Data and Computer Communications

CHAPTER 11

Local Area Network Overview

Bus Topology

- Topology
  - Refers to the way in which the endpoints, or stations, attached to the network are interconnected
- Bus topology
  - All stations attach, through a tap, directly to a linear transmission medium, or bus
  - Full-duplex operation between the station and the tap allows data to be transmitted onto the bus and received from the bus
  - A transmission from any station propagates the length of the medium in both directions and can be received by all other stations
  - At each end of the bus is a terminator, which absorbs any signal, removing it from the bus

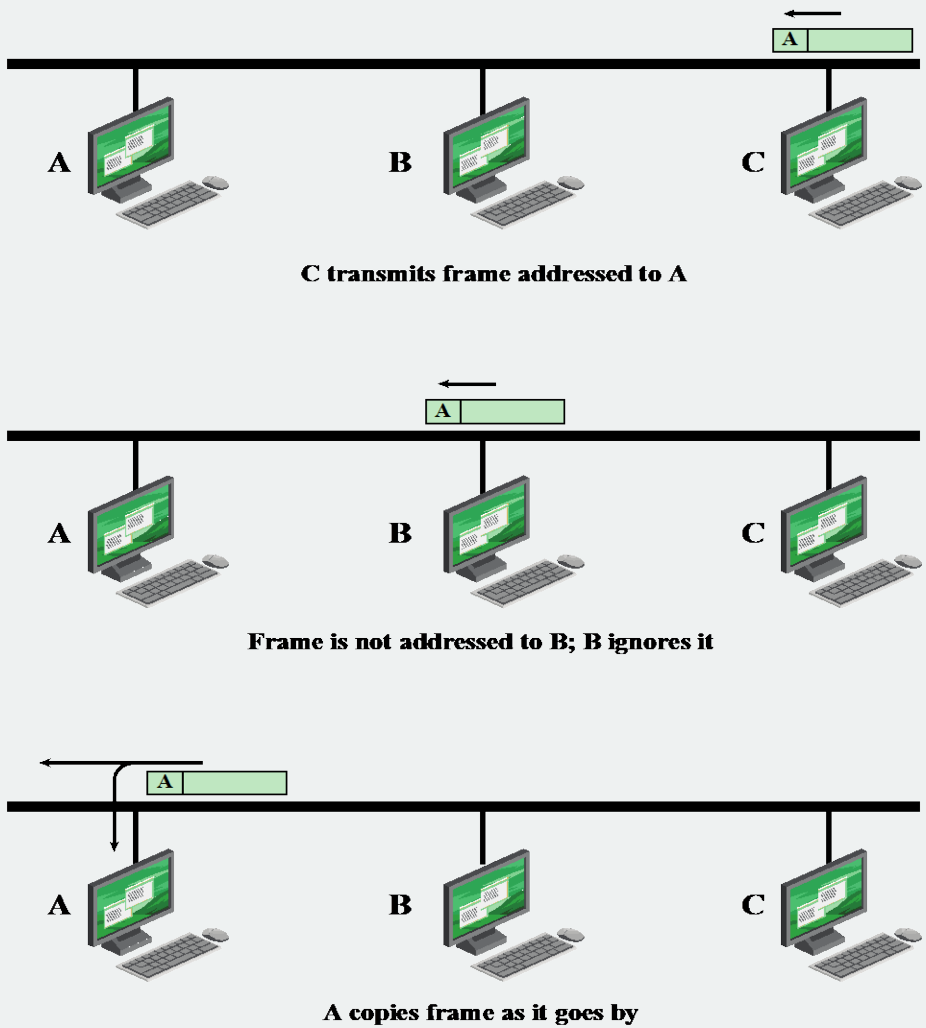


Figure 11.1 Frame Transmission on a Bus LAN

Star Topology

- Each station connects to common central node
  - Usually via two point-to-point links
    - One for transmission and one for reception

Central node

- Operate in broadcast fashion
- Physical star, logical bus
- Only one station can transmit at a time (hub)
- Can act as frame switch

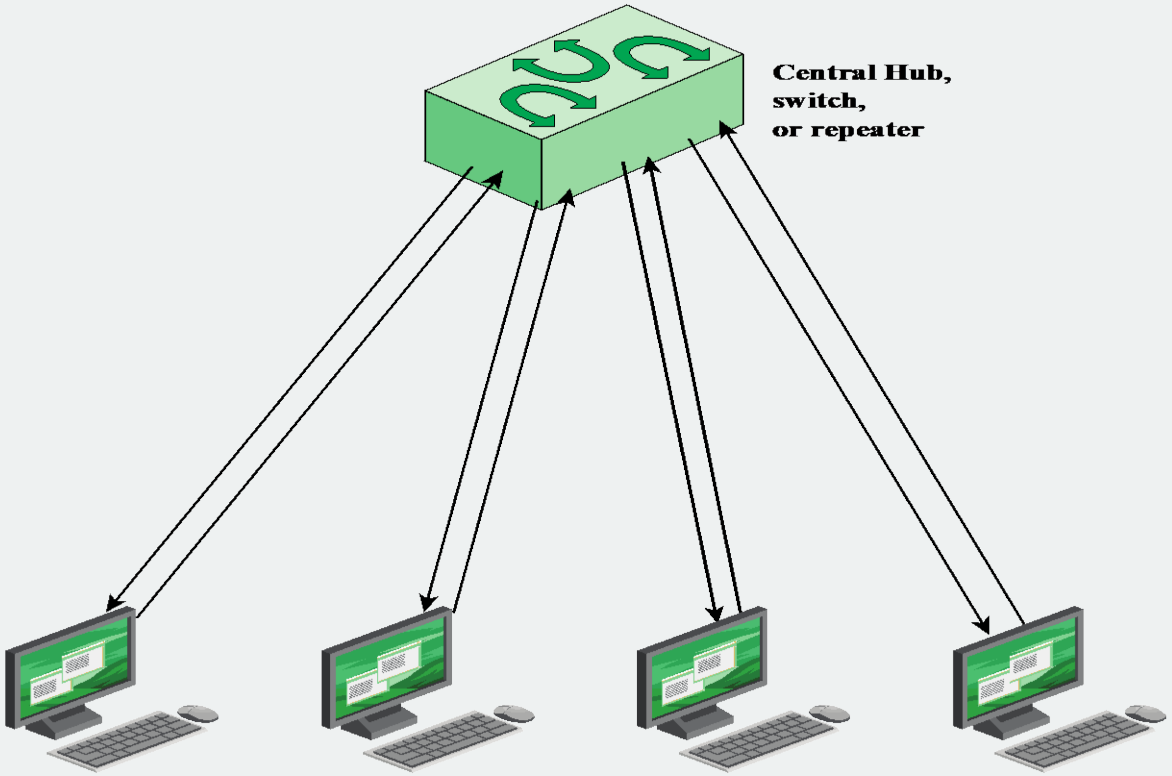


Figure 11.2 Star Topology

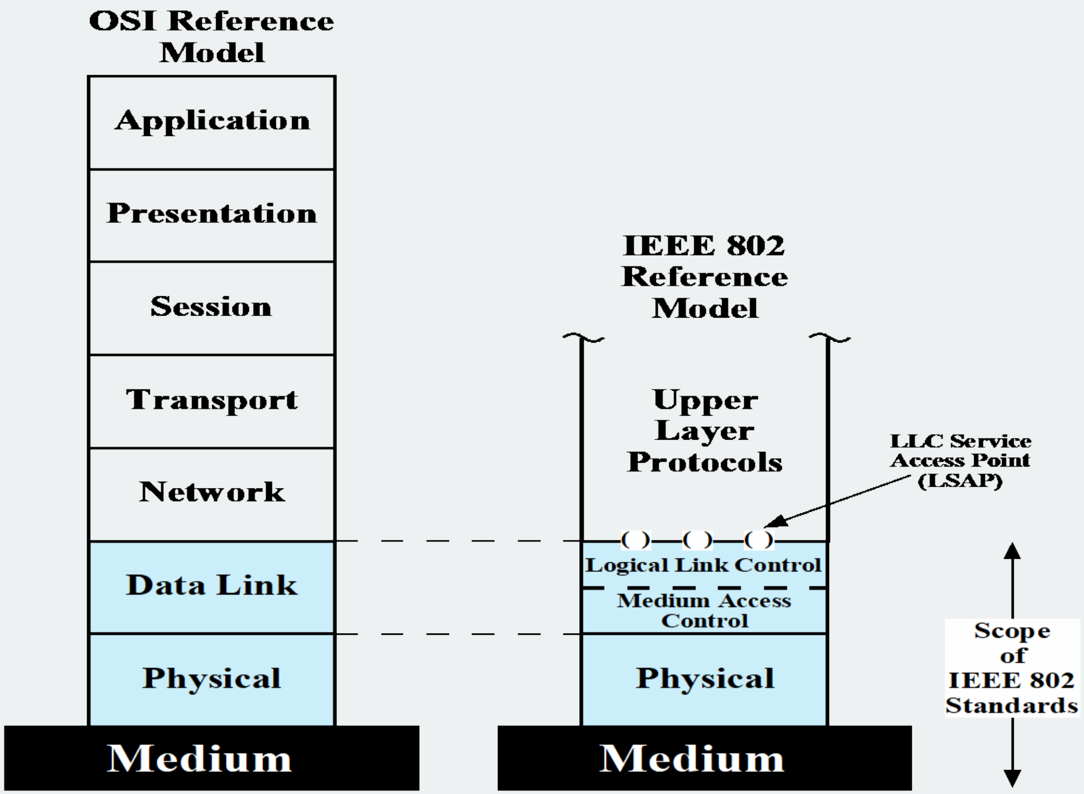


Figure 11.3 IEEE 802 Protocol Layers Compared to OSI Model

IEEE 802 Reference Model

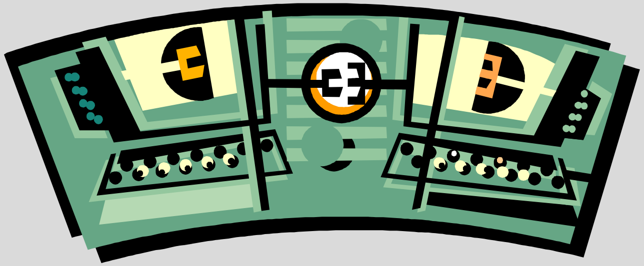
- Lowest layer corresponds to the physical layer of the OSI model
- Includes a specification of the transmission medium and the topology

Includes functions such as:

- Encoding/decoding of signals
- Preamble generation/removal
- Bit transmission/reception

IEEE 802 Layers

- **Logical Link Control Layer (LLC)**
  - Provide interface to higher levels
  - Perform flow and error control



- **Media Access Control (MAC)**
  - On transmit assemble data into frame
  - On reception disassemble frame, perform address recognition and error detection
  - Govern access to LAN transmission medium

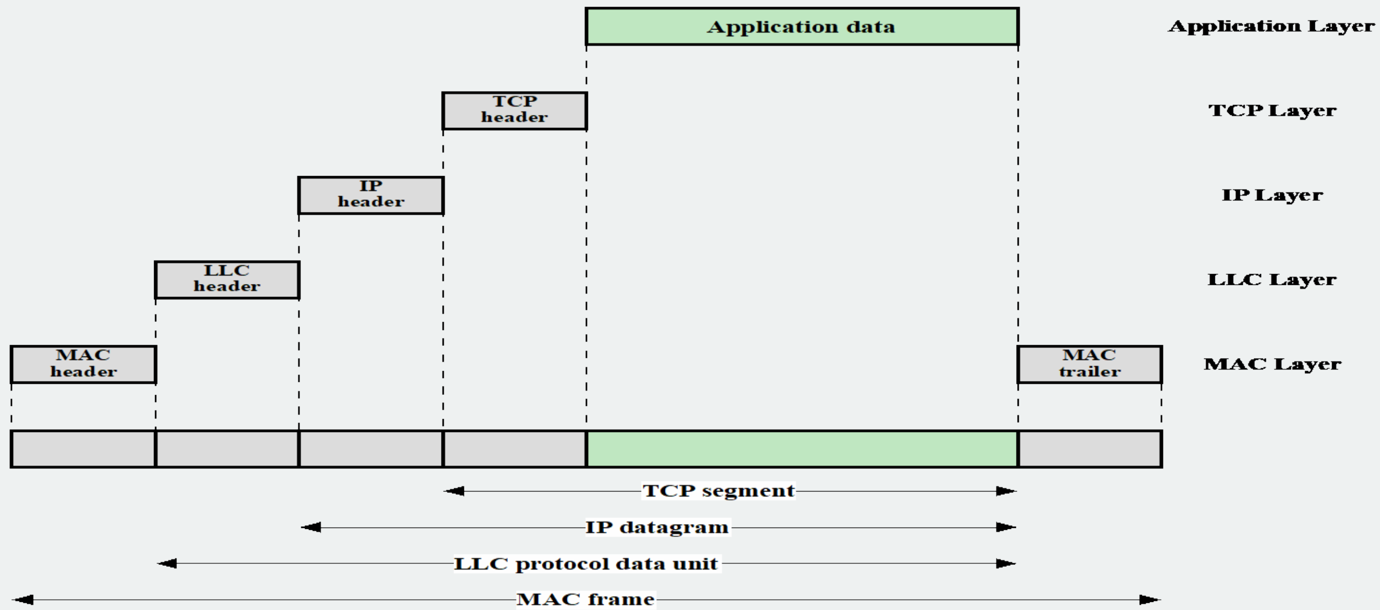


Figure 11.4 LAN Protocols in Context

Logical Link Control

- Transmission of link level PDUs between stations
- Must support multi-access, shared medium
- Relieved of some details of link access by the MAC layer
- Addressing involves specifying source and destination LLC users
    - Referred to as service access points (SAPs)

LLC Services

Unacknowledged connectionless service

- Data-gram style service
- Delivery of data is not guaranteed

Connection-mode service

- Logical connection is set up between two users
- Flow and error control are provided

Acknowledged connectionless service

- Datagrams are to be acknowledged, but no logical connection is set up

LLC Service Alternatives

Unacknowledged connectionless service

- Requires minimum logic
- Avoids duplication of mechanisms
- Preferred option in most cases

Connection-mode service

- Used in simple devices
- Provides flow control and reliability mechanisms

Acknowledged connectionless service

- Large communication channel needed
- Time critical or emergency control signals

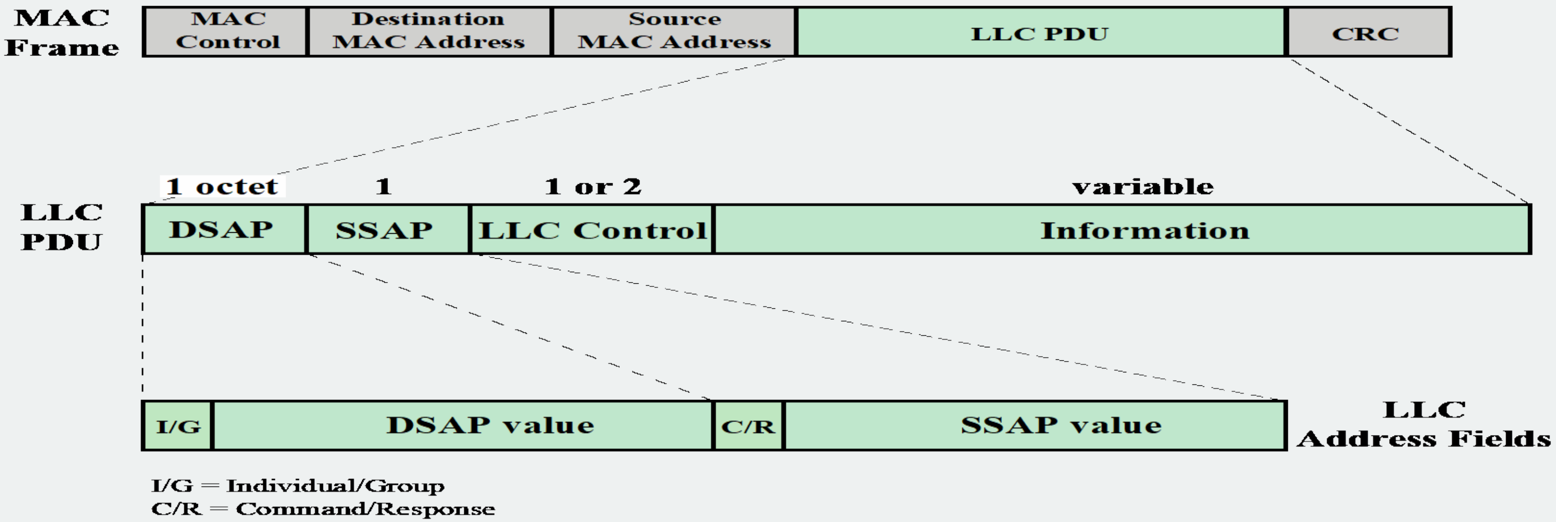


Figure 11.5 LLC PDU in a Generic MAC Frame Format

Medium Access Control (MAC) Protocol

- Controls access to the transmission medium
- Key parameters:
  - **Where**
    - Greater control, single point of failure
    - More complex, but more redundant
  - **How**
    - Synchronous
      - Capacity dedicated to connection, not optimal
    - Asynchronous
      - Response to demand
      - Round robin, reservation, contention

