CSMC 417

Computer Networks

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Set 5

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Chapter 4

The Medium Access Control Sublayer

MAC
Medium Access Control Sublayer

- Local Area Networks
  - Broadcast Channels
  - Multi-access Channels
  - Random Access Channels

What is it all about?

- Consider an audioconference where
  - if one person speaks, all can hear
  - if more than one person speaks at the same time, both voices are garbled
- How should participants coordinate actions so that
  - the number of messages exchanged per second is maximized
  - time spent waiting for a chance to speak is minimized
- This is the *multiple access* problem

Some simple solutions

- Use a moderator
  - a speaker must wait for moderator to call on him or her, even if no one else wants to speak
  - what if the moderator's connection breaks?
- Distributed solution
  - speak if no one else is speaking
  - but if two speakers are waiting for a third to finish, guarantee collision
- Designing good schemes is surprisingly hard!

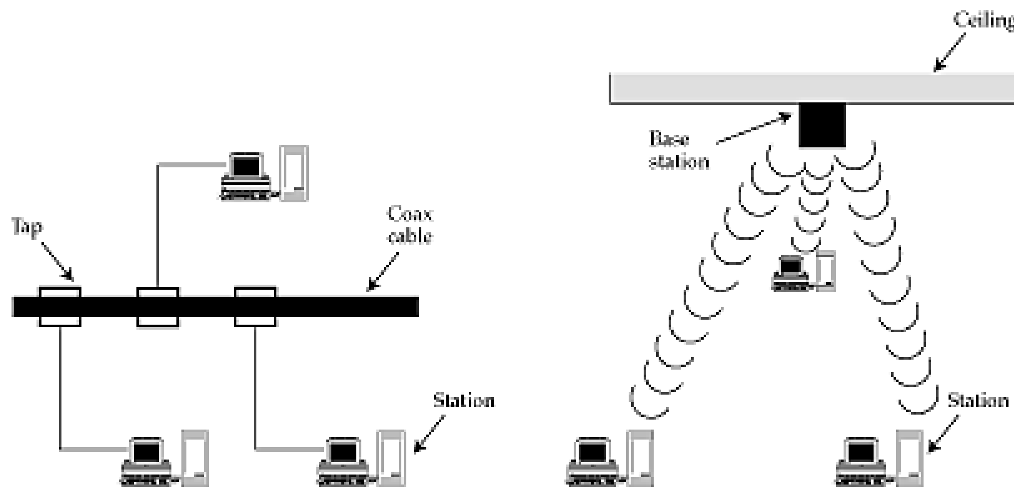
Outline

- Contexts for the problem
- Choices and constraints
- Performance metrics
- Base technologies
- Centralized schemes
- Distributed schemes

Contexts for the multiple access problem

- Broadcast transmission medium
  - message from any transmitter is received by all receivers
- Colliding messages are garbled
- Goal
  - maximize message throughput
  - minimize mean waiting time
- Shows up in five main contexts

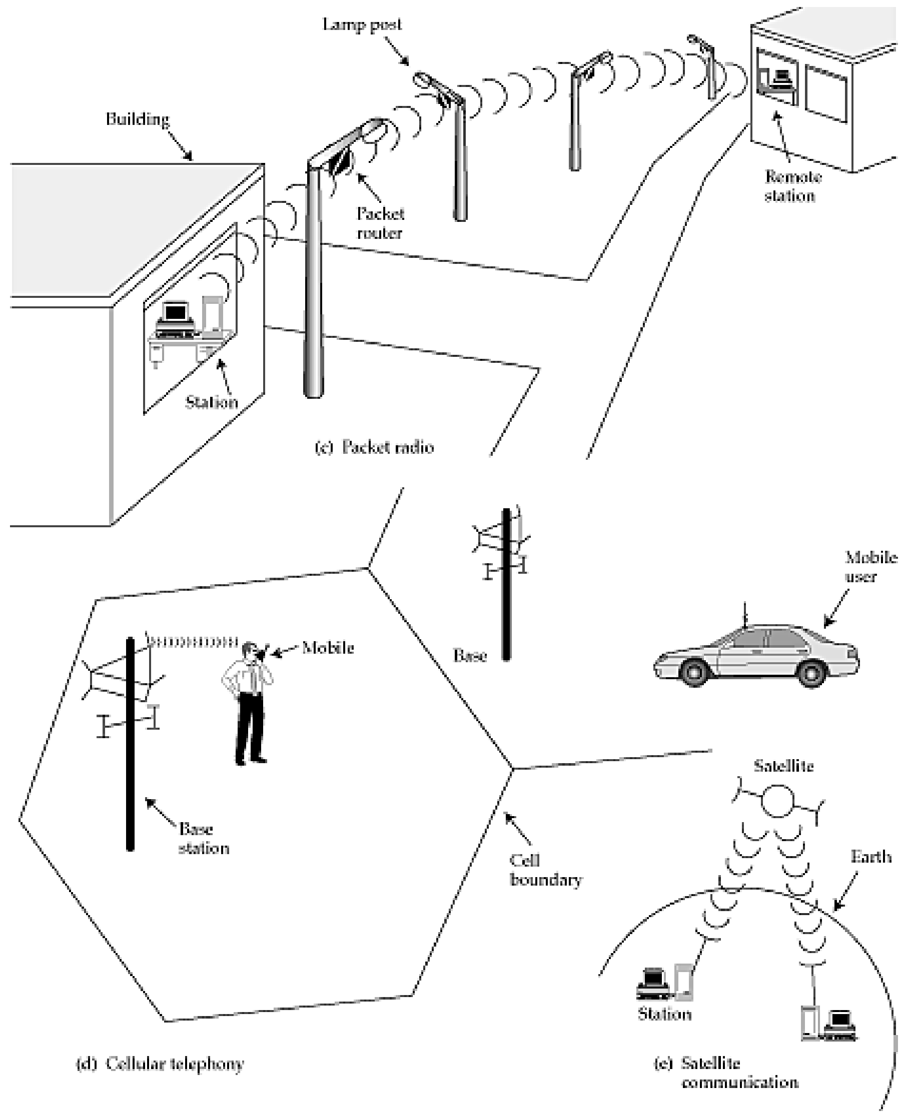
Contexts



(a) Wired lan

(b) Wireless lan

Contexts



Lamp post
Building
Packet router
Remote station
Station
(c) Packet radio
Base
Mobile user
Mobile
Base station
Cell boundary
Satellite
Earth
Station
(d) Cellular telephony
(e) Satellite communication

Solving the problem

- First, choose a base technology
  - to isolate traffic from different stations
  - can be in time domain or frequency domain
- Then, choose how to allocate a limited number of transmission resources to a larger set of contending users

Choices

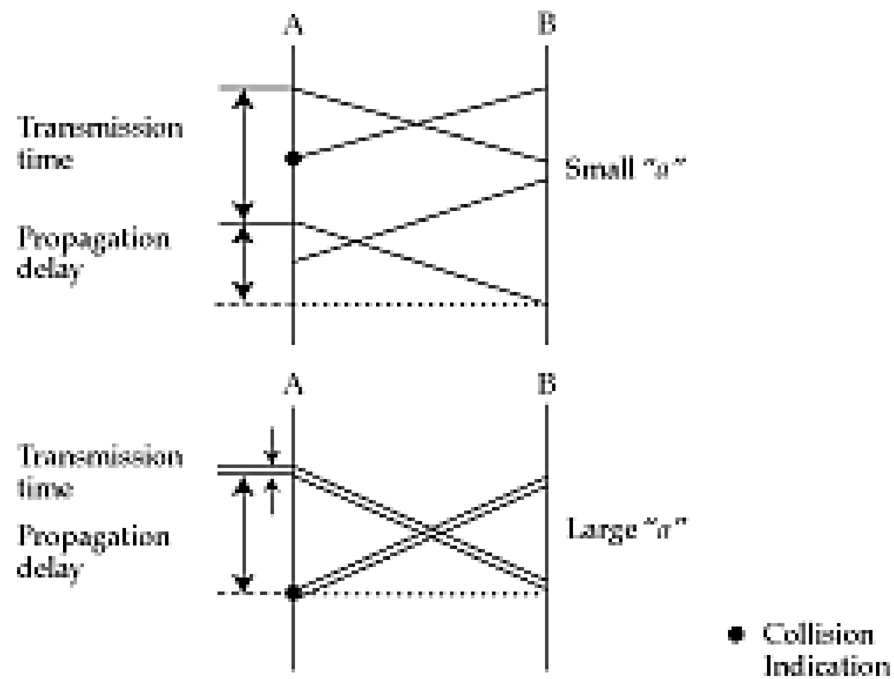
- Centralized vs. distributed design
  - is there a moderator or not?
  - in a centralized solution one of the stations is a master and the others are slaves
    - master->slave = downlink
    - slave->master = uplink
  - in a distributed solution, all stations are peers
- Circuit-mode vs. packet-mode
  - do stations send steady streams or bursts of packets?
  - with streams, doesn't make sense to contend for every packet
  - allocate resources to streams
  - with packets, makes sense to contend for every packet to avoid wasting bandwidth

Constraints

- Spectrum scarcity
  - radio spectrum is hard to come by
  - only a few frequencies available for long-distance communication
  - multiple access schemes must be careful not to waste bandwidth
- Radio link properties
  - radio links are error prone
    - fading
    - multipath interference
  - hidden terminals
    - transmitter heard only by a subset of receivers
  - capture
    - on collision, station with higher power overpowers the other
    - lower powered station may never get a chance to be heard

The parameter 'a'

- The number of packets sent by a source before the farthest station receives the first bit



Performance metrics

- Normalized throughput
  - fraction of link capacity used to carry non-retransmitted packets
  - example
    - with no collisions, 1000 packets/sec
    - with a particular scheme and workload, 250 packets/sec
    - => *goodput = 0.25*
- Mean delay
  - amount of time a station has to wait before it successfully transmits a packet
    - depends on the load and the characteristics of the medium

Performance metrics

- Stability
  - with heavy load, is all the time spent on resolving contentions?
  - => unstable
  - with a stable algorithm, throughput does not decrease with offered load
  - if infinite number of uncontrolled stations share a link, then instability is guaranteed
  - but if sources reduce load when overload is detected, can achieve stability
- Fairness
  - no single definition
  - ‘no-starvation’: source eventually gets a chance to send
  - max-min fair share: will study later

Base technologies

- Isolates data from different sources
- Three basic choices
  - Frequency division multiple access (FDMA)
  - Time division multiple access (TDMA)
  - Code division multiple access (CDMA)

FDMA

- Simplest
- Best suited for analog links
- Each station has its own frequency band, separated by guard bands
- Receivers tune to the right frequency
- Number of frequencies is limited
  - reduce transmitter power; reuse frequencies in non-adjacent cells
  - example: voice channel = 30 KHz
  - 833 channels in 25 MHz band
  - with hexagonal cells, partition into 118 channels each
  - but with N cells in a city, can get 118N calls => win if N > 7

TDMA

- All stations transmit data on same frequency, but at different times
- Needs time synchronization
- Pros
  - users can be given different amounts of bandwidth
  - mobiles can use idle times to determine best base station
  - can switch off power when not transmitting
- Cons
  - synchronization overhead
  - greater problems with multipath interference on wireless links

CDMA

- Users separated both by time and frequency
- Send at a different frequency at each time slot (frequency hopping)
- Or, convert a single bit to a code (direct sequence)
  - receiver can decipher bit by inverse process
- Pros
  - hard to spy
  - immune from narrowband noise
  - no need for all stations to synchronize
  - no hard limit on capacity of a cell
  - all cells can use all frequencies

CDMA

- Cons
  - implementation complexity
  - need for power control
    - to avoid capture
  - need for a large contiguous frequency band (for direct sequence)
  - problems installing in the field

FDD and TDD

- Two ways of converting a wireless medium to a duplex channel
- In Frequency Division Duplex, uplink and downlink use different frequencies
- In Time Division Duplex, uplink and downlink use different time slots
- Can combine with FDMA/TDMA
- Examples
  - TDD/FDMA in second-generation cordless phones
  - FDD/TDMA/FDMA in digital cellular phones

Centralized access schemes

- One station is master, and the other are slaves
  - slave can transmit only when master allows
- Natural fit in some situations
  - wireless LAN, where base station is the only station that can see everyone
  - cellular telephony, where base station is the only one capable of high transmit power

Centralized access schemes

- Pros
  - simple
  - master provides single point of coordination
- Cons
  - master is a single point of failure
    - need a re-election protocol
    - master is involved in every single transfer => added delay

Circuit mode

- When station wants to transmit, it sends a message to master using packet mode
- Master allocates transmission resources to slave
- Slave uses the resources until it is done
- No contention during data transfer
- Used primarily in cellular phone systems
  - EAMPS: FDMA
  - GSM/IS-54: TDMA
  - IS-95: CDMA

Polling and probing

- Centralized packet-mode multiple access schemes
- Polling
  - master asks each station in turn if it wants to send (roll-call polling)
  - inefficient if only a few stations are active, overhead for polling messages is high, or system has many terminals
- Probing
  - stations are numbered with consecutive logical addresses
  - assume station can listen both to its own address and to a set of multicast addresses
  - master does a binary search to locate next active station

Reservation-based schemes

- When ‘a’ is large, can’t use a distributed scheme for packet mode (too many collisions)
  - mainly for satellite links
- Instead master coordinates access to link using reservations
- Some time slots devoted to reservation messages
  - can be smaller than data slots => minislots
- Stations contend for a minislot (or own one)
- Master decides winners and grants them access to link
- Packet collisions are only for minislots, so overhead on contention is reduced

Distributed schemes

- Compared to a centralized scheme
  - more reliable
  - have lower message delays
  - often allow higher network utilization
  - but are more complicated
- Almost all distributed schemes are packet mode (why?)

Decentralized polling

- Just like centralized polling, except there is no master
- Each station is assigned a slot that it uses
  - if nothing to send, slot is wasted
- Also, all stations must share a time base

Decentralized probing

- Also called tree based multiple access
- All stations in left subtree of root place packet on medium
- If a collision, root <- root ->left_son, and try again
- On success, everyone in root->right_son places a packet etc.
- (If two nodes with successive logical addresses have a packet to send, how many collisions will it take for one of them to win access?)
- Works poorly with many active stations, or when all active stations are in the same subtree

Carrier Sense Multiple Access (CSMA)

- A fundamental advance: check whether the medium is active before sending a packet (i.e carrier sensing)
- Unlike polling/probing a node with something to send doesn't have to wait for a master, or for its turn in a schedule
- If medium idle, then can send
- If collision happens, detect and resolve
- Works when 'a' is small

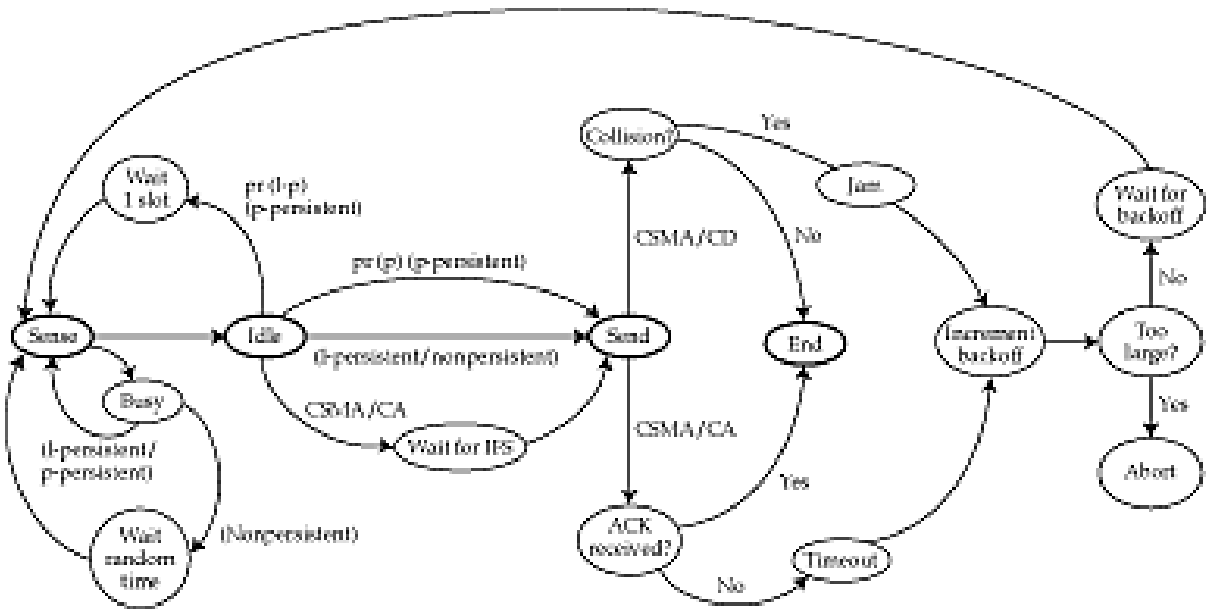
Simplest CSMA scheme

- Send a packet as soon as medium becomes idle
- If, on sensing busy, wait for idle -> persistent
- If, on sensing busy, set a timer and try later -> non-persistent
- Problem with persistent: two stations waiting to speak will collide

How to solve the collision problem

- Two solutions
- p-persistent: on idle, transmit with probability p:
  - hard to choose p
  - if p small, then wasted time
  - if p large, more collisions
- exponential backoff
  - on collision, choose timeout randomly from doubled range
  - backoff range adapts to number of contending stations
  - no need to choose p
  - need to detect collisions: collision detect circuit => CSMA/CD

Summary of CSMA schemes



Ethernet

- The most widely used LAN
- Standard is called IEEE 802.3
- Uses CSMA/CD with exponential backoff
- Also, on collision, place a jam signal on wire, so that all stations are aware of collision and can increment timeout range
- ‘a’ small =>time wasted in collision is around 50 microseconds
- Ethernet requires packet to be long enough that a collision is detected before packet transmission completes (a <= 1)
  - packet should be at least 64 bytes long for longest allowed segment
- Max packet size is 1500 bytes
  - prevents hogging by a single station

More on Ethernet

- First version ran at 3 Mbps and used ‘thick’ coax
- These days, runs at 10 Mbps, and uses ‘thin’ coax, or twisted pair (Category 3 and Category 5)
- Ethernet types are coded as <Speed><Baseband or broadband><physical medium>
  – Speed = 3, 10, 100 Mbps
  – Baseband = within building, broadband = on cable TV
  – Physical medium:
    - “2” is cheap 50 Ohm cable, upto 185 meters
    - “T” is unshielded twisted pair (also used for telephone wiring)
    - “36” is 75 Ohm cable TV cable, upto 3600 meters

Recent developments

- Switched Ethernet
  - each station is connected to switch by a separate UTP wire
  - line card of switch has a buffer to hold incoming packets
  - fast backplane switches packet from one line card to others
  - simultaneously arriving packets do not collide (until buffers overflow)
  - higher intrinsic capacity than 10BaseT (and more expensive)

Fast Ethernet variants

- Fast Ethernet (IEEE 802.3u)
  - same as 10BaseT, except that line speed is 100 Mbps
  - spans only 205 m
  - big winner
  - most current cards support both 10 and 100 Mbps cards (10/100 cards) for about $80
- 100VG Anylan (IEEE 802.12)
  - station makes explicit service requests to master
  - master schedules requests, eliminating collisions
  - not a success in the market
- Gigabit Ethernet
  - aims to continue the trend
  - still undefined, but first implementation will be based on fiber links

Channel Allocation Problem

- Static Channel Allocation
  - FDM
  - TDM
- Dynamic Channel Allocation
  - Station model
    - N Independent Stations
  - Single Channel
  - Collision
  - Time
    - Continuous
    - Slotted
  - Carrier Sense
    - Available
    - Not available

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

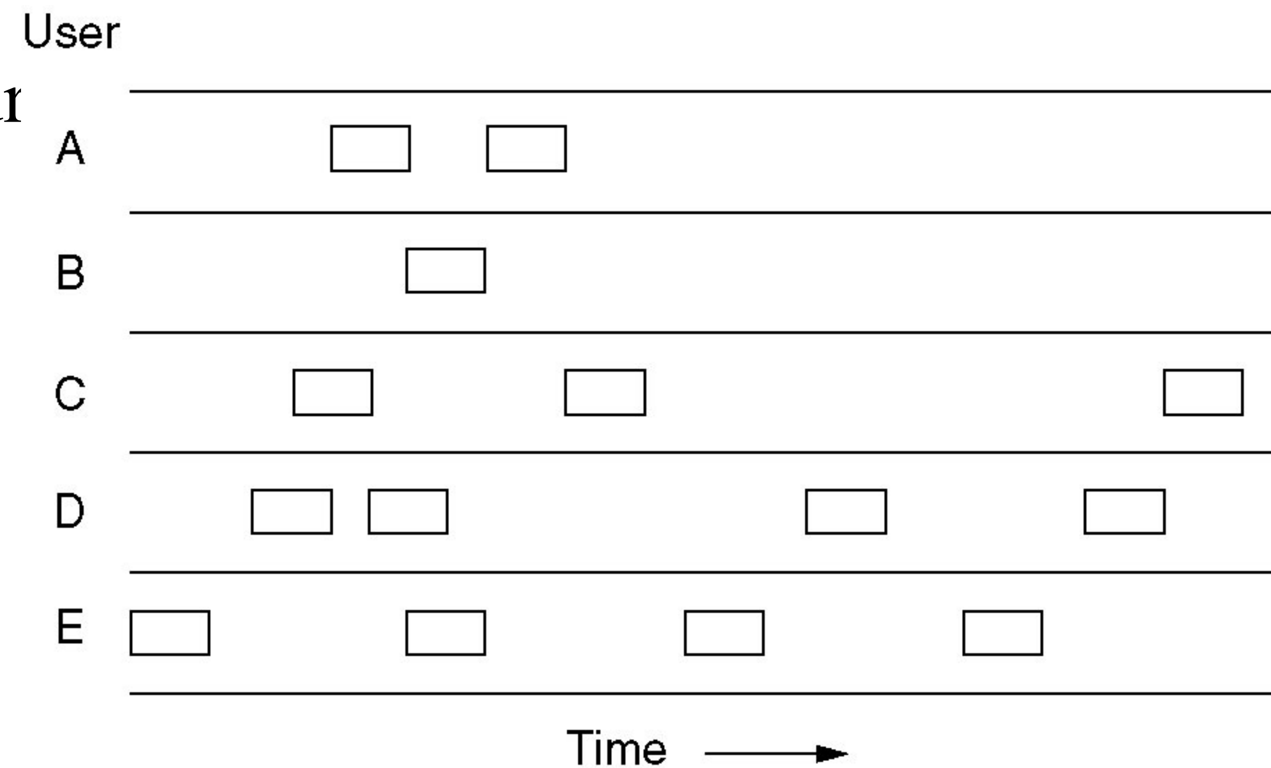
- Station Model.
- Single Channel Assumption.
- Collision Assumption.
- (a) Continuous Time.
  (b) Slotted Time.
- (a) Carrier Sense.
  (b) No Carrier Sense.

