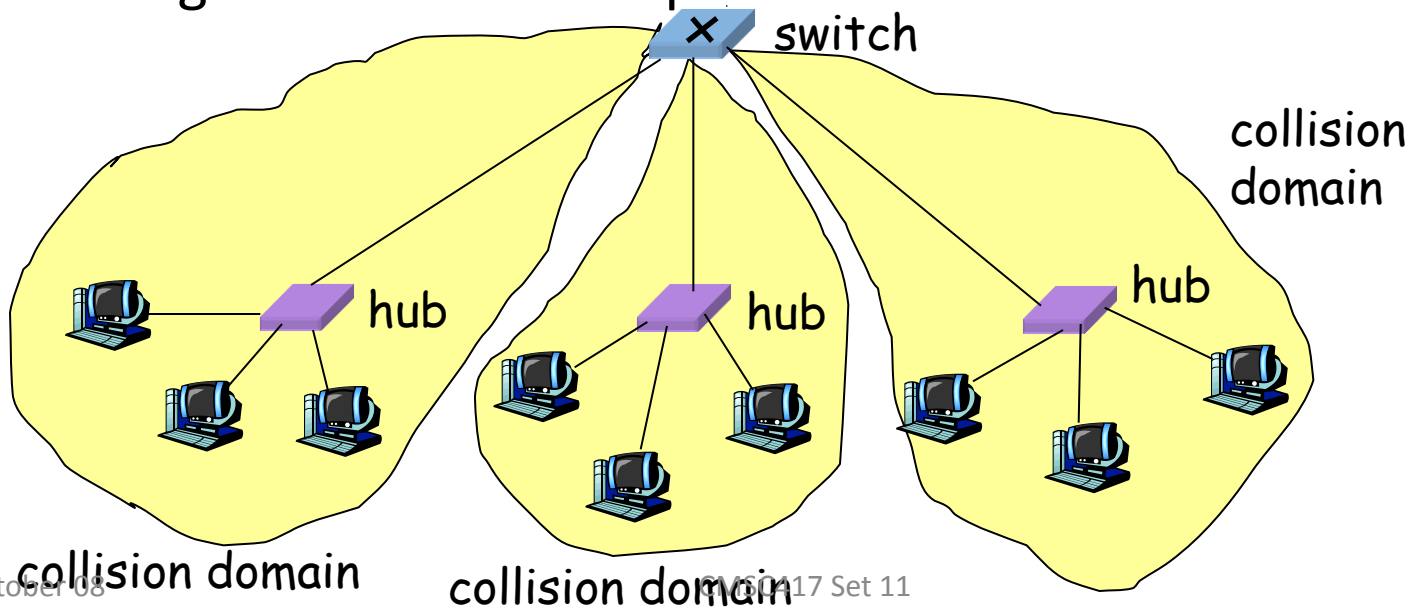
Switched Ethernet (2)



An Ethernet switch.

Switch: Traffic Isolation

- Switch breaks subnet into LAN segments
- Switch filters packets
 - Same-LAN-segment frames not usually forwarded onto other LAN segments
 - Segments become separate collision domains

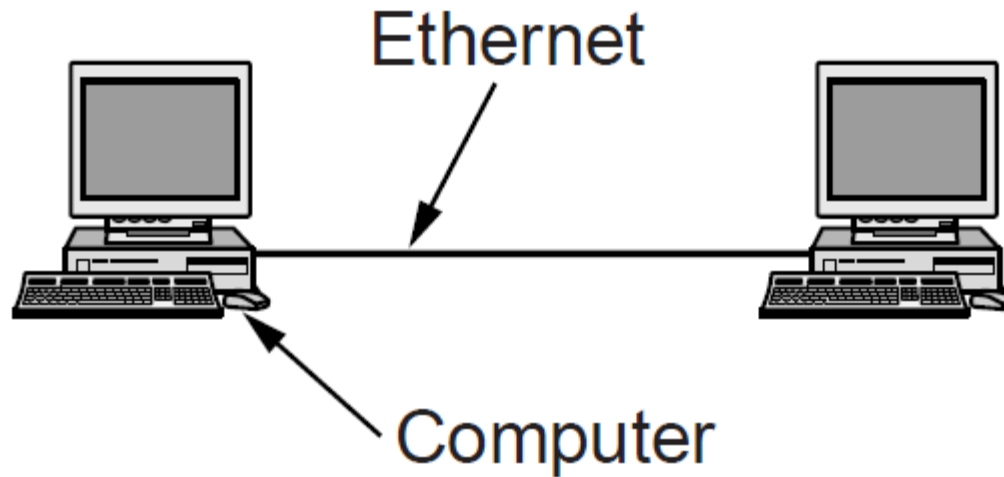


Fast Ethernet

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 (Cat 5 UTP)
100Base-FX	Fiber optics	2000 m	Full duplex at 100 Mbps; long runs

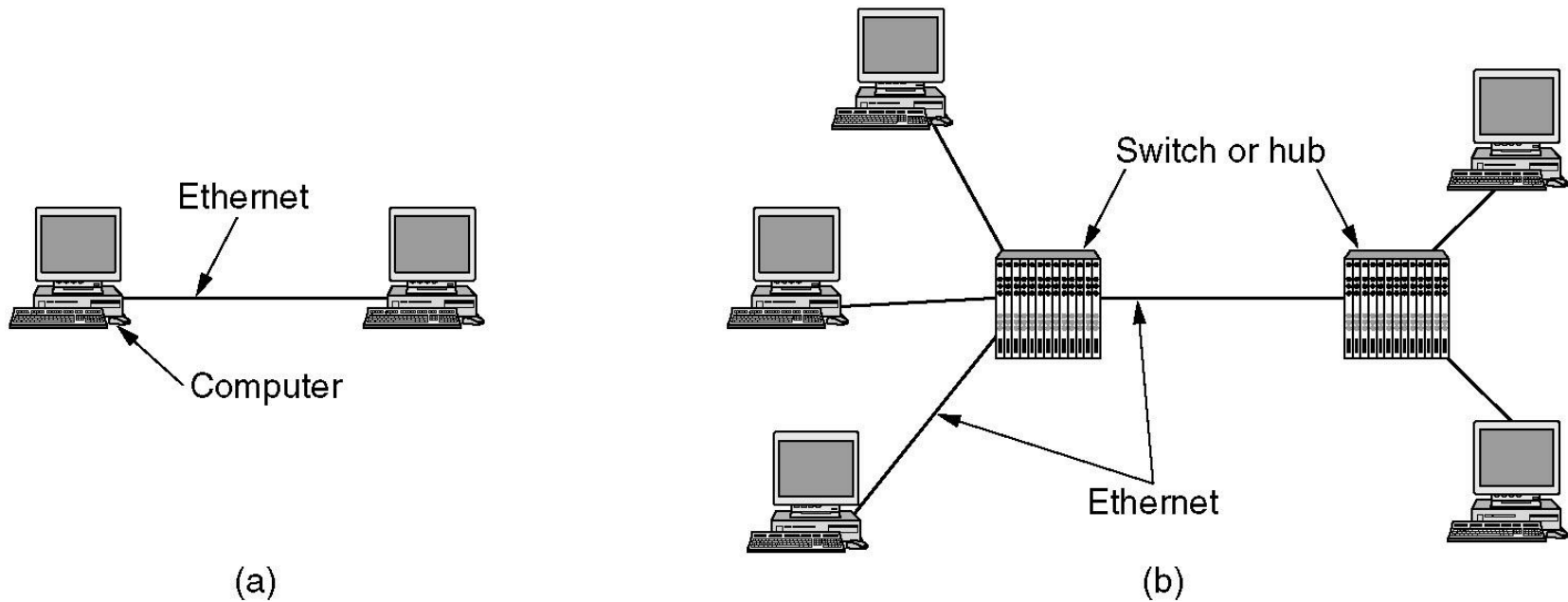
The original fast Ethernet cabling.

Gigabit Ethernet (1)



A two-station Ethernet

Gigabit Ethernet



(a) A two-station Ethernet. **(b)** A multistation Ethernet.

Gigabit Ethernet (2)

Gigabit Ethernet cabling.

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

10 Gigabit Ethernet

Name	Cable	Max. segment	Advantages
10GBase-SR	Fiber optics	Up to 300 m	Multimode fiber (0.85 μ)
10GBase-LR	Fiber optics	10 km	Single-mode fiber (1.3 μ)
10GBase-ER	Fiber optics	40 km	Single-mode fiber (1.5 μ)
10GBase-CX4	4 Pairs of twinax	15 m	Twinaxial copper
10GBase-T	4 Pairs of UTP	100 m	Category 6a UTP

Gigabit Ethernet cabling

Benefits of Ethernet

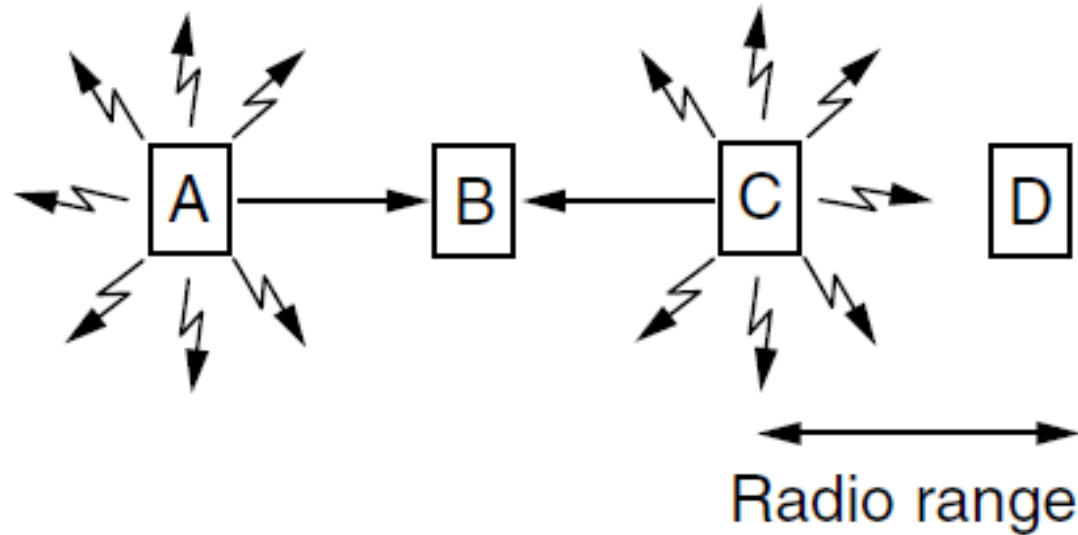
- Easy to administer and maintain
- Inexpensive
- Increasingly higher speed

- Moved from shared media to switches
 - Change everything except the frame format
 - A good general lesson for evolving the Internet

Unreliable, Connectionless Service

- Connectionless
 - No handshaking between sending and receiving adapter.
- Unreliable
 - Receiving adapter doesn't send ACKs or NACKs
 - Packets passed to network layer can have gaps
 - Gaps will be filled if application is using TCP
 - Otherwise, the application will see the gaps

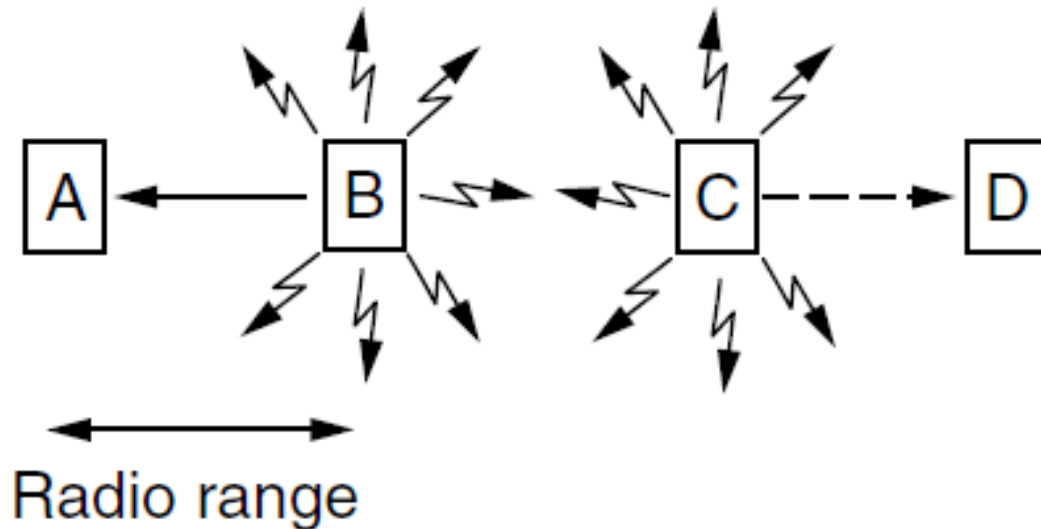
Wireless LAN Protocols (1)



(a)

A wireless LAN. (a) A and C are hidden terminals when transmitting to B.

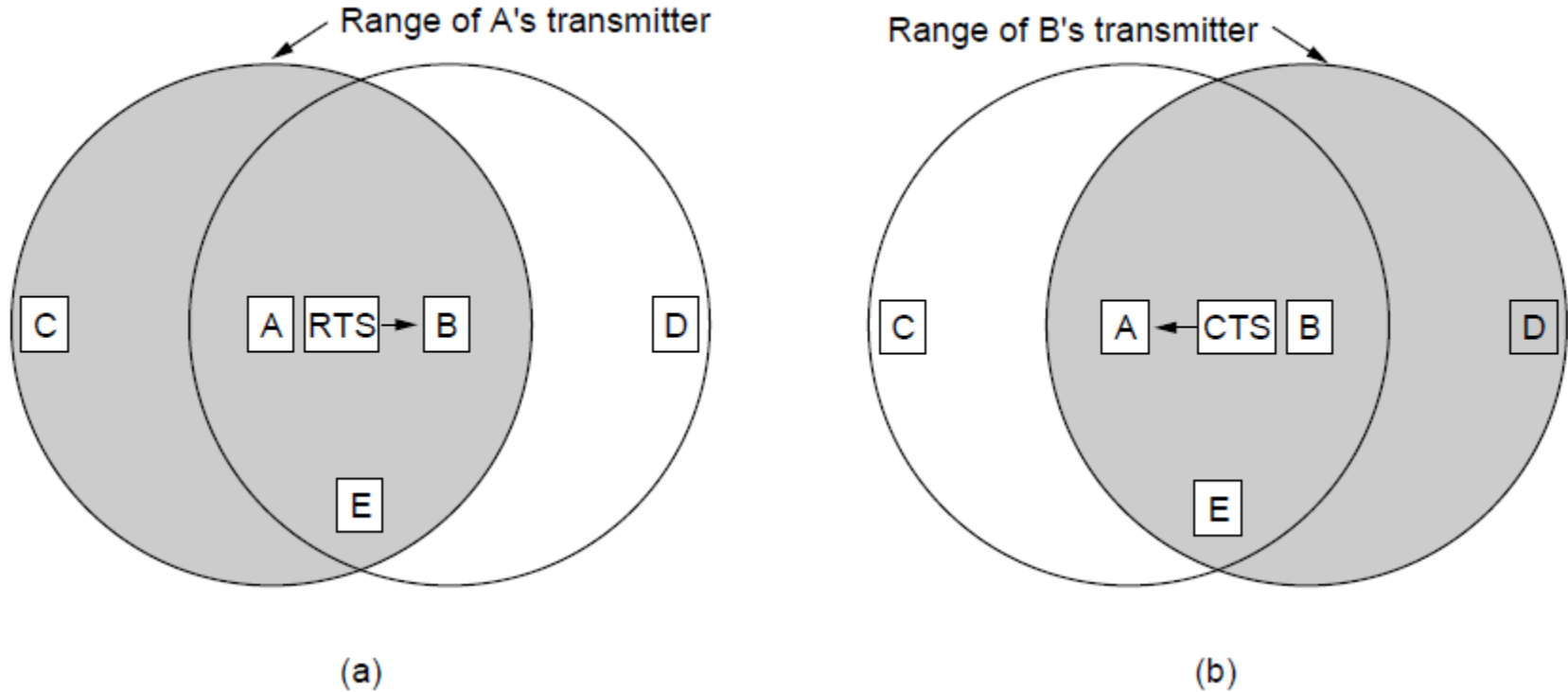
Wireless LAN Protocols (2)



(b)

A wireless LAN. (b) B and C are exposed terminals when transmitting to A and D.