Asynchronous Systems

Round robin

- Each station given turn to transmit data

Reservation

- Divide medium into slots
- Good for stream traffic

Contention

- All stations contend for time
- Good for bursty traffic
- Simple to implement
- Tends to collapse under heavy load

MAC Frame Handling

- MAC layer receives data from LLC layer
- PDU is referred to as a MAC frame
- MAC layer detects errors and discards frames
- LLC optionally retransmits unsuccessful frames

Bridges

- Connects similar LANs with identical physical and link layer protocols
- Minimal processing
- Can map between MAC formats
- Reasons for use:
  - Reliability
  - Performance
  - Security
  - Geography

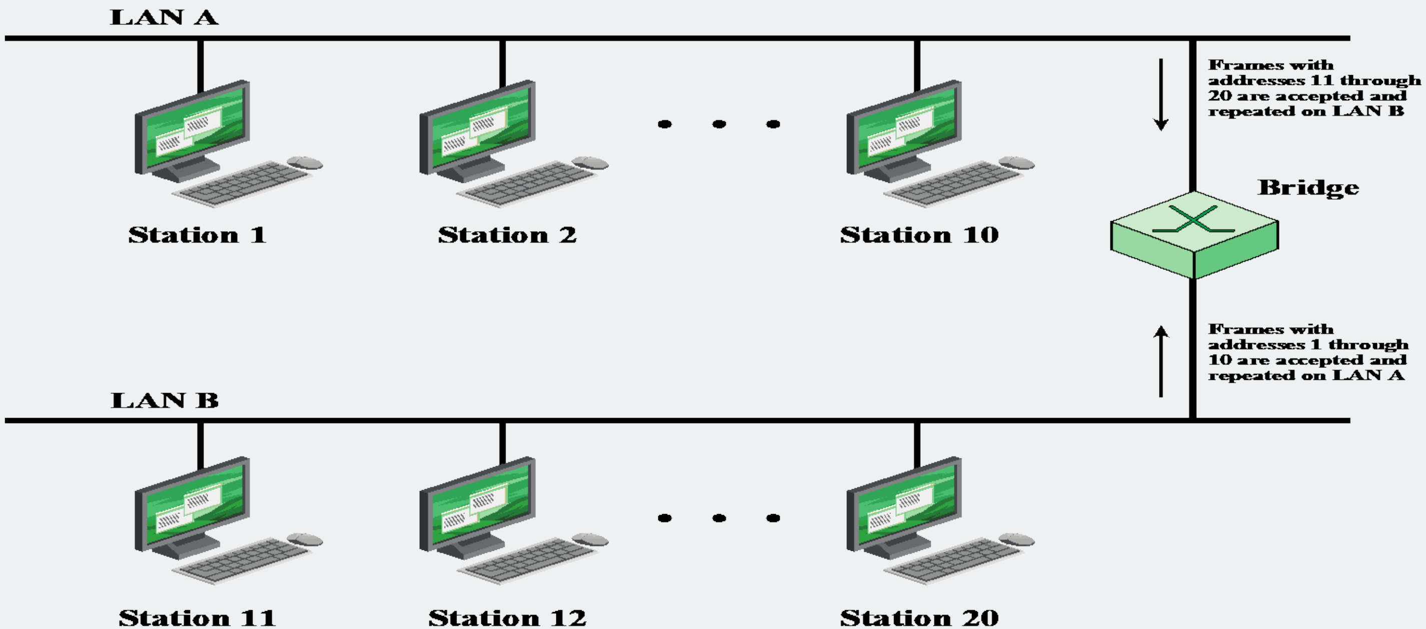


Figure 11.6 Bridge Operation

Bridge Design Aspects

- Makes no modification to the content or format of the frames it receives
- Should contain enough buffer space to meet peak demands
- Must contain routing and addressing intelligence
- May connect more than two LANs
- Bridging is transparent to stations

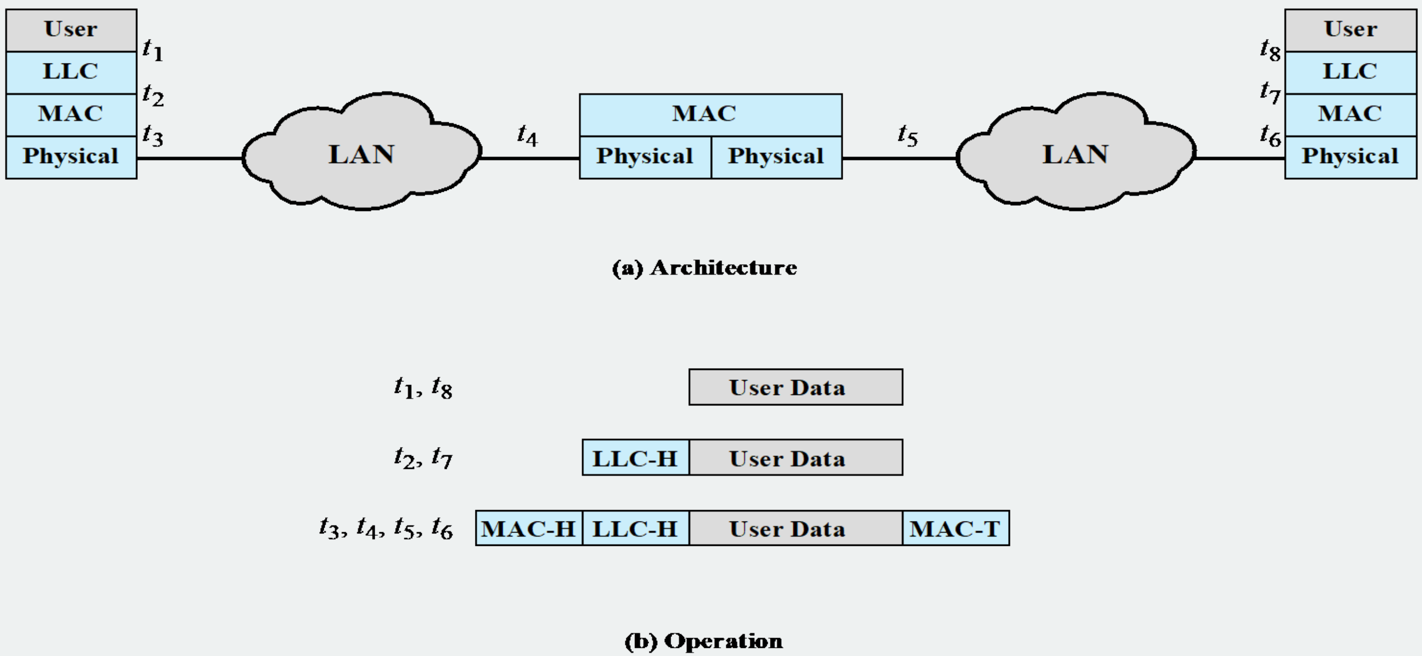


Figure 11.7 Connection of Two LANs by a Bridge

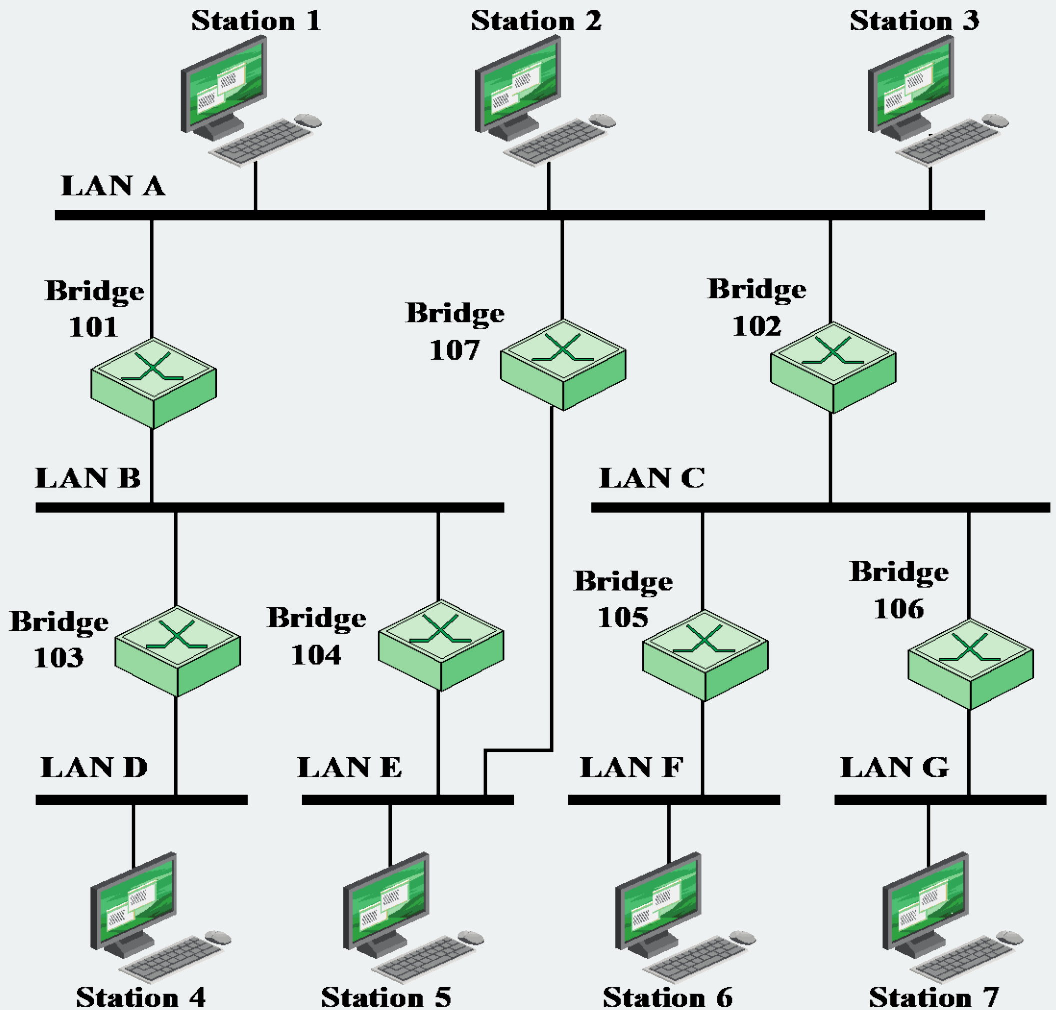
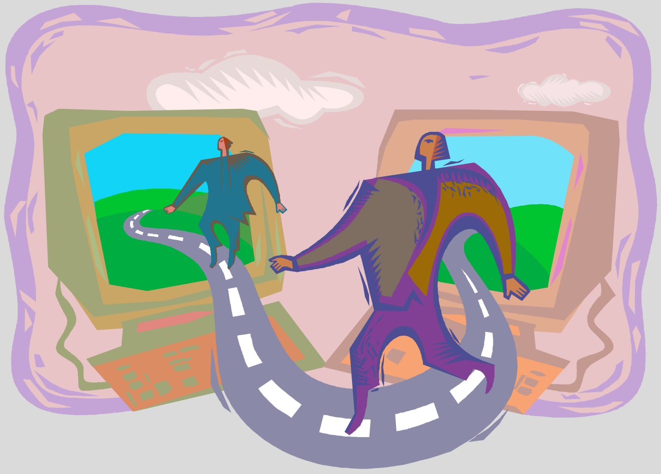


Figure 11.8 Configuration of Bridges and LANs, with Alternate Routes

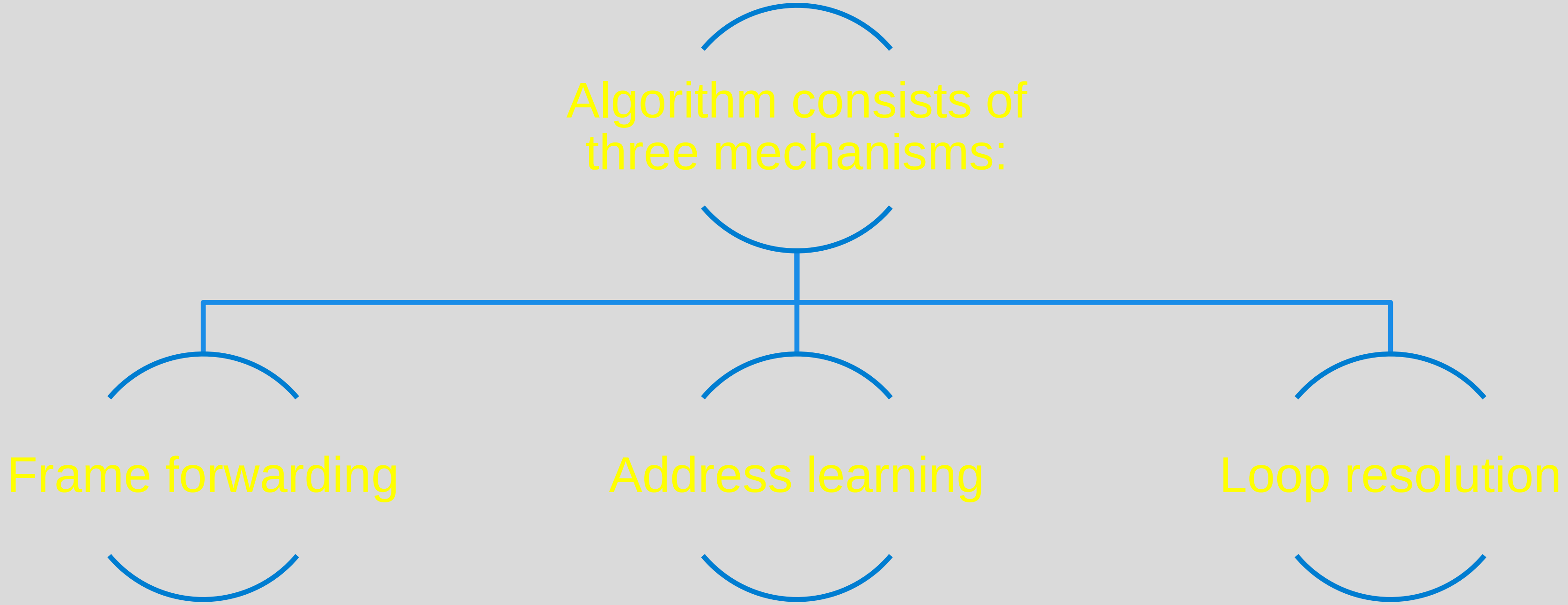
Fixed Routing

- Simplest and most common strategy
- Suitable for small internets and internets that are relatively stable
- Afixed route is selected for each pair of LANs
  - Usually least hop route
- Only change when topology changes
- Widely used but limited flexibility



Spanning Tree

- Bridge automatically develops routing table
- Automatically updates routing table in response to changing topology



Frame Forwarding

- Maintain forwarding database for each port attached to a LAN
- For a frame arriving on port X:

Search forwarding database to see if MAC address is listed for any port except port X