Multiple Access Protocols

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

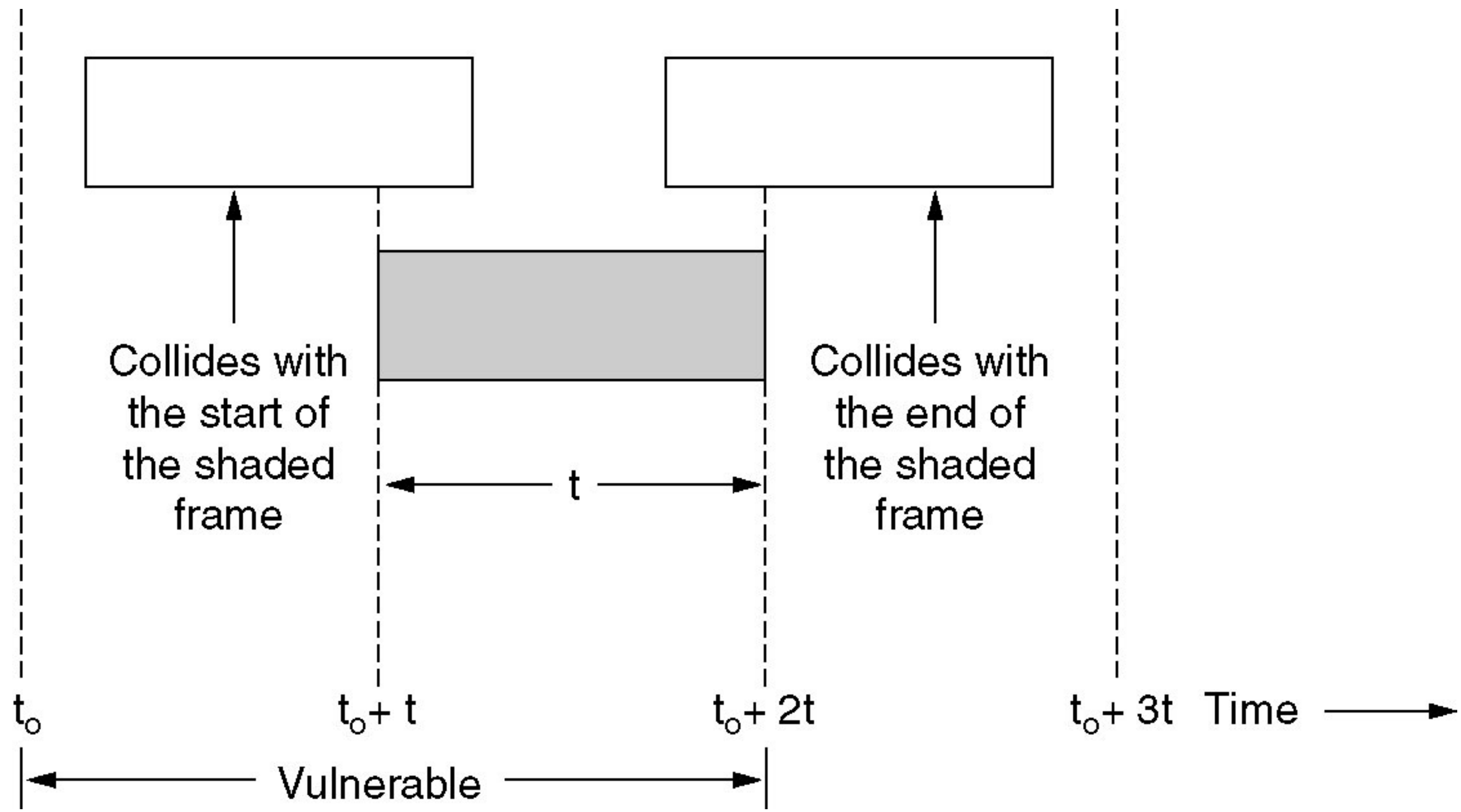
Pure ALOHA

In pur



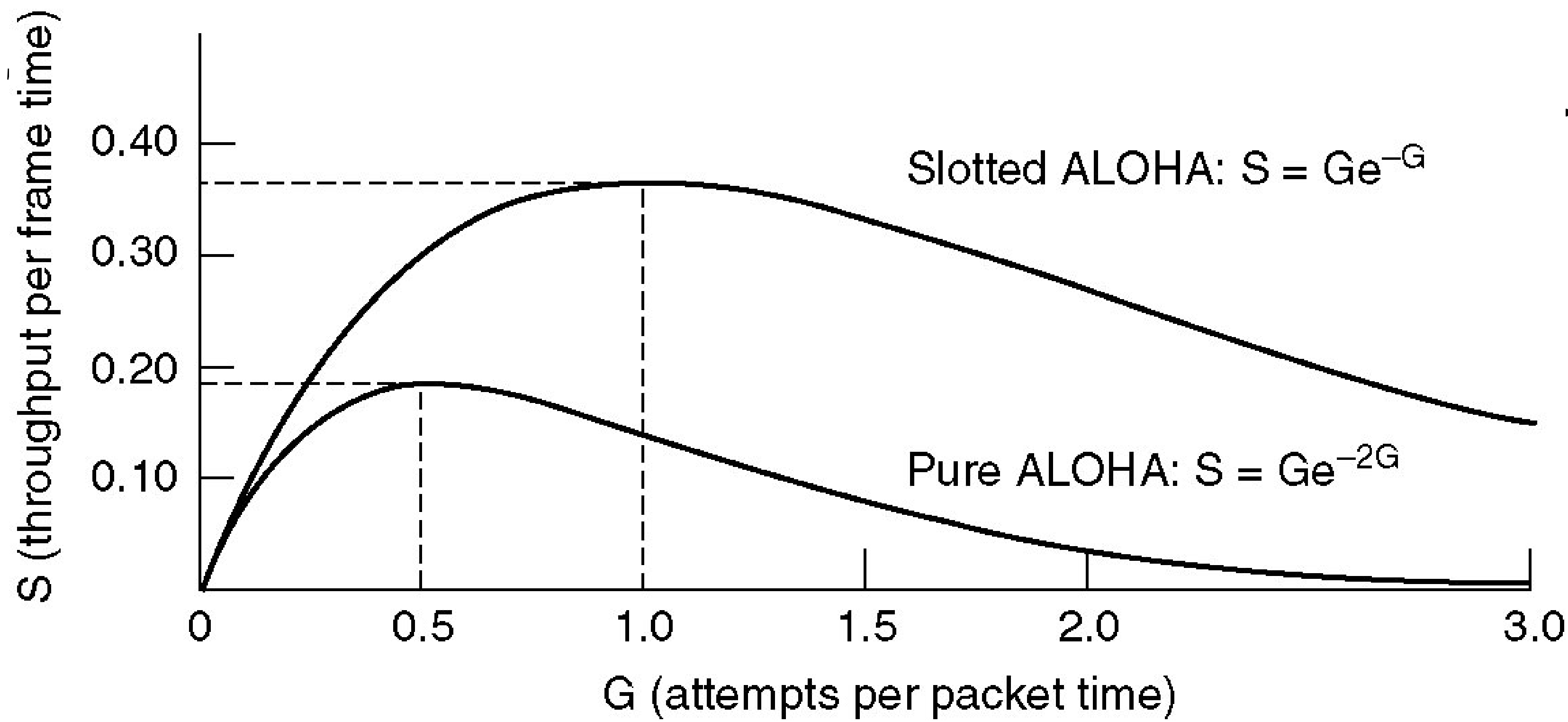
pletely

Pure ALOHA (2)



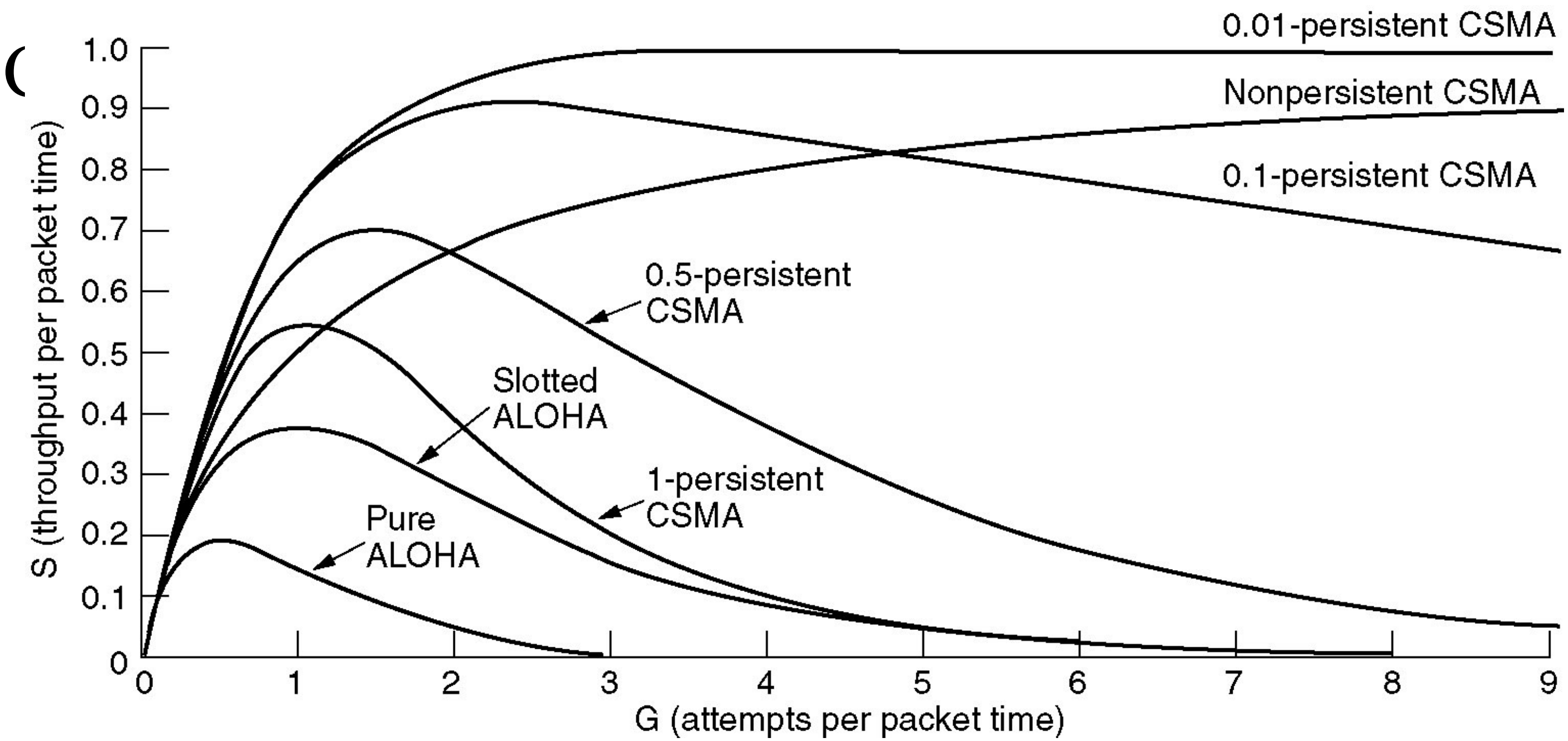
Collides with the start of the shaded frame
t
Collides with the end of the shaded frame
t_o
$t_o + t$
$t_o + 2t$
$t_o + 3t$
Time
Vulnerable

Pure ALOHA (3)

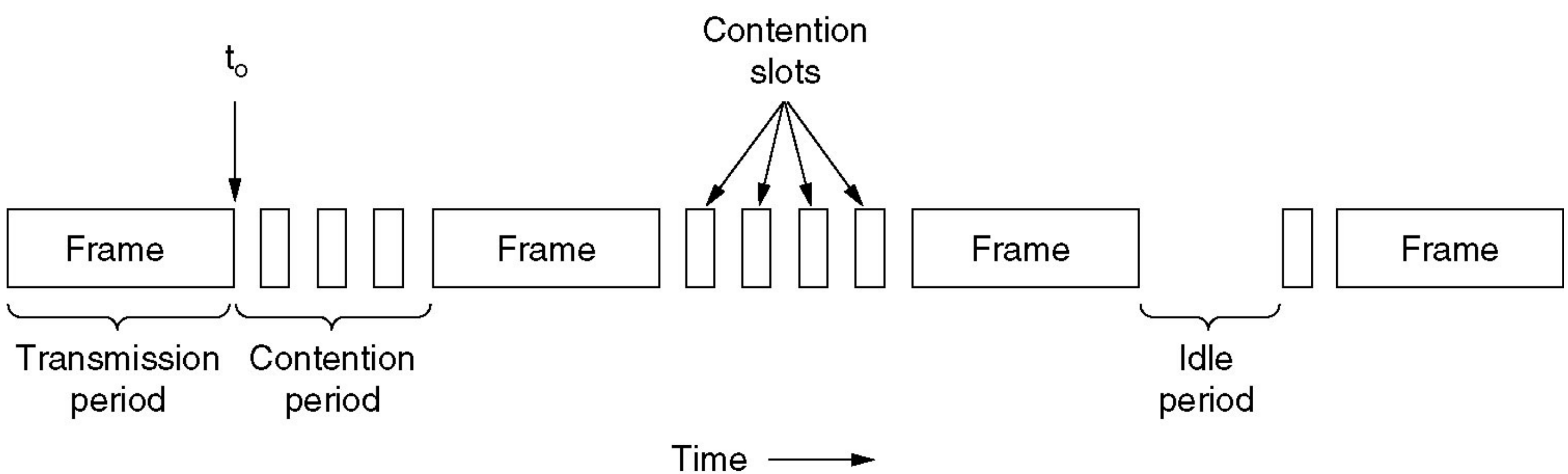


S (throughput per frame time)
0.40
0.30
0.20
0.10
0
0.5
1.0
1.5
2.0
3.0
G (attempts per packet time)
Slotted ALOHA: $S = Ge^{-G}$
Pure ALOHA: $S = Ge^{-2G}$

Persistent and Nonpersistent CSMA



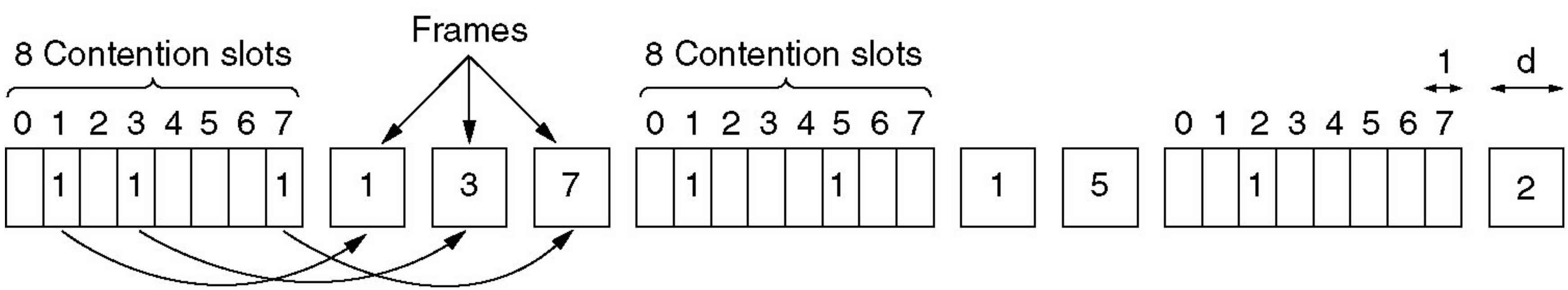
CSMA with Collision Detection



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

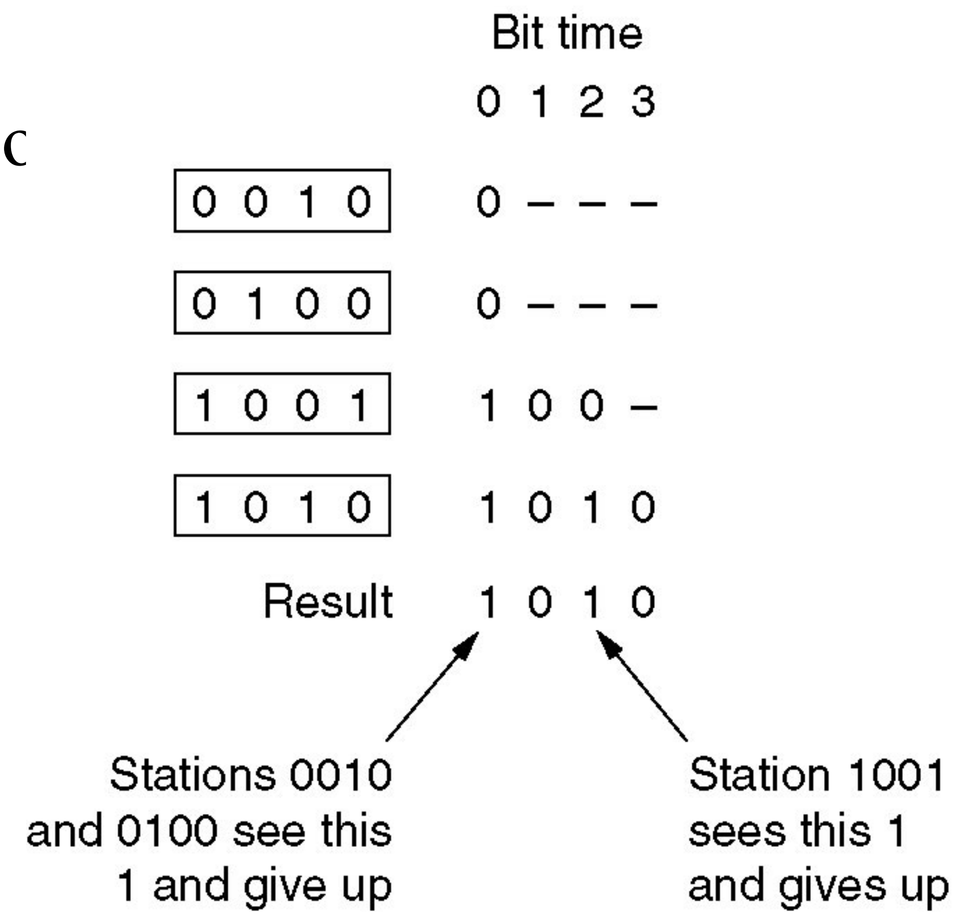
Collision-Free Protocols

The basic bit-map protocol.