Wireless LAN Protocols (3)

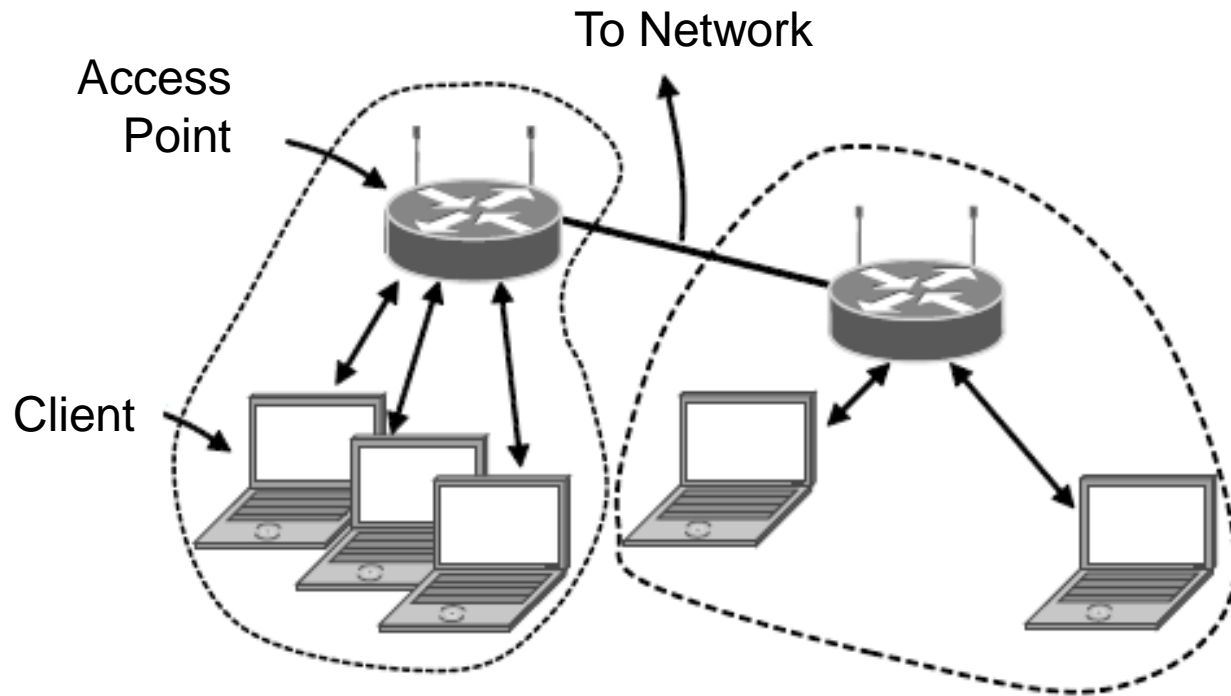


The MACA protocol. (a) *A sending an RTS to B.* (b) *B responding with a CTS to A.*

Wireless LANs

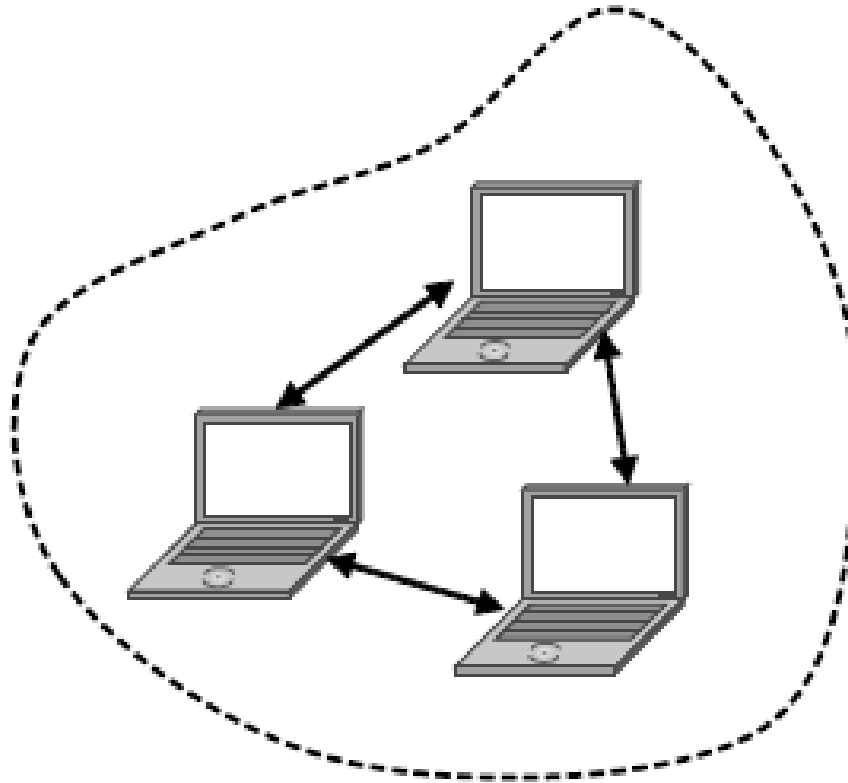
- The 802.11 Protocol Stack
- The 802.11 Physical Layer
- The 802.11 MAC Sublayer Protocol
- The 802.11 Frame Structure
- Services

802.11 Architecture and Protocol Stack (1)



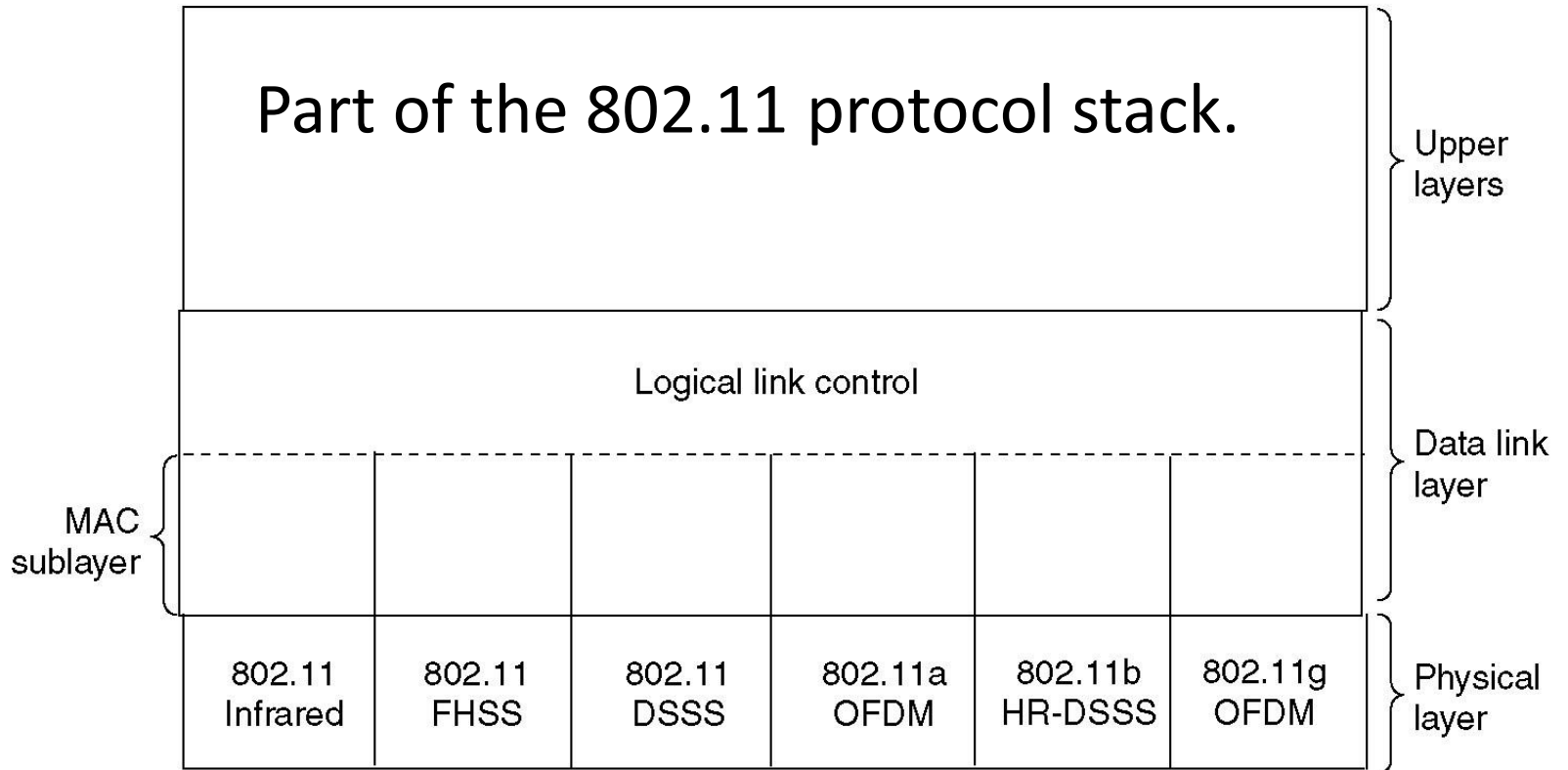
802.11 architecture – infrastructure mode

802.11 Architecture and Protocol Stack (2)

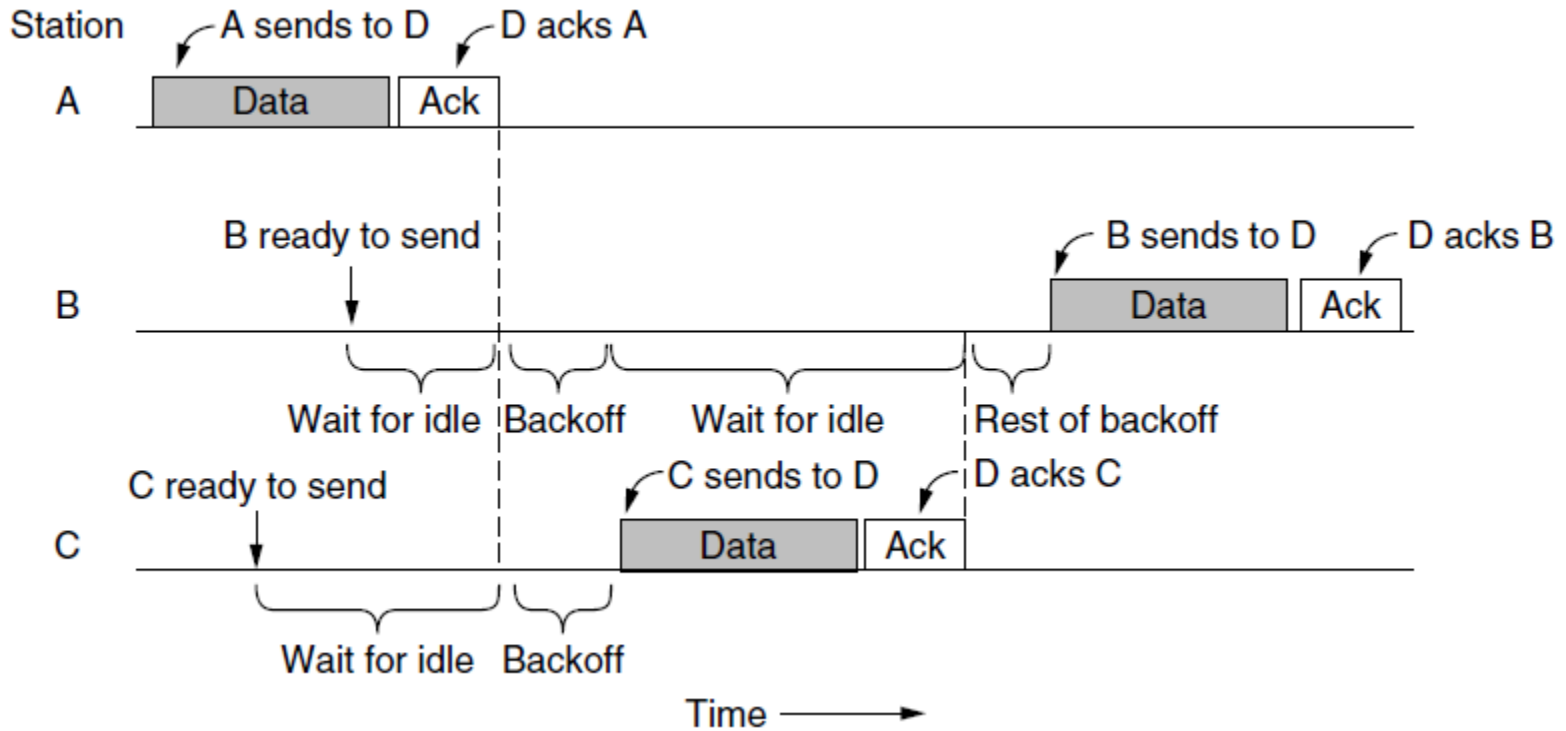


802.11 architecture – ad-hoc mode

The 802.11 Protocol Stack



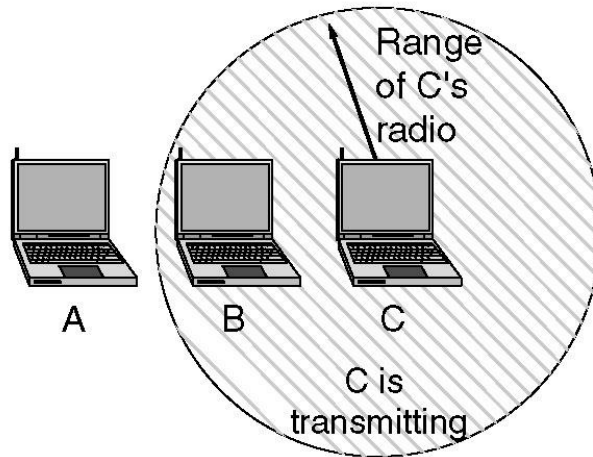
The 802.11 MAC Sublayer Protocol



Sending a frame with CSMA/CA.

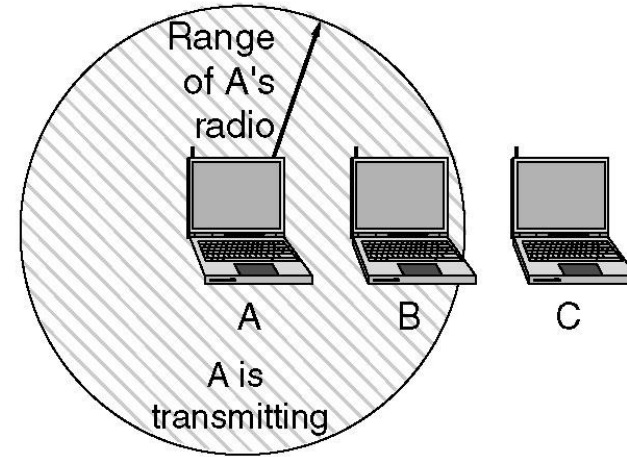
The 802.11 MAC Sublayer Protocol

A wants to send to B
but cannot hear that
B is busy



(a)

B wants to send to C
but mistakenly thinks
the transmission will fail



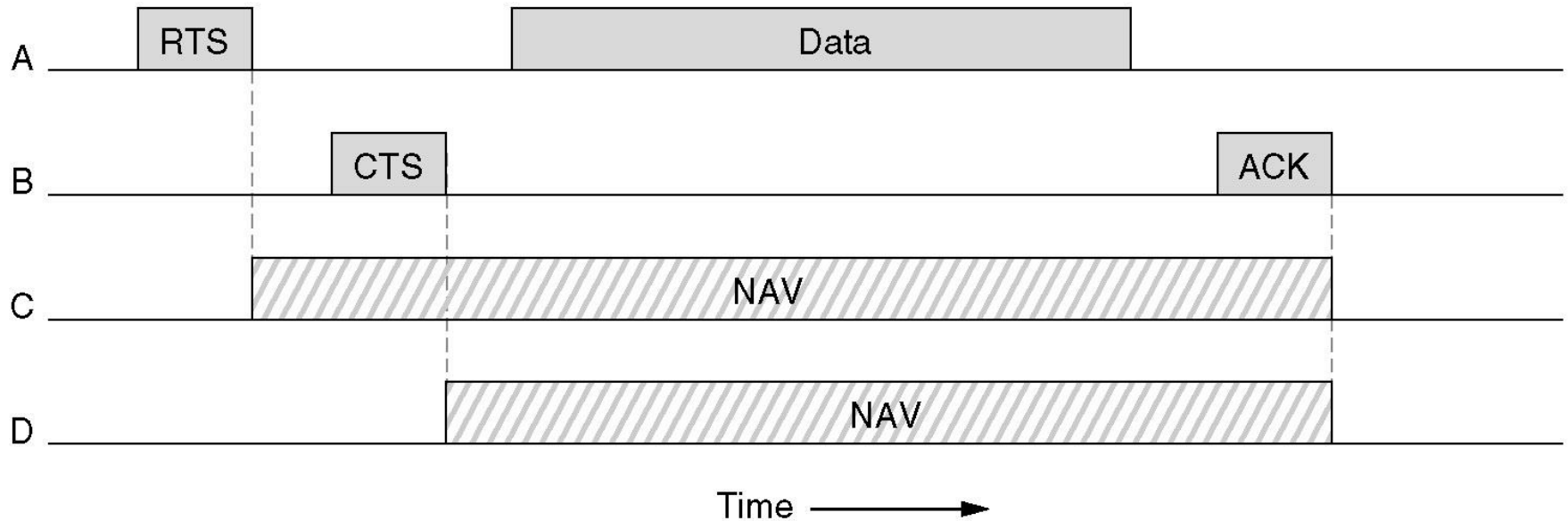
(b)

(a) The hidden station problem.