↓

If destination MAC address is not found, forward frame out all ports except the one from which it was received

↓

If the destination address is in the forwarding database for some port y, check port y for blocking or forwarding state

↓

If port y is not blocked, transmit frame through port y onto the LAN to which that port attaches

Address Learning

- Can preload forwarding database
- When frame arrives at port X, it has come from the LAN attached to port X
- Use source address to update forwarding database for port X to include that address
- Have a timer on each entry in database
- If timer expires, entry is removed
- Each time frame arrives, source address checked against forwarding database
  - If present, timer is reset and direction recorded
  - If not present, entry is created and timer set

Spanning Tree Algorithm

- Address learning works for tree layout if there are no alternate routes in the network
  - Alternate route means there is a closed loop
- For any connected graph there is a spanning tree maintaining connectivity with no closed loops
- Algorithm must be dynamic

IEEE 802.1 Spanning Tree Algorithm:

- Each bridge assigned unique identifier
- Cost assigned to each bridge port
- Exchange information between bridges to find spanning tree
- Automatically updated whenever topology changes

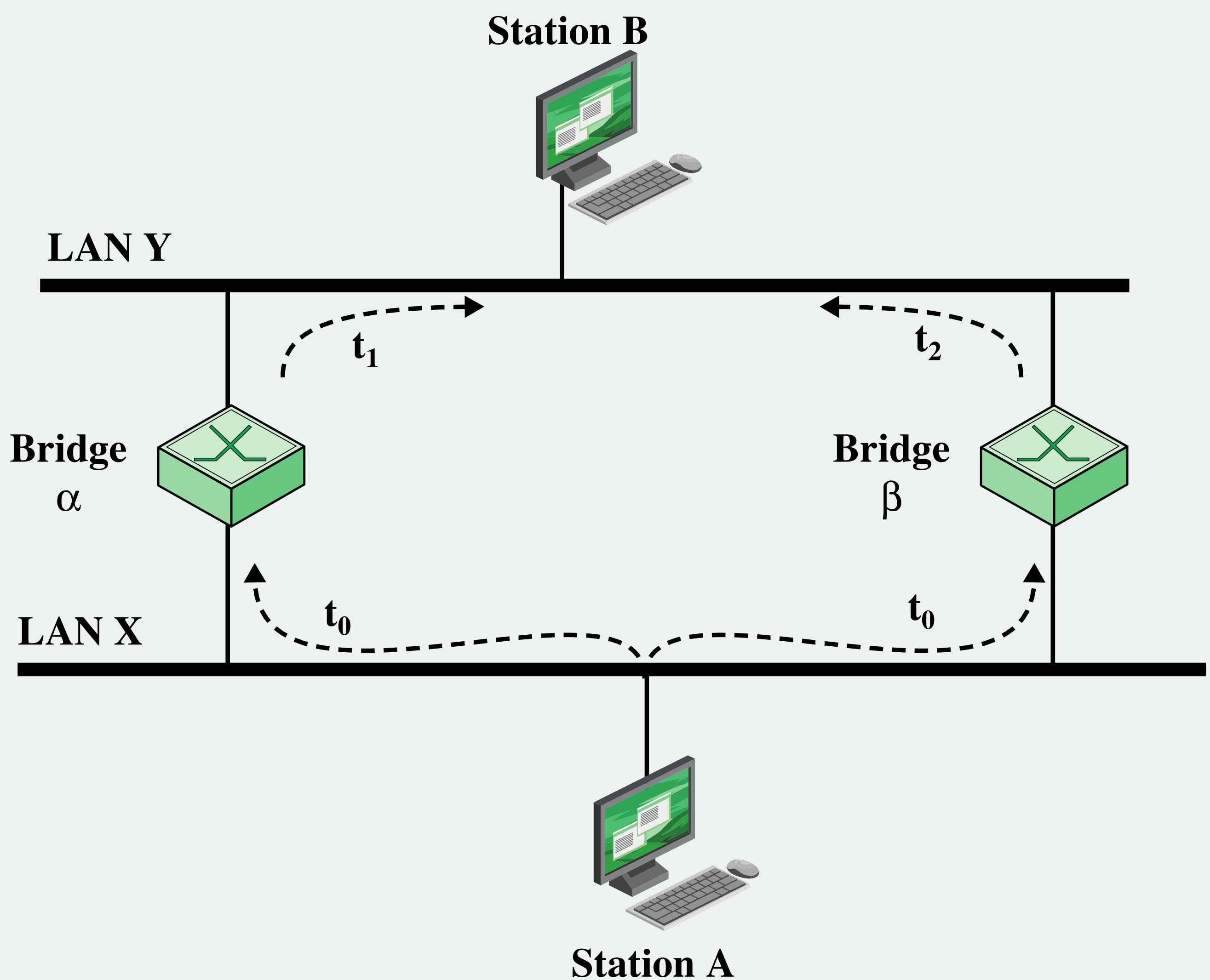


Figure 11.9 Loop of Bridges

Hubs

- Active central element of star layout
- Each station connected to hub by two lines
- Hub acts as a repeater
- Length of a line is limited to about 100m
- Opticalfiber may be used to about 500m
- Physically a star, logically a bus
- Transmissionfrom any one station is received by all other stations
- If two stations transmit at the same time there will be a collision

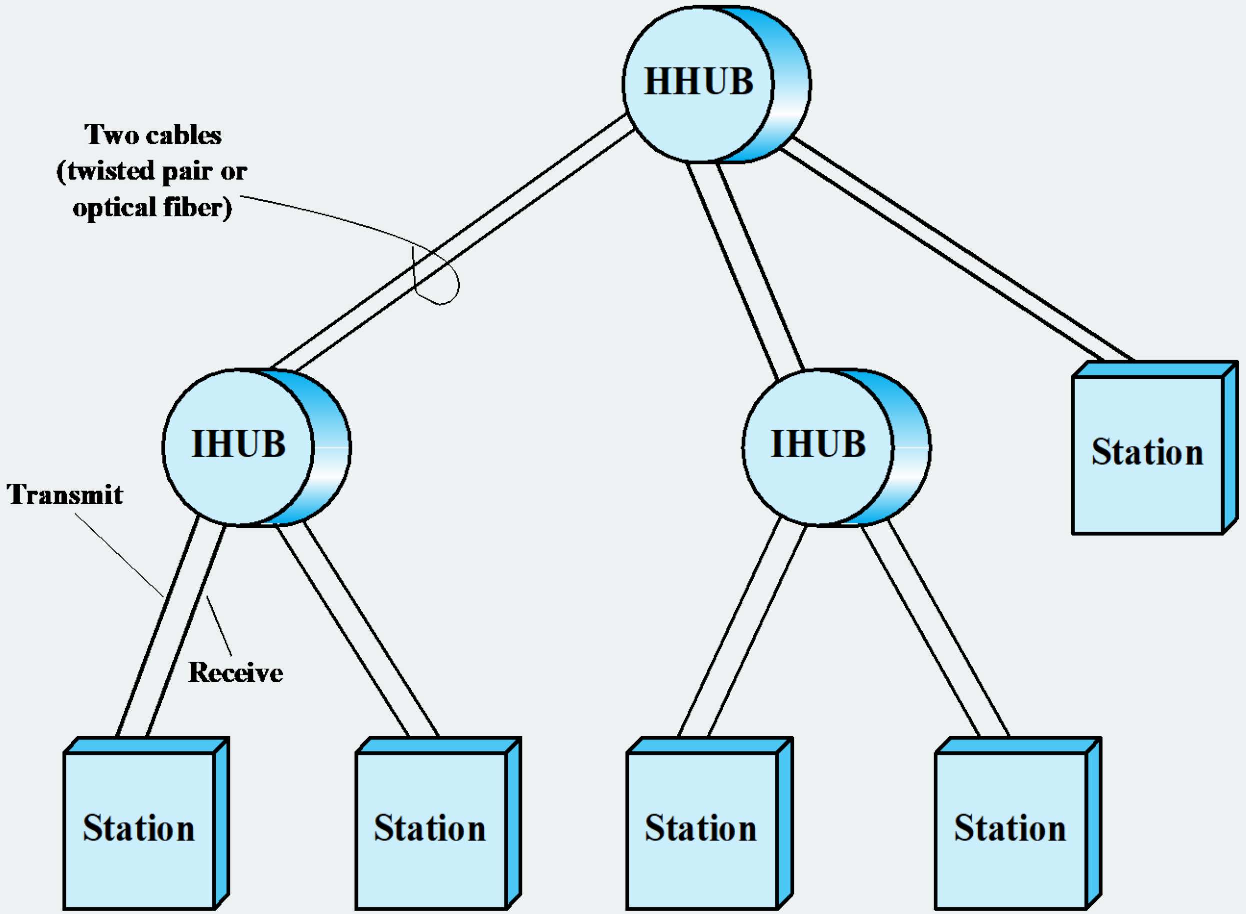


Figure 11.10 Two-Level Star Topology

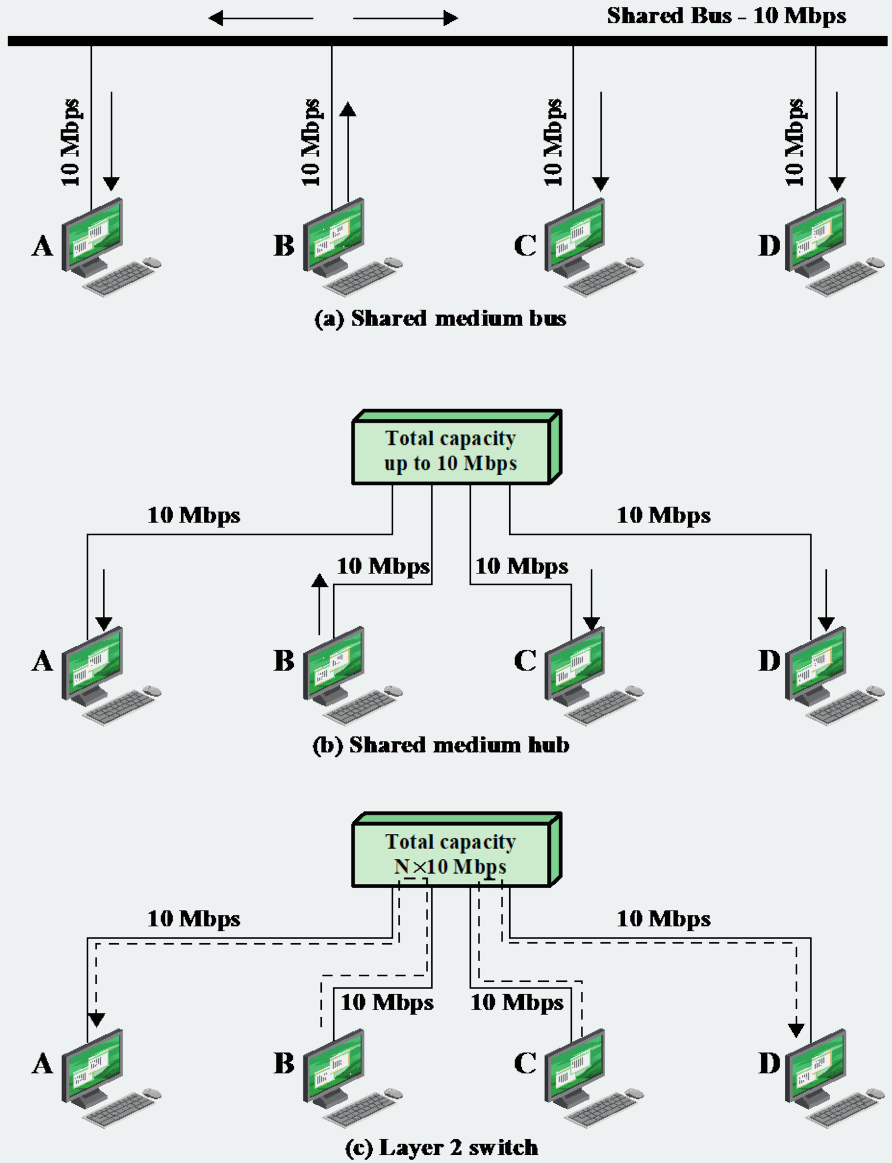


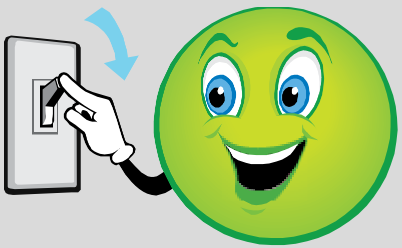
Figure 15.11 LAN Hubs and Switches

Layer 2 Switch Benefits

- No change is required to the software or hardware of the attached devices to convert a bus LAN or a hub LAN to a switched LAN
- Have dedicated capacity equal to original LAN
  - Assuming switch has sufficient capacity to keep up with all devices
- Scales easily
  - Additional devices attached to switch by increasing capacity of layer 2

Types of Layer 2 Switches

- Store-and-forward switch
  - Accepts frame on input line, buffers briefly, routes to appropriate output line
  - See delay between sender and receiver
  - Boosts overall integrity



- Cut-through switch
  - Usedestination address at beginning of frame
  - Switchbegins repeating frame onto output line as soon asdestination address is recognized
  - Yields highestpossible throughput
  - Risk of propagating bad frames

Layer 2 Switch vs. Bridge

- Differences between switches and bridges:

Bridge	Switch
Frame handling done in software	Performs frame forwarding in hardware
Analyzes and forwards one frame at a time	Can handle multiple frames at a time
Uses store-and-forward operation	Can have cut-through operation

- Layer2 switch can be viewed as full-duplex hub
- Incorporates logic to function as multiport bridge
- New installations typically include layer 2 switches with bridge functionality rather than bridges

Defining VLANs

- Broadcast domain consisting of a group of end stations not limited by physical location and communicate as if they were on a common LAN
- Membership by:
  - Port group
  - MAC address
  - Protocol information