Collision-Free Protocols (2)

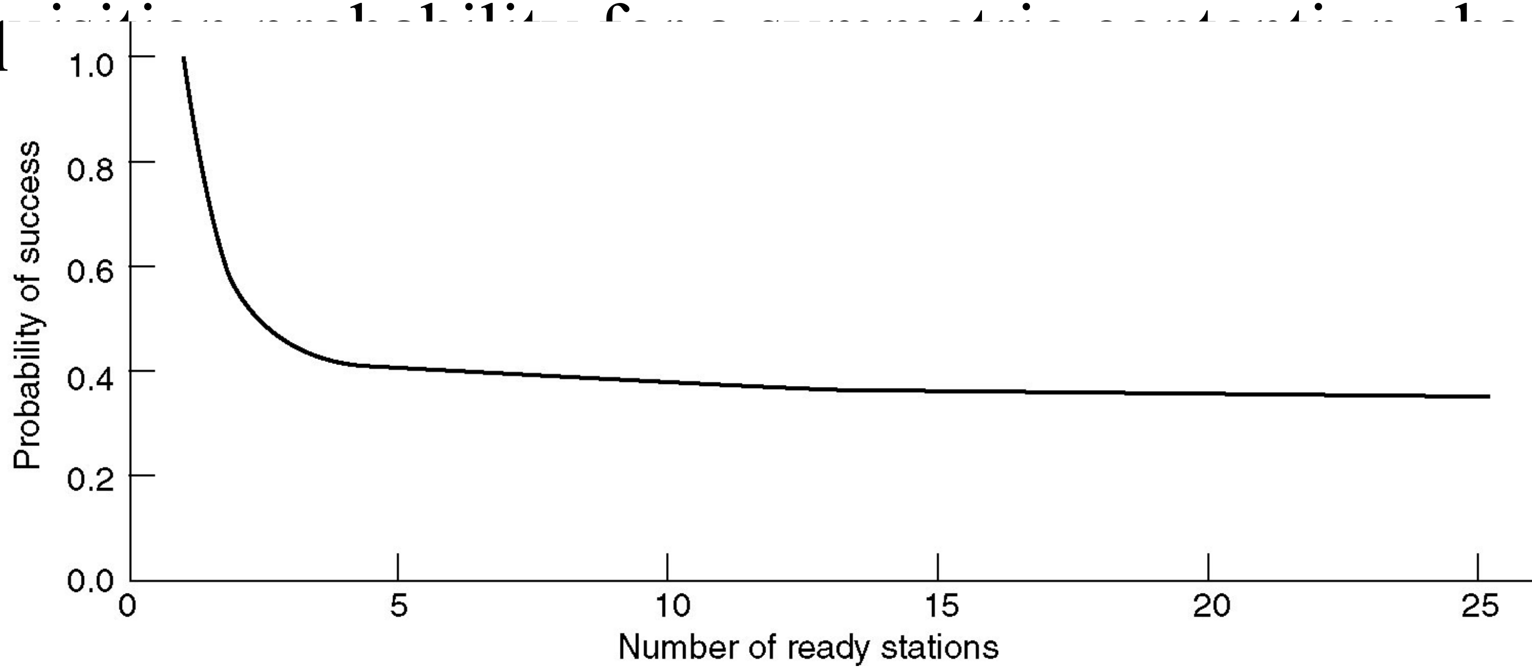
The binary cc



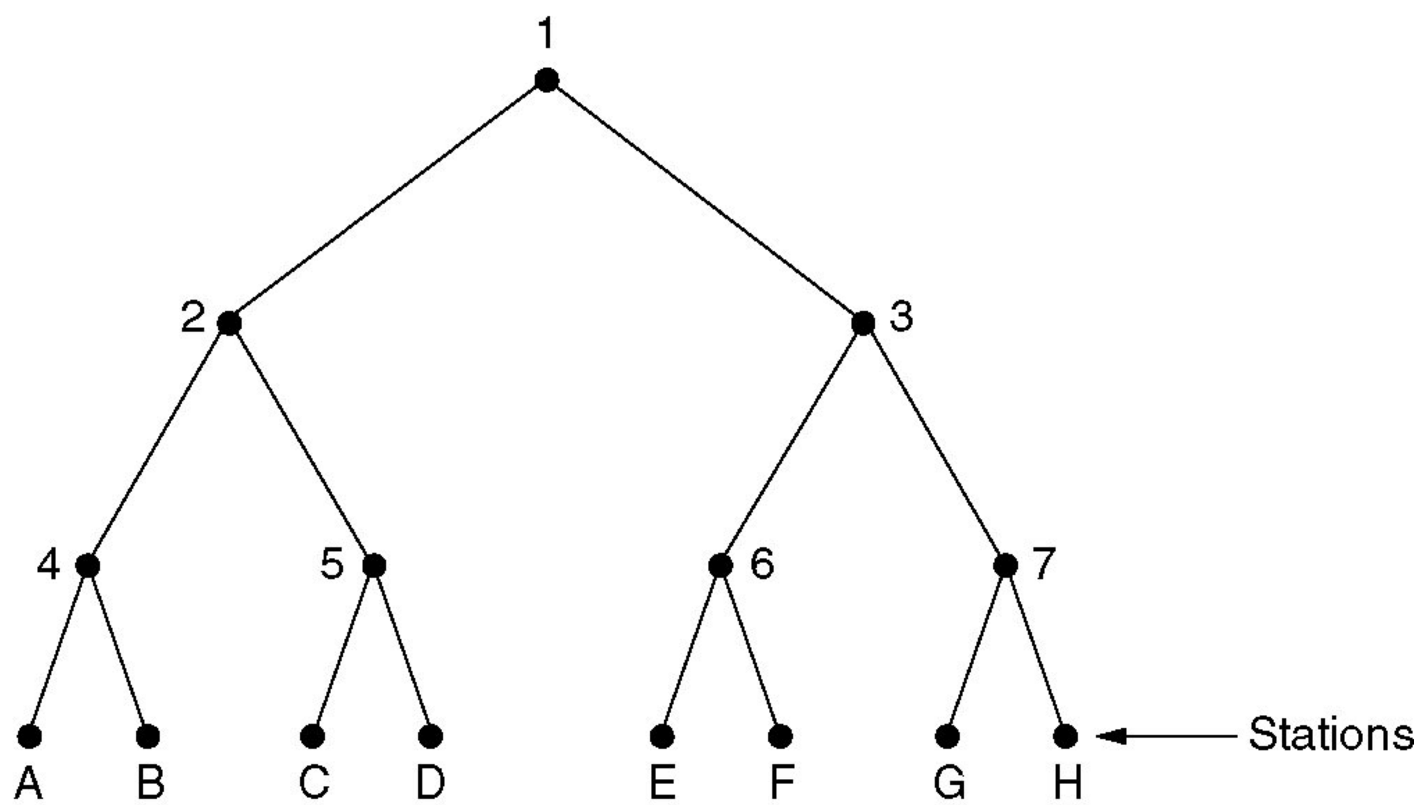
cates silence.

Limited-Contention Protocols

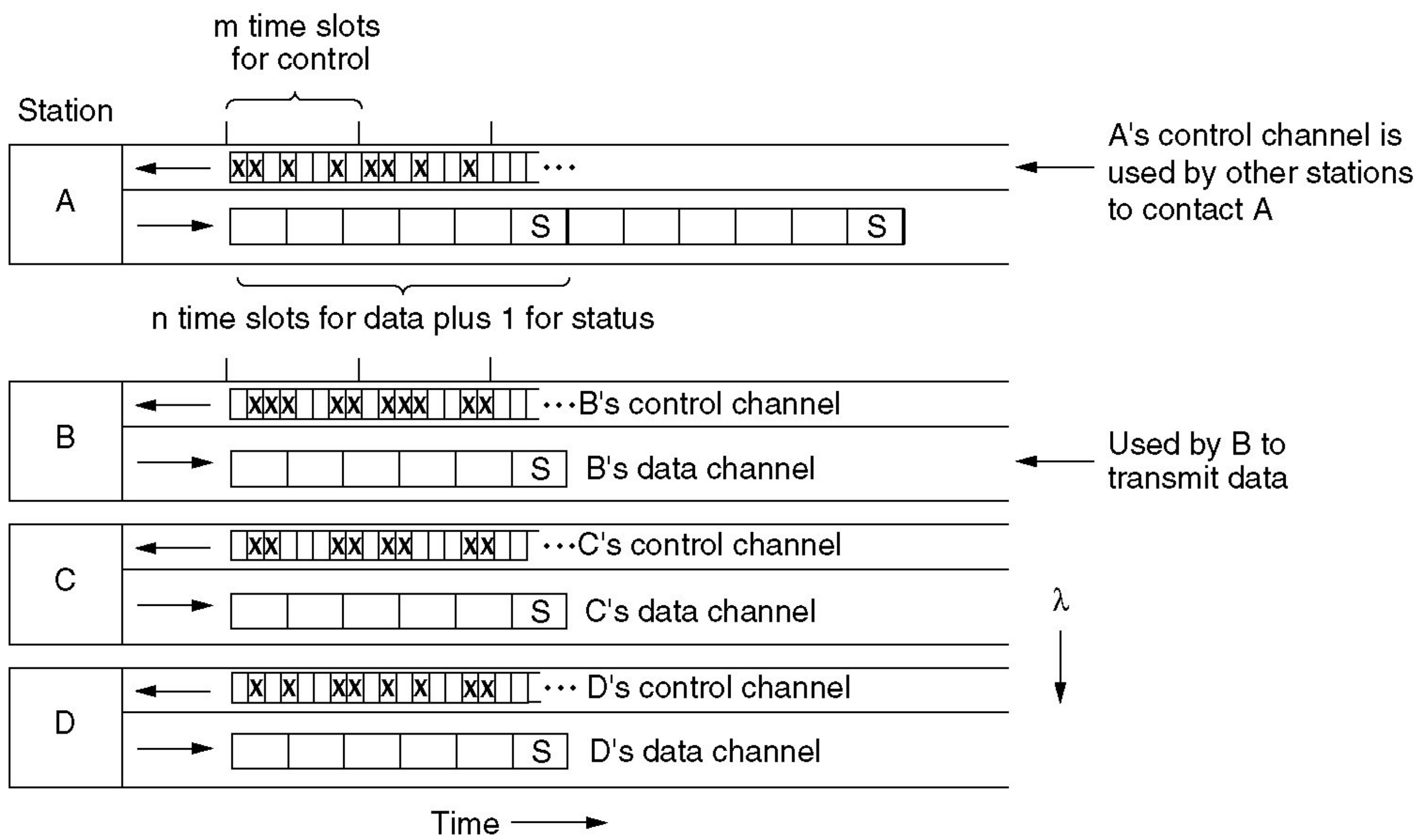
Acq nnel.



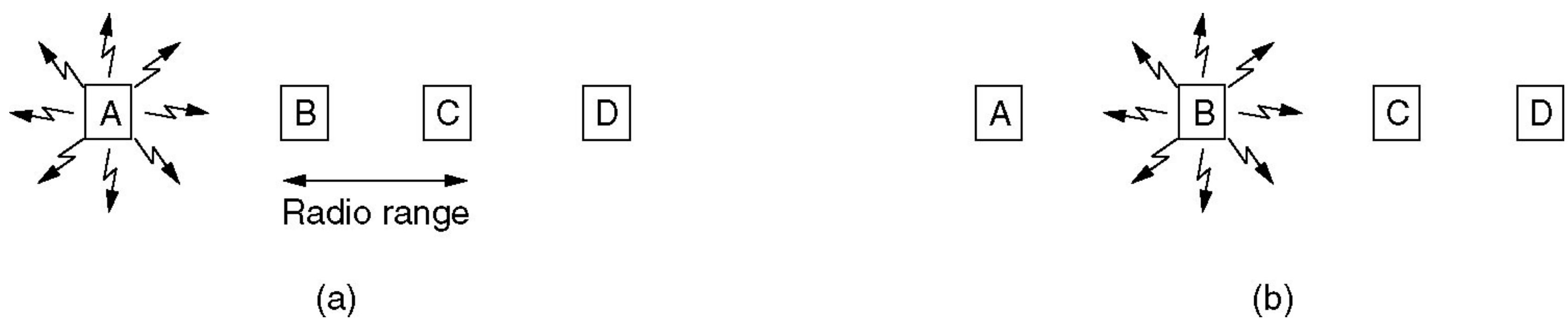
Adaptive Tree Walk Protocol



Wavelength Division Multiple Access Protocols

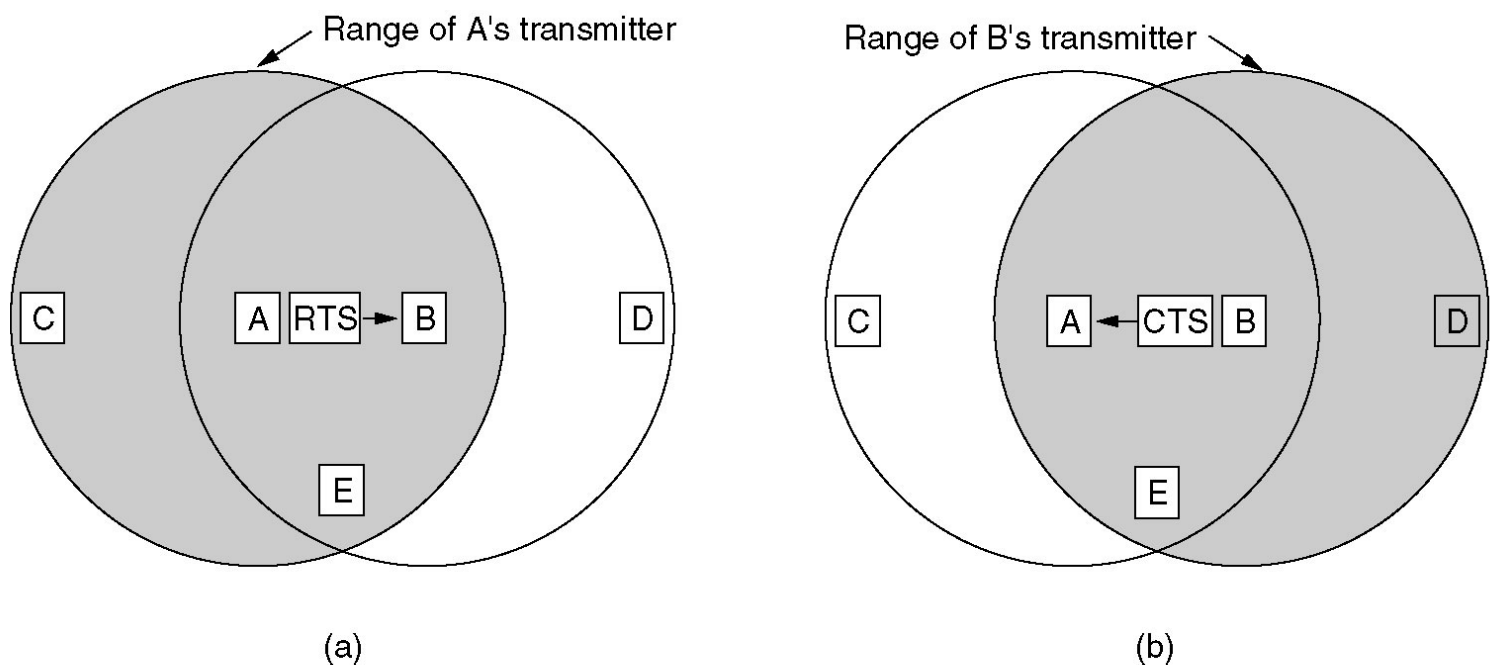


Wireless LAN Protocols



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

Wireless LAN Protocols (2)



The MACA protocol. (a) A sending an RTS to B.

(b) B responding with a CTS to A.

Dealing with hidden terminals

- CSMA/CA works when every station can receive transmissions from every other station
- Not always true
- Hidden terminal
  - some stations in an area cannot hear transmissions from others, though base can hear both
- Exposed terminal
  - some (but not all) stations can hear transmissions from stations not in the local area

Dealing with hidden and exposed terminals

- In both cases, CSMA/CA doesn't work
  - with hidden terminal, collision because carrier not detected
  - with exposed terminal, idle station because carrier incorrectly detected
- Two solutions
- Busy Tone Multiple Access (BTMA)
  - uses a separate "busy-tone" channel
  - when station is receiving a message, it places a tone on this channel
  - everyone who might want to talk to a station knows that it is busy
    - even if they cannot hear transmission that that station hears
  - this avoids both problems (why?)

Ethernet

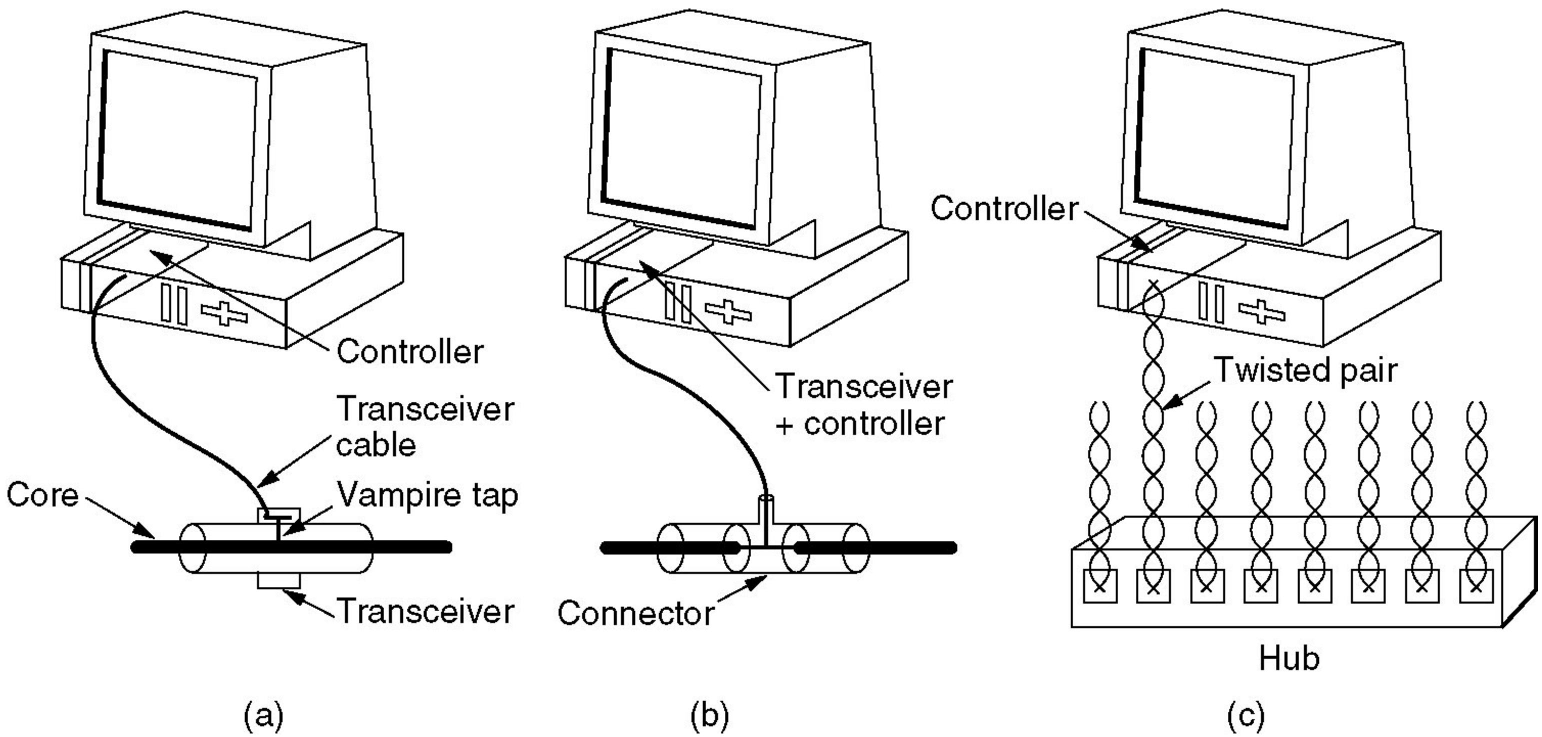
- Ethernet Cabling
- Manchester Encoding
- The Ethernet MAC Sublayer Protocol
- The Binary Exponential Backoff Algorithm
- Ethernet Performance
- Switched Ethernet
- Fast Ethernet
- Gigabit Ethernet
- IEEE 802.2: Logical Link Control
- Retrospective on Ethernet

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.

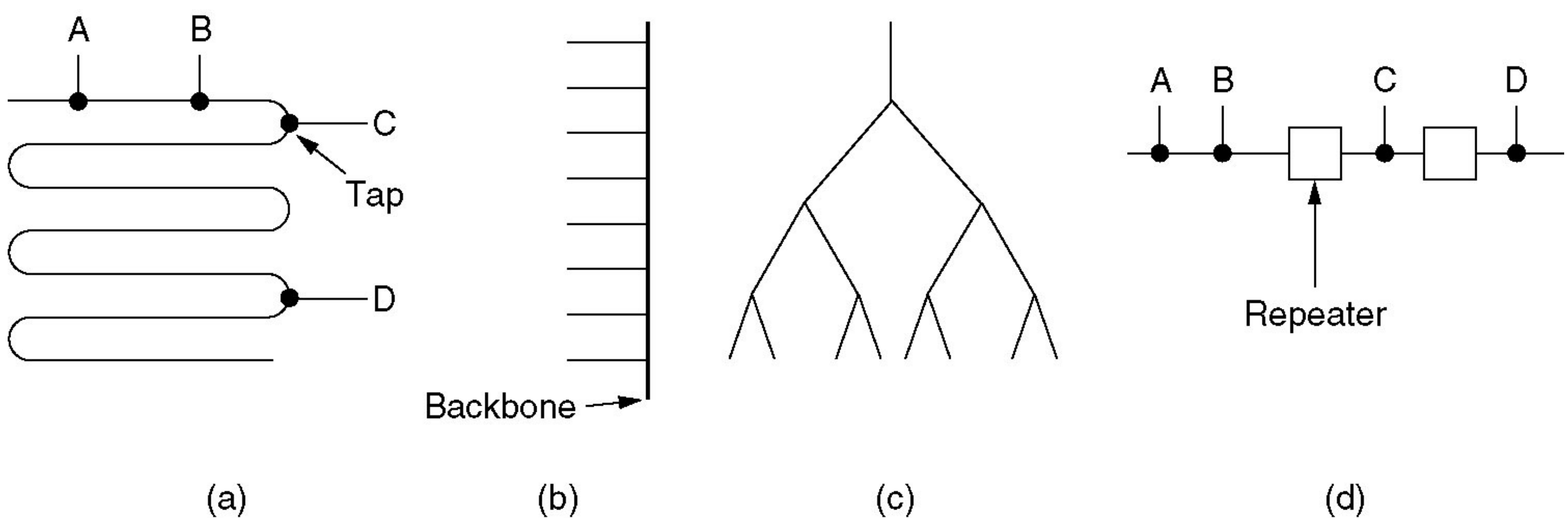
Ethernet Cabling (2)



Three kinds of Ethernet cabling.