(b) The exposed station problem.

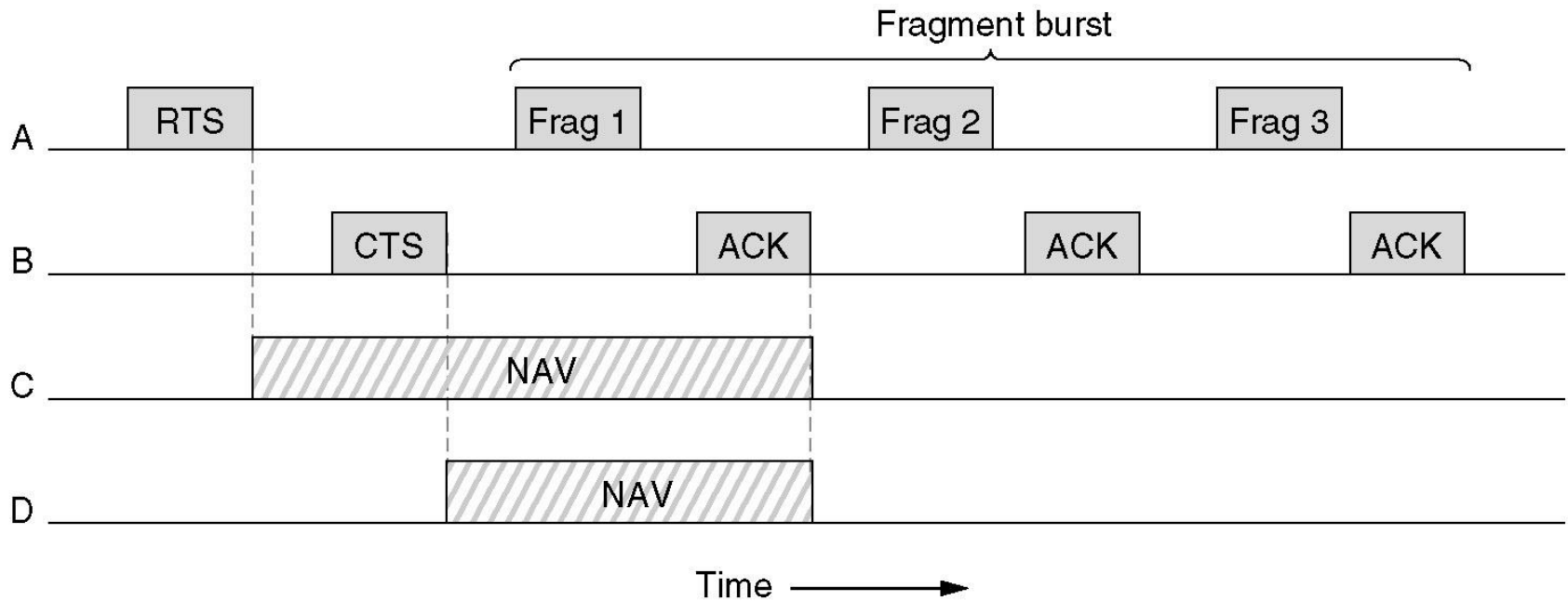
The 802.11 MAC Sublayer Protocol (2)

The use of virtual channel sensing using CSMA/CA.

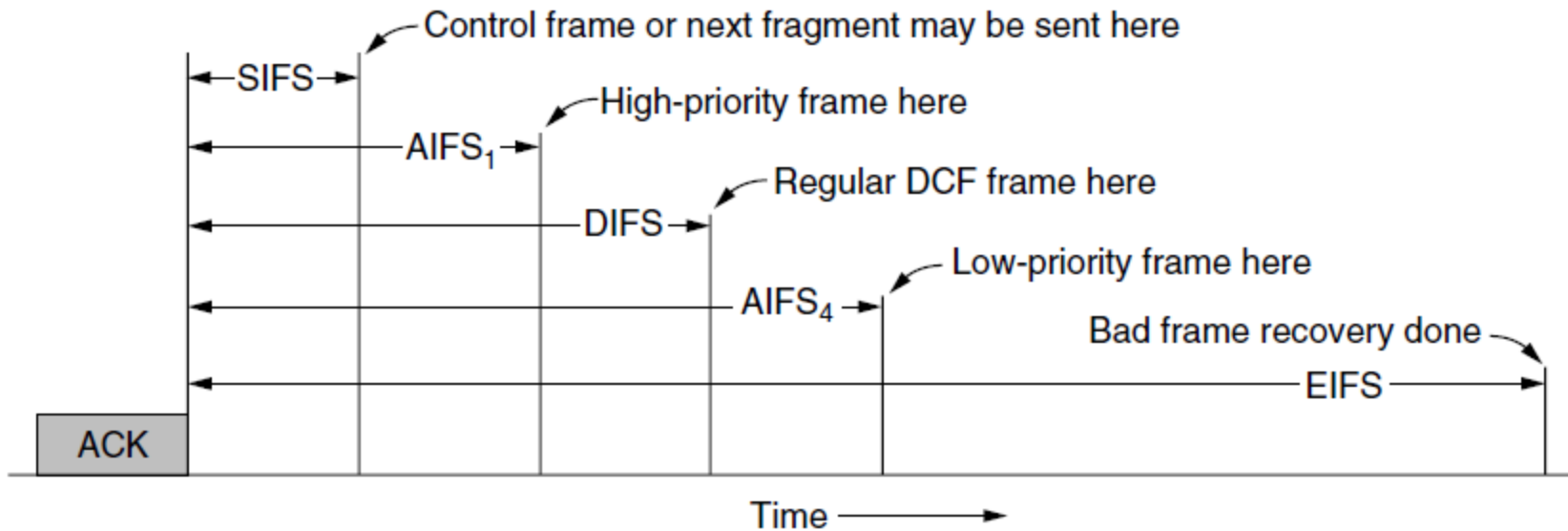


The 802.11 MAC Sublayer Protocol (3)

A fragment burst.



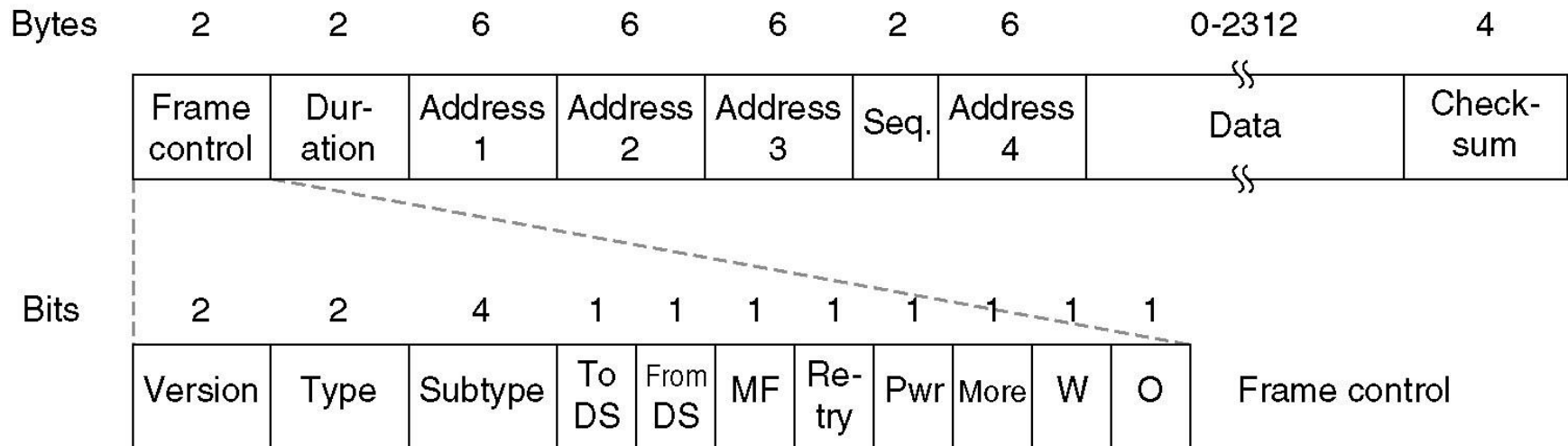
The 802.11 MAC Sublayer Protocol (5)



Interframe spacing in 802.11

The 802.11 Frame Structure

The 802.11 data frame.



802.11 Services

Distribution Services

- Association
- Disassociation
- Reassociation
- Distribution
- Integration

802.11 Services

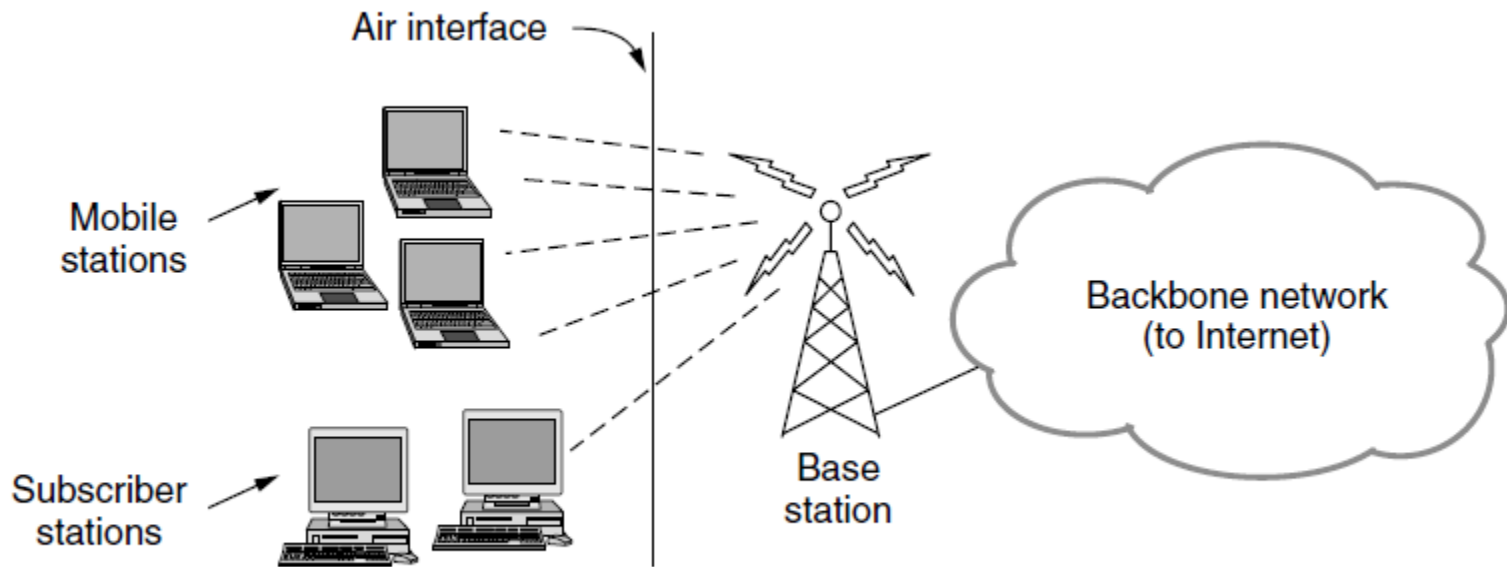
Intracell Services

- Authentication
- Deauthentication
- Privacy
- Data Delivery

Broadband Wireless

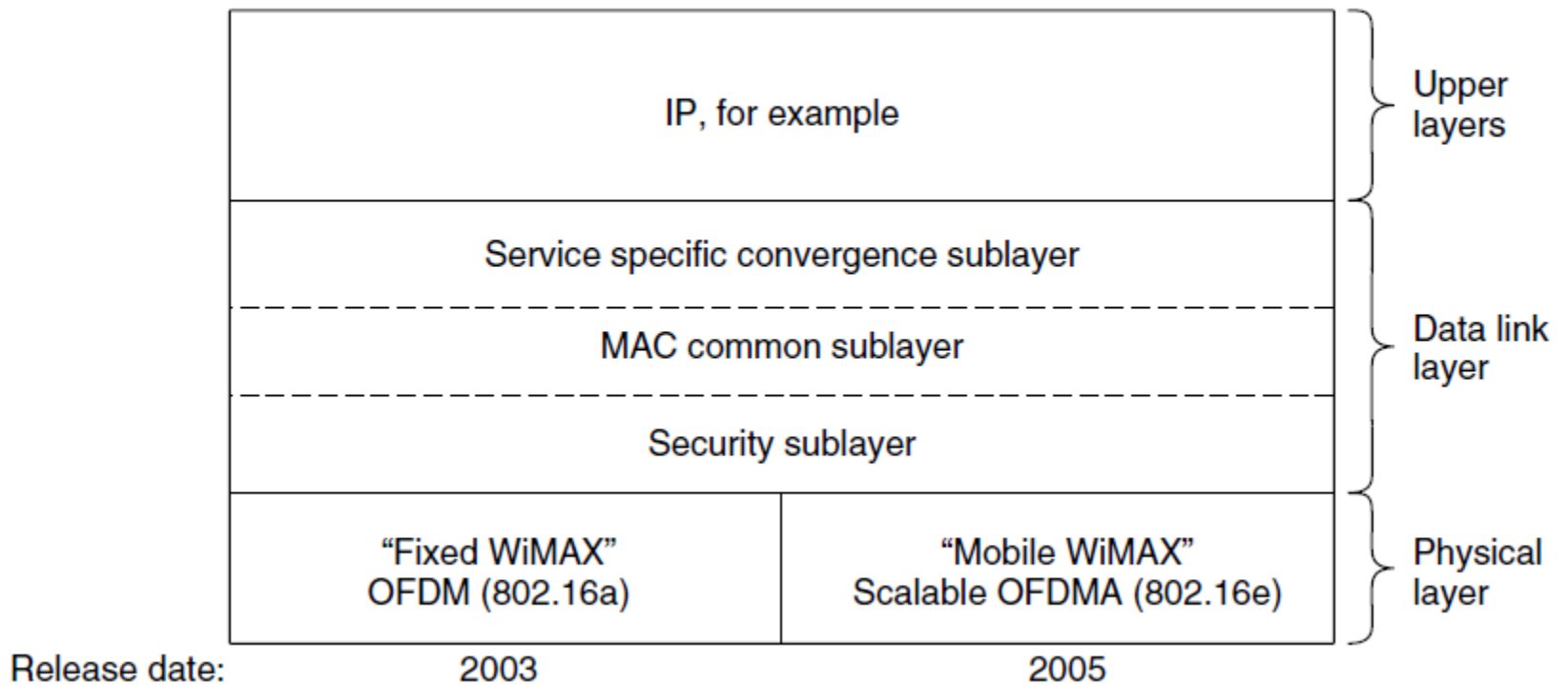
- Comparison of 802.11 and 802.16
- The 802.16 Protocol Stack
- The 802.16 Physical Layer
- The 802.16 MAC Sublayer Protocol
- The 802.16 Frame Structure