Inaho for takeout.   Love to All   Tricia

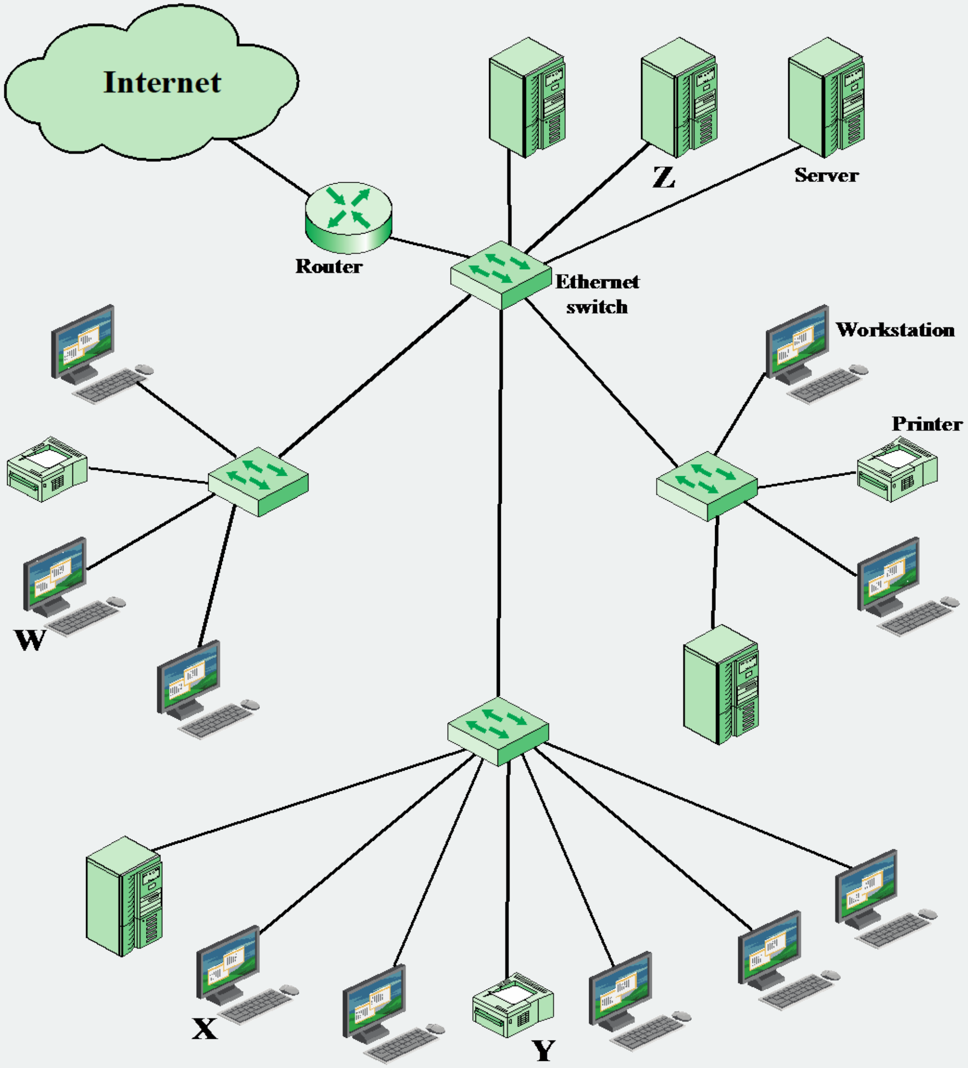


Figure 11.12 A LAN Configuration

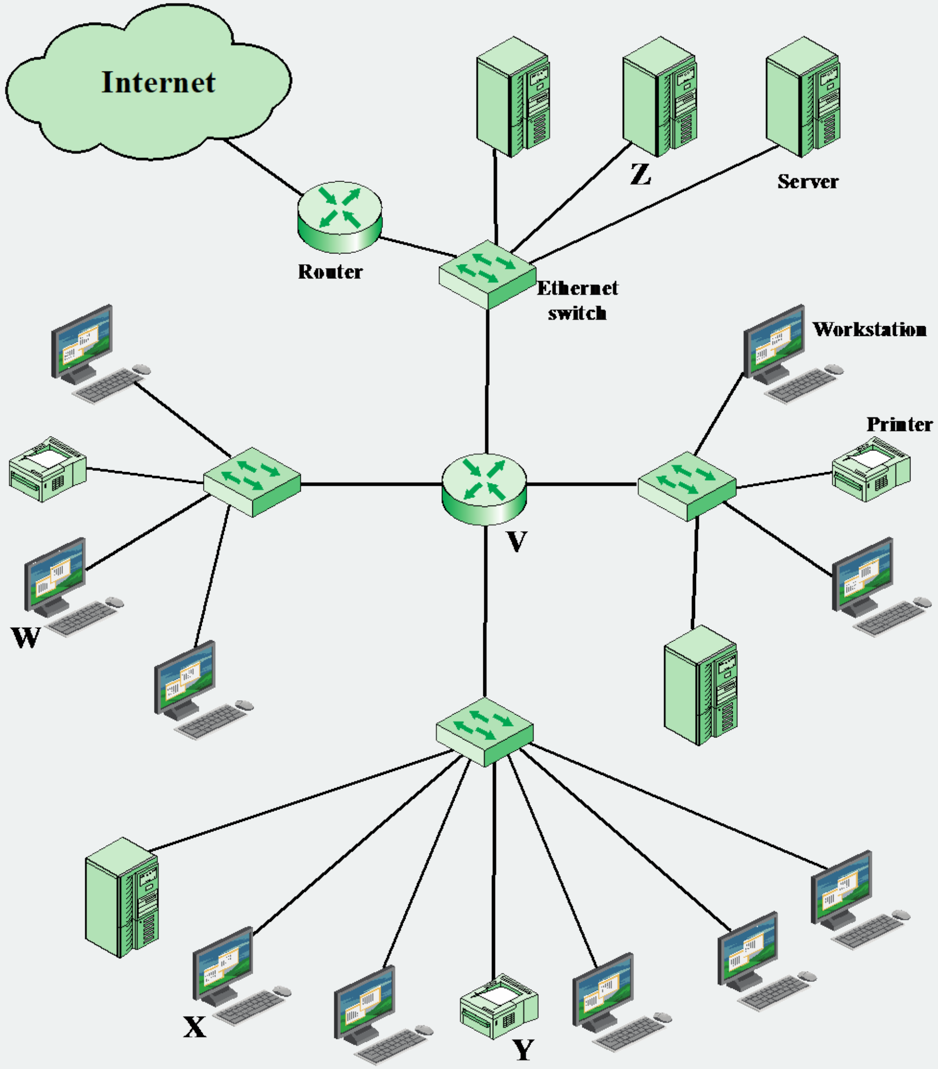


Figure 11.13 A Partitioned LAN

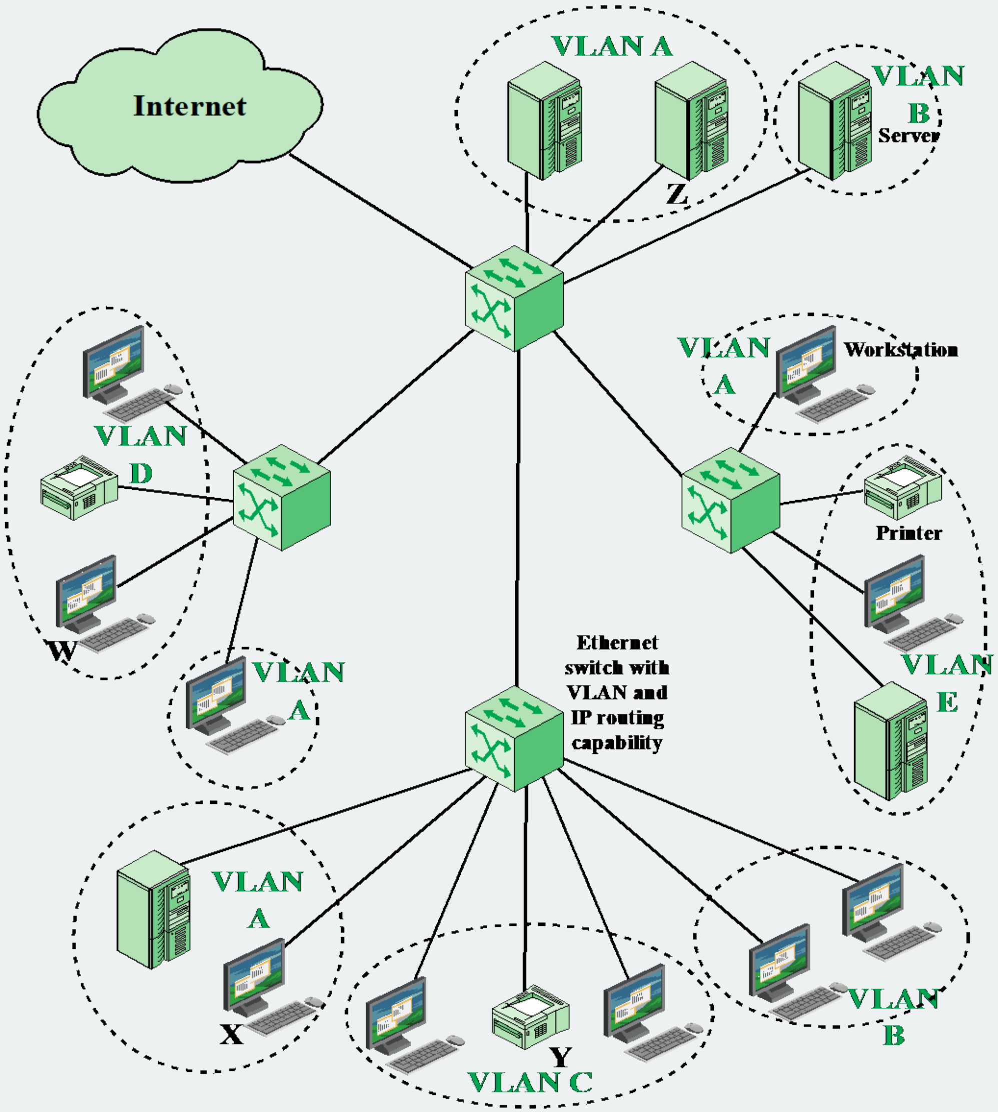


Figure 11.14 A VLAN Configuration

CHAPTER 12

Ethernet

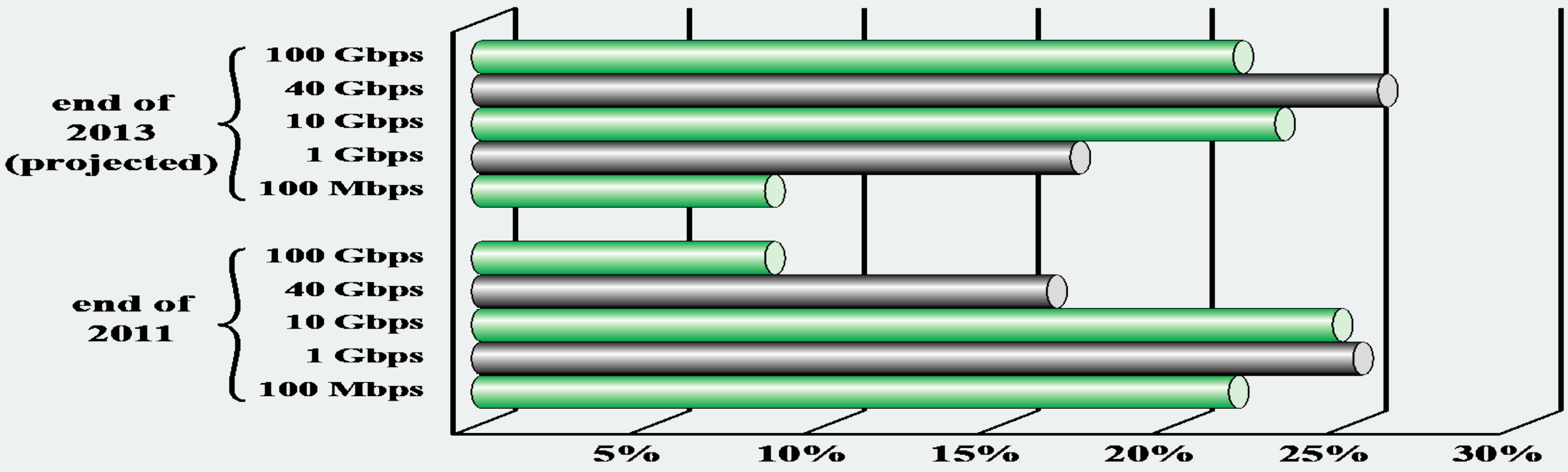


Figure 12.1 Data Center Study—Percentage of Ethernet Links by Speed

Traditional Ethernet

Earliest was ALOHA

- Developed for packet radio networks
- Station may transmit a frame at any time
- Maximum utilization of channel about 18%

Next came slotted ALOHA

- Organized slots equal to transmission time
- Increased utilization to about 37%

CSMA/CD Precursors

- Carrier Sense Multiple Access (CSMA)
  - Station listens to determine if there is another transmission in progress
  - If idle, station transmits
  - Waits for acknowledgment
  - If no acknowledgment, collision is assumed and station retransmits
  - Utilization far exceeds ALOHA

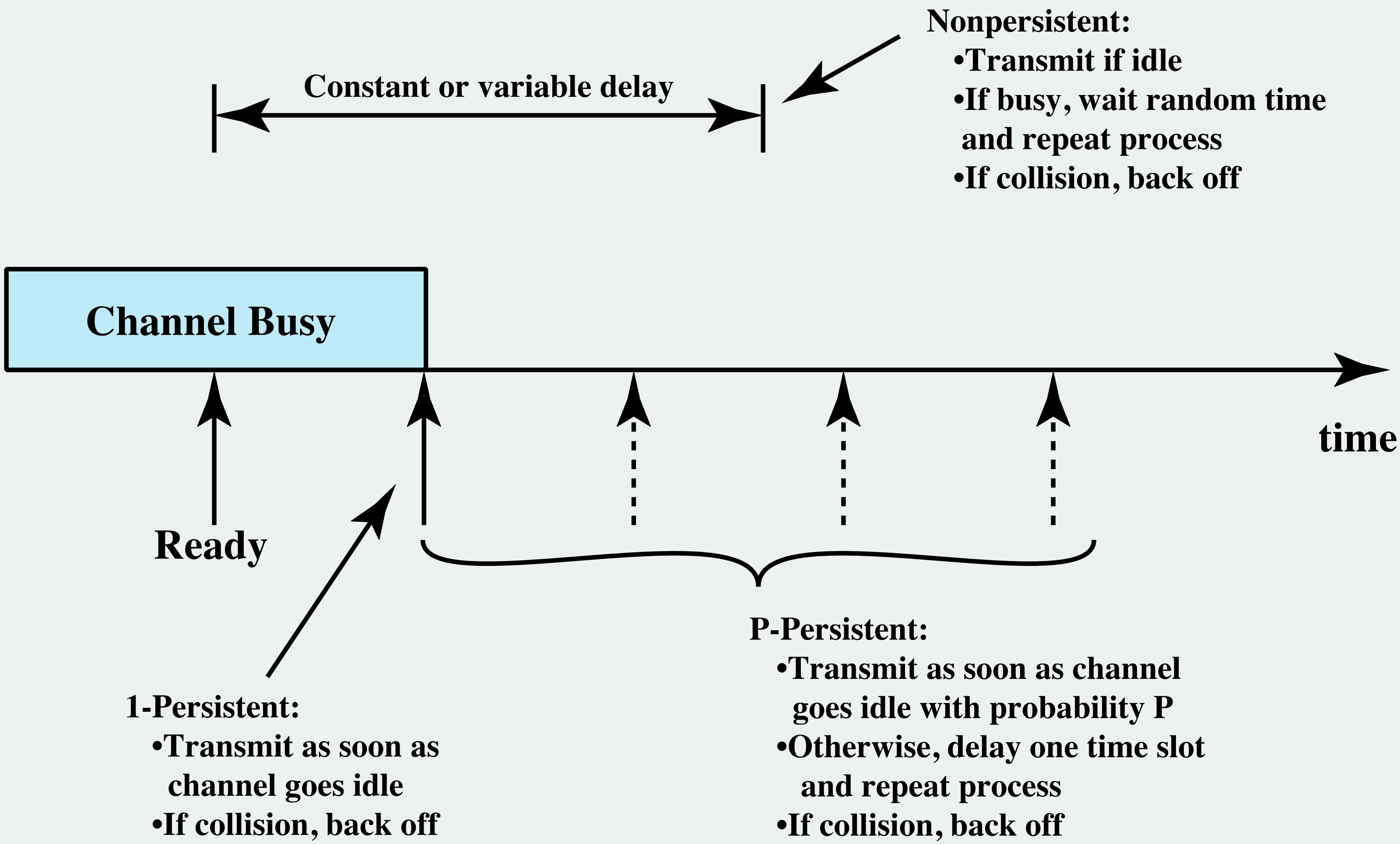


Figure 12.2 CSMA Persistence and Backoff

Nonpersistent CSMA

If the medium is idle, transmit; otherwise, go to step 2

If the medium is busy, wait an amount of time drawn from a probability distribution and repeat step 1

Disadvantage:

Capacity is wasted because the medium will generally remain idle following the end of a transmission even if there are one or more stations waiting to transmit

1-Persistent CSMA

- Avoids idle channel time
- Rules:
    1. If medium is idle, transmit
    2. If medium is busy, listen until idle; then transmit immediately
- Stations are selfish
- If two or more stations are waiting, a collision is guaranteed

P-Persistent CSMA

- Acompromise to try and reduce collisions and idle time
- P-persistent CSMA rules:
  1. Ifmedium is idle, transmit with probability *p*, and delay one time unit with probability (1–*p*)
  2. If medium is busy, listen until idle and repeat step 1
  3. If transmission is delayed one time unit, repeat step 1
- Issue of choosing effective value of *p* to avoid instability under heavy load

Value of *p*?