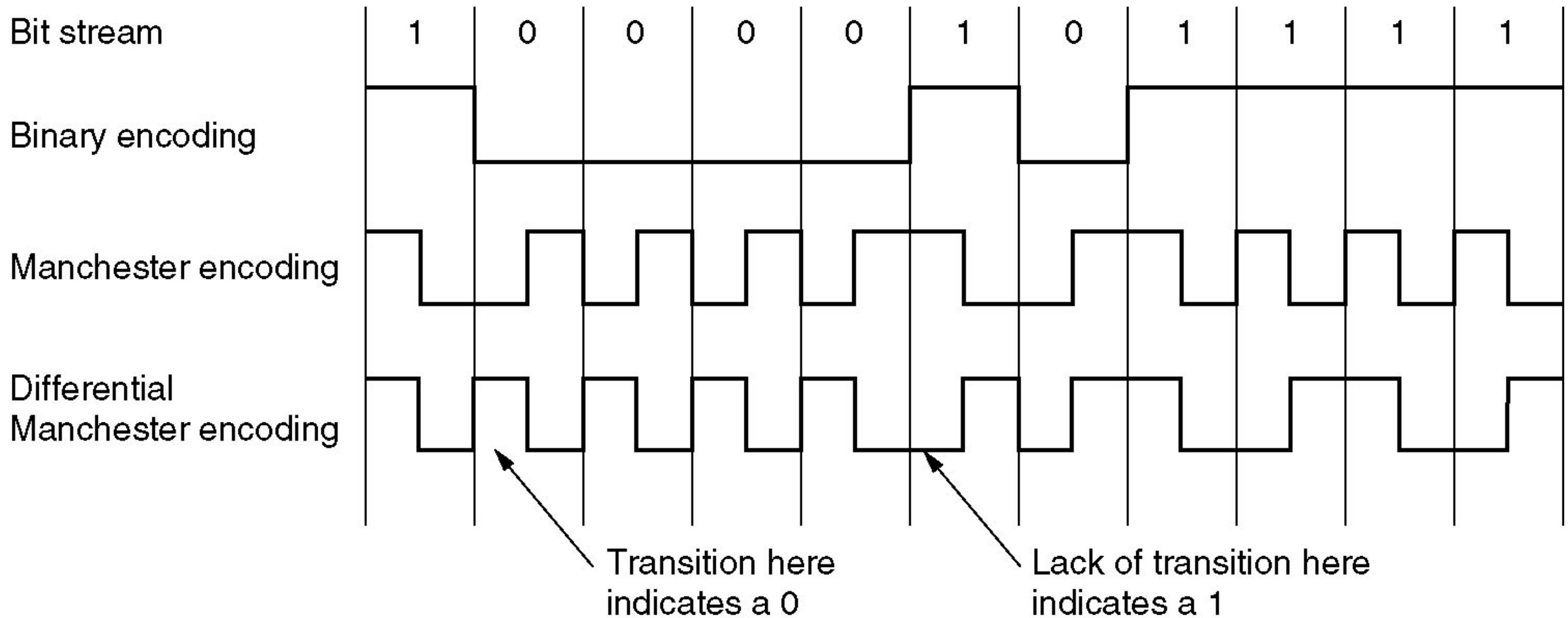
(a) 10Base5, (b) 10Base2, (c) 10Base-T.

Ethernet Cabling (3)



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

Ethernet Cabling (4)



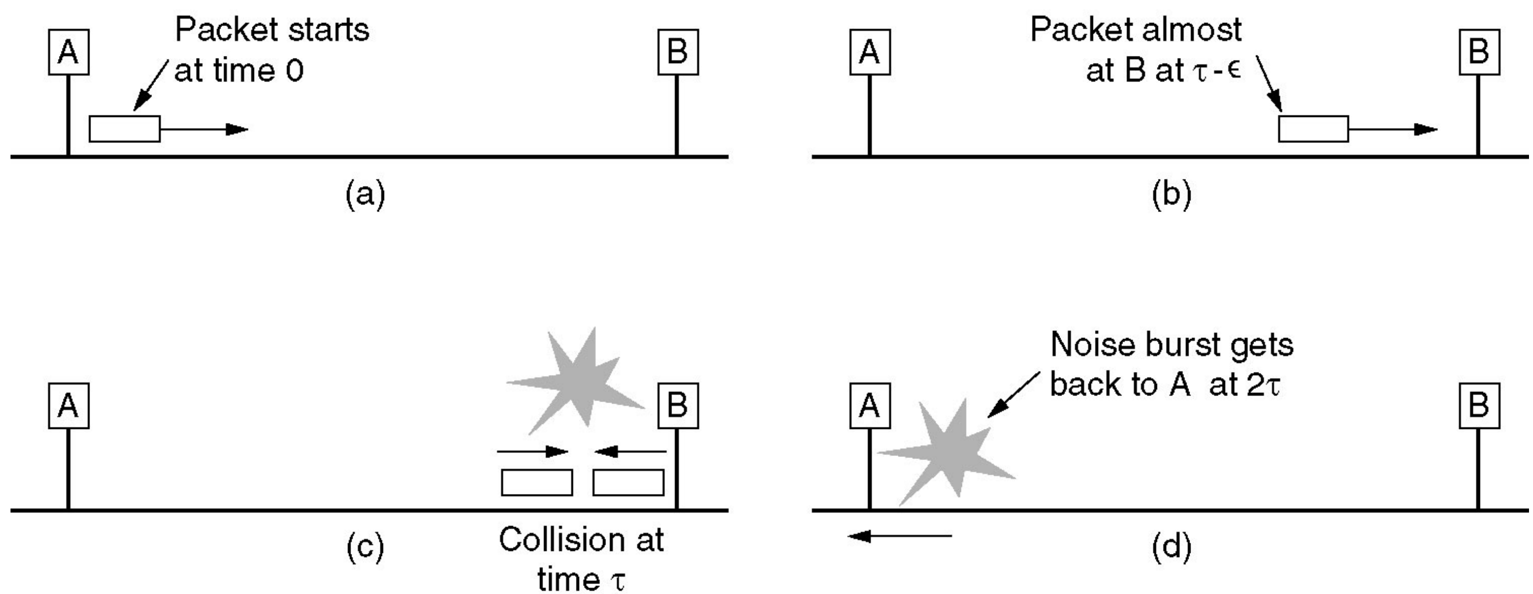
(a) Binary encoding, (b) Manchester encoding, (c) Differential Manchester encoding.

Ethernet MAC Sublayer Protocol

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

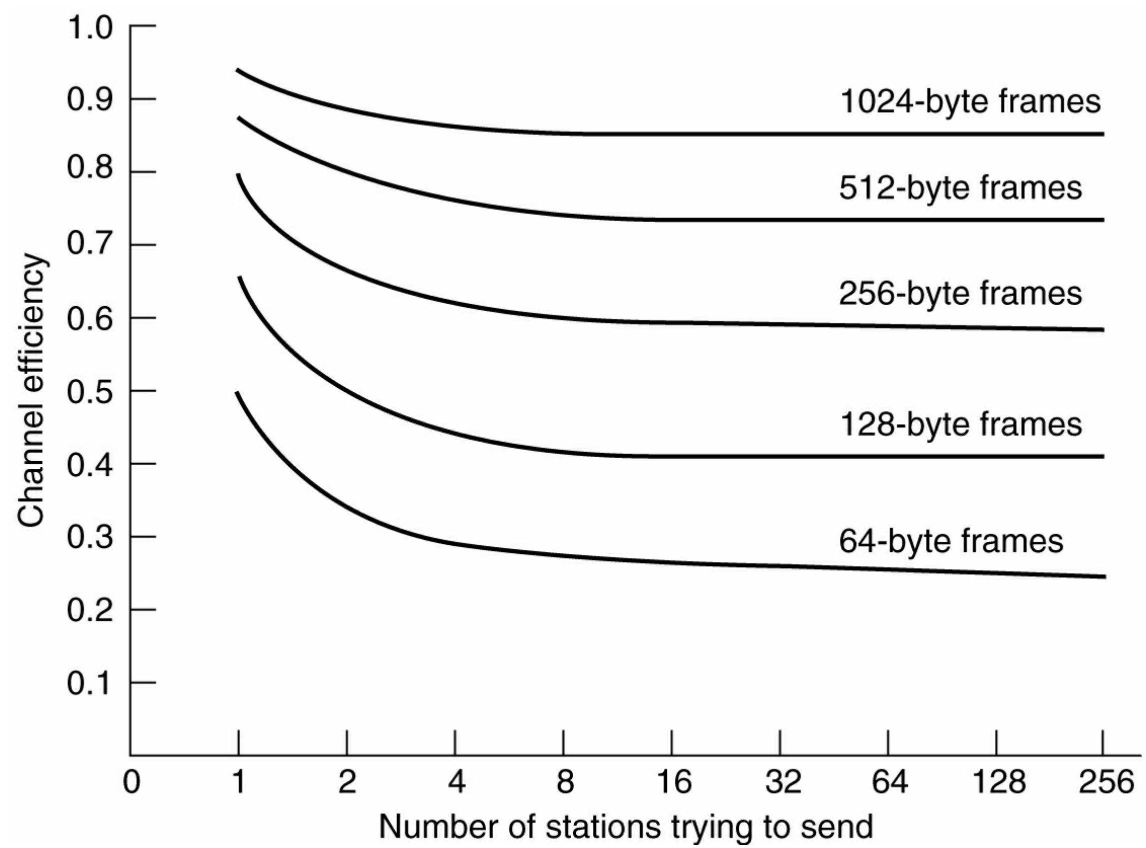
Frame formats. (a) DIX Ethernet, (b) IEEE 802.3.

Ethernet MAC Sublayer Protocol (2)



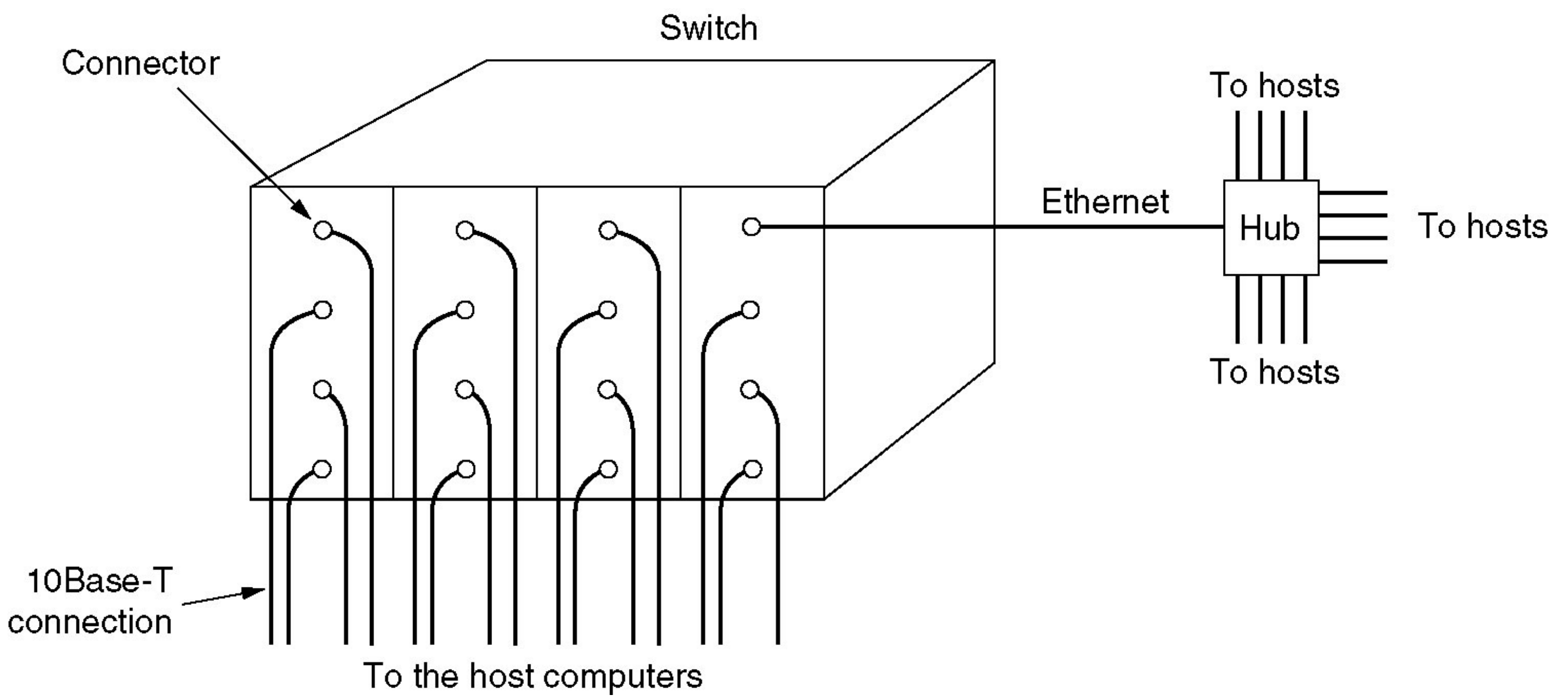
Collision detection can take as long as 2τ.

Ethernet Performance



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

Switched Ethernet



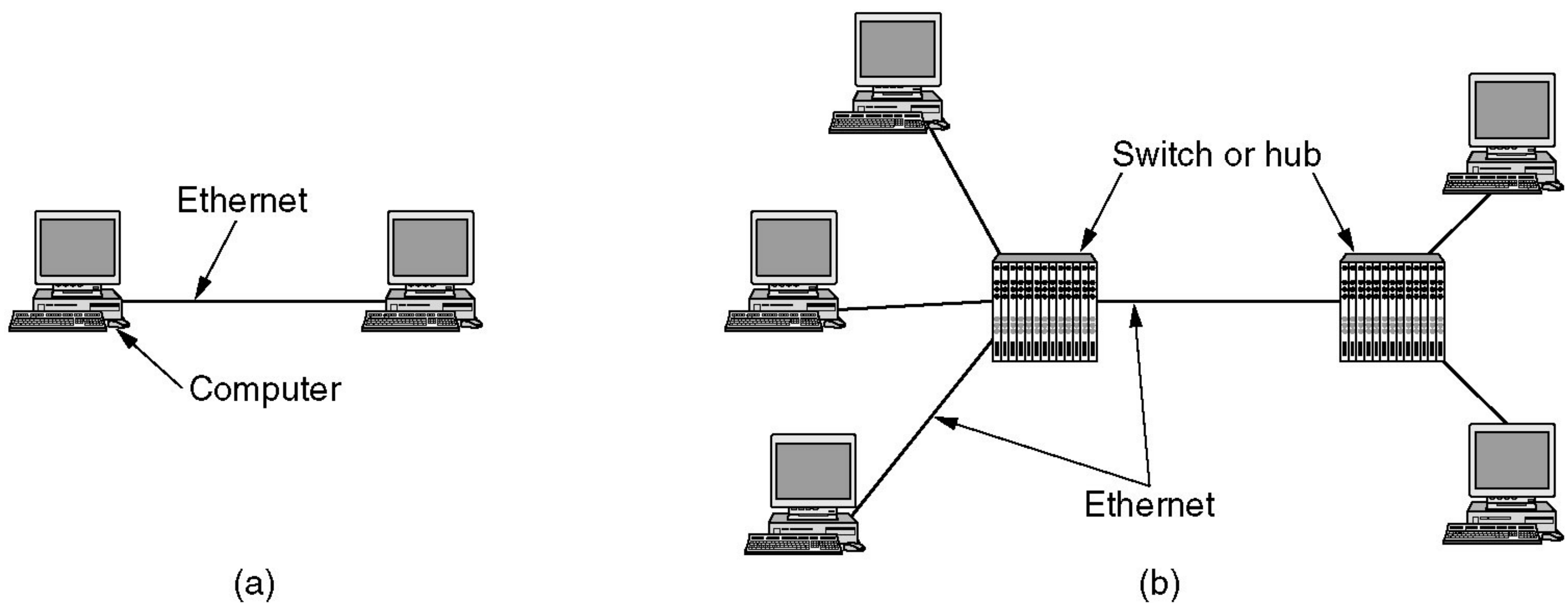
A simple example of switched Ethernet.

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



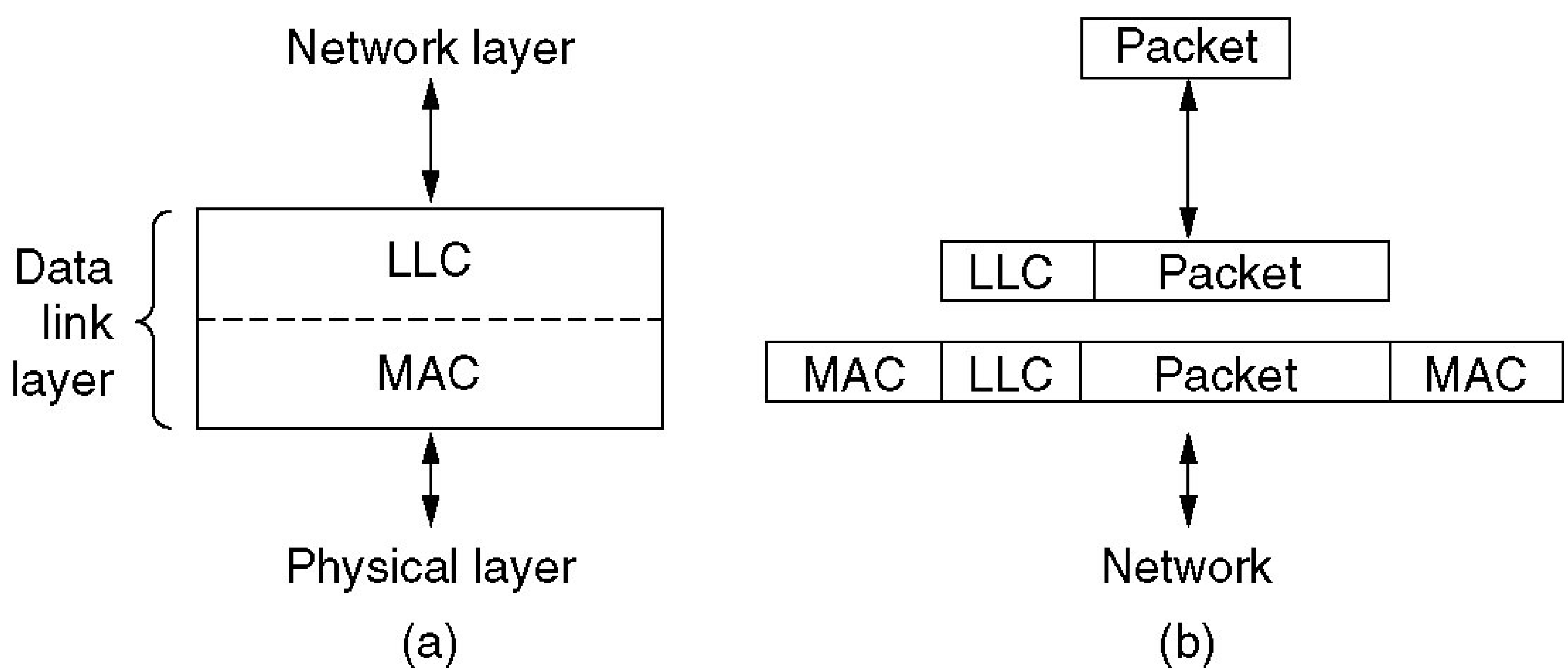
(a) A two-station Ethernet. (b) A multistation Ethernet.

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

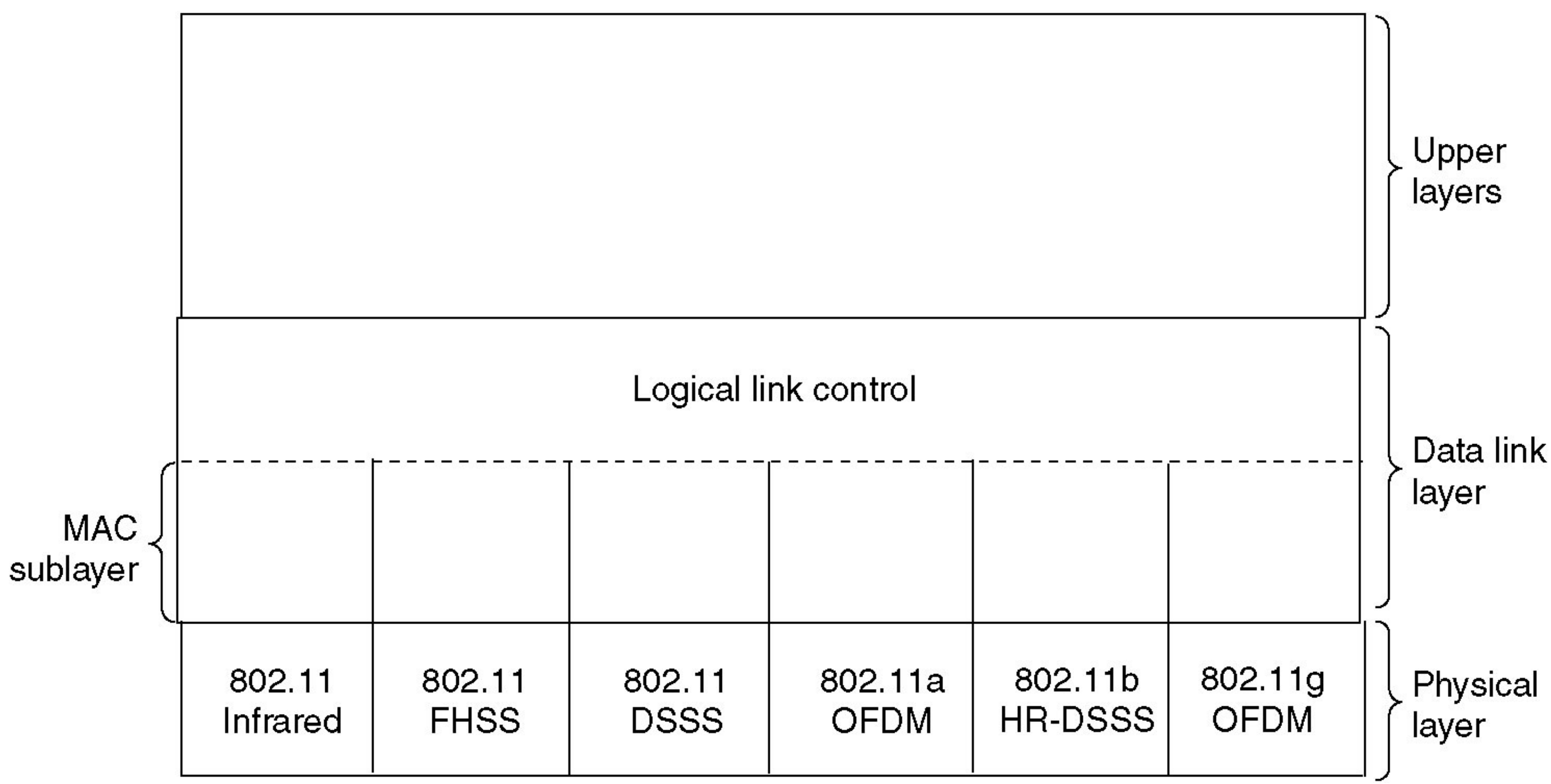


(a) Position of LLC. (b) Protocol formats.