Comparison of 802.16 with 802.11 and 3G



The 802.16 architecture

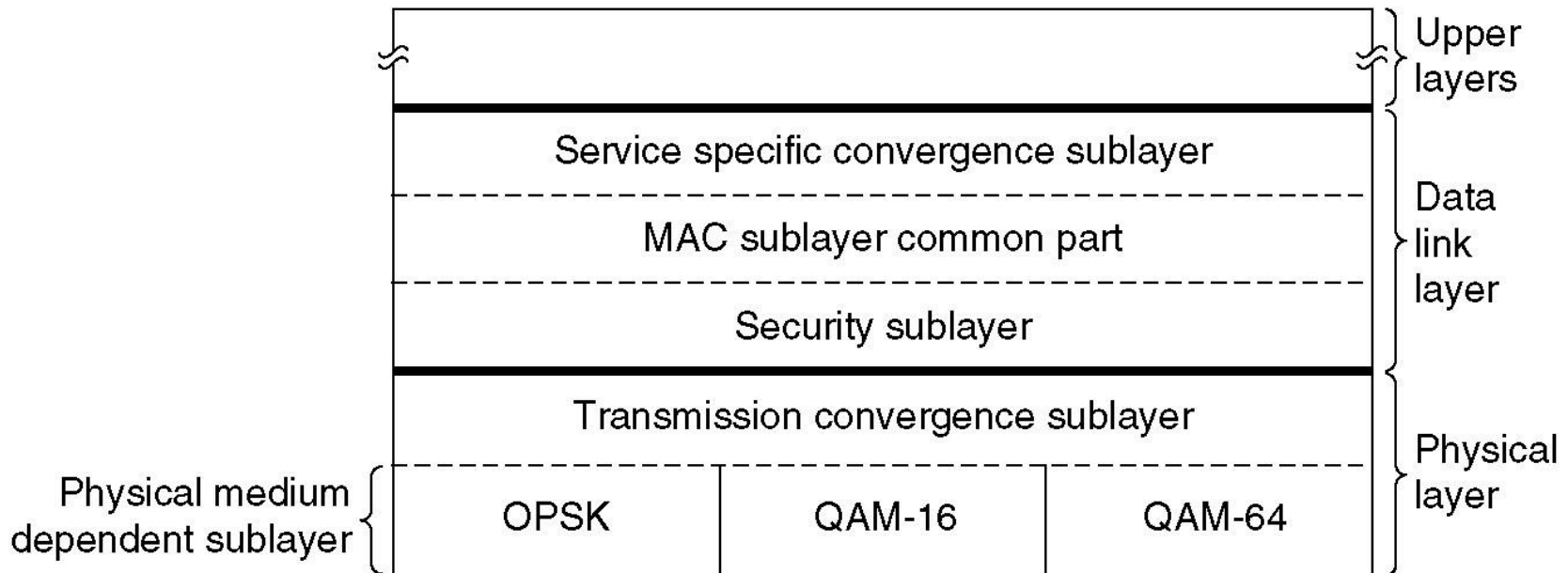
802.16 Architecture and Protocol Stack



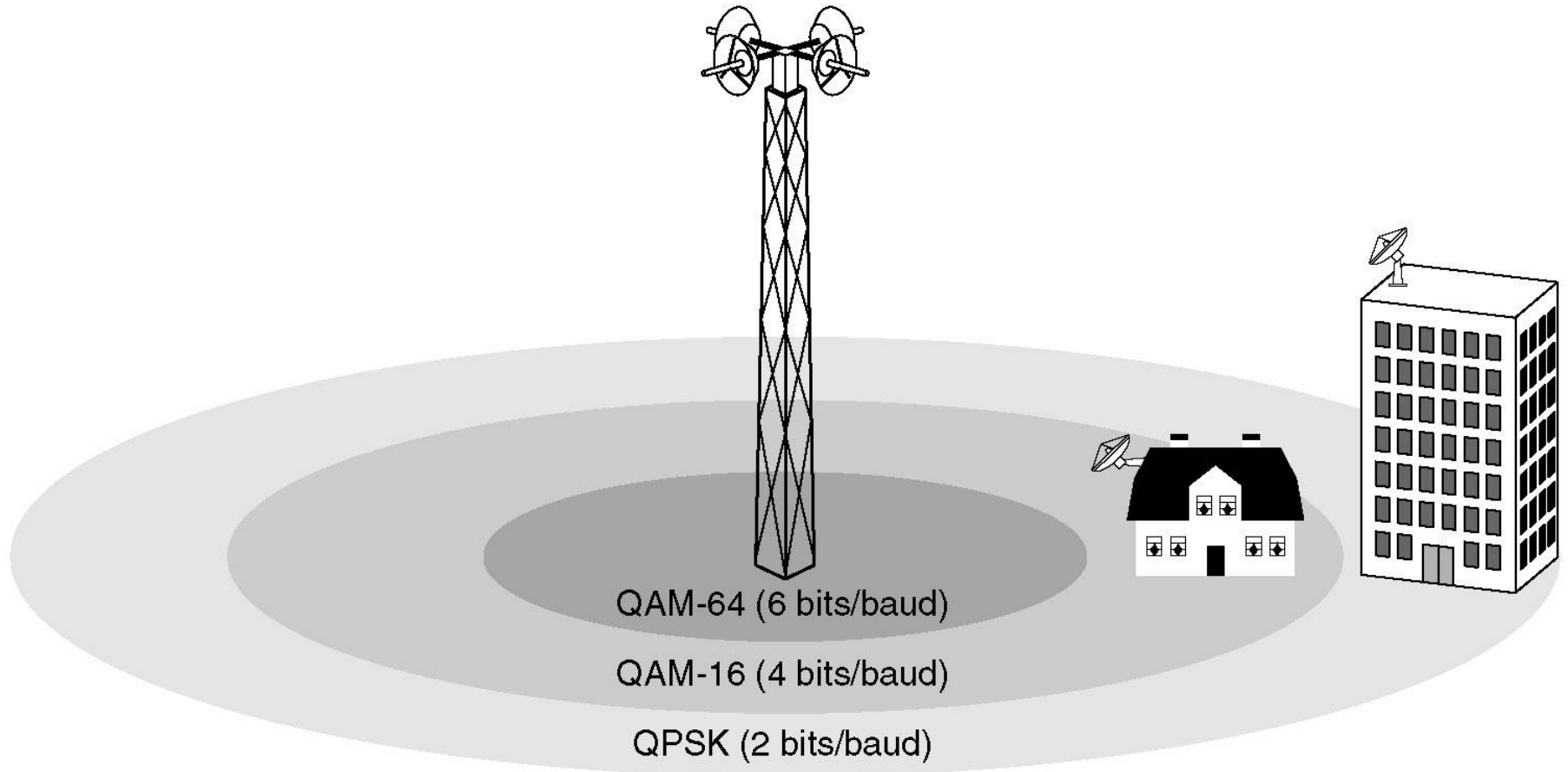
The 802.16 protocol stack

The 802.16 Protocol Stack

The 802.16 Protocol Stack.

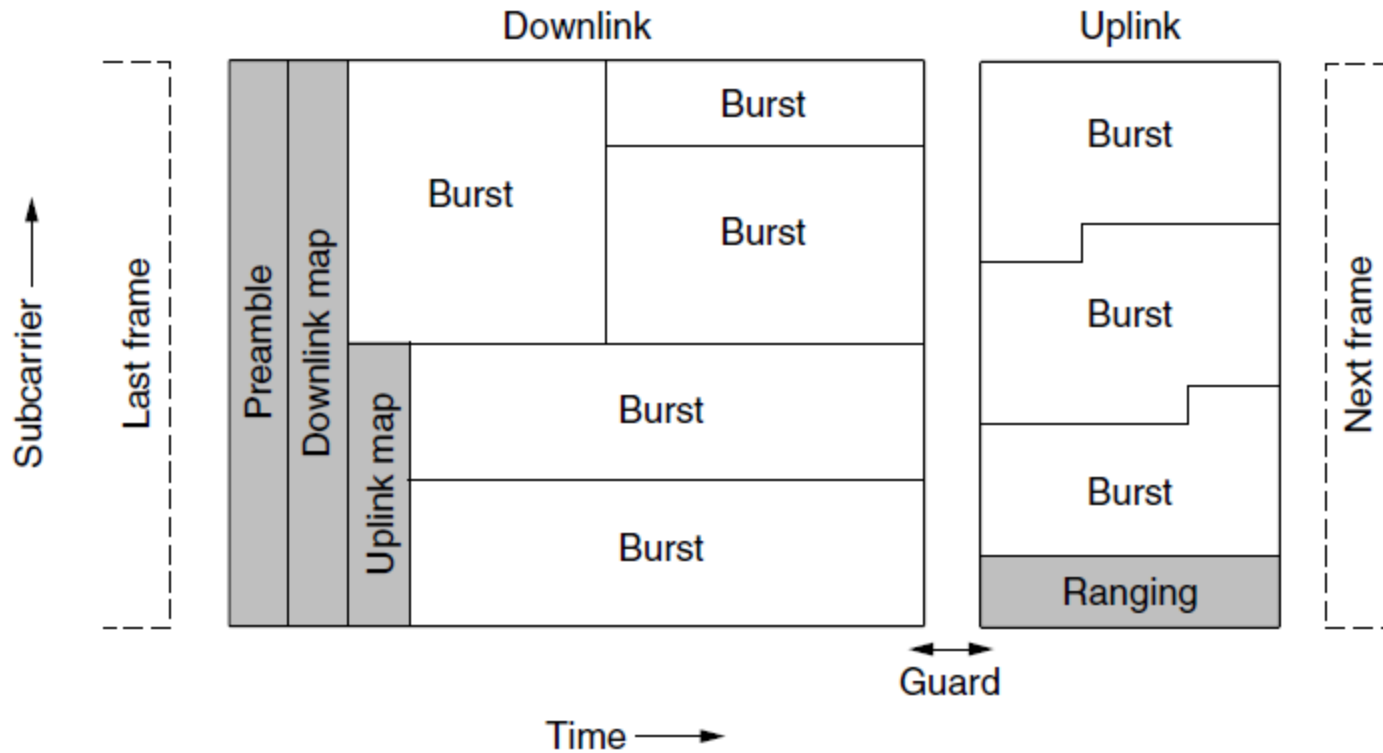


The 802.16 Physical Layer



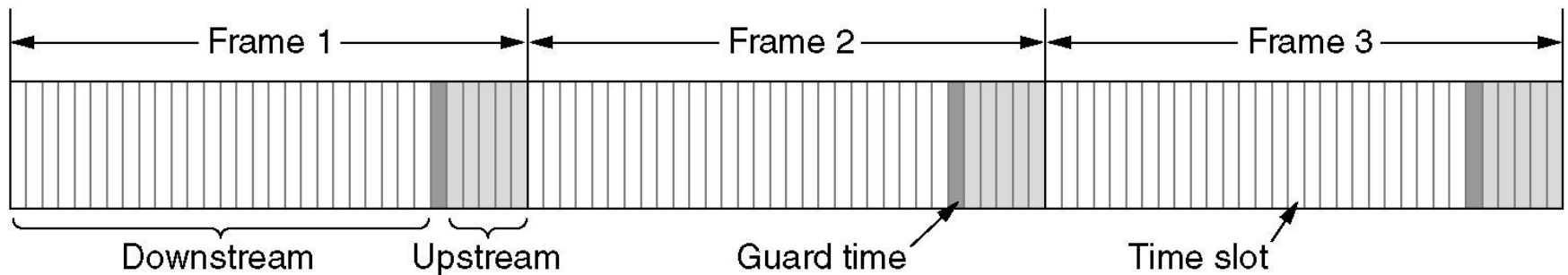
The 802.16 transmission environment.

802.16 Physical Layer



The 802.16 Physical Layer (2)

Frames and time slots for time division duplexing.



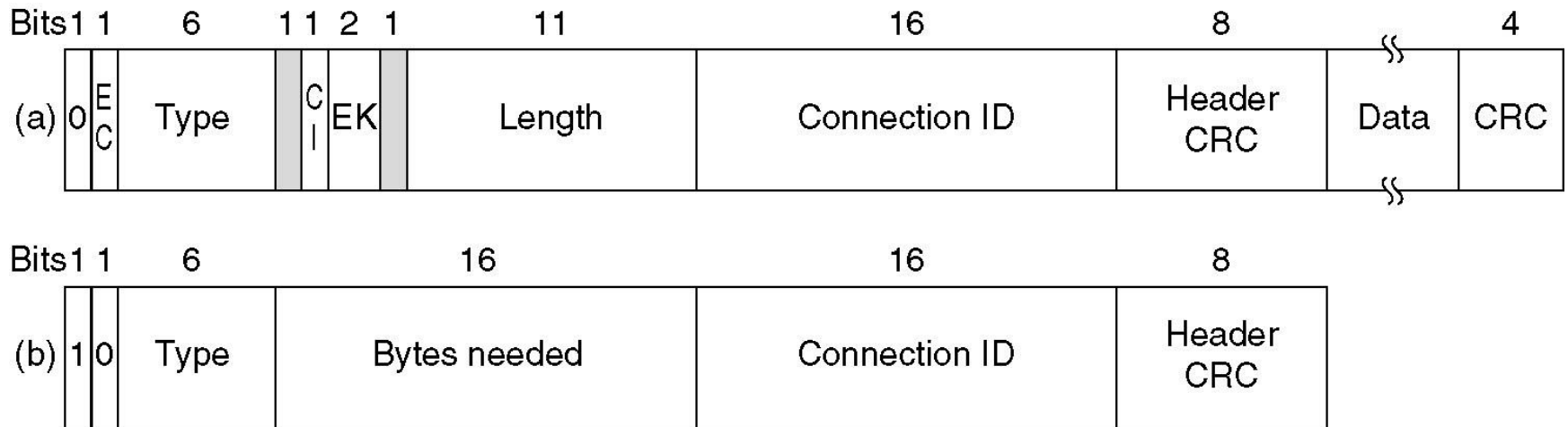
802.16 MAC Sublayer Protocol

Classes of service

1. Constant bit rate service.
2. Real-time variable bit rate service.
3. Non-real-time variable bit rate service.
4. Best-effort service.

The 802.16 Frame Structure

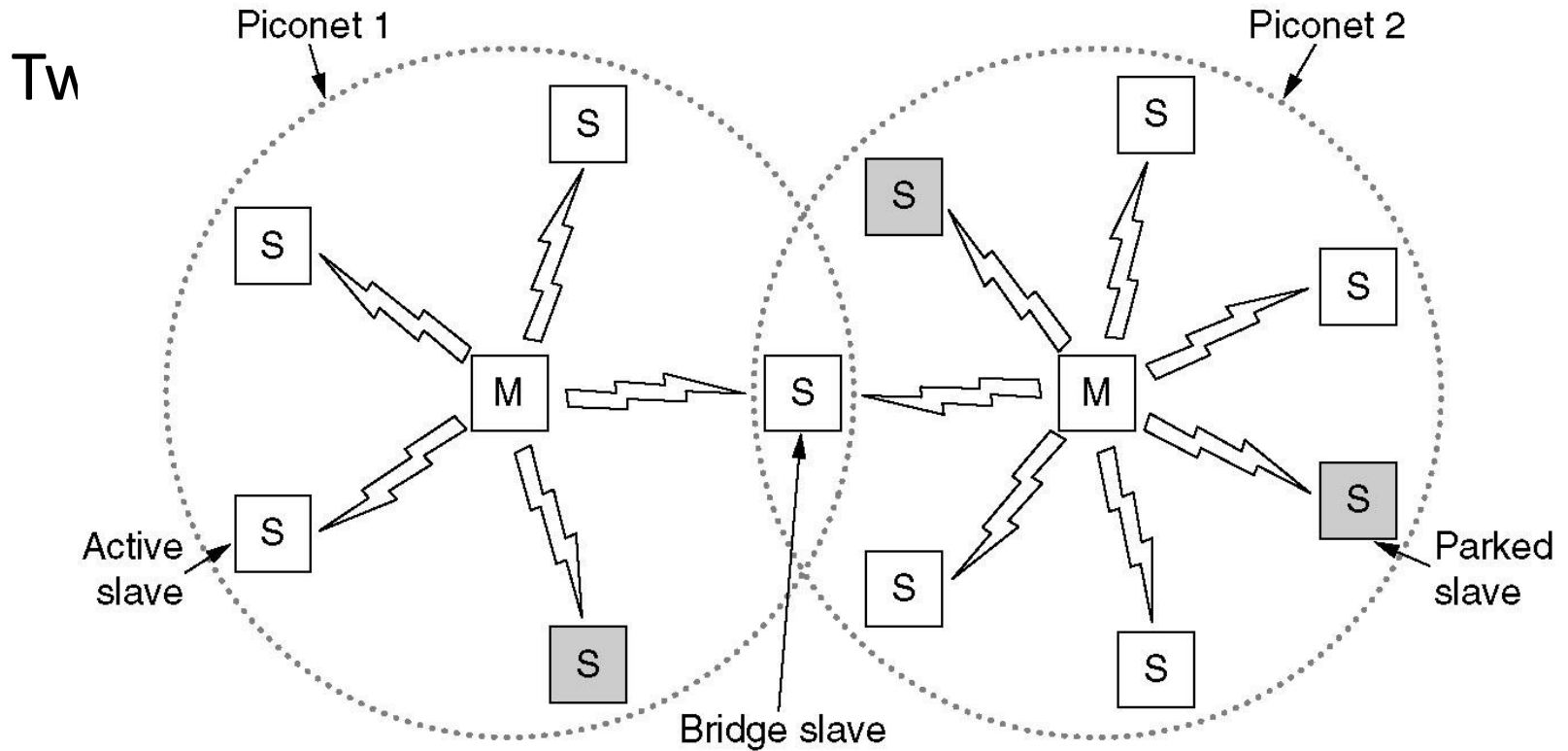
(a) A generic frame. (b) A bandwidth request frame.