- Have *n* stations waiting to send
- At end of transmission, expected number of stations is *np*
  - If *np*>1 on average there will be a collision
- Repeated transmissionattempts meancollisions are likely
- Eventually all stations will be trying to send, causing continuous collisions, with throughput dropping to zero
- To avoid catastrophe, *np*<1 for expected peaks of *n*
  - If heavy load expected,*p* must be small
  - Smaller *p* means stations wait longer

Description of CSMA/CD

1. If the medium is idle, transmit; otherwise, go to step 2

2. If the medium is busy, continue to listen until the channel is idle, then transmit immediately

3. If a collision is detected, transmit a brief jamming signal to assure that all stations know that there has been a collision and cease transmission

4. After transmitting the jamming signal, wait a random amount of time, referred to as the ***backoff***, then attempt to transmit again

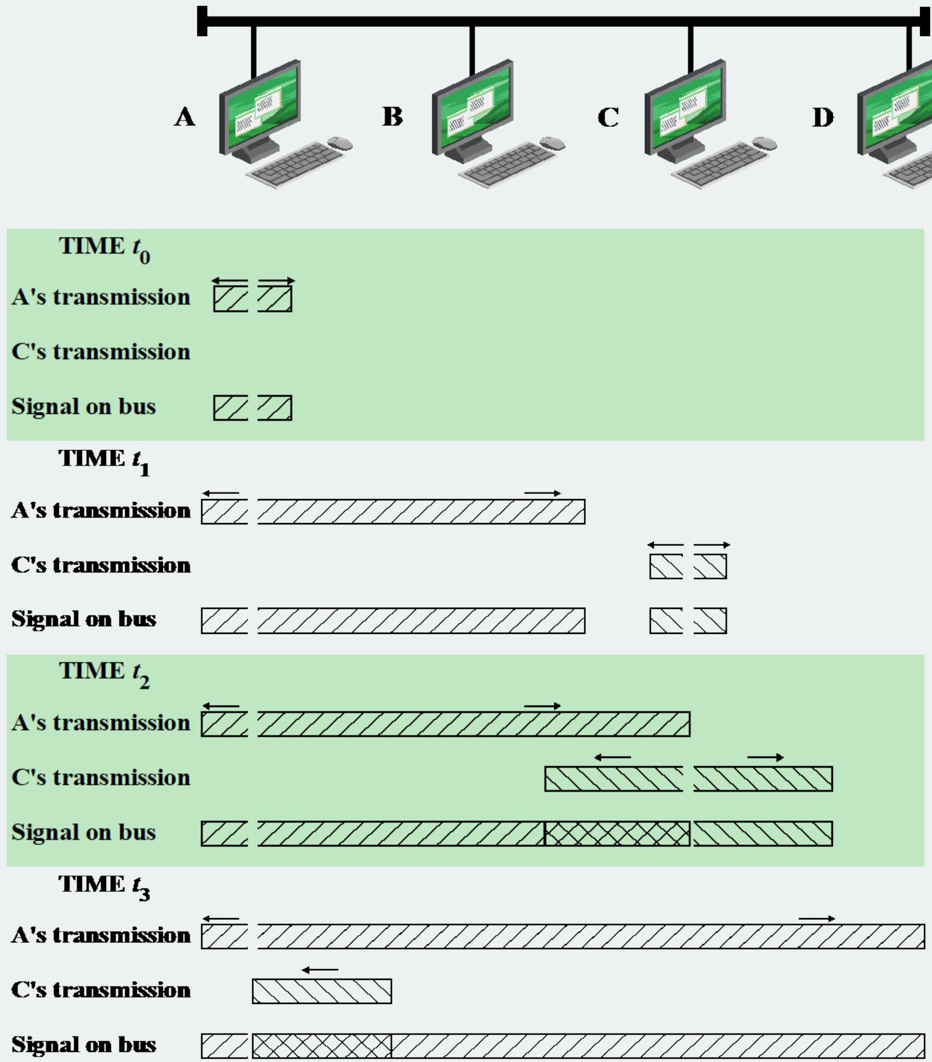


Figure 12.3 CSMA/CD Operation

Which Persistence Algorithm?

- IEEE 802.3 uses 1-persistent
- Both nonpersistent and p-persistent have performance problems

1-persistent seems more unstable than p-persistent

- Because of greed of the stations
- Wasted time due to collisions is short
- With random backoff unlikely to collide on next attempt to send

Binary Exponential Backoff

- IEEE 802.3 and Ethernet both use binary exponential backoff
- A station will attempt to transmit repeatedly in the face of repeated collisions
  - On first 10 attempts, mean random delay doubled
  - Value then remains the same for 6 further attempts
  - After 16 unsuccessful attempts, station gives up and reports error
- 1-persistent algorithm with binary exponential backoff is efficient over wide range of loads
- Backoff algorithm has last-in, first-out effect

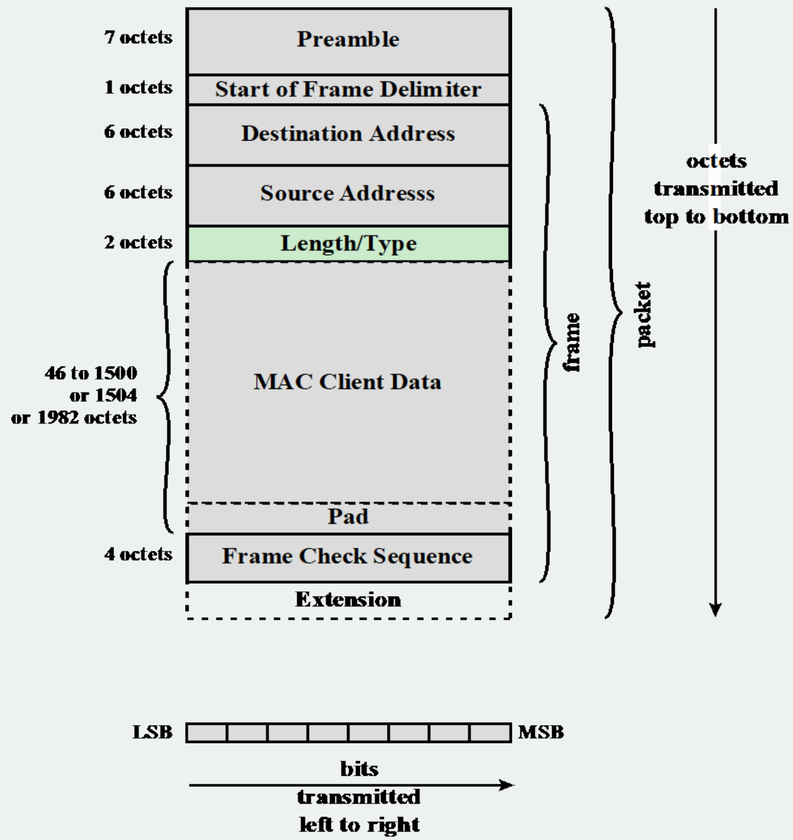


Figure 12.4 IEEE 802.3 MAC Frame Format

Table 12.1
IEEE 802.3 10-Mbps Physical Layer Medium Alternatives

	10BASE5	10BASE2	10BASE-T	10BASE-FP
Transmission medium	Coaxial cable (50 ohm)	Coaxial cable (50 ohm)	Unshielded twisted pair	850-nm optical fiber pair
Signaling technique	Baseband (Manchester)	Baseband (Manchester)	Baseband (Manchester)	Manchester/on-off
Topology	Bus	Bus	Star	Star
Maximum segment length (m)	500	185	100	500
Nodes per segment	100	30	—	33
Cable diameter (mm)	10	5	0.4 to 0.6	62.5/125 µm

Table 12.2

IEEE 802.3 100BASE-T Physical Layer Medium Alternatives

	100BASE-TX		100BASE-FX	100BASE-T4
Transmission medium	2 pair, STP	2 pair, Category 5 UTP	2 optical fibers	4 pair, Category 3, 4, or 5 UTP
Signaling technique	MLT-3	MLT-3	4B5B, NRZI	8B6T, NRZ
Data rate	100 Mbps	100 Mbps	100 Mbps	100 Mbps
Maximum segment length	100 m	100 m	100 m	100 m
Network span	200 m	200 m	400 m	200 m

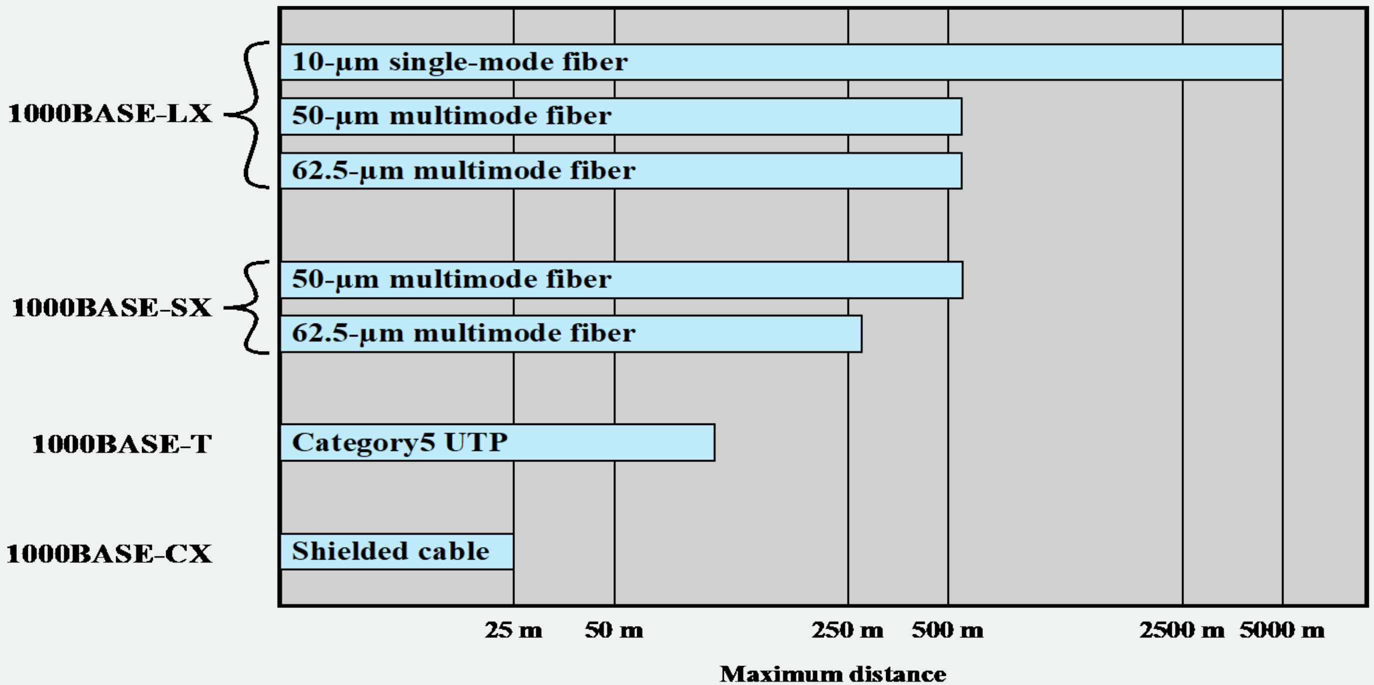


Figure 12.5 Gigabit Ethernet Medium Options (log scale)

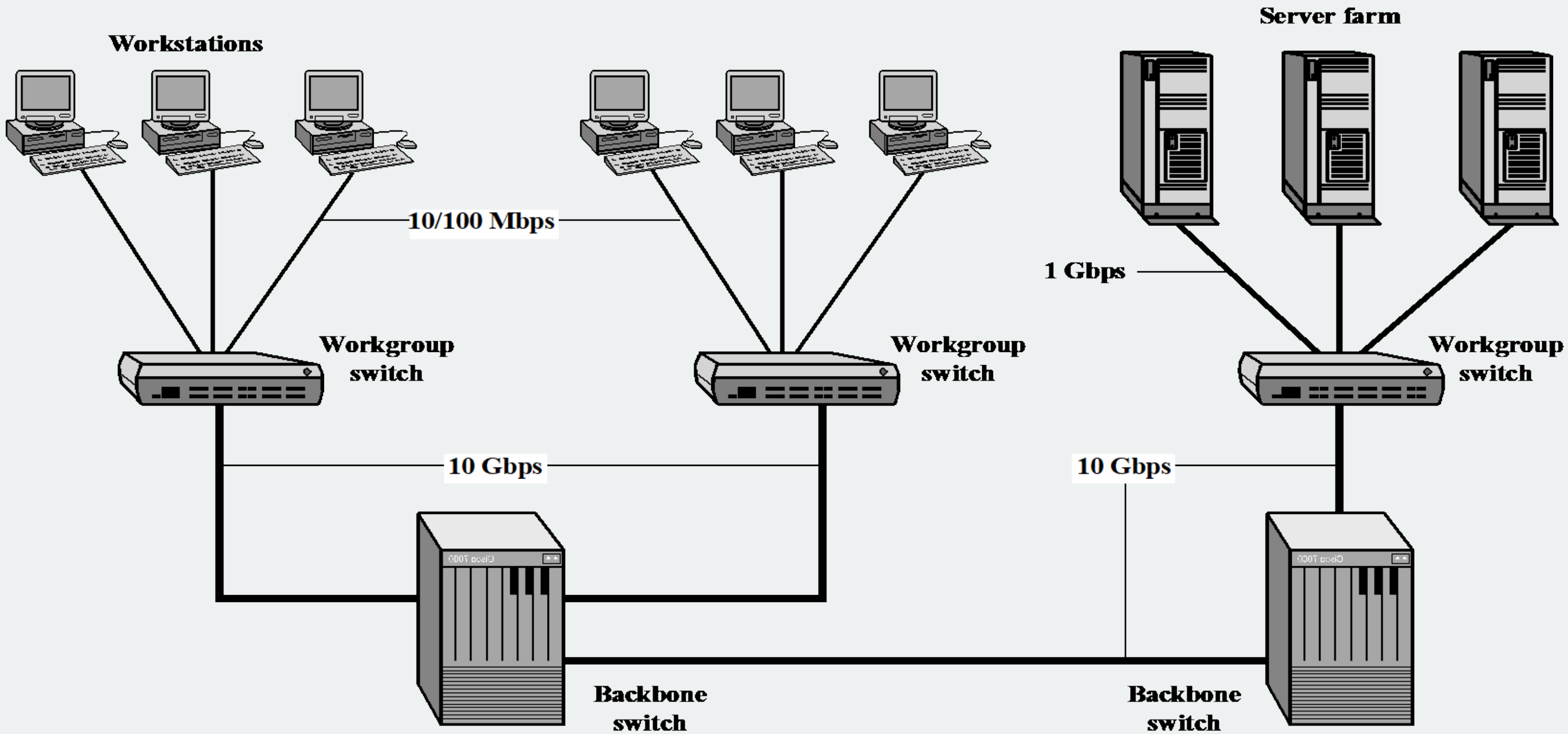


Figure 12.6 Example 10 Gigabit Ethernet Configuration

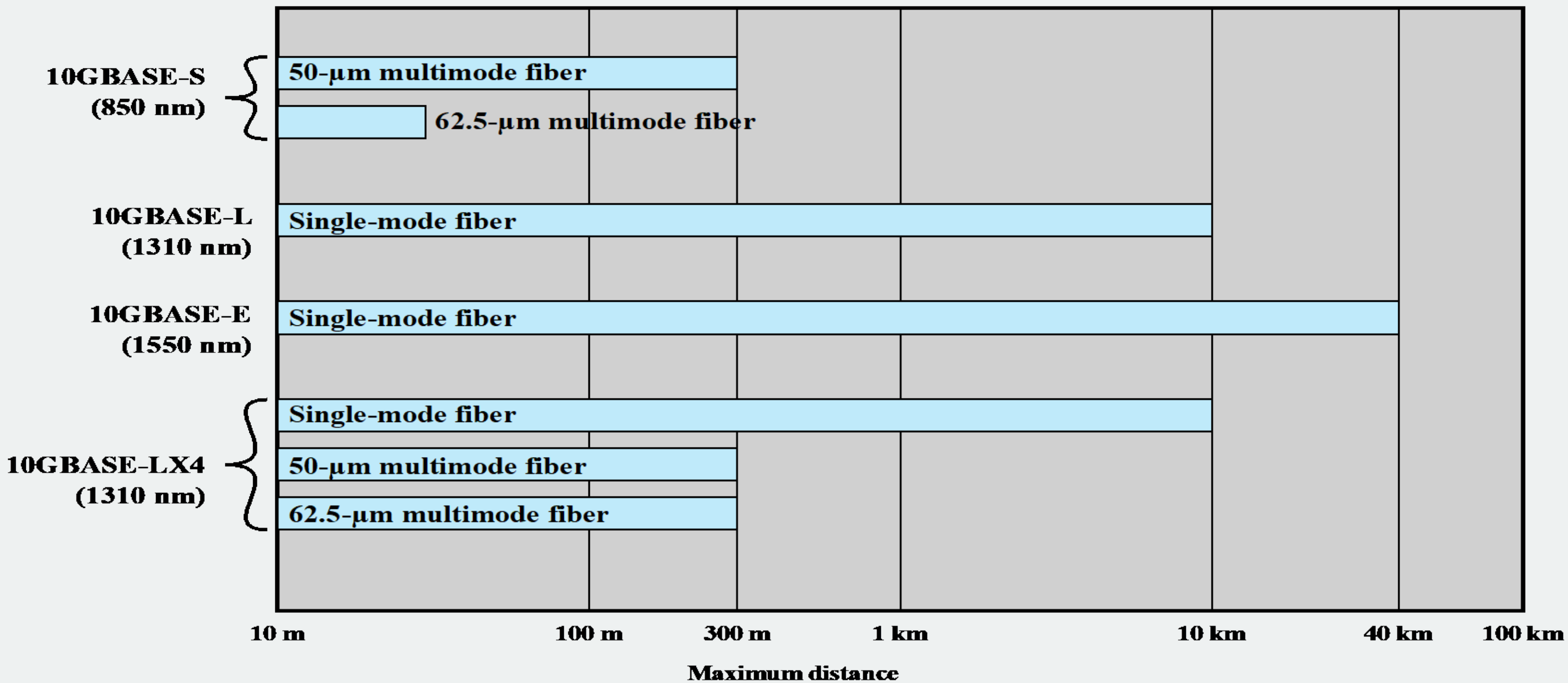


Figure 12.7 10-Gbps Ethernet Distance Options (log scale)