Wireless LANs

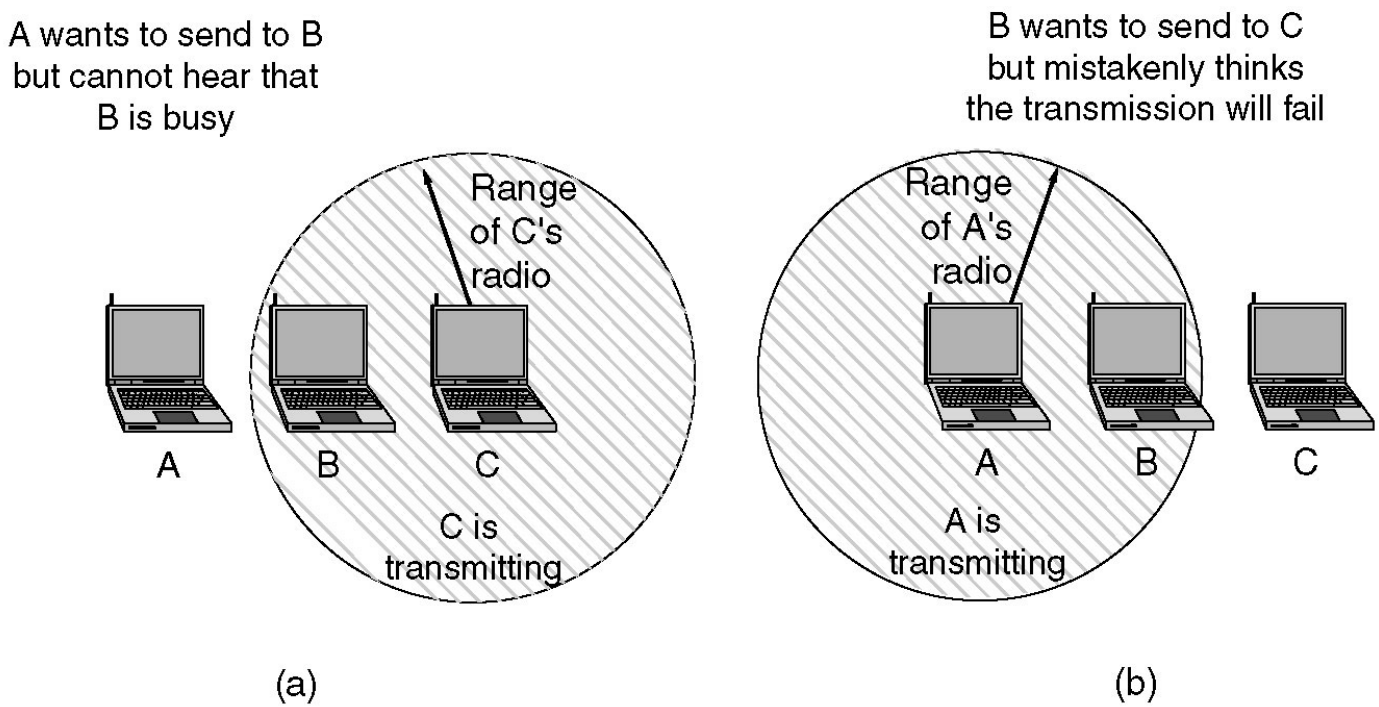
- The 802.11 Protocol Stack
- The 802.11 Physical Layer
- The 802.11 MAC Sublayer Protocol
- The 802.11 Frame Structure
- Services

The 802.11 Protocol Stack



Part of the 802.11 protocol stack.

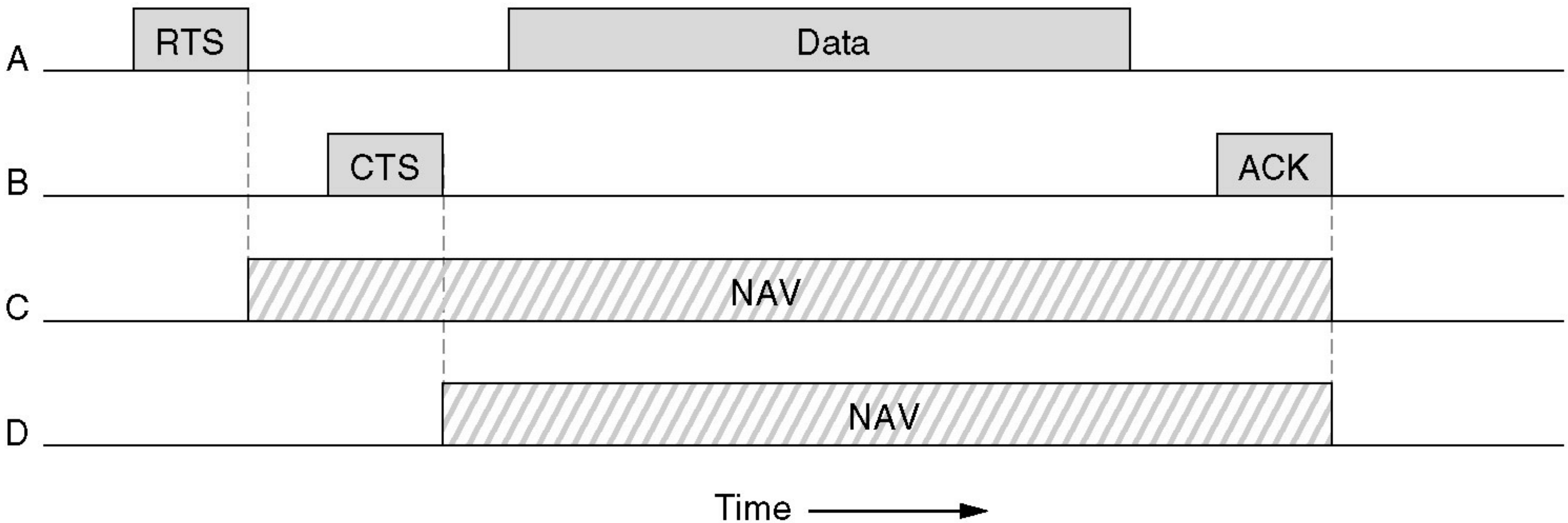
The 802.11 MAC Sublayer Protocol



(a) The hidden station problem.

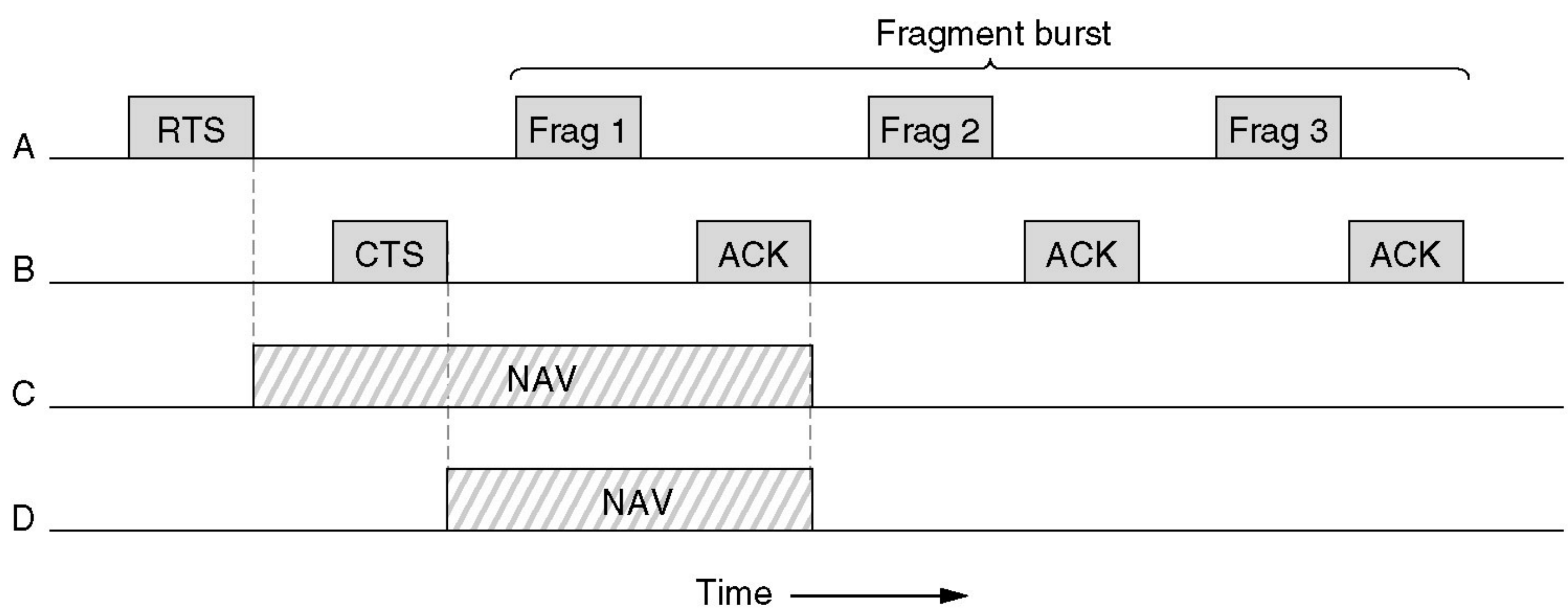
(b) The exposed station problem.

The 802.11 MAC Sublayer Protocol (2)



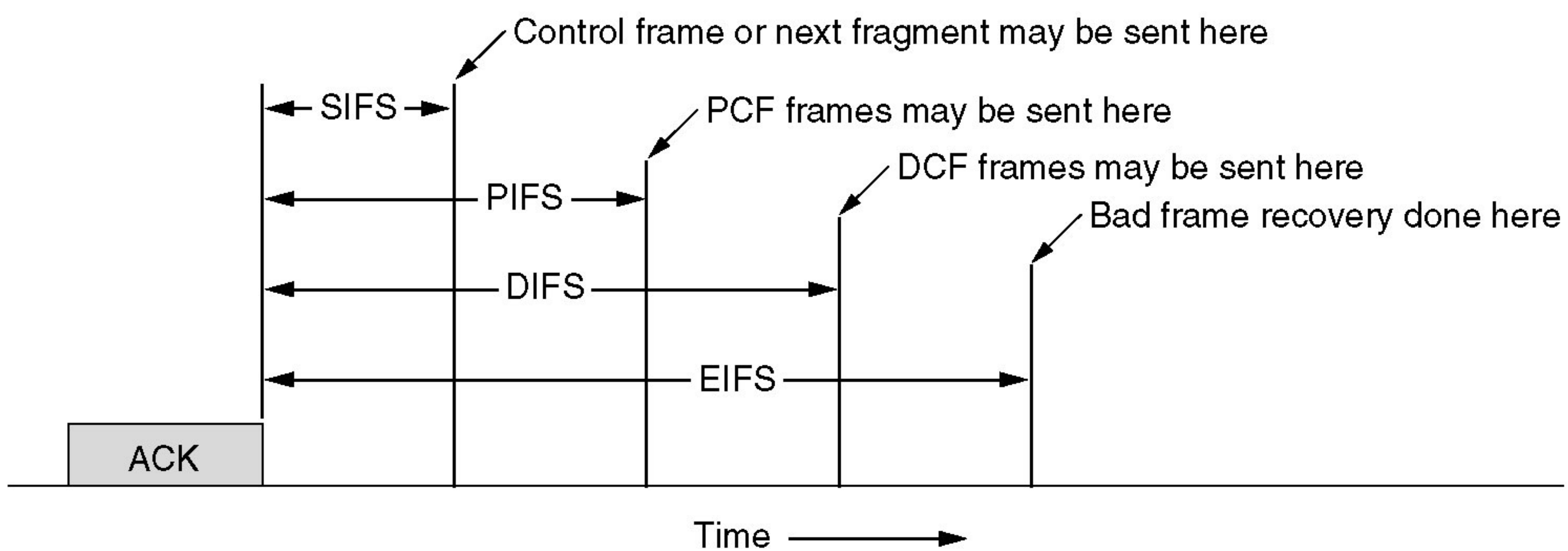
The use of virtual channel sensing using CSMA/CA.

The 802.11 MAC Sublayer Protocol (3)



A fragment burst.

The 802.11 MAC Sublayer Protocol (4)



Interframe spacing in 802.11.

The 802.11 Frame Structure

Bytes	2	2	6	6	6	2	6	0-2312	4
	Frame control	Dur-ation	Address 1	Address 2	Address 3	Seq.	Address 4	Data	Check-sum

Bits	2	2	4	1	1	1	1	1	1	1	1
Frame control	Version	Type	Subtype	To DS	From DS	MF	Re-try	Pwr	More	W	O

The 802.11 data frame.

802.11 Services

Distribution Services

- Association
- Disassociation
- Reassociation
- Distribution
- Integration

802.11 Services

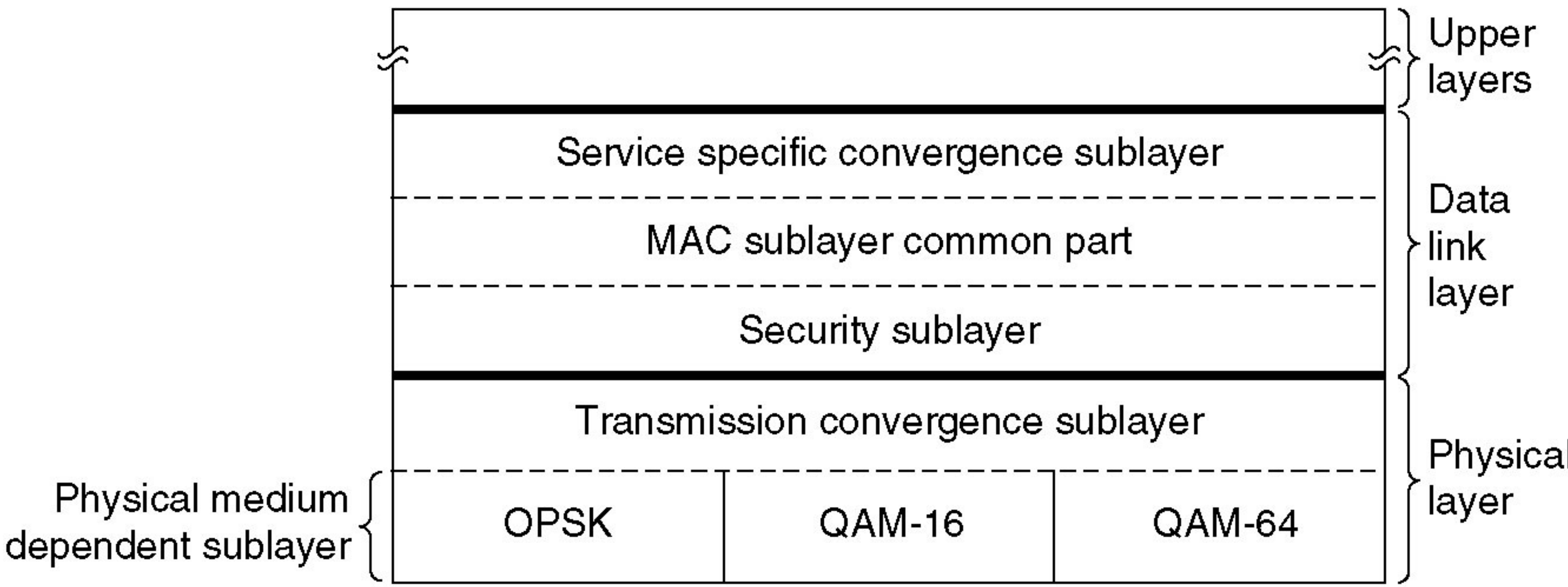
Intracell Services

- Authentication
- Deauthentication
- Privacy
- Data Delivery

Broadband Wireless

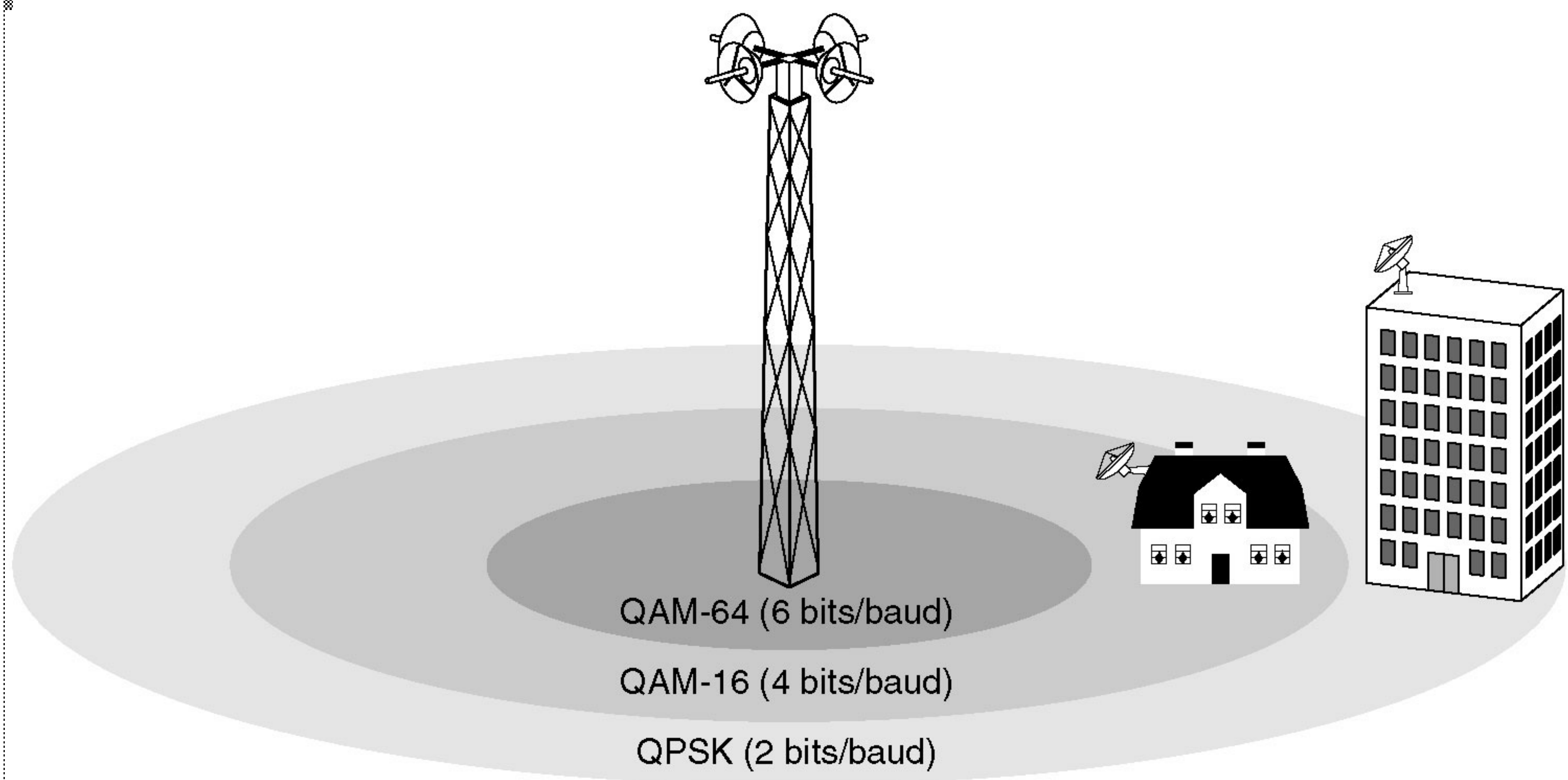
- Comparison of 802.11 and 802.16
- The 802.16 Protocol Stack
- The 802.16 Physical Layer
- The 802.16 MAC Sublayer Protocol
- The 802.16 Frame Structure

The 802.16 Protocol Stack

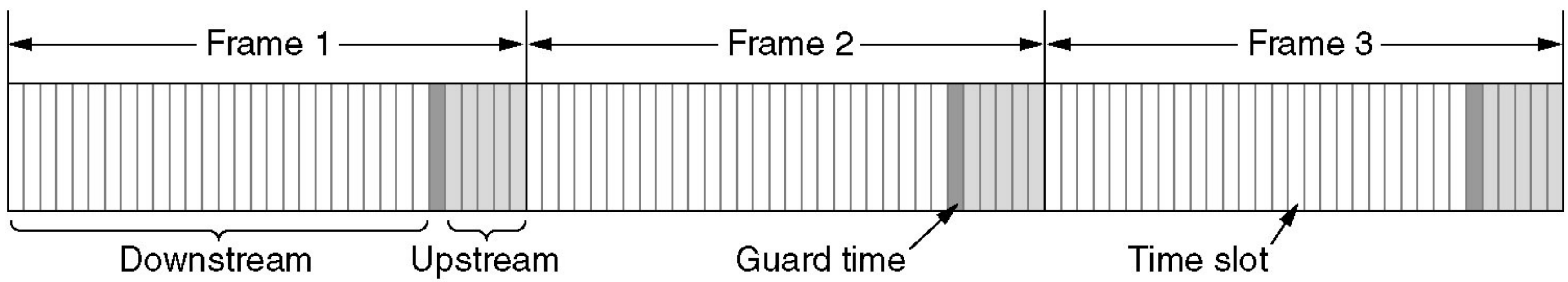


The 802.16 Protocol Stack.