Bluetooth

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

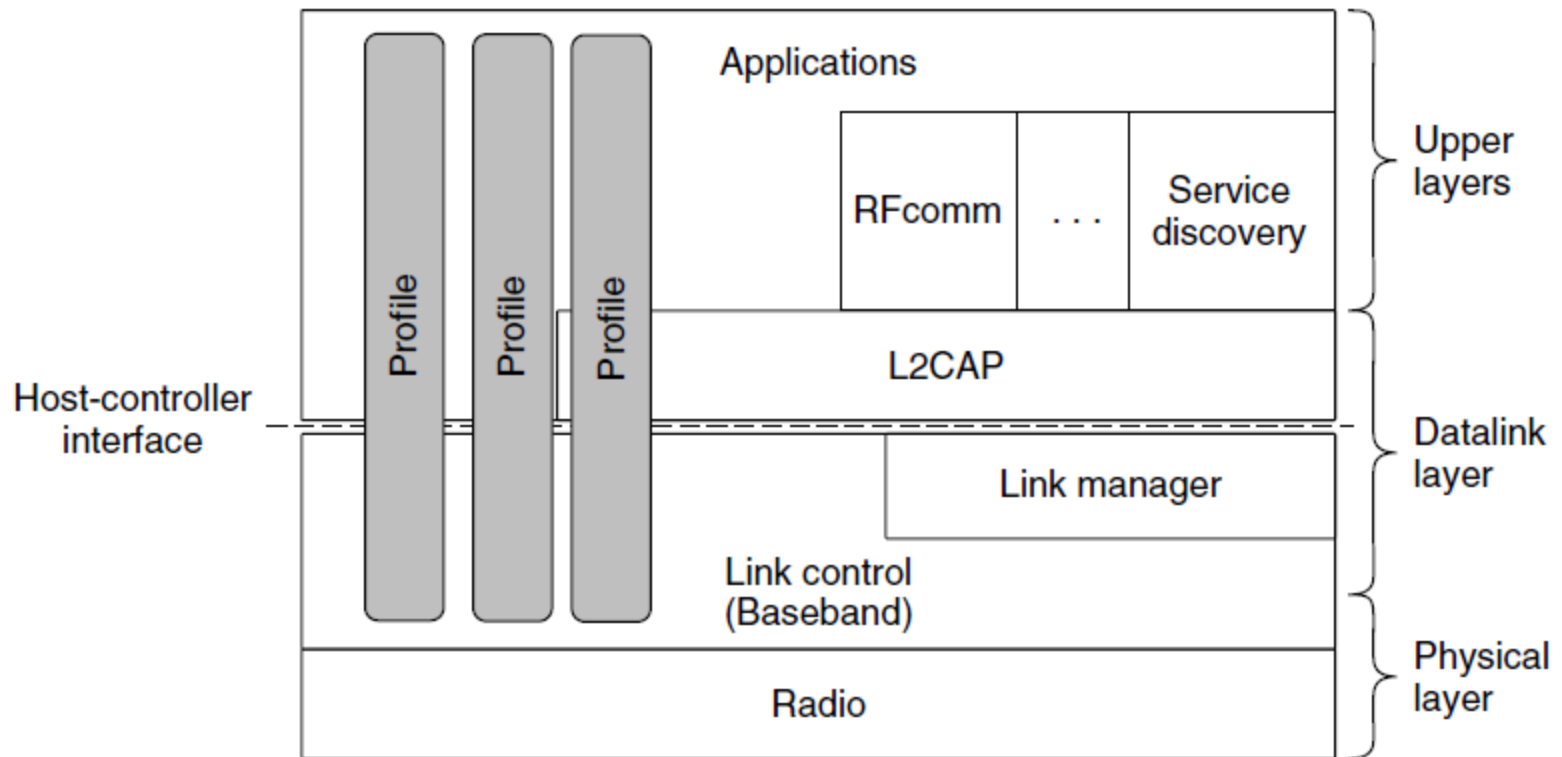
Bluetooth Architecture



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

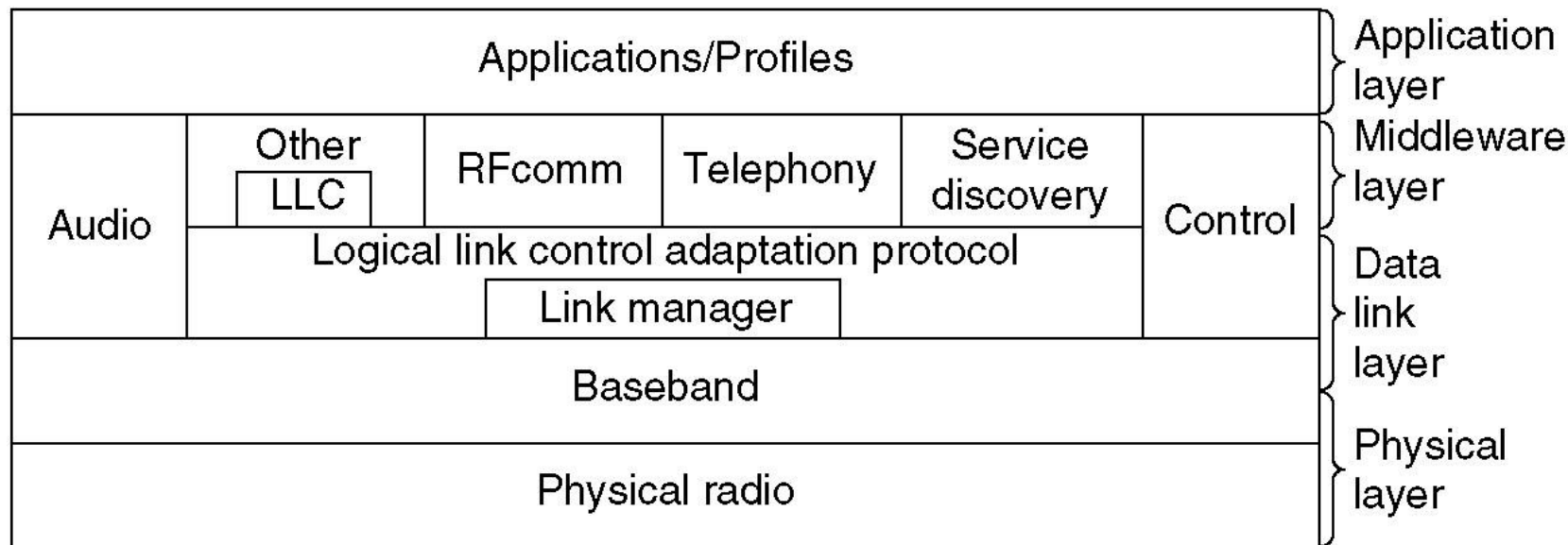
Bluetooth Protocol Stack



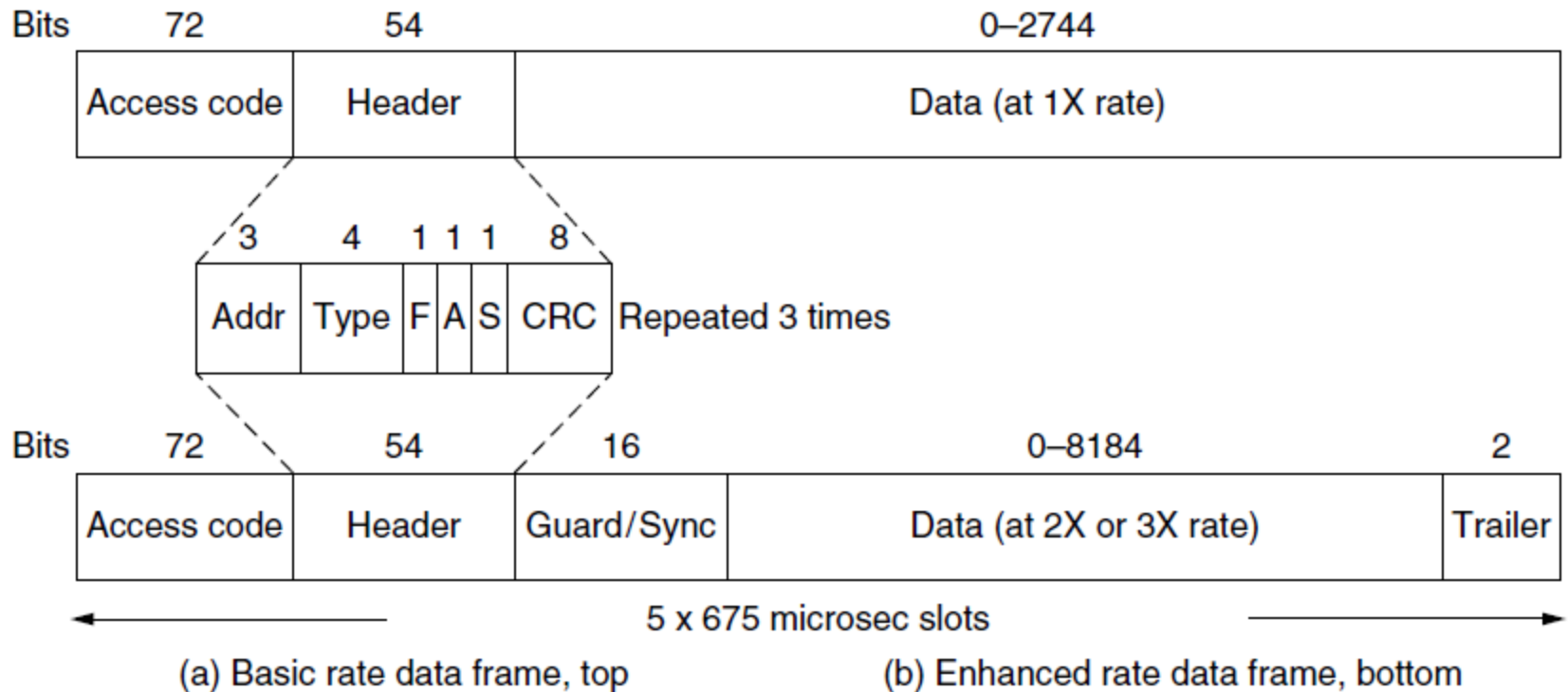
The Bluetooth protocol architecture.

The Bluetooth Protocol Stack

The 802.15 version of the Bluetooth protocol architecture.



Bluetooth Frame Structure

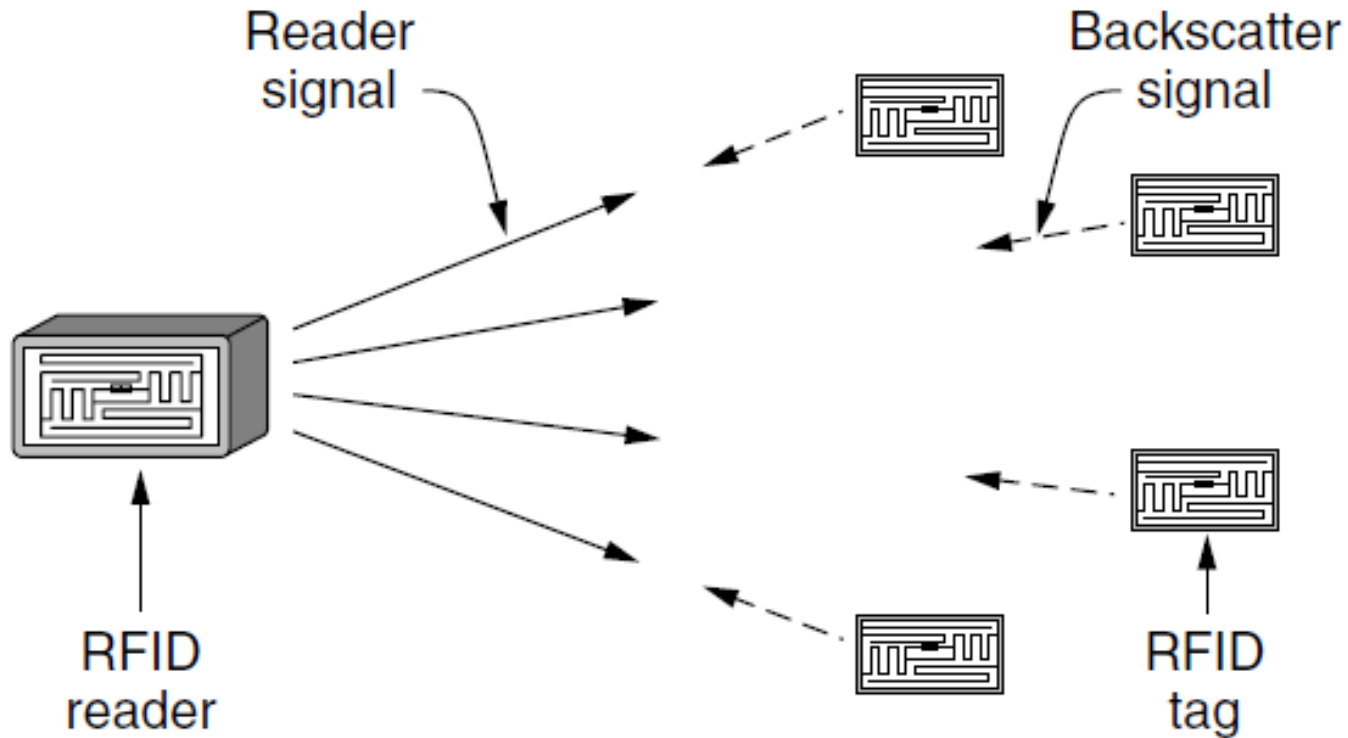


Typical Bluetooth data frame at (a) basic, and (b) enhanced, data rates.

RFID

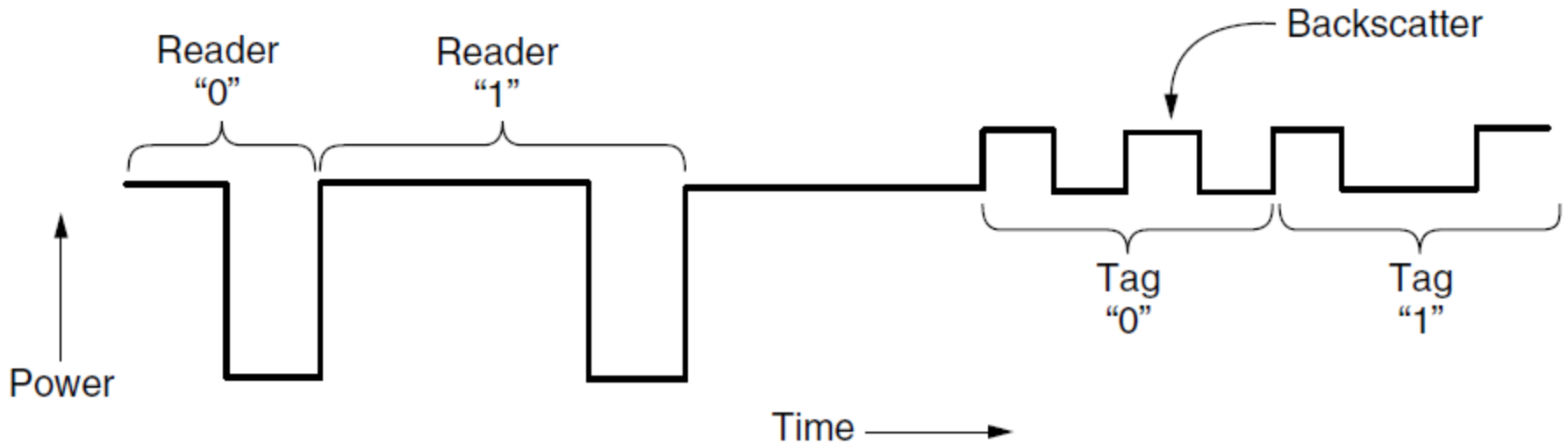
- EPC Gen 2 architecture
- EPC Gen 2 physical layer
- EPC Gen 2 tag identification layer
- Tag identification message formats

EPC Gen 2 Architecture



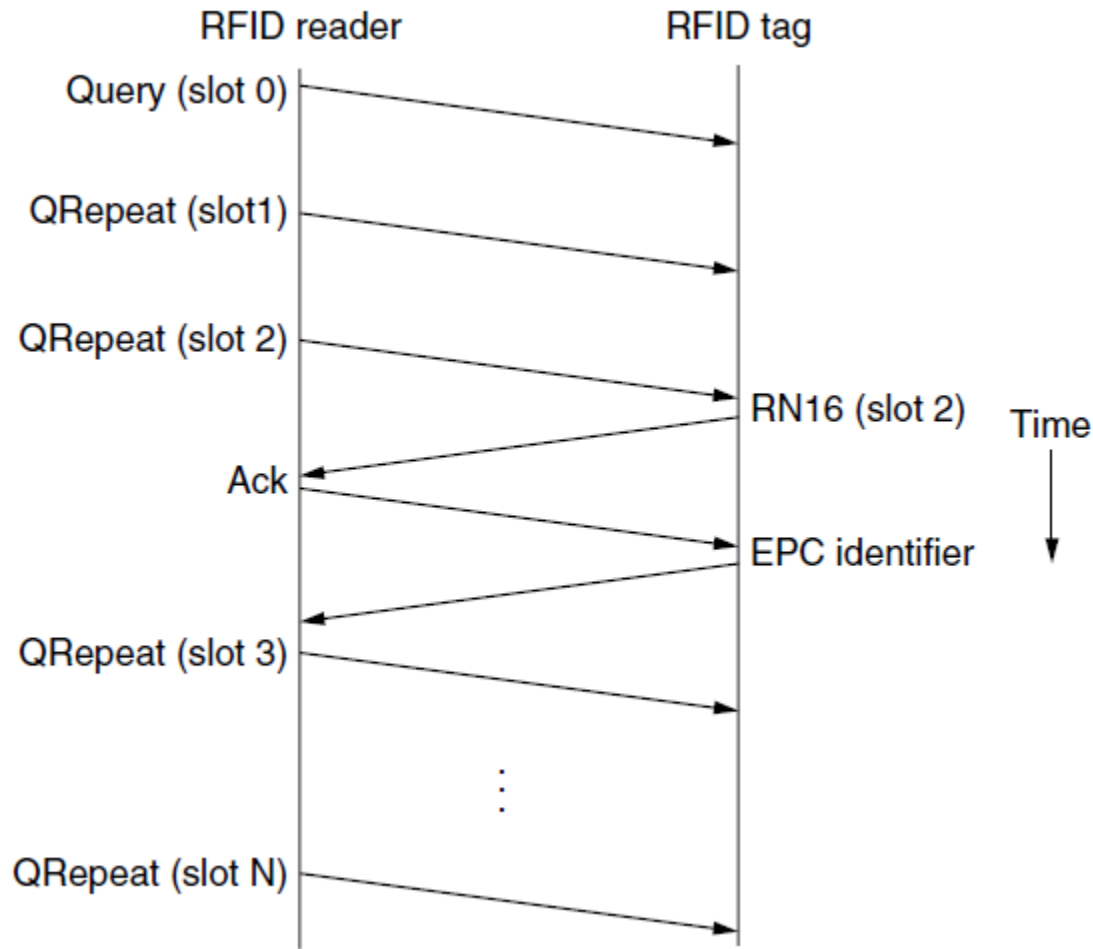
RFID architecture.