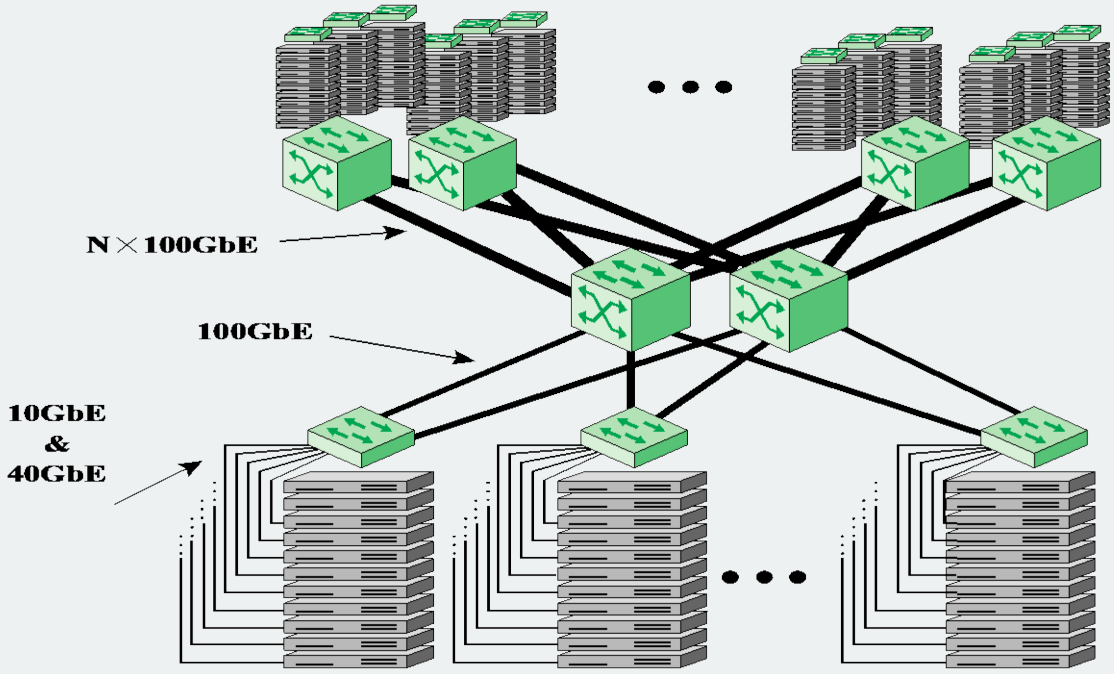


Figure 12.8 Example 100-Gbps Ethernet Configuration for Massive Blade Server Site

CHAPTER 13

Wireless LANs

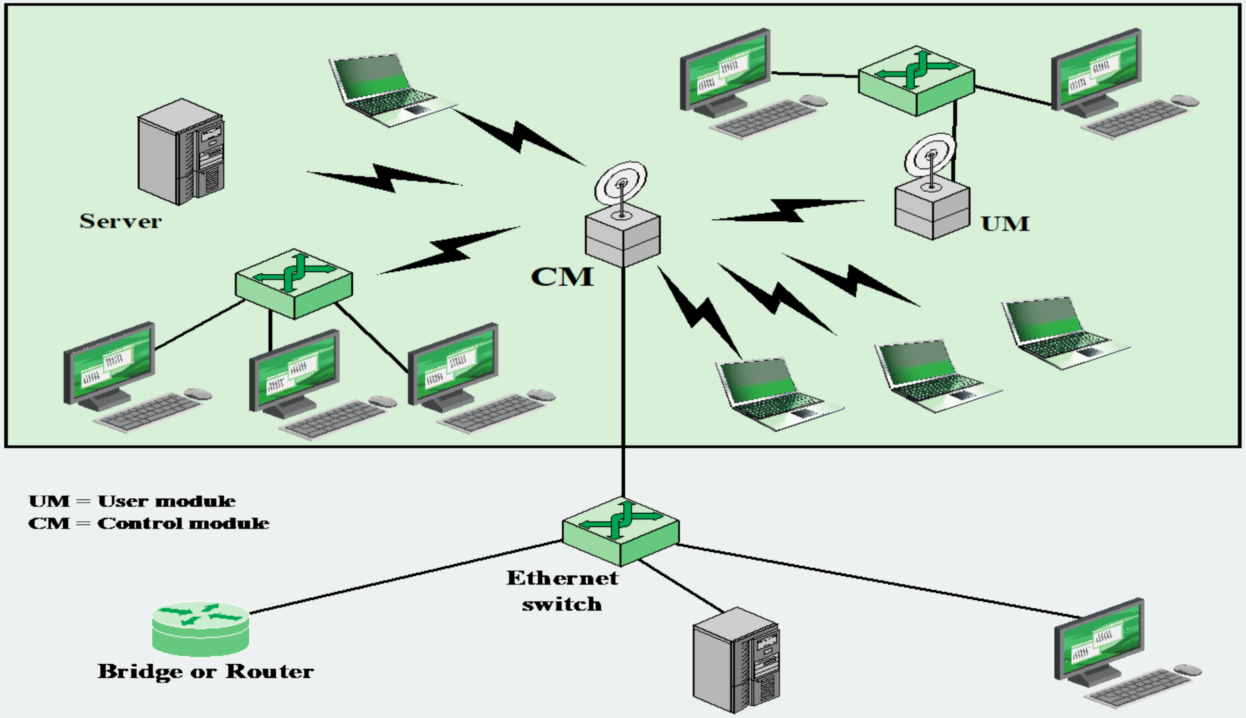


Figure 13.1 Example Single-Cell Wireless LAN Configuration

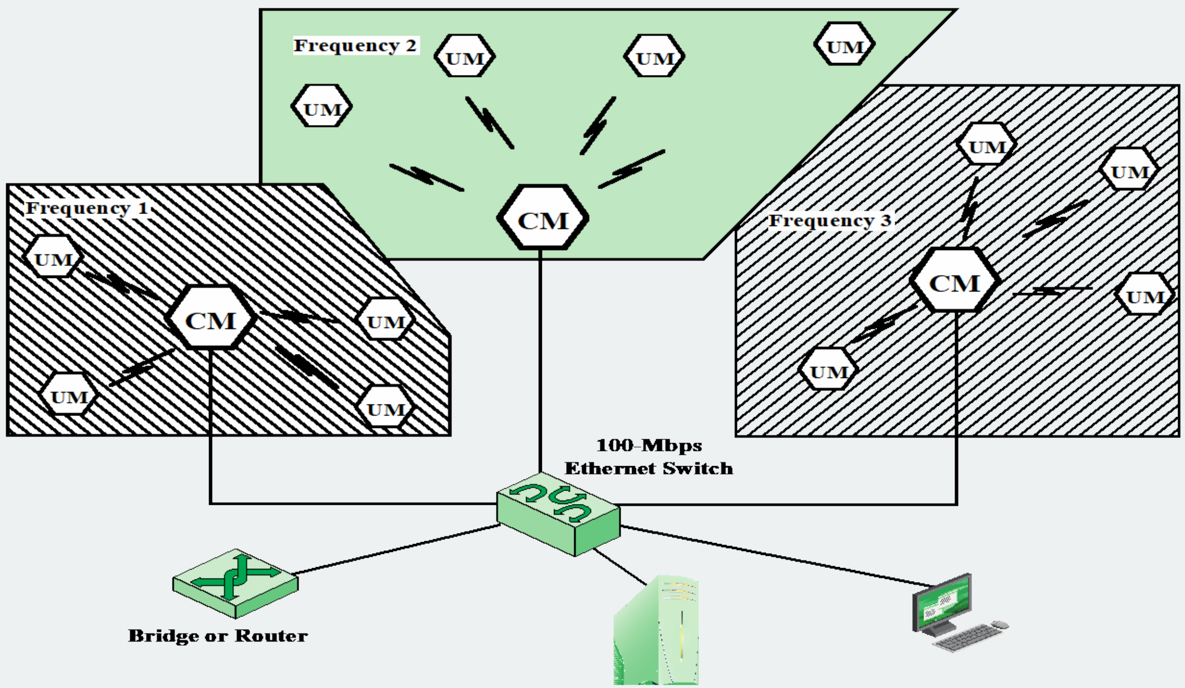


Figure 13.2 Example Multiple-Cell Wireless LAN Configuration

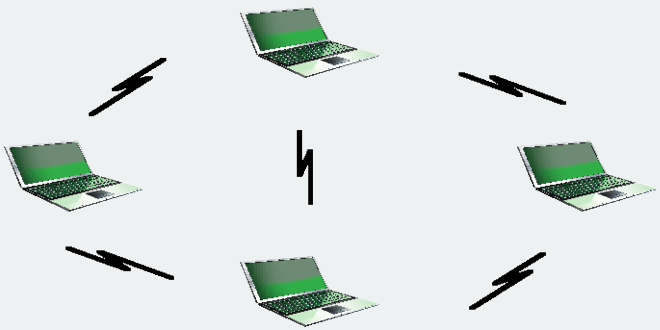


Figure 13.3 Ad Hoc Wireless LAN Configuration

Wireless LAN Requirements

- Throughput
- Number of nodes
- Connection to backbone LAN
- Service area
- Battery power consumption
- Transmission robustness and security
- Collocated network operation
- License-free operation
- Handoff/roaming
- Dynamic configuration

Table 13.1
Key IEEE 802.11 Standards

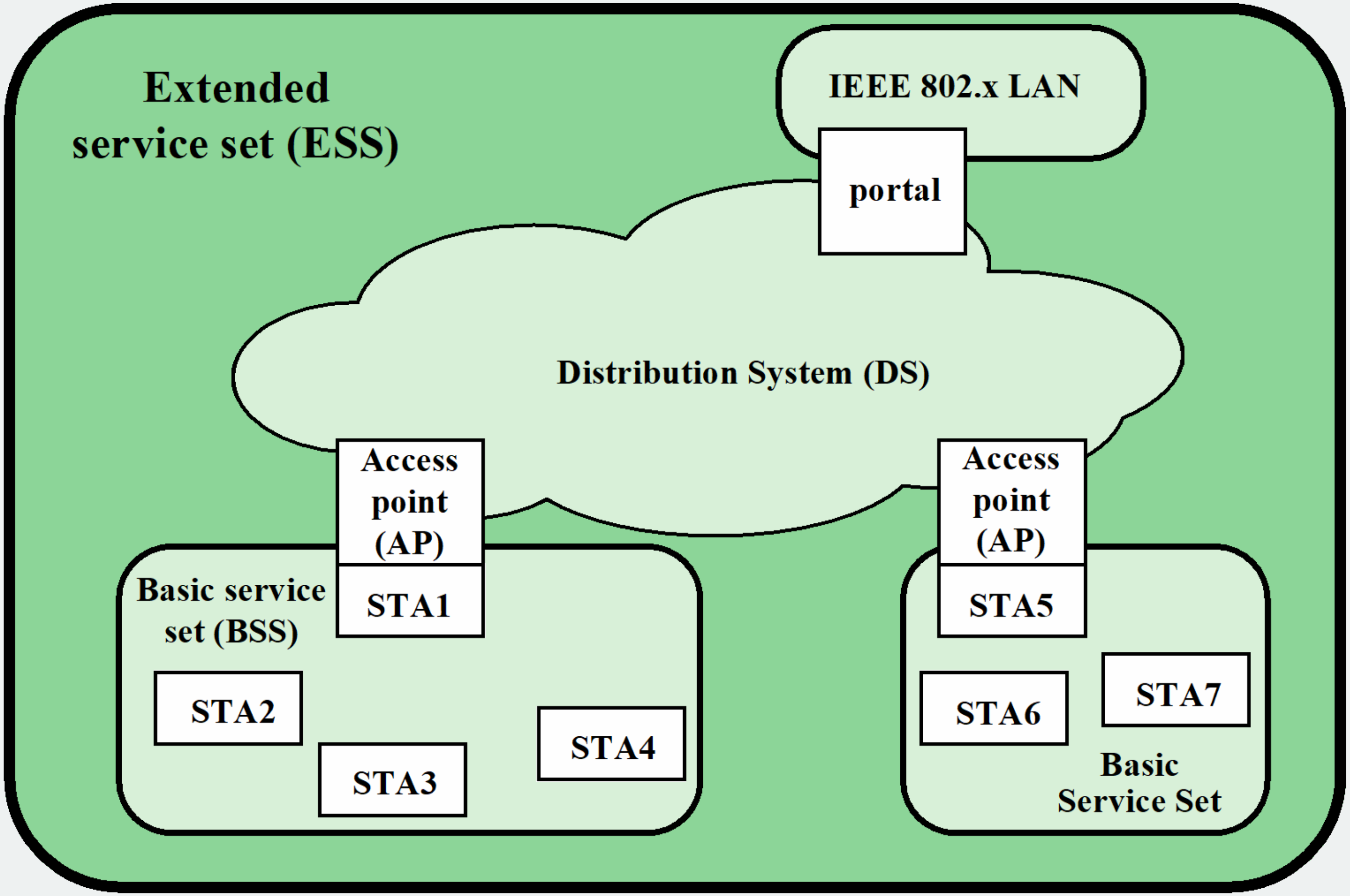
Standard	Scope
IEEE 802.11a	Physical layer: 5-GHz OFDM at rates from 6 to 54 Mbps
IEEE 802.11b	Physical layer: 2.4-GHz DSSS at 5.5 and 11 Mbps
IEEE 802.11c	Bridge operation at 802.11 MAC layer
IEEE 802.11d	Physical layer: Extend operation of 802.11 WLANs to new regulatory domains (countries)
IEEE 802.11e	MAC: Enhance to improve quality of service and enhance security mechanisms
IEEE 802.11g	Physical layer: Extend 802.11b to data rates >20 Mbps
IEEE 802.11i	MAC: Enhance security and authentication mechanisms
IEEE 802.11n	Physical/MAC: Enhancements to enable higher throughput
IEEE 802.11T	Recommended practice for the evaluation of 802.11 wireless performance
IEEE 802.11ac	Physical/MAC: Enhancements to support 0.5-1 Gbps in 5-GHz band
IEEE 802.11ad	Physical/MAC: Enhancements to support ≥ 1 Gbps in the 60-GHz band