The 802.16 Physical Layer



The 802.16 Physical Layer (2)



Frames and time slots for time division duplexing.

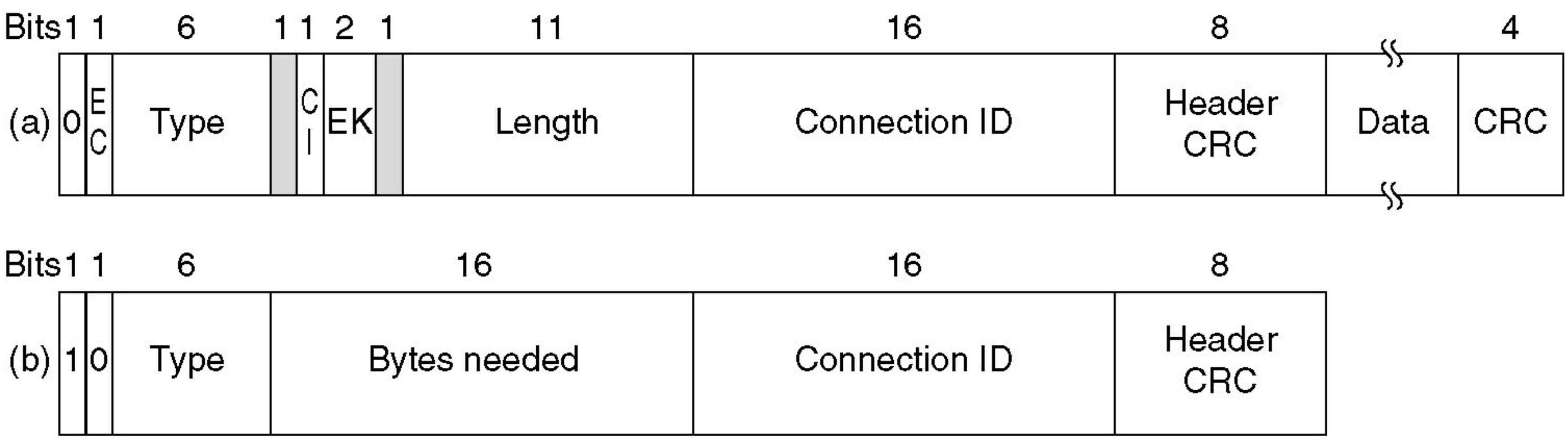
The 802.16 MAC Sublayer Protocol

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

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

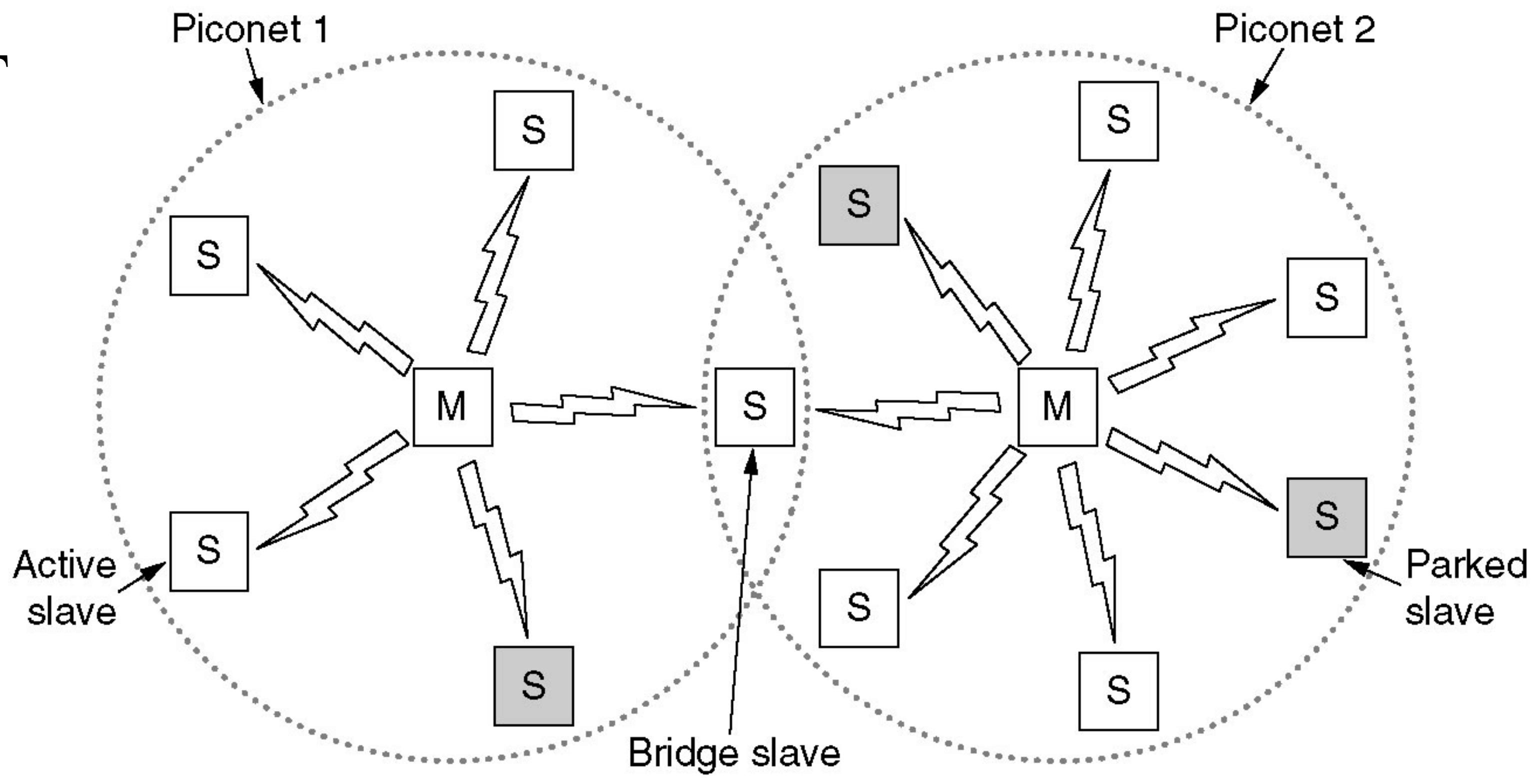


Bluetooth

- 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

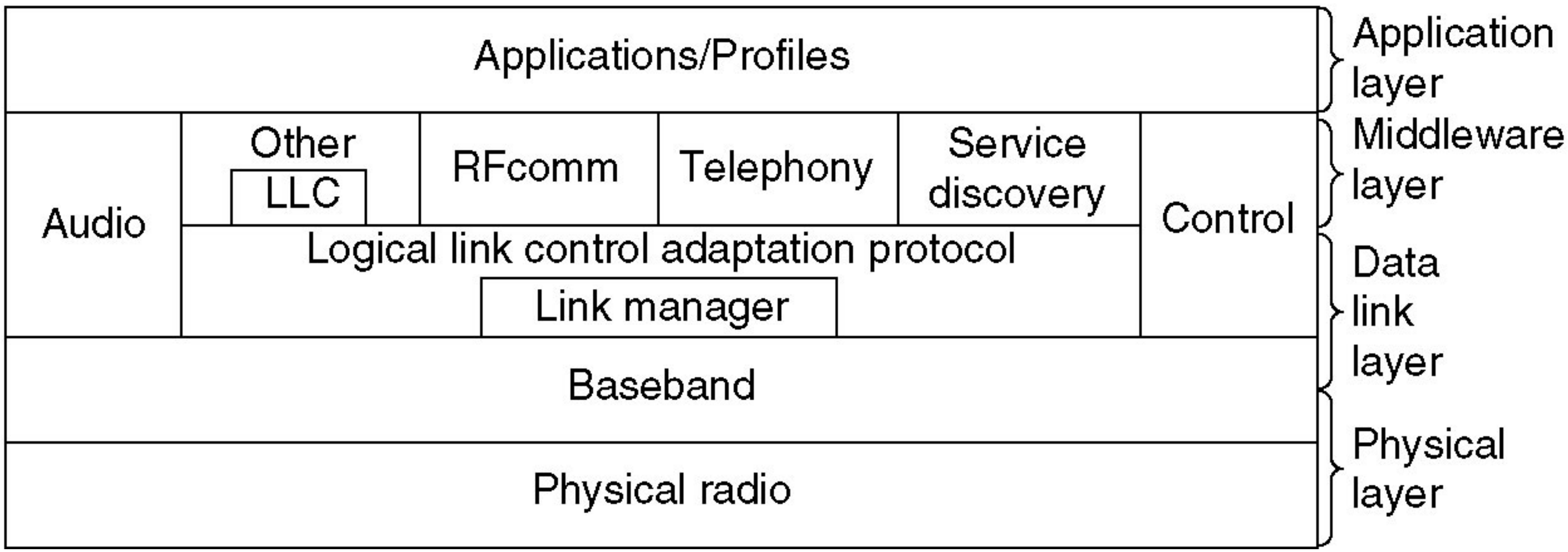
T



Bluetooth Applications

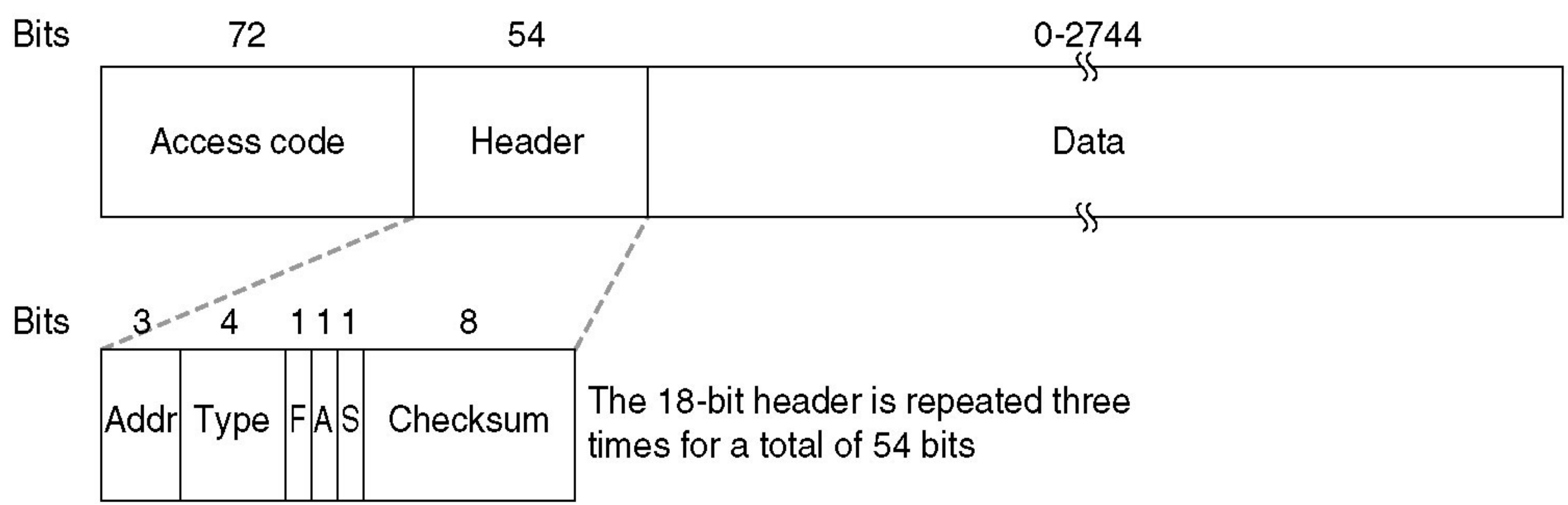
Name	Description
Generic access	Procedures for link management
Service discovery	Protocol for discovering offered services
Serial port	Replacement for a serial port cable
Generic object exchange	Defines client-server relationship for object movement
LAN access	Protocol between a mobile computer and a 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 Protocol Stack



The 802.15 version of the Bluetooth protocol architecture.

The Bluetooth Frame Structure



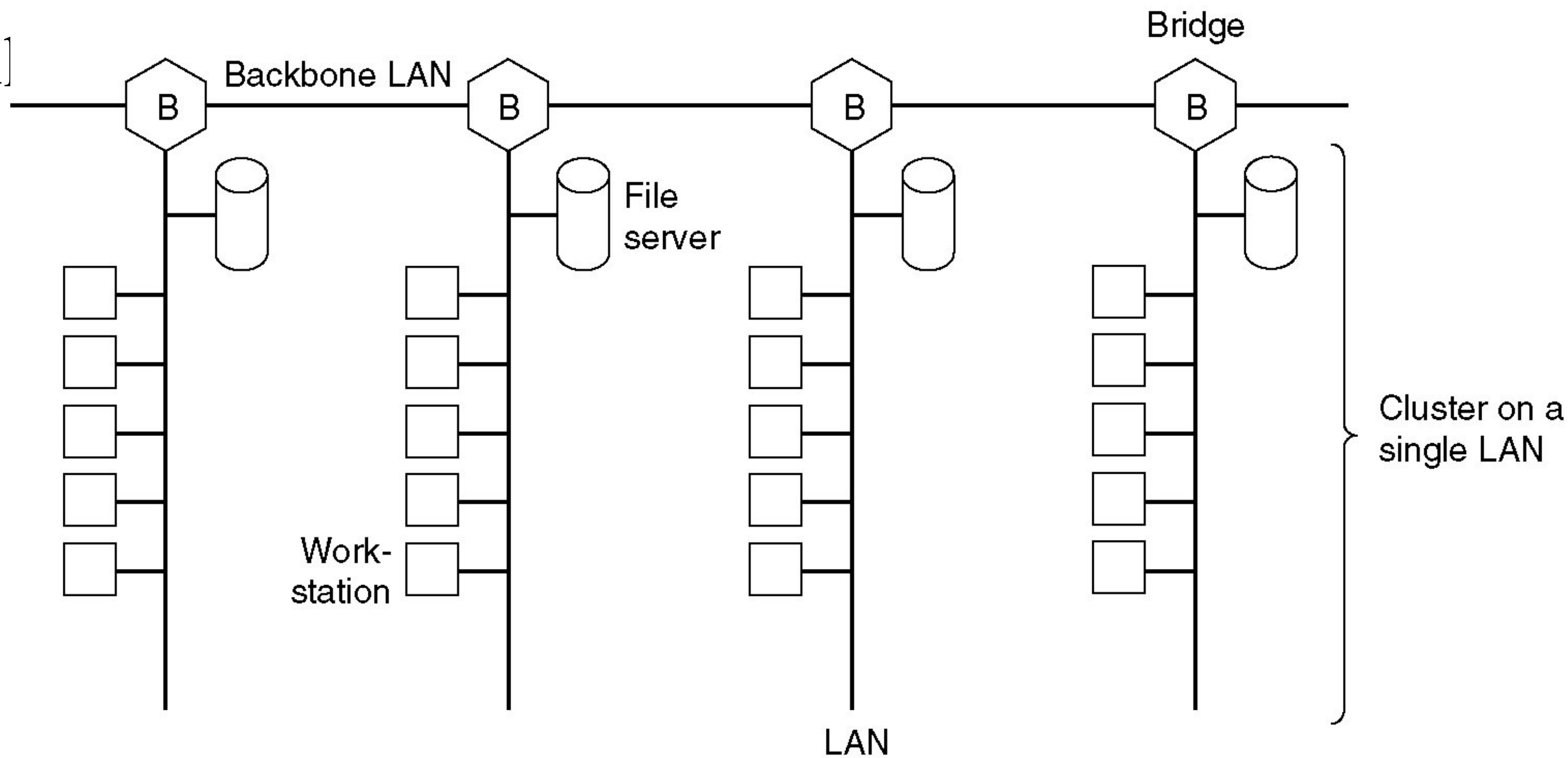
A typical Bluetooth data frame.

Data Link Layer Switching

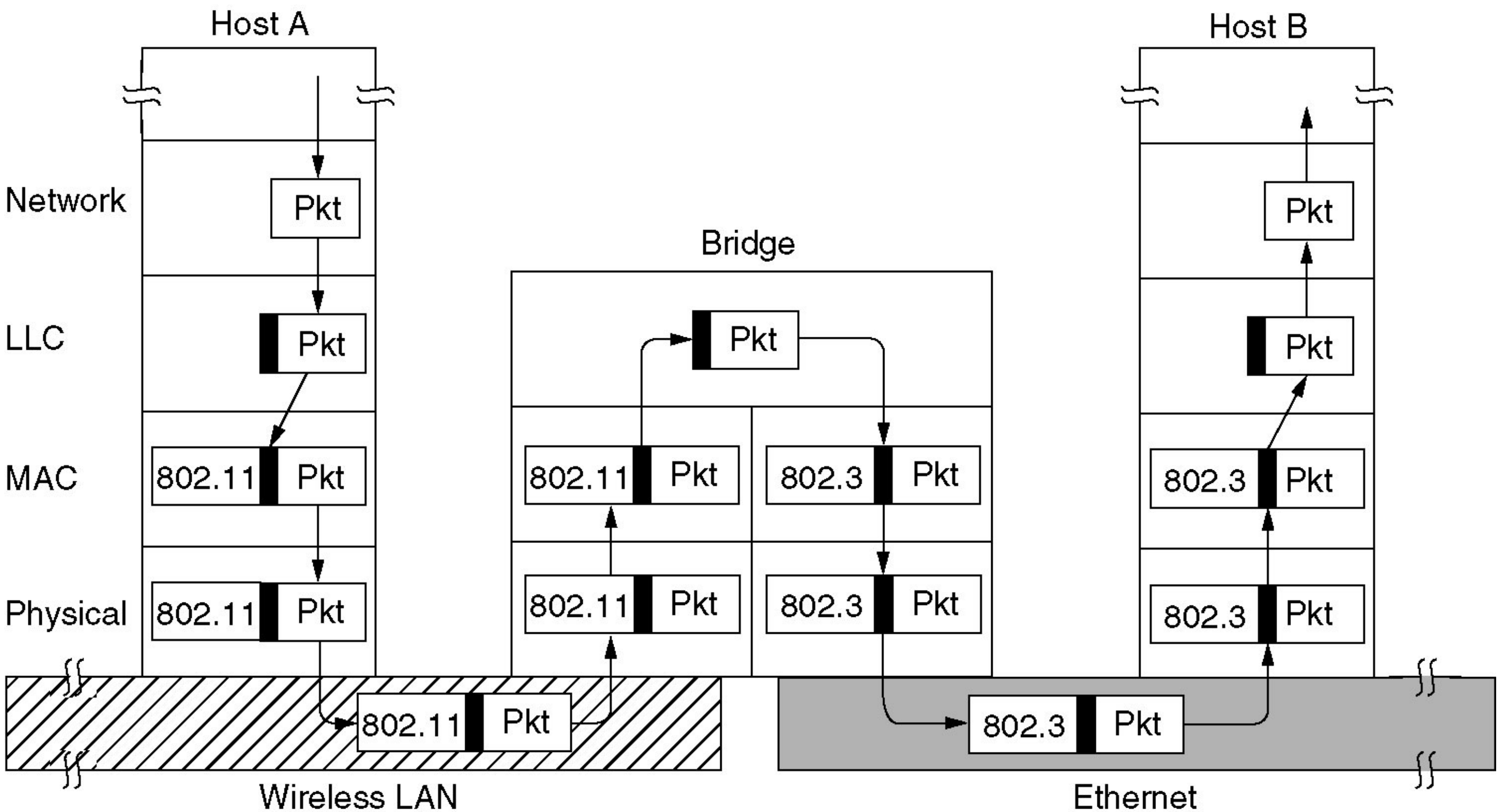
- Bridges from 802.x to 802.y
- Local Internetworking
- Spanning Tree Bridges
- Remote Bridges
- Repeaters, Hubs, Bridges, Switches, Routers, Gateways
- Virtual LANs