EPC Gen 2 Physical Layer



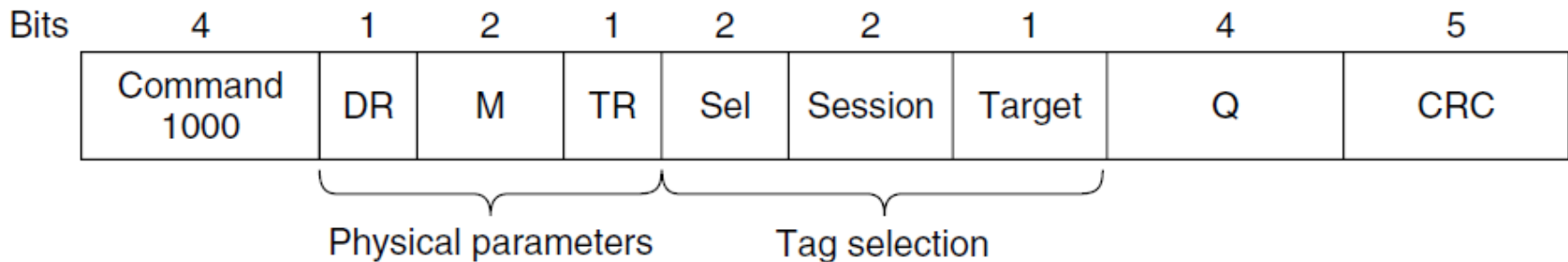
Reader and tag backscatter signals.

EPC Gen 2 Tag Identification Layer



Example message exchange to identify a tag.

Tag Identification Message Formats

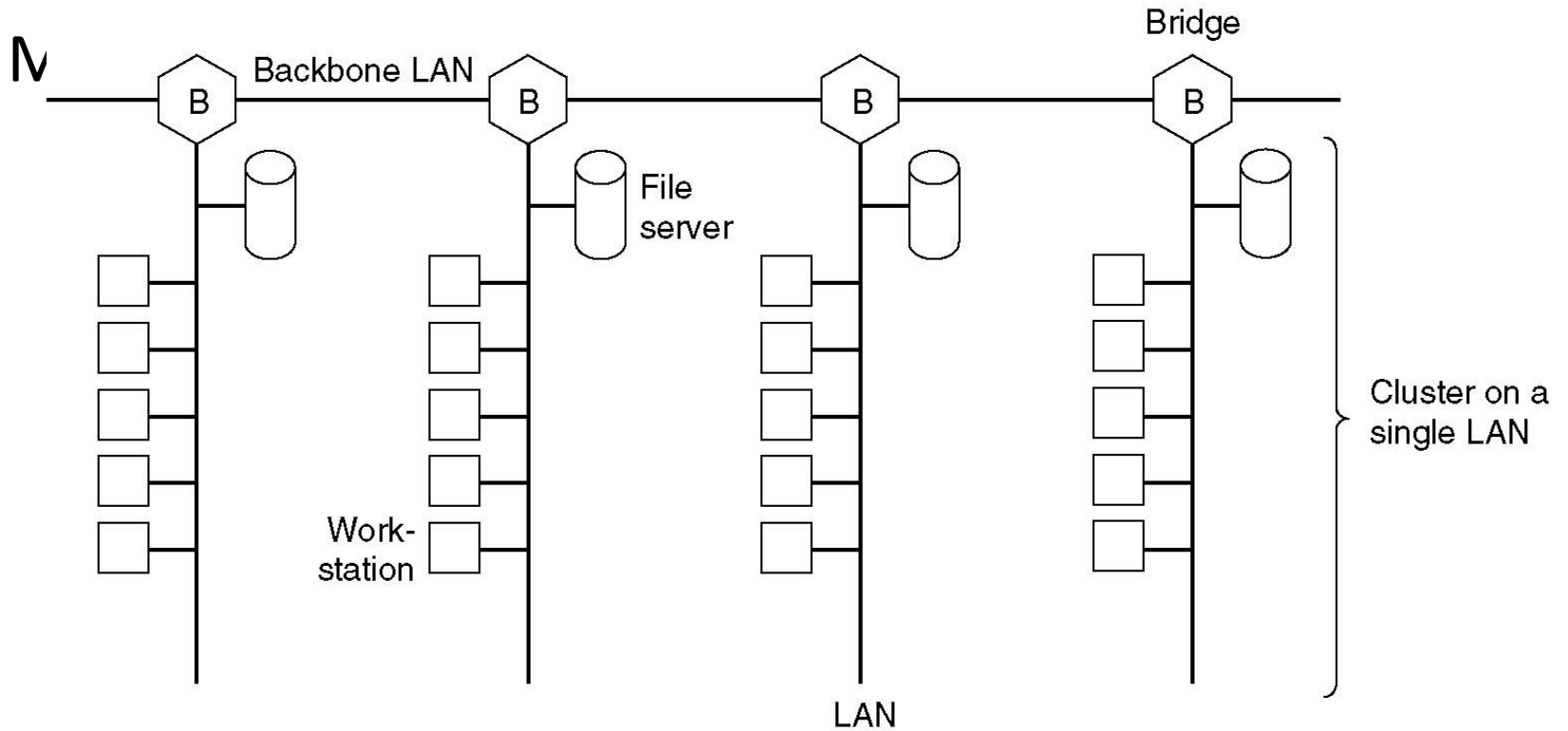


Format of the Query message.

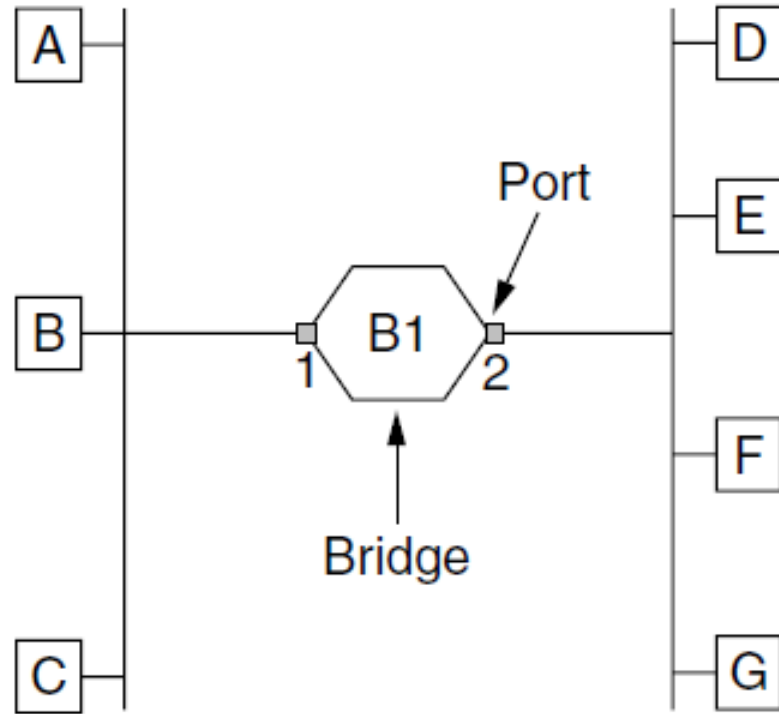
Data Link Layer Switching

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

Data Link Layer Switching

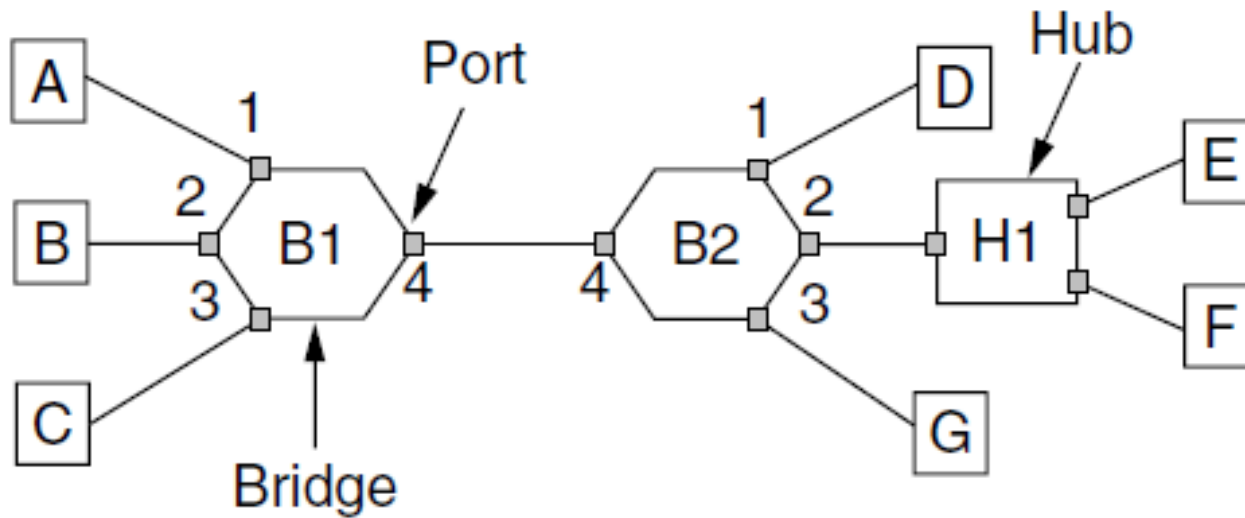


Learning Bridges (1)



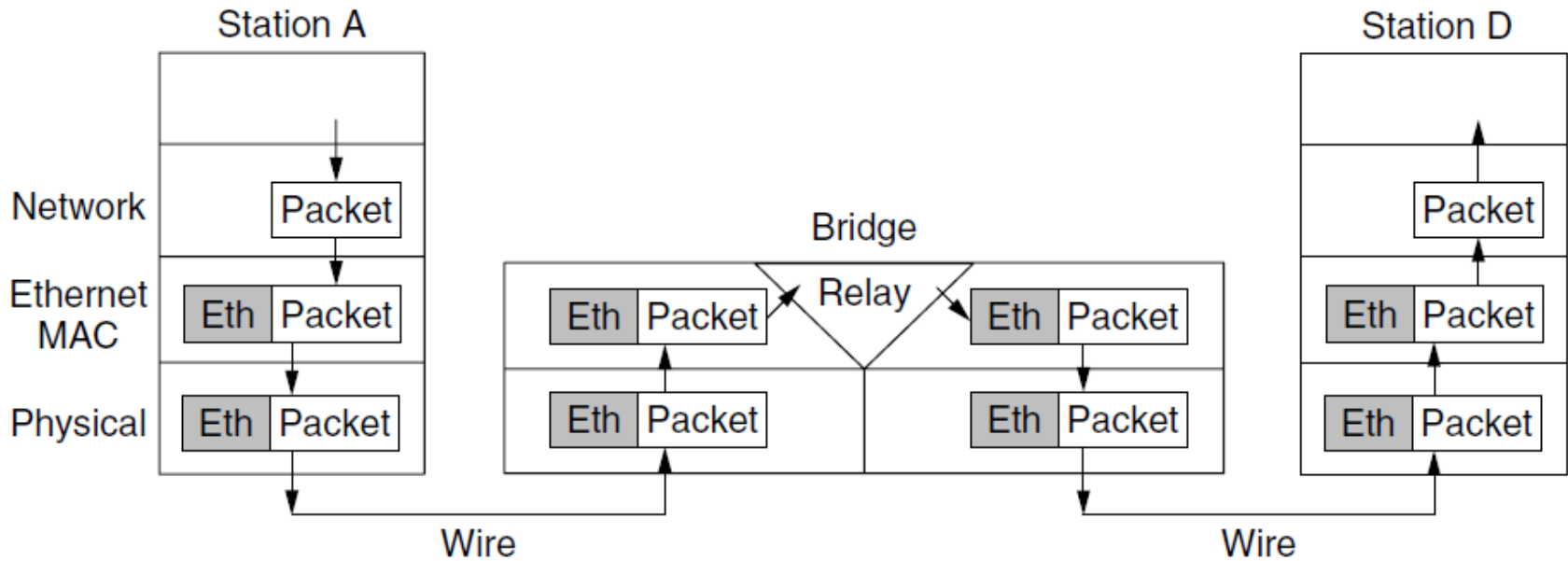
Bridge connecting two multidrop LANs

Learning Bridges (2)



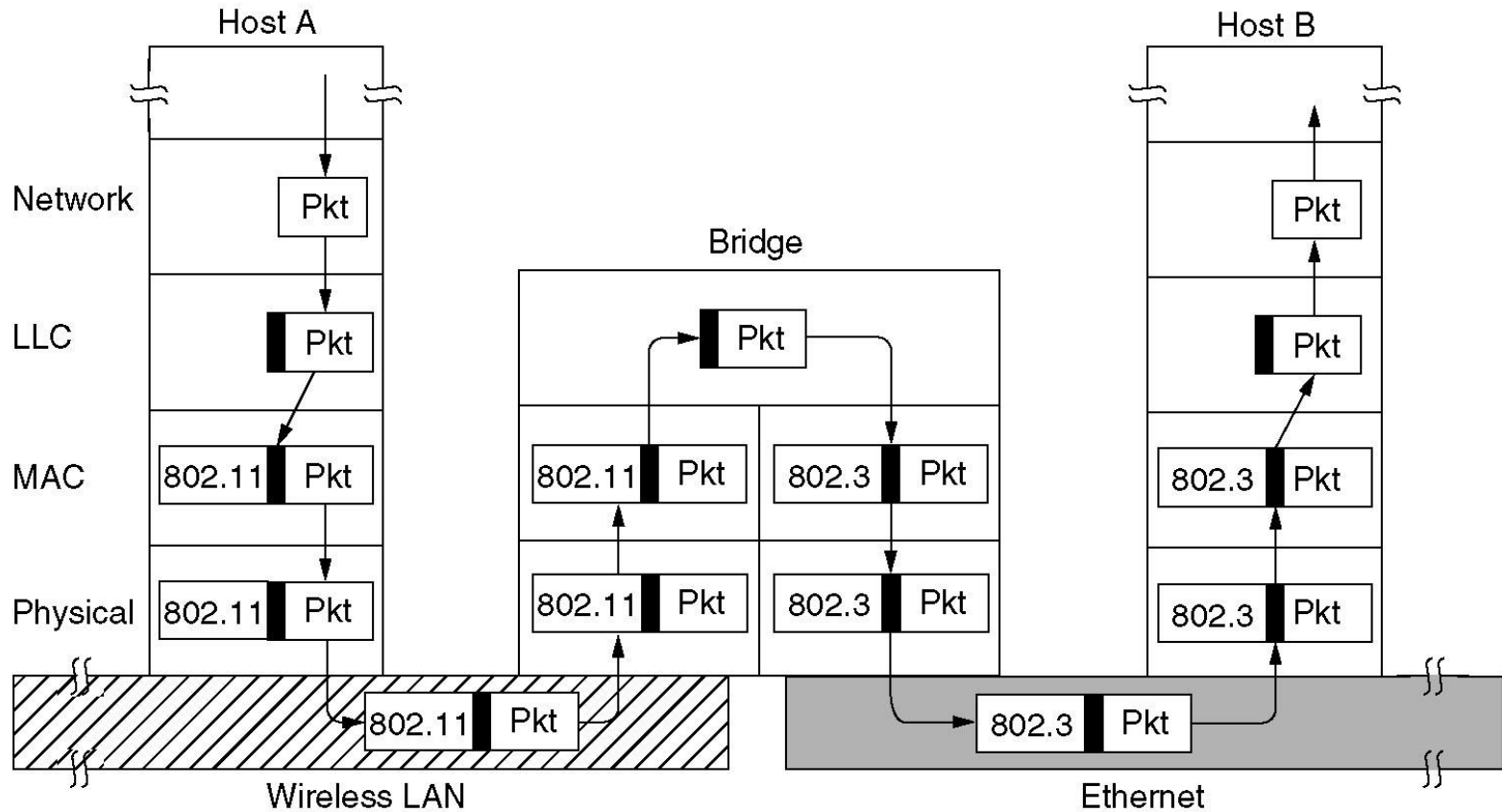
Bridges (and a hub) connecting seven point-to-point stations.