(Table can be found on page 424 in the textbook)

Table 13.2
IEEE 802.11 Terminology

Access point (AP)	Any entity that has station functionality and provides access to the distribution system via the wireless medium for associated stations
Basic service set (BSS)	A set of stations controlled by a single coordination function
Coordination function	The logical function that determines when a station operating within a BSS is permitted to transmit and may be able to receive PDUs
Distribution system (DS)	A system used to interconnect a set of BSSs and integrated LANs to create an ESS
Extended service set (ESS)	A set of one or more interconnected BSSs and integrated LANs that appear as a single BSS to the LLC layer at any station associated with one of these BSSs
Frame	Synonym for MAC protocol data unit
MAC protocol data unit (MPDU)	The unit of data exchanged between two peer MAC entities using the services of the physical layer
MAC service data unit (MSDU)	Information that is delivered as a unit between MAC users
Station	Any device that contains an IEEE 802.11 conformant MAC and physical layer

(Table can be found on page 424 in the textbook)

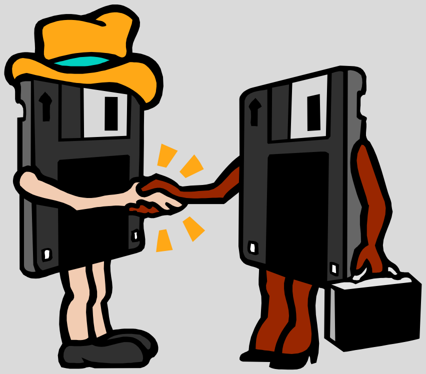


STA = station

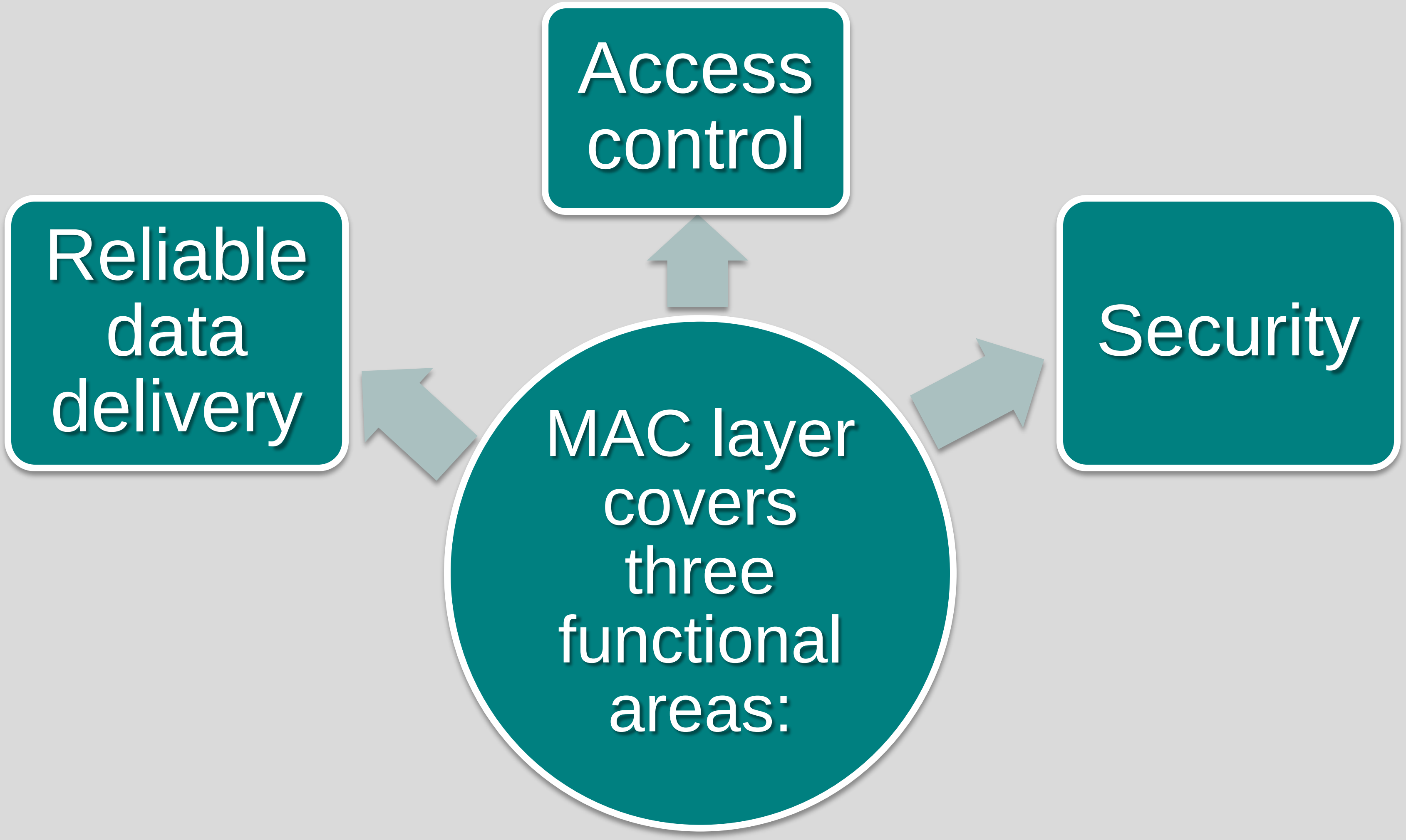
Figure 13.4 IEEE 802.11 Architecture

Wi-Fi Alliance

- There is always a concern whether products from different vendors will successfully interoperate
- Wireless Ethernet Compatibility Alliance (WECA)
  - Industry consortium formed in 1999
- Renamed the Wi-Fi (Wireless Fidelity) Alliance
  - Created a test suite to certify interoperability for 802.11 products



Medium Access Control



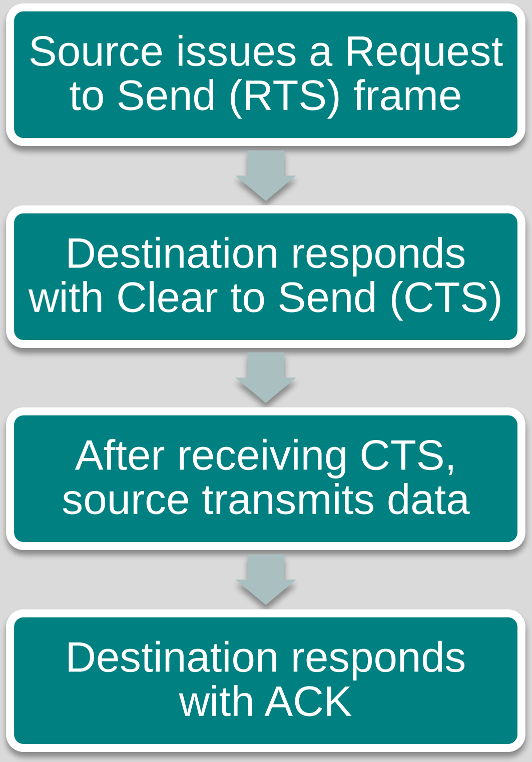
Reliable Data Delivery

- Can be dealt with at a higher layer
- More efficient to deal with errors at MAC level
- 802.11 includes frame exchange protocol
  - Station receiving frame returns acknowledgment (ACK) frame
  - Exchange treated as atomic unit
  - If no ACK within short period of time, retransmit
- 802.11 physical and MAC layers unreliable
  - Noise, interference, and other propagation effects result in loss of frames
  - Even with error-correction codes, frames may not successfully be received

Four Frame Exchange

- RTS alerts all stations within range of source that exchange is under way
- CTS alerts all stations within range of destination
- Other stations don’t transmit to avoid collision
- RTS/CTS exchange is a required function of MAC but may be disabled

- Can use four-frame exchange for better reliability



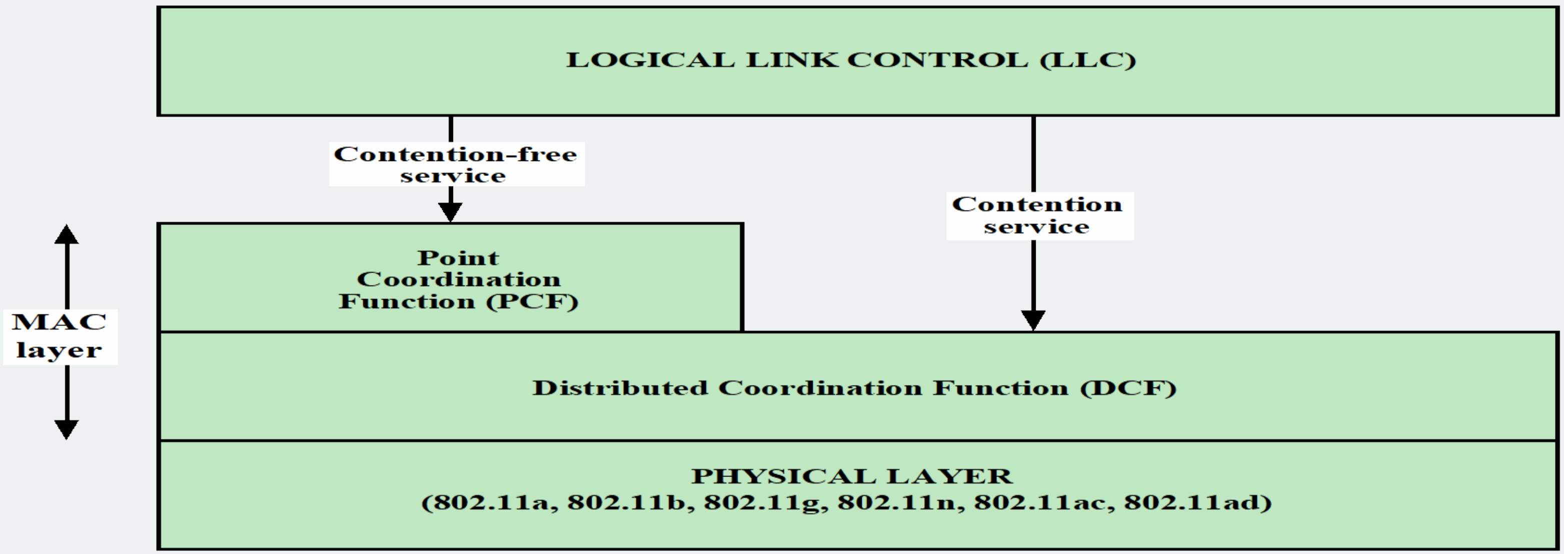
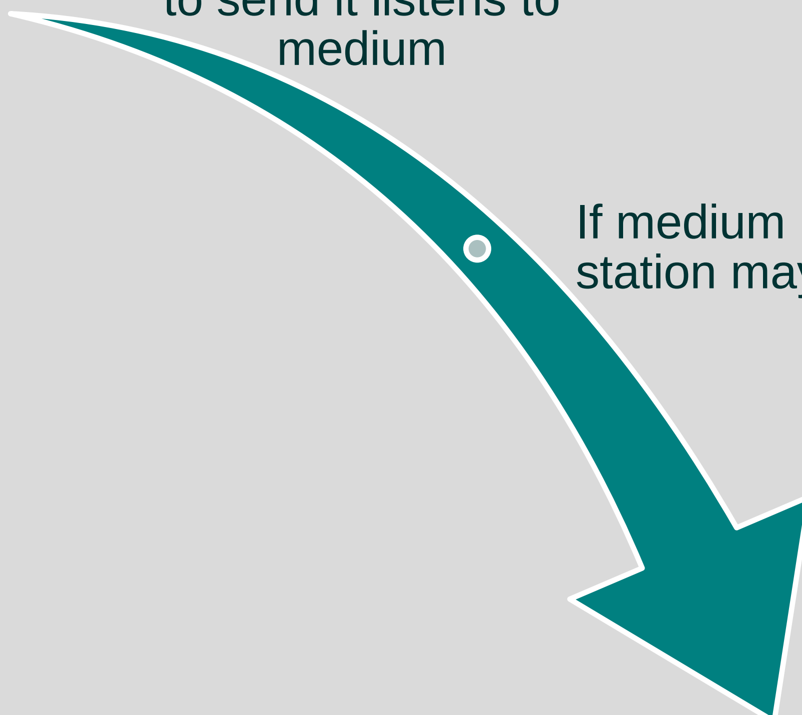


Figure 13.5 IEEE 802.11 Protocol Architecture

Distributed Coordination Function (DCF)

- DCF sublayer uses CSMA algorithm
- Does not include a collision detection function because it is not practical on a wireless network
- Includes a set of delays that amounts as a priority scheme



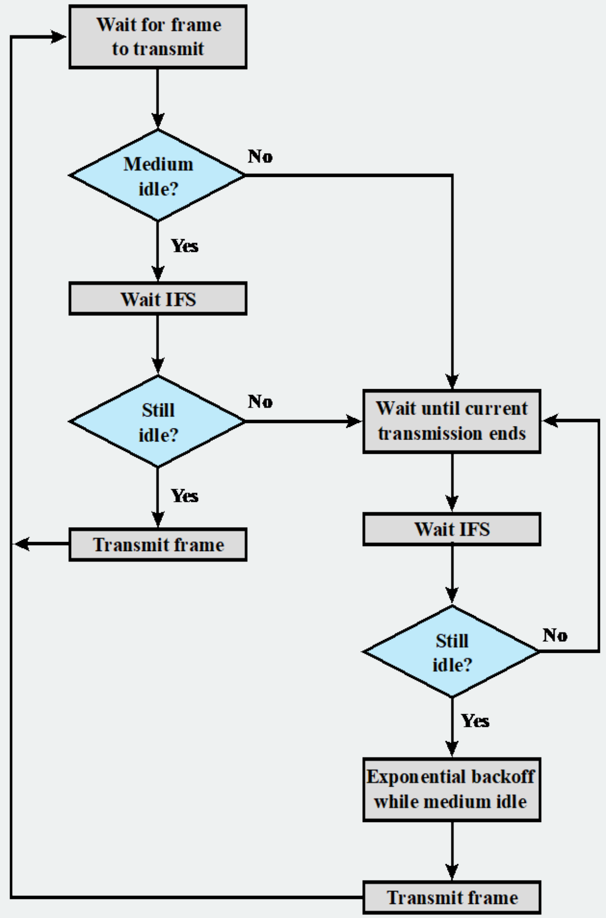
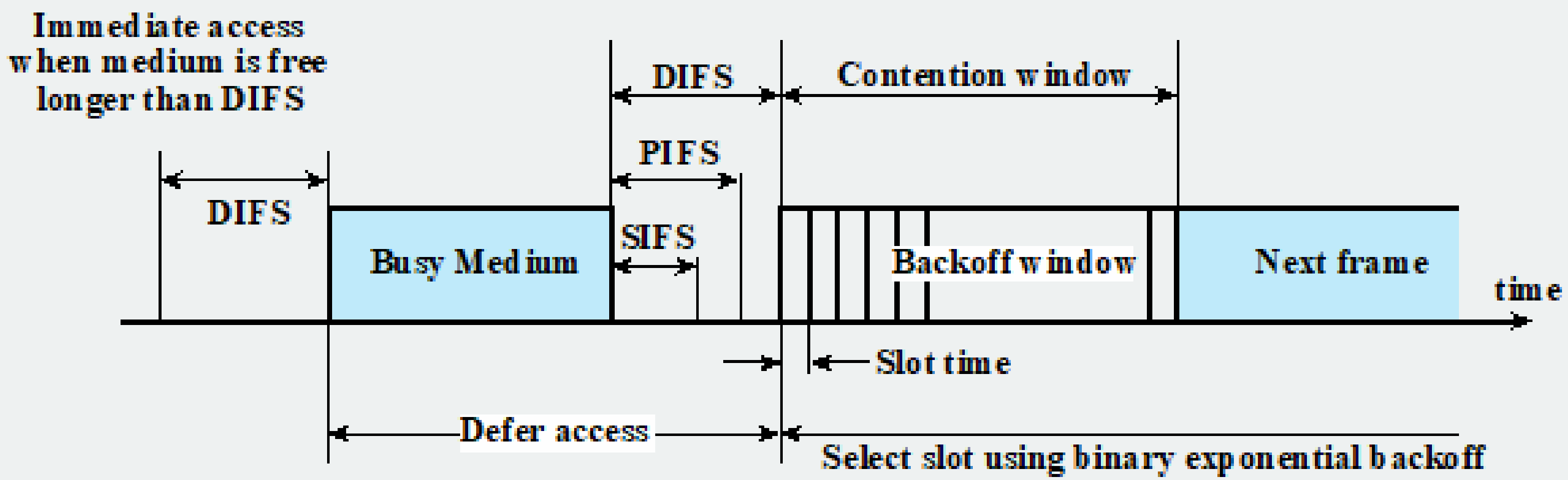