Data Link Layer Switching

Mu 1

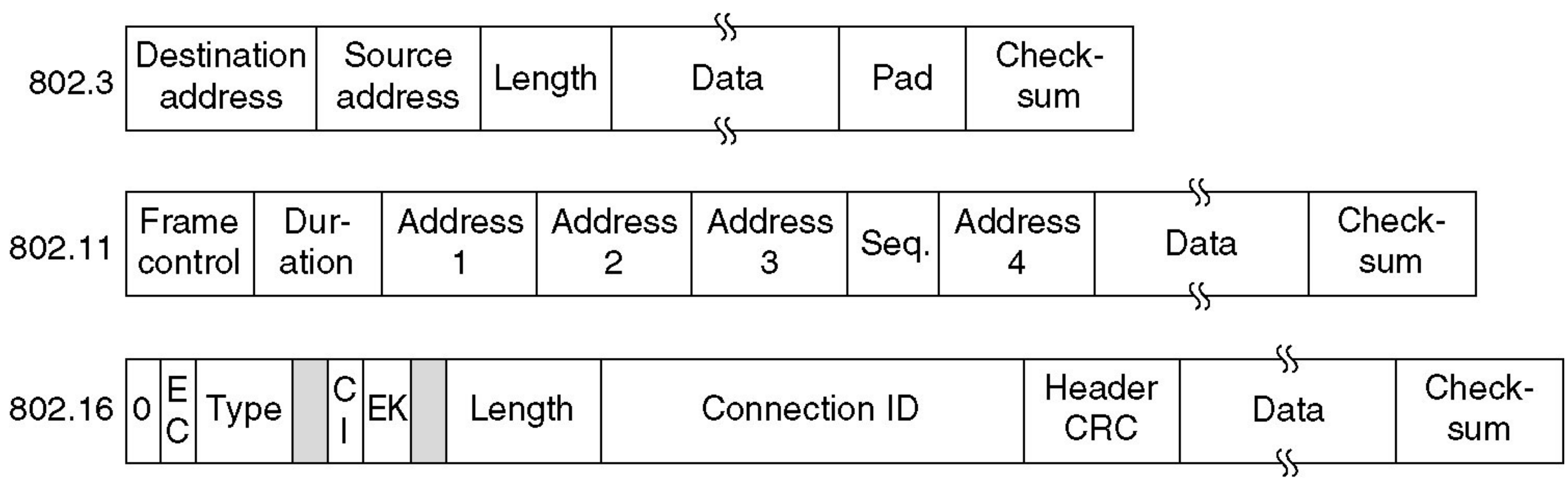


Bridges from 802.x to 802.y



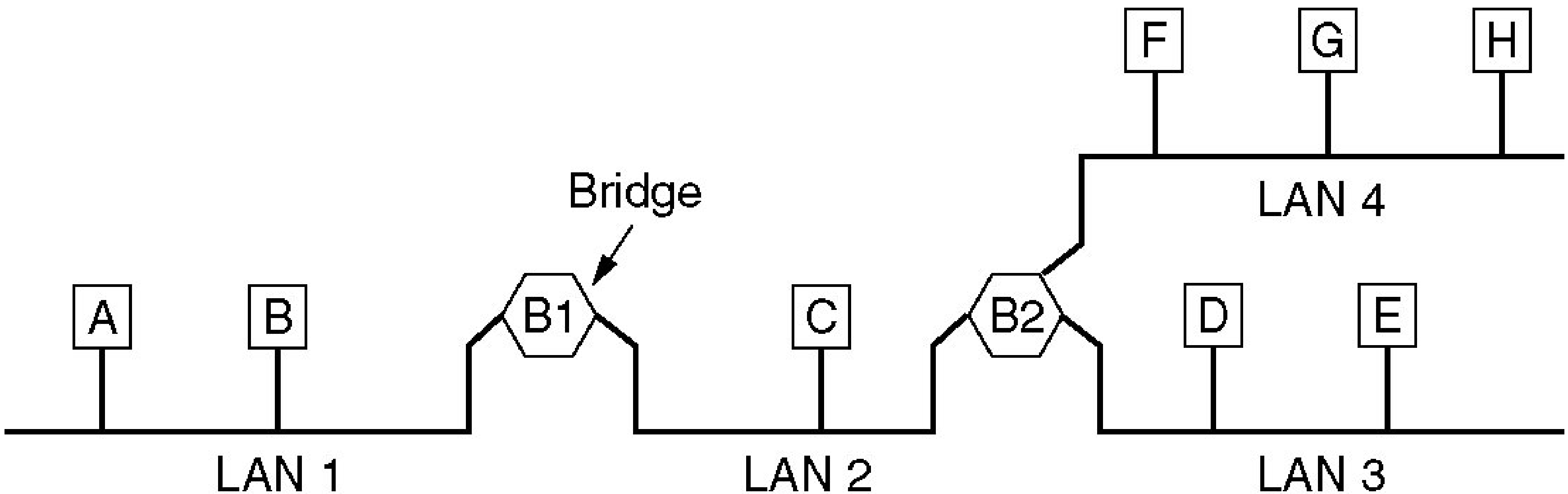
Operation of a LAN bridge from 802.11 to 802.3.

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



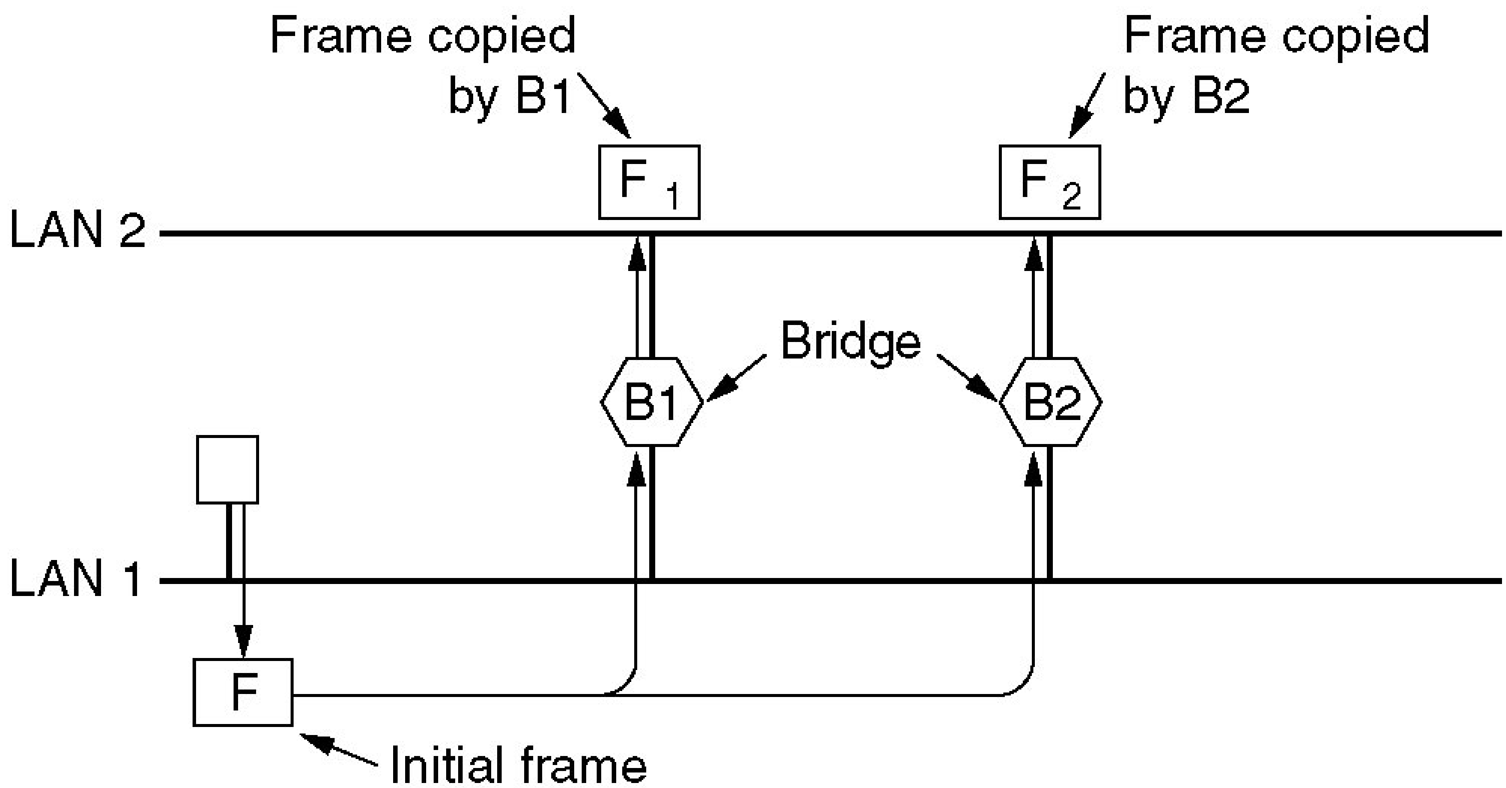
The IEEE 802 frame formats. The drawing is not to scale.

Local Internetworking



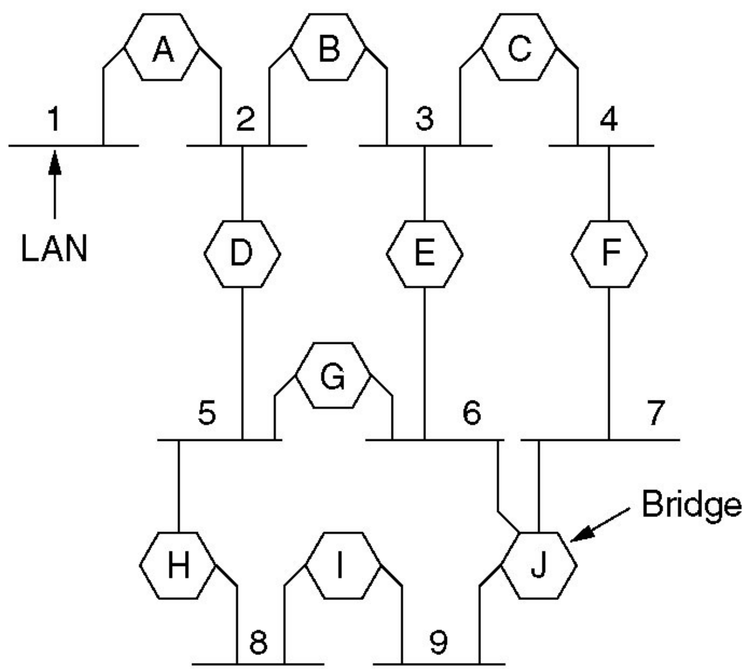
A configuration with four LANs and two bridges.

Spanning Tree Bridges

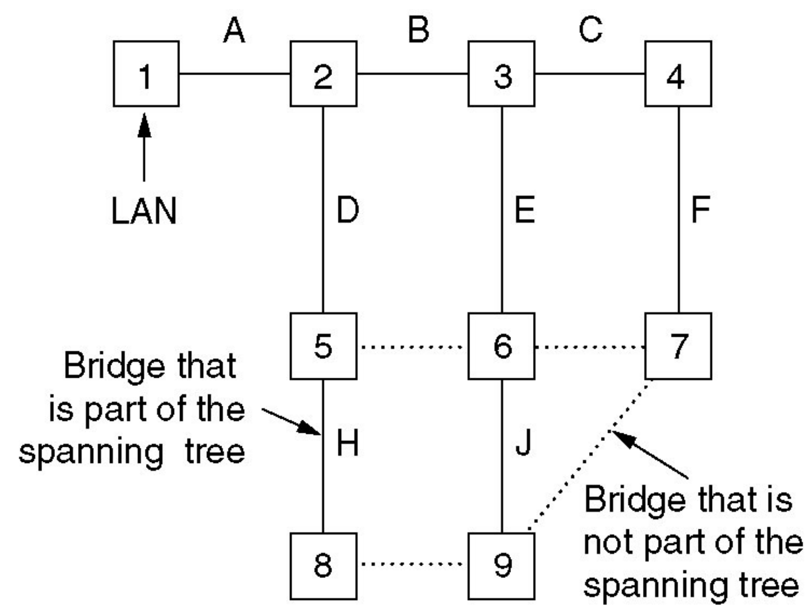


Two parallel transparent bridges.

Spanning Tree Bridges (2)



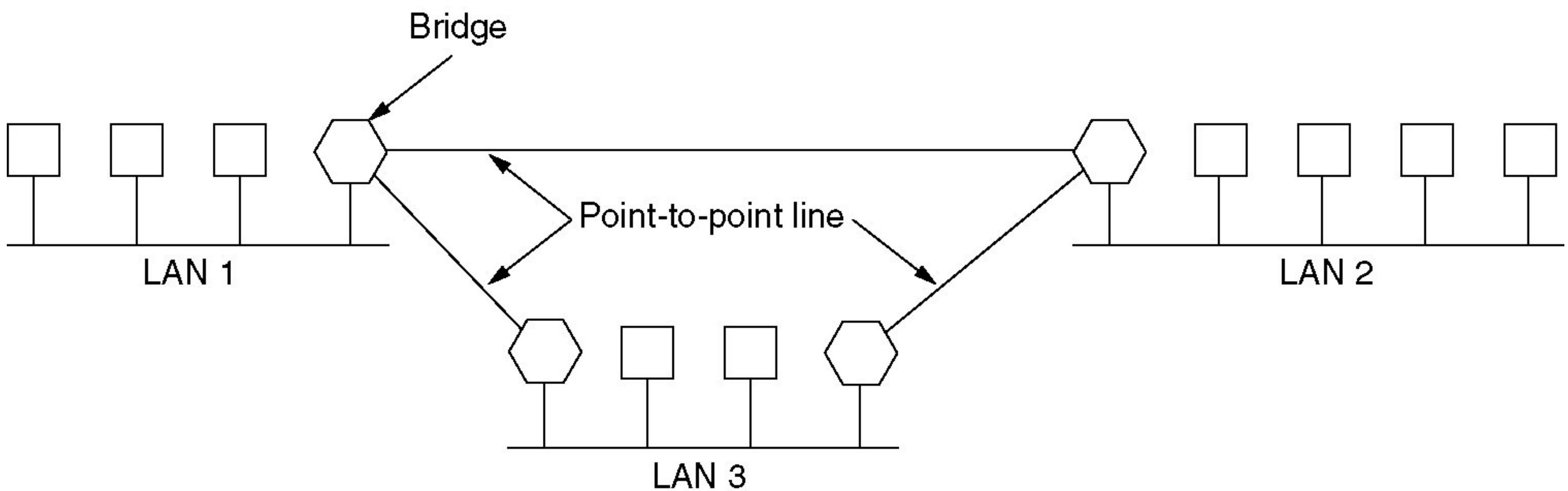
(a)



(b)

(a) Interconnected LANs. (b) A spanning tree covering the LANs. The dotted lines are not part of the spanning tree.

Remote Bridges



Remote bridges can be used to interconnect distant LANs.

Repeaters, Hubs, Bridges, Switches, Routers and Gateways

Application layer	Application gateway
Transport layer	Transport gateway
Network layer	Router
Data link layer	Bridge, switch
Physical layer	Repeater, hub

(a)

Packet (supplied by network layer)

Frame header	Packet header	TCP header	User data	CRC

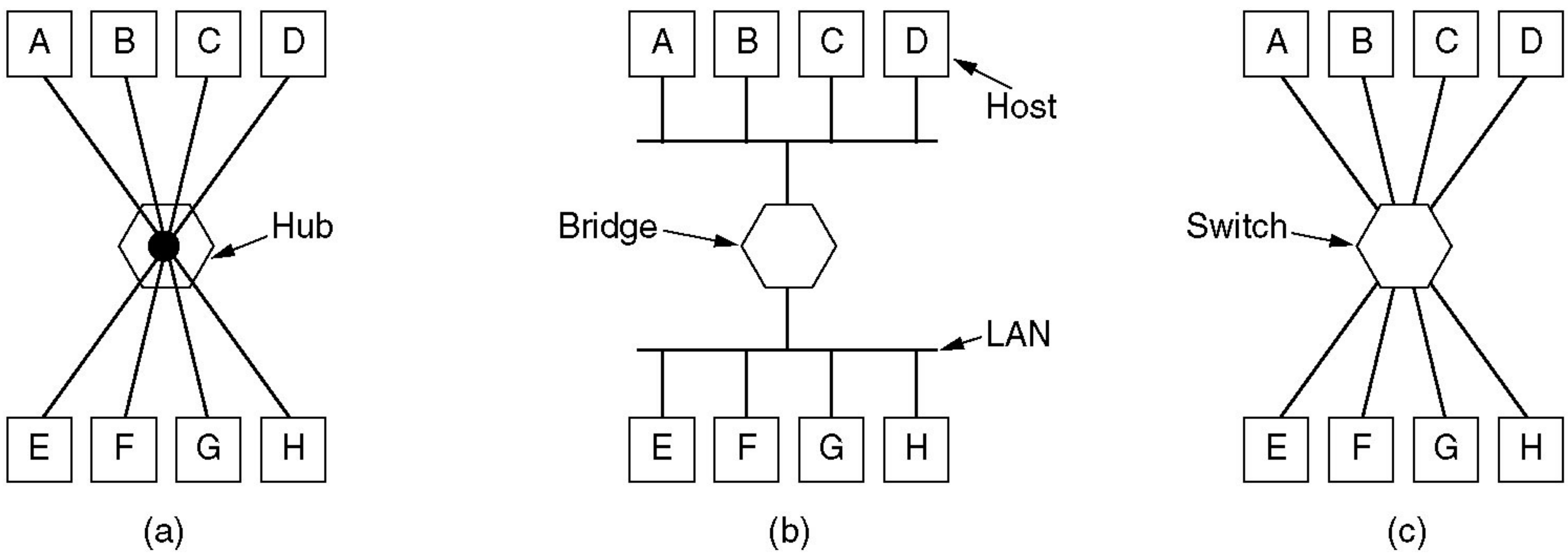
Frame (built by data link layer)

(b)

(a) Which device is in which layer.

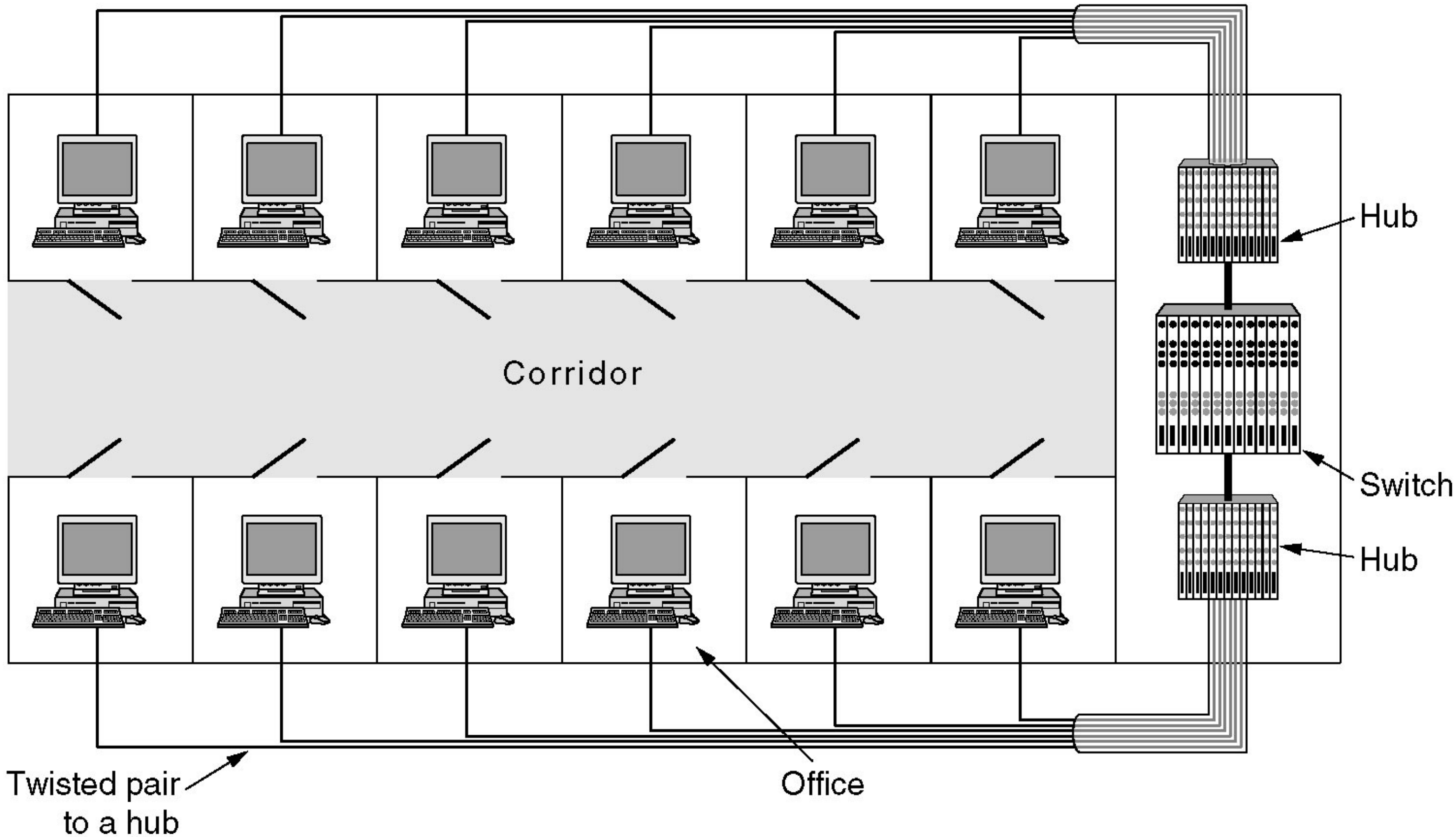
(b) Frames, packets, and headers.