Learning Bridges (3)



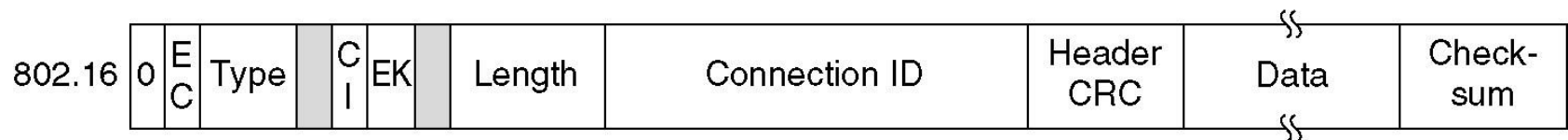
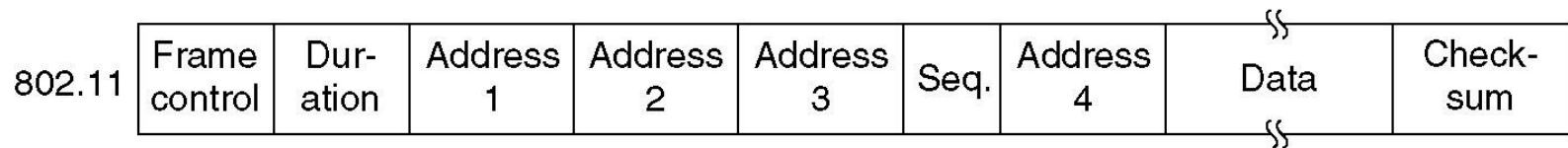
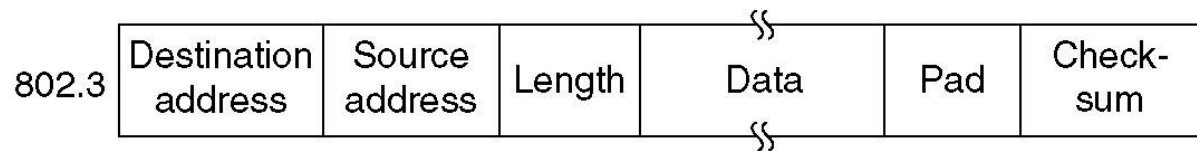
Protocol processing at a bridge.

Bridges from 802.x to 802.y



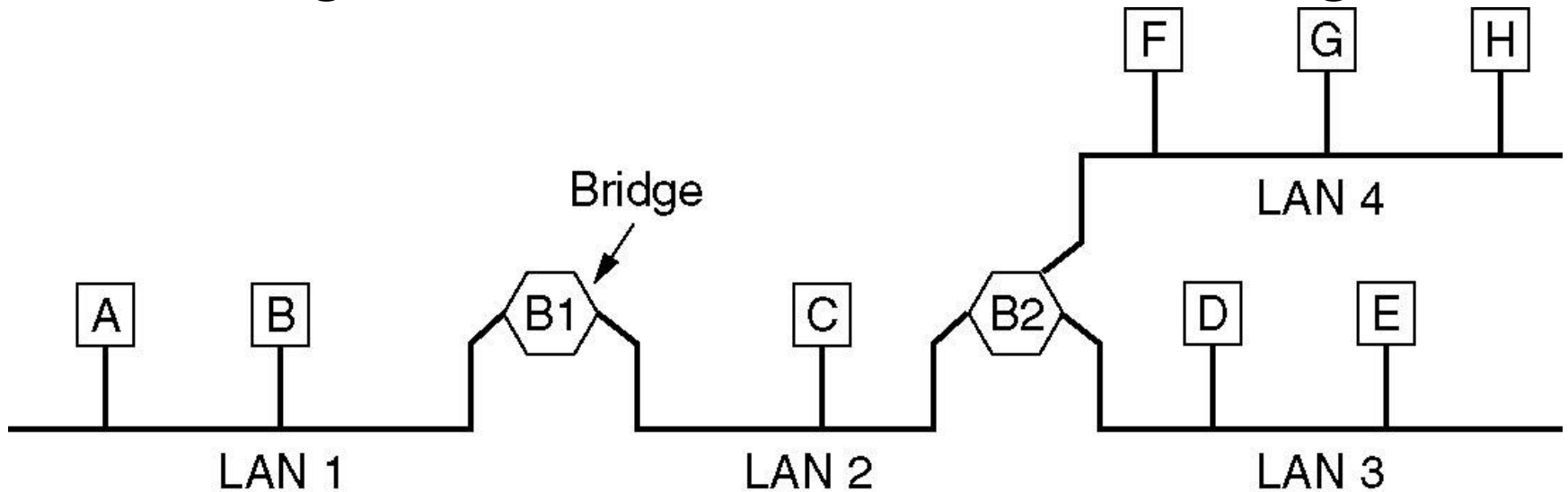
Bridges from 802.x to 802.y (2)

The IEEE 802 frame formats. The drawing is not to

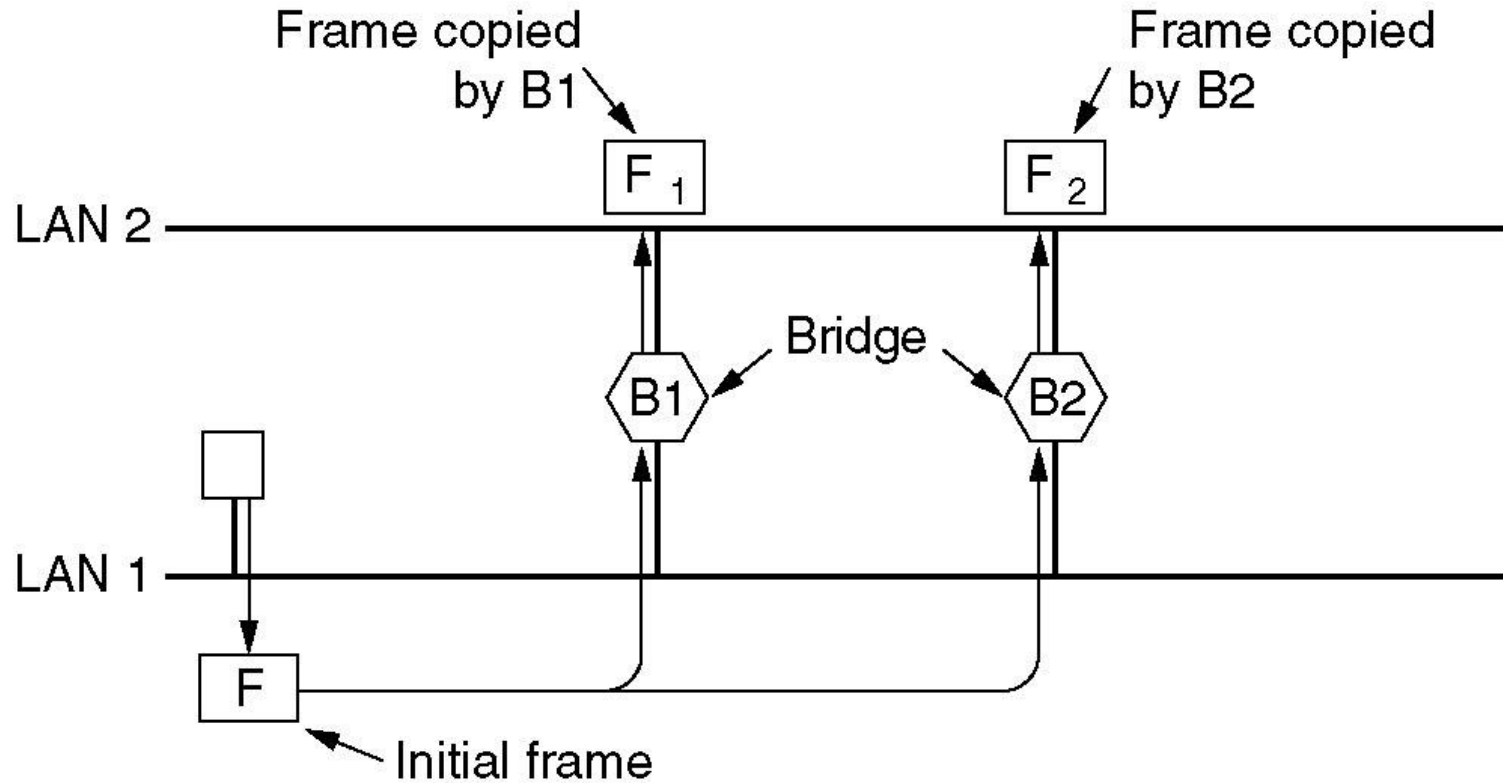


Local Internetworking

A configuration with four LANs and two bridges.

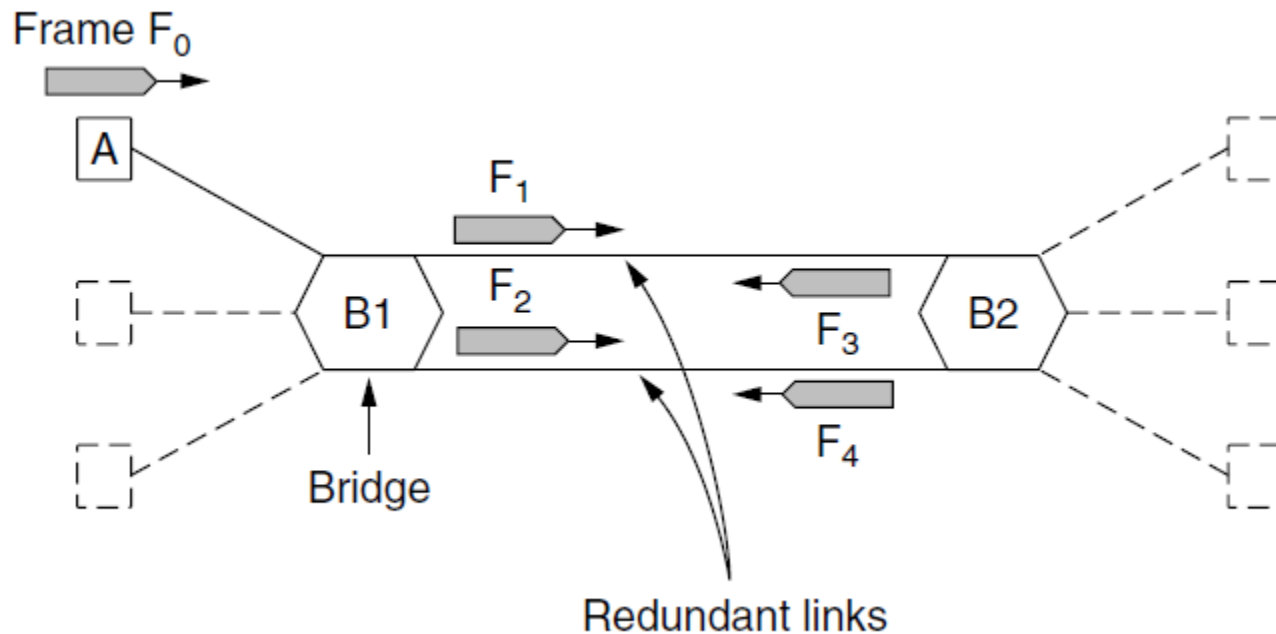


Spanning Tree Bridges

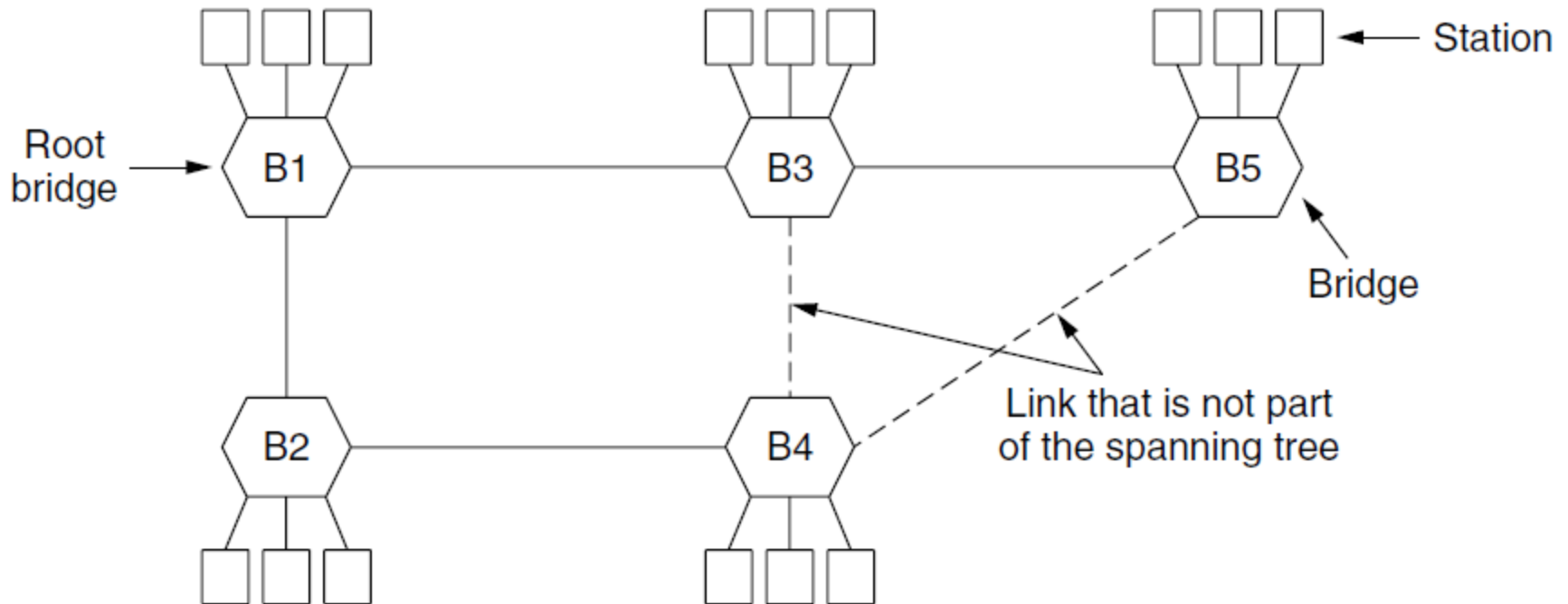


Spanning Tree Bridges (1)

Bridges with two parallel links



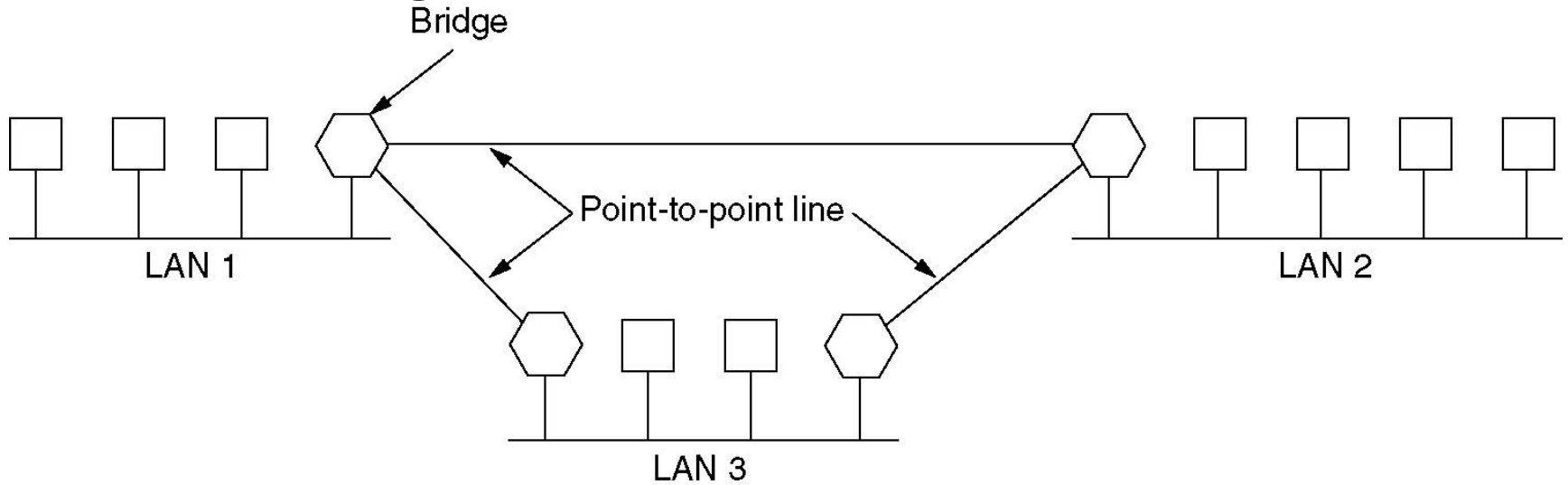
Spanning Tree Bridges (2)



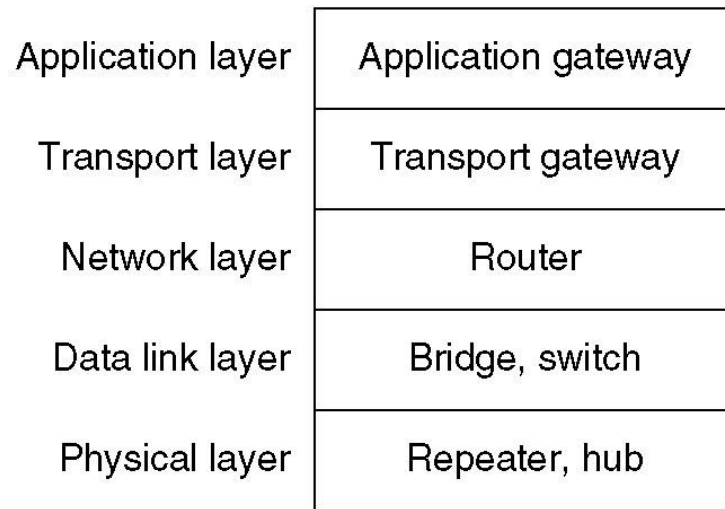
A spanning tree connecting five bridges. The dotted lines are links that are not part of the spanning tree.

Remote Bridges

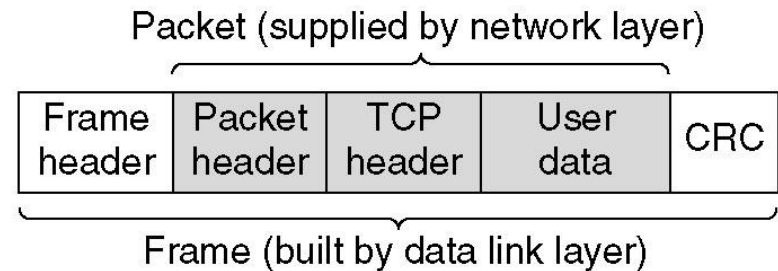
Remote bridges can be used to interconnect distant



Repeaters, Hubs, Bridges, Switches, Routers and Gateways



(a)



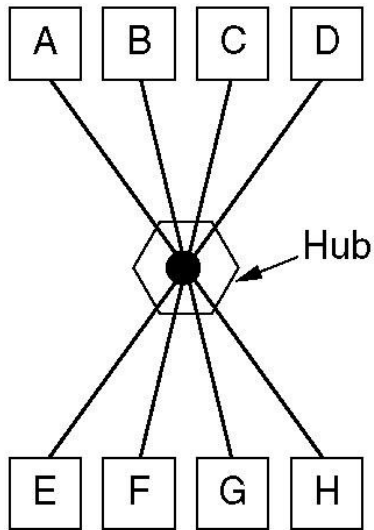
(b)

(a) Which device is in which layer.

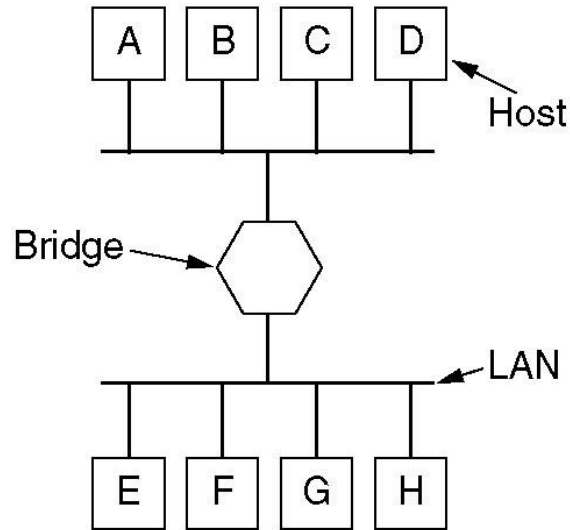
(b) Frames, packets, and headers.

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

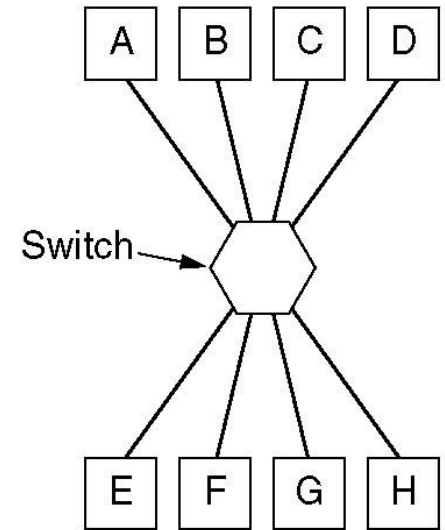
(a) A hub. (b) A bridge. (c) a switch.



(a)



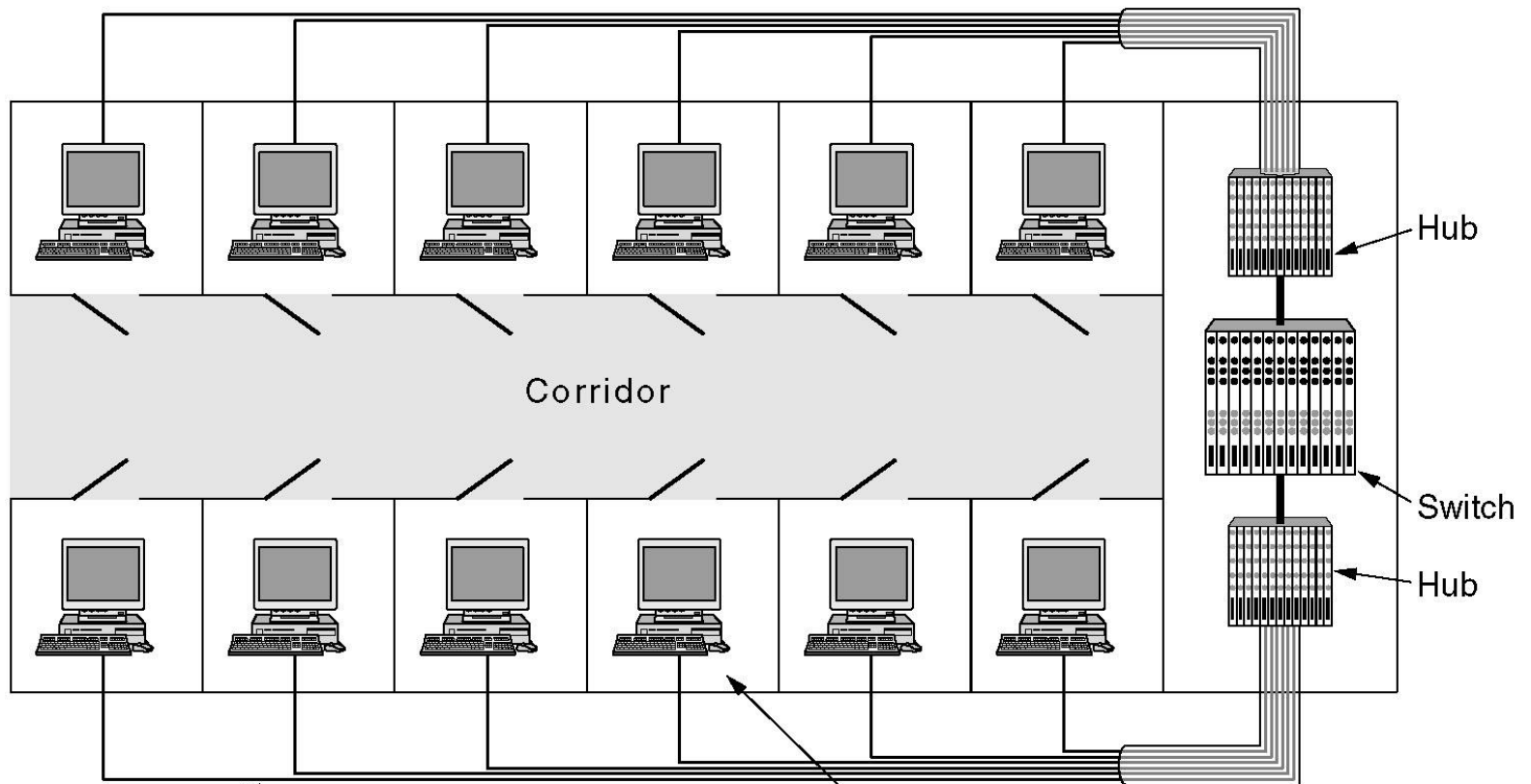
(b)



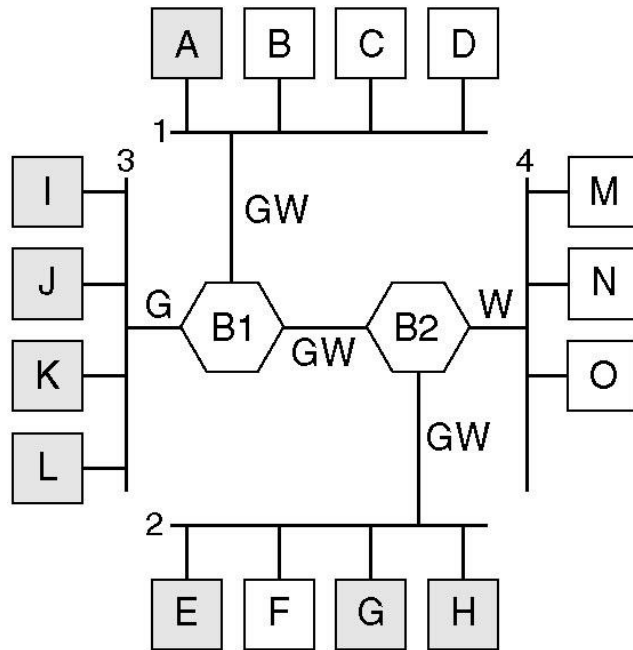
(c)

Virtual LANs

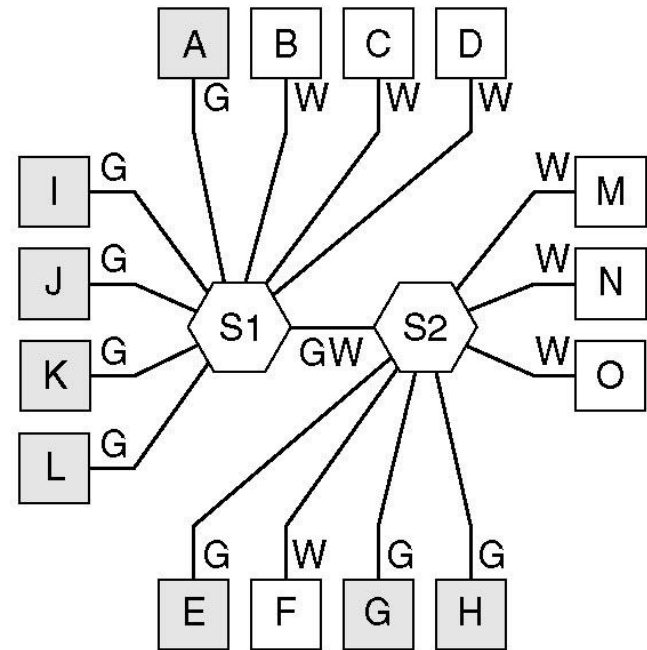
A building with centralized wiring using hubs and a switch.



Virtual LANs (2)



(a)

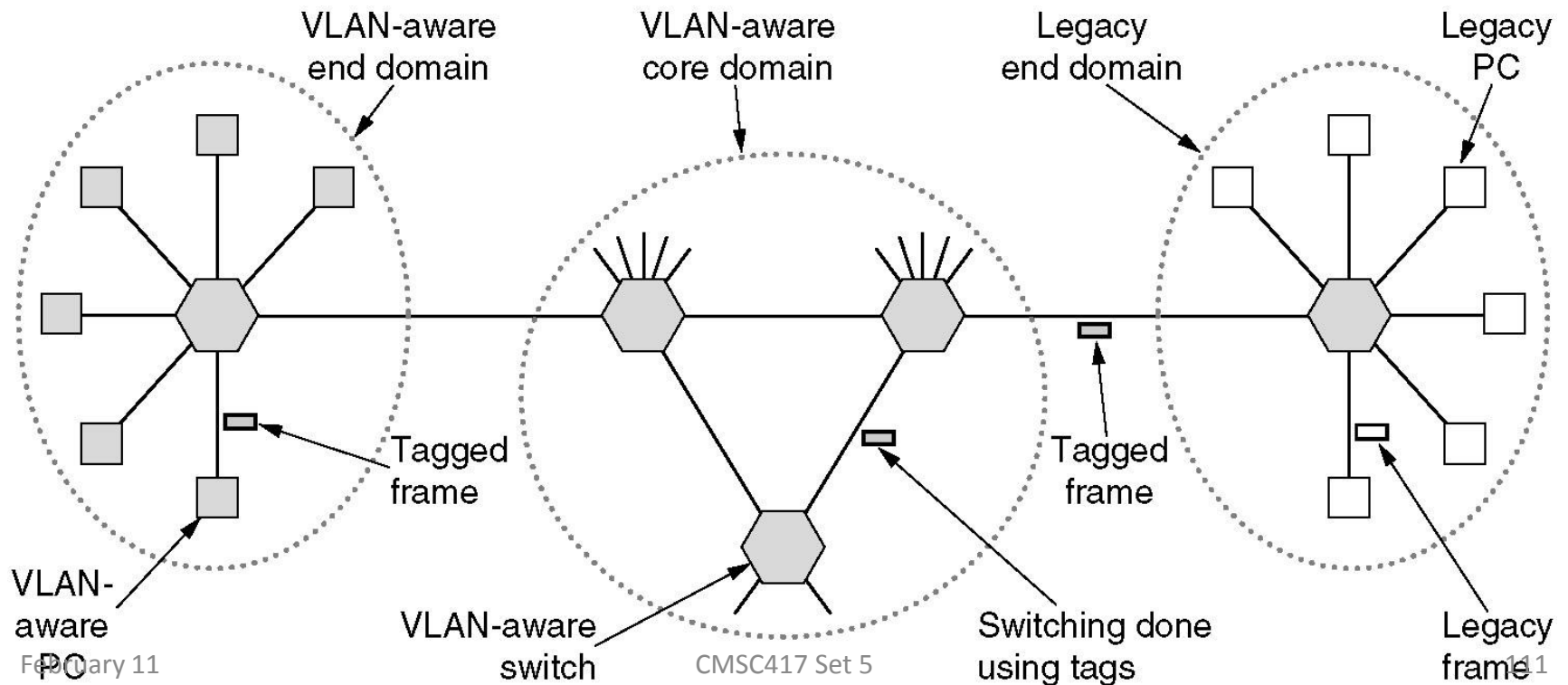


(b)

(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.

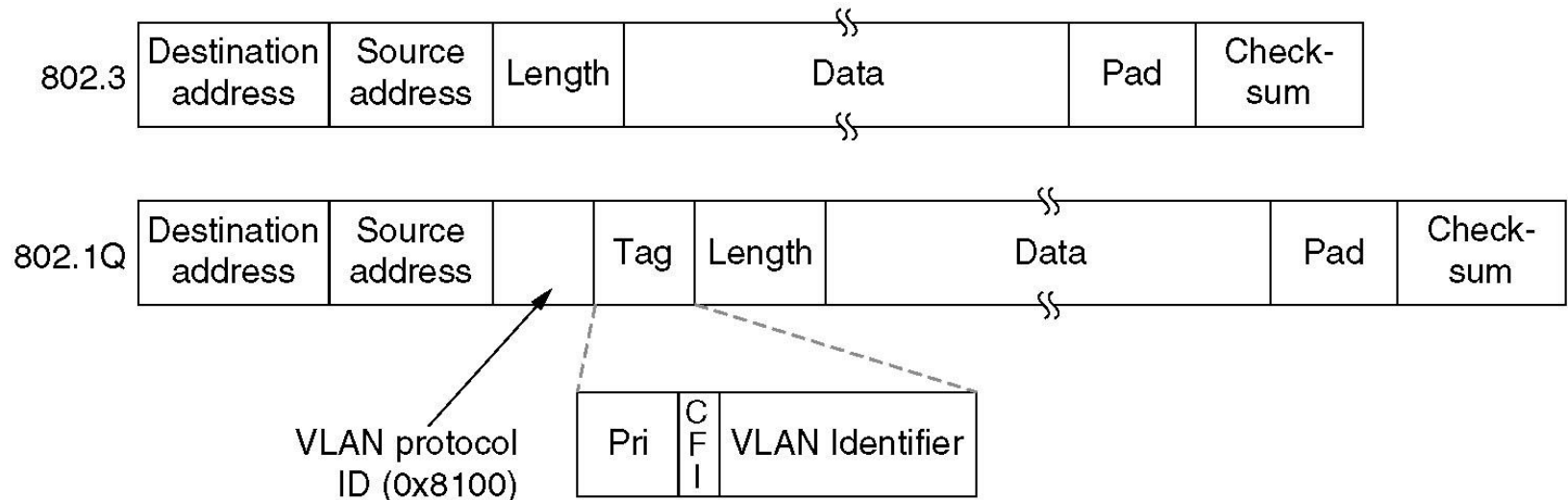
The IEEE 802.1Q Standard

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)

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.