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



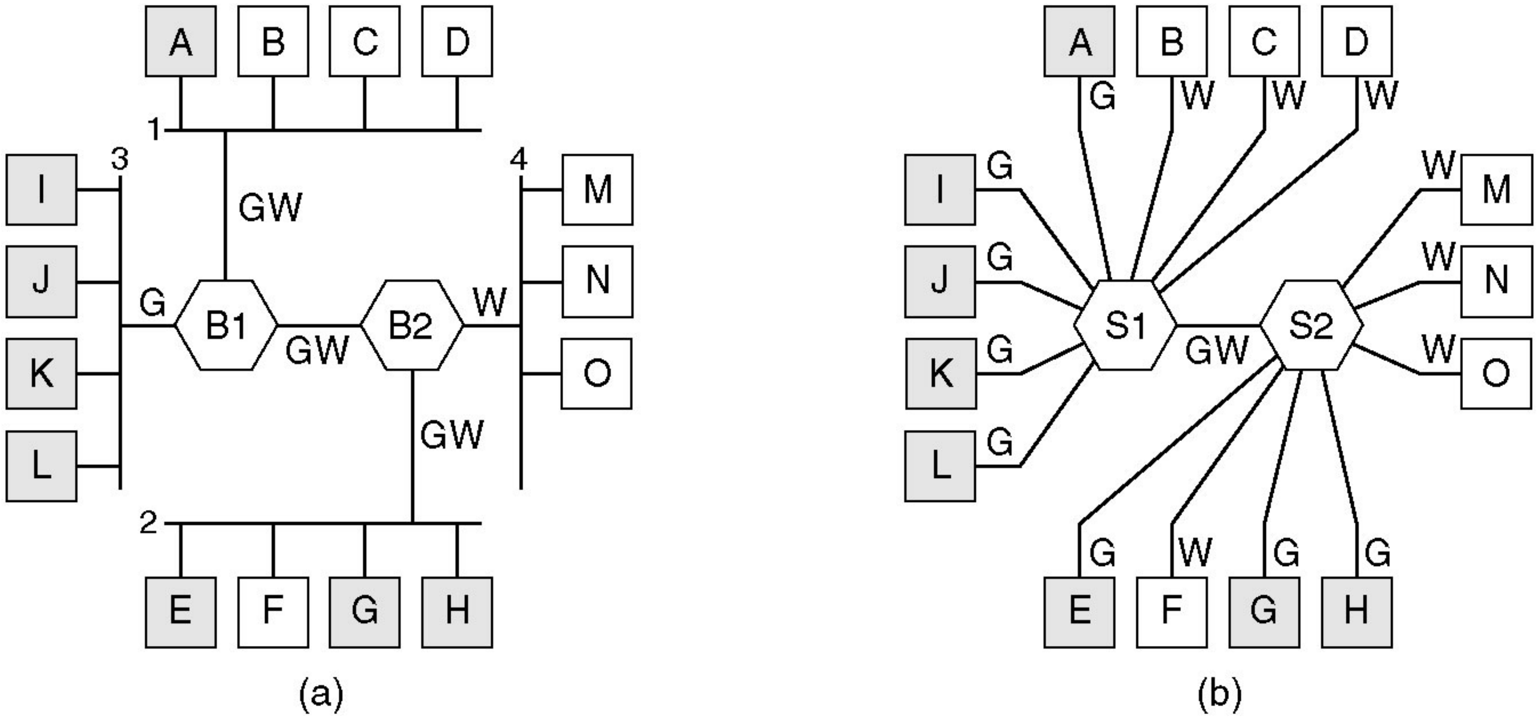
(a) A hub. (b) A bridge. (c) a switch.

Virtual LANs



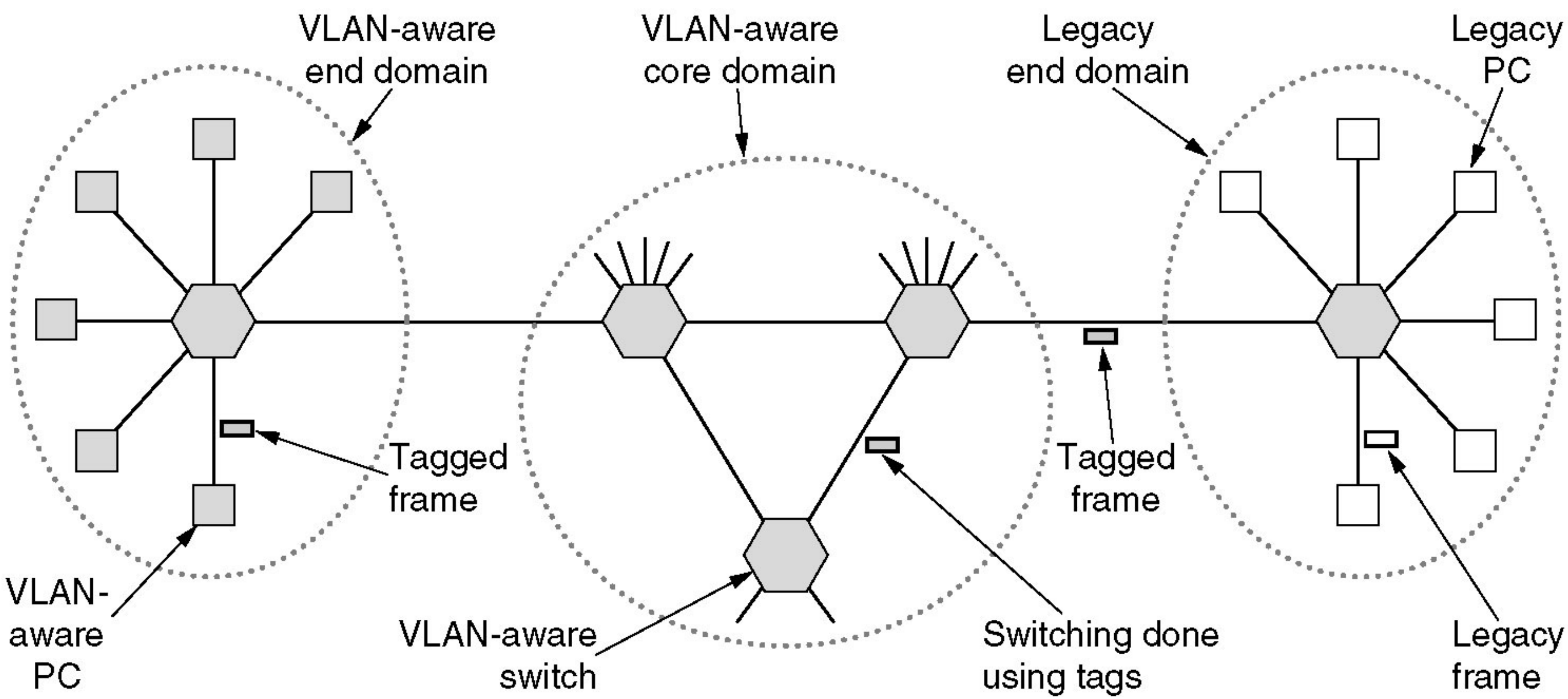
A building with centralized wiring using hubs and a switch.

Virtual LANs (2)



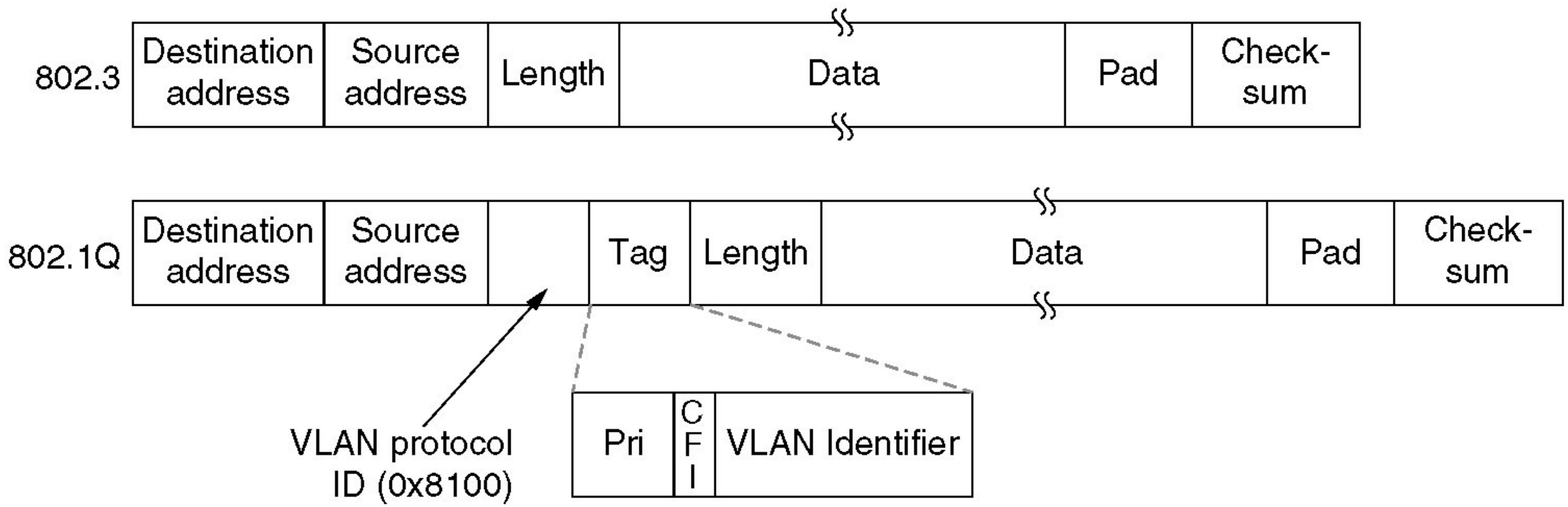
(a) Four physical LANs organized into two VLANs, gray and white, by two bridges. (b) The same 15 machines organized into two VLANs by switches.

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.

802.2 Logical Link Control

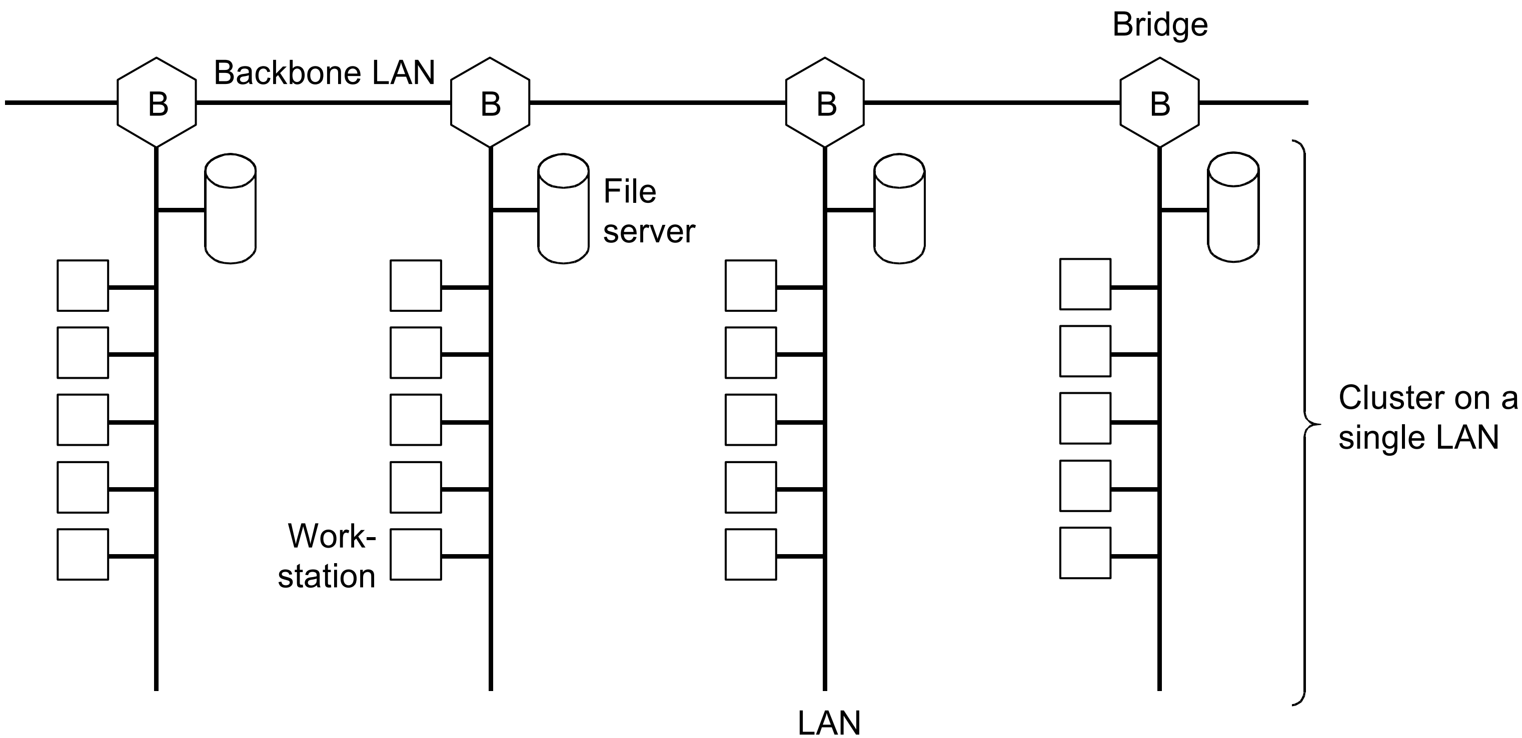
LLC
MAC

LLC	Packet

MAC	LLC	Packet	MAC

- Network layer sends packet using LLC primitives
- LLC adds its header containing sequence and acknowledgement numbers and passes it to MAC
- LLC Service Options
  - unreliable datagram service
  - acknowledged datagram service
  - reliable connection oriented service

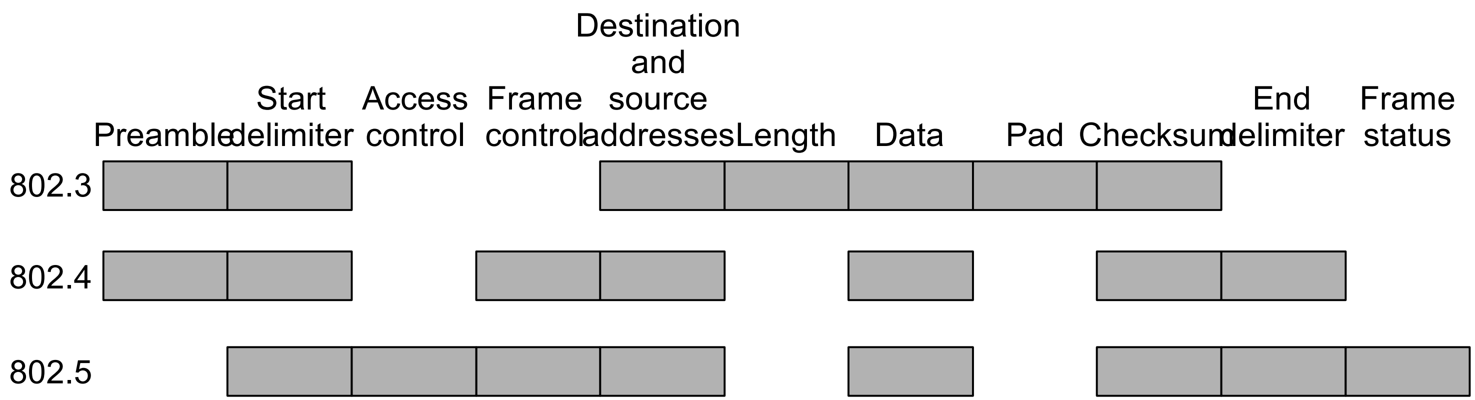
Bridges


Bridge
Backbone LAN
B
B
B
B
File
server
Work-
station
LAN
Cluster on a
single LAN

Bridges

- Used to connect multiple LANS
- Data Link Layer operation
  - Do not examine network layer headers
- Only forward frames if necessary
  - Security / Firewalls
- Format matching

Bridges



Spring 2003

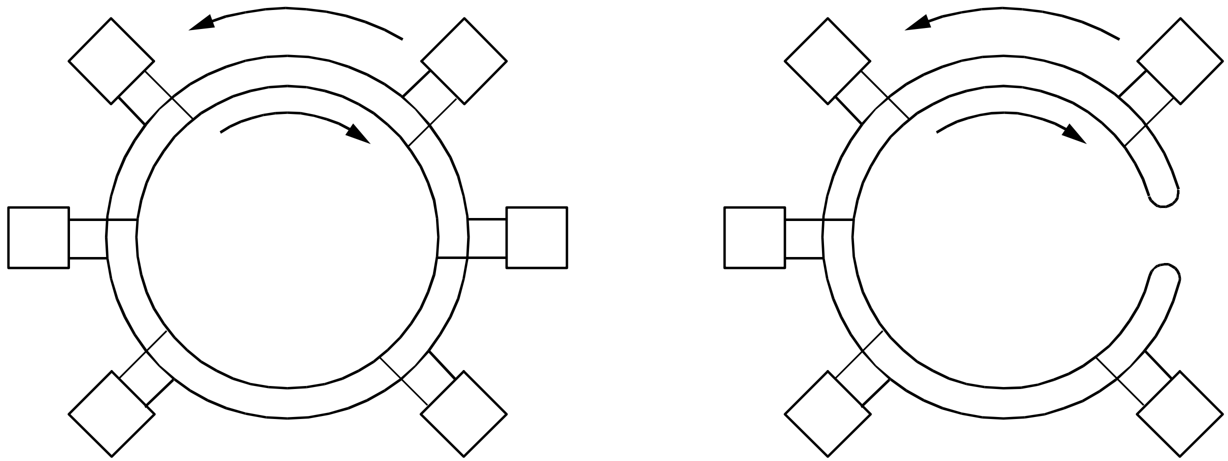
High Speed LANS

- FDDI - Fiber Distributed Data Interface
- Fast Ethernet
- HIPPI - High Performance Parallel Interface
- Fiber Channel

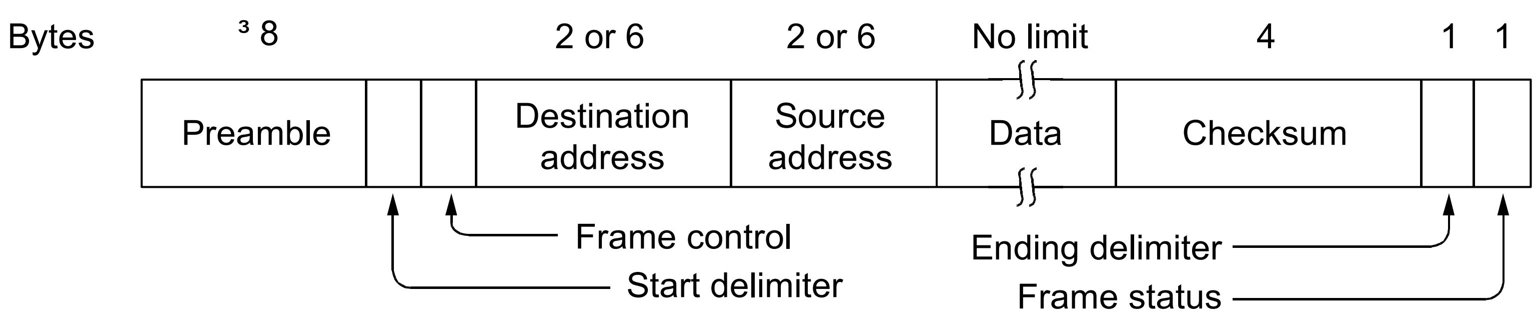
Fiber Distributed Data Interface

- FDDI is the most popular token-ring base LAN
- Dual counterrotating rings, each at 100 Mbps
- Uses both copper and fiber links
- Supports both non-realtime and realtime traffic
  - token is guaranteed to rotate once every Target Token Rotation Time (TTRT)
  - station is guaranteed a synchronous allocation within every TTRT
- Supports both single attached and dual attached stations
  - single attached (cheaper) stations are connected to only one of the rings

FDDI

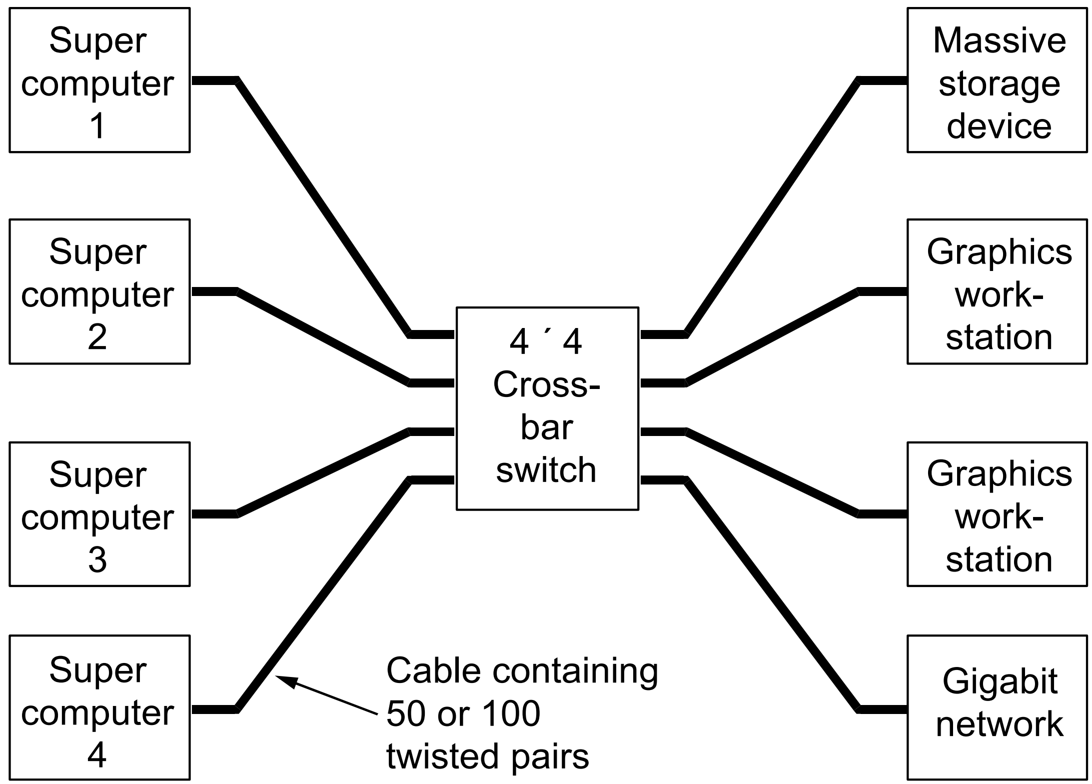


(a) (b)



Bytes
³ 8
2 or 6
2 or 6
No limit
4
1 1
Preamble
Destination address
Source address
Data
Checksum
Frame control
Start delimiter
Ending delimiter
Frame status

HIPPI



Spring 2003

Fiber Channel

- Fiber based
- Handles
  - data channels
    - HIPPI, IBM, SCSI
  - Network
    - 802, IP, ATM
- Basic Structure is a crossbar switch
  - Connections established for one packet, or longer
- Services
  - Circuit switching
  - Packet switching
    - With guaranteed delivery
    - Without guaranteed delivery

Fiber Channel