Figure 13.6 IEEE 802.11 Medium Access Control Logic

Priority IFS Values

SIFS (short IFS)	PIFS (point coordination function IFS)	DIFS (distributed coordination function IFS)
For all immediate response actions	Used by the centralized controller in PCF scheme when issuing polls	Used as minimum delay for asynchronous frames contending for access



(a) Basic Access Method

SIFS

- Any station using SIFS to determine transmission opportunity has the highest priority
- Used in the following circumstances:
  - Acknowledgment (ACK)
    - Station responds with an ACK frame after waiting only for a SIFS gap
    - Provides for efficient collision recovery
  - Clear to Send (CTS)
    - Station ensures data frame gets through by issuing RTS
  - Poll response

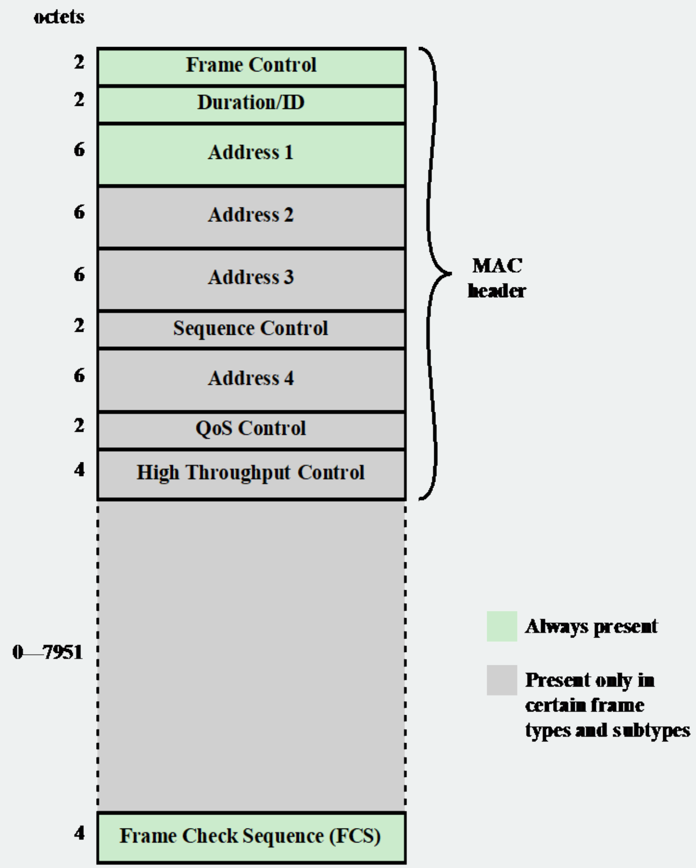


Figure 13.8 IEEE 802.11 MAC Frame Format

Control Frames

Power Save-Poll (PS-Poll)

- Request AP transmit buffered frame when in power-saving mode

Request to Send (RTS)

- First frame in four-way frame exchange

Clear to Send (CTS)

- Second frame in four-way exchange

Acknowledgment (ACK)

- Acknowledges correct receipt

Contention-Free (CF)-end

- Announces end of contention-free period part of PCF

CF-End + CF-Ack:

- Acknowledges CF-end to end contention-free period and release stations from associated restrictions

Data Frames

- Eight data frame subtypes
  - Organized in two groups
    - First four carry upper-level data
    - Remaining do not carry any user data
- Data
  - Simplestdata frame, contention or contention-free use
- Data + CF-Ack
  - Carriesdata and acknowledges previously received data during contention-free period
- Data + CF-Poll
  - Used by point coordinator to deliver data and request send
- Data + CF-Ack + CF-Poll
  - Combines Data + CF-Ack and Data + CF-Poll

Management Frames

Used to manage communications between stations and APs

Management of associations

- Request, response, reassociation, dissociation, and authentication

Table 13.4
IEEE 802.11 Physical Layer Standards

Standard	802.11a	802.11b	802.11g	802.11n	802.11ac	802.11ad
Year introduced	1999	1999	2003	2000	2012	2014
Maximum data transfer speed	54 Mbps	11 Mbps	54 Mbps	65 to 600 Mbps	78 Mbps to 3.2 Gbps	6.76 Gbps
Frequency band	5 GHz	2.4 GHz	2.4 GHz	2.4 or 5 GHz	5 GHz	60 GHz
Channel bandwidth	20 MHz	20 MHz	20 MHz	20, 40 MHz	40, 80, 160 MHz	2160 MHz
Highest order modulation	64 QAM	11 CCK	64 QAM	64 QAM	256 QAM	64 QAM
Spectrum usage	DSSS	OFDM	DSSS, OFDM	OFDM	SC-OFDM	SC, OFDM
Antenna configuration	1×1 SISO	1×1 SISO	1×1 SISO	Up to 4×4 MIMO	Up to 8×8 MIMO, MU-MIMO	1×1 SISO

Table 13.5
Estimated Distance (m) Versus Data Rate

Data Rate (Mbps)	802.11b	802.11a	802.11g
1	90+	—	90+
2	75	—	75
5.5(b)/6(a/g)	60	60+	65
9	—	50	55
11(b)/12(a/g)	50	45	50
18	—	40	50
24	—	30	45
36	—	25	35
48	—	15	25
54	—	10	20

IEEE 802.11n

- Has enhancements in three general areas:
  - Multiple-input-multiple-output (MIMO) antenna architecture
    - Most important enhancement
  - Radio transmission scheme
    - Increased capacity
  - MAC enhancements
    - Most significant change is to aggregate multiple MAC frames into a single block for transmission

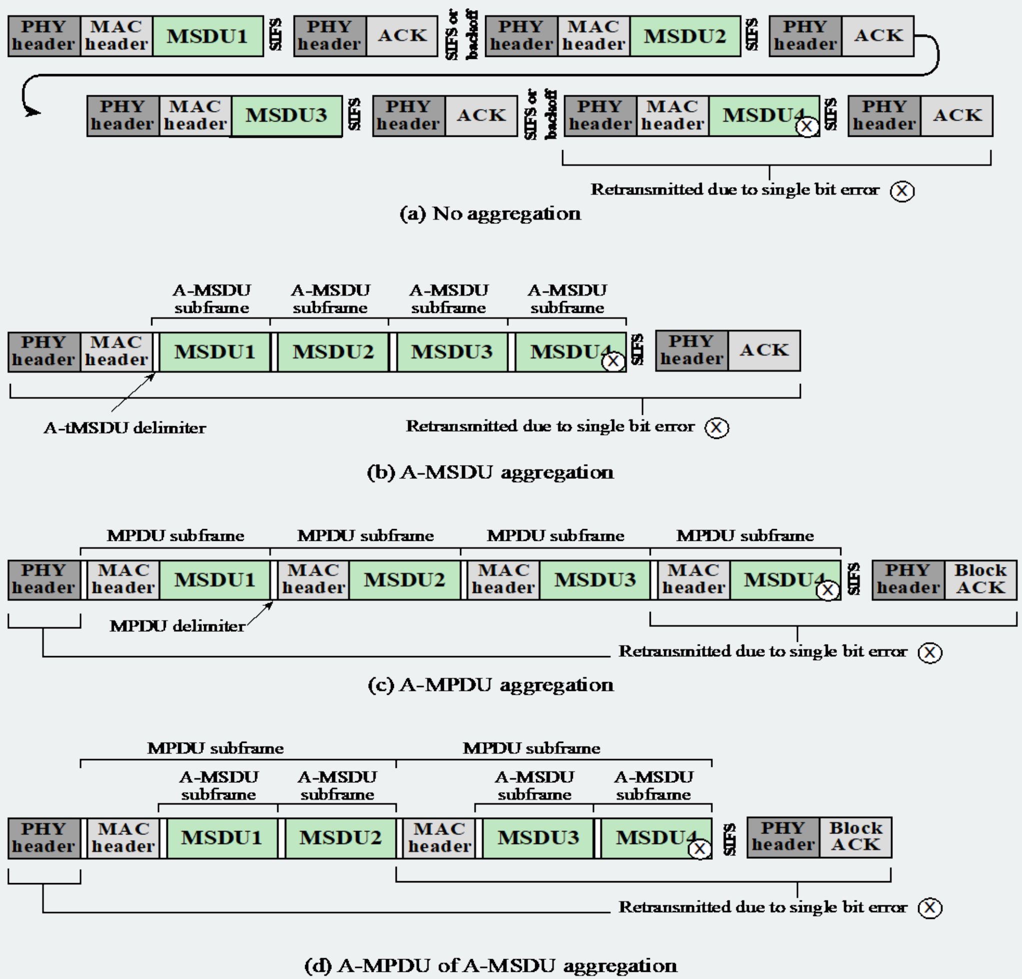


Figure 13.11 Forms of Aggregation

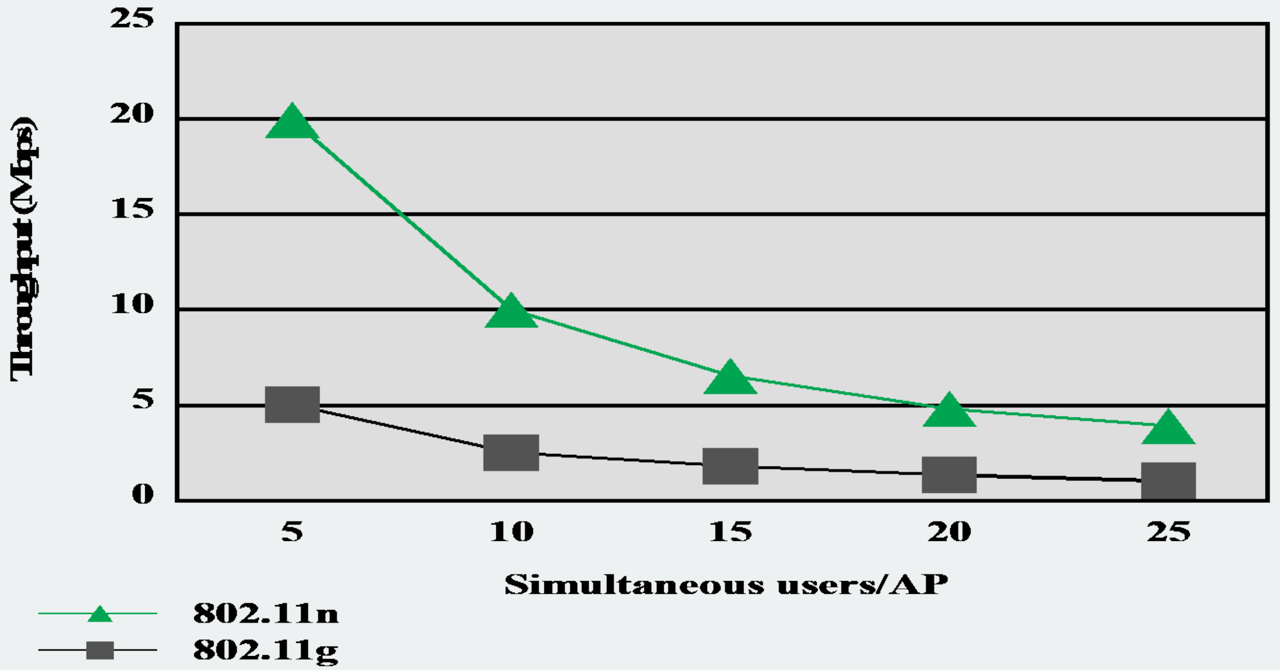


Figure 13.12 Average Throughput per User

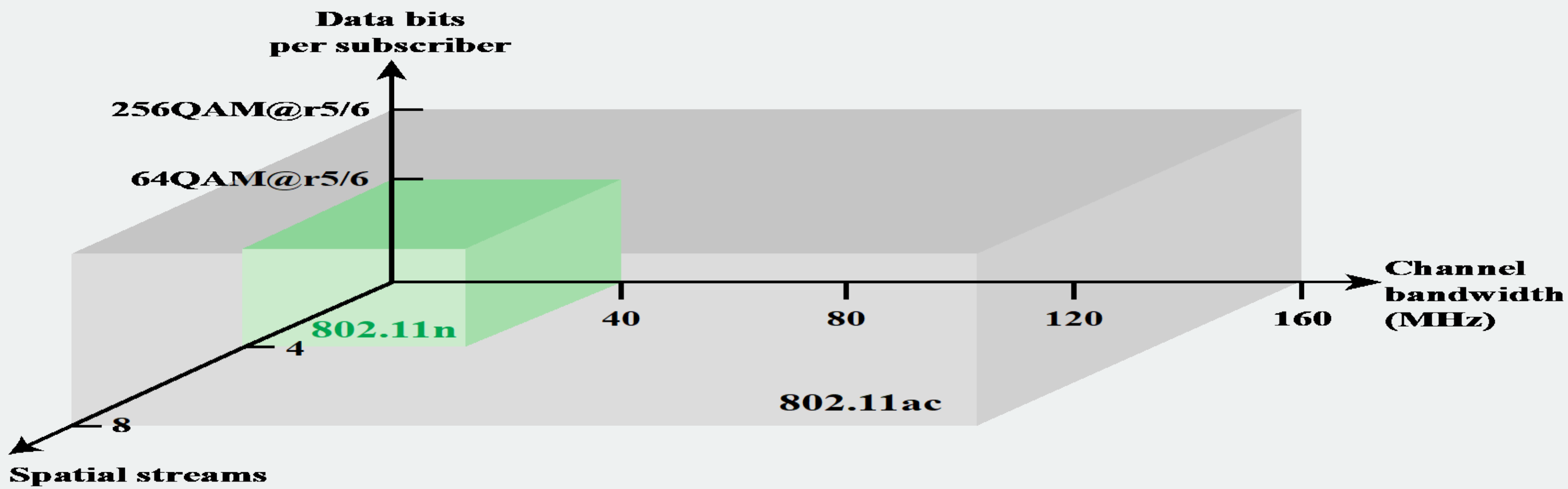


Figure 13.13 IEEE 802.11 Performance Factors

IEEE 802.11ac

- Includes the option of multiuser MIMO (MU-MIMO)
  - On the downlink the transmitter is able to use its antenna resources to transmit multiple frames to different stations, all at the same time and over the same frequency spectrum
  - Each antenna of a MU-MIMO AP can simultaneously communicate with a different single-antenna device, such as a smartphone or tablet
- Requires that every 802.11ac transmission be sent as an A-MPDU aggregate

IEEE 802.11ad

- A version of 802.11 operating in the 60-GHz frequency band
  - Offers the potential for much wider channel bandwidth than the 5-GHz band
  - Few devices operate in the 60-GHz which means communications would experience less interference than in the other bands used by 802.11
- Undesirable propagation characteristics:
  - Losses are much higher in this range than in the ranges used for traditional microwave systems
  - Multipath losses can be quite high
  - Millimeter-wave signals generally don't penetrate solid objects

802.11ac and 802.11ad Differences

802.11ac

- Supports a MIMO antenna configuration

802.11ad

- Is designed for single-antenna operation
- Has a huge channel bandwidth of 2160 MHz

Table 13.6

IEEE 802.11ad Modulation and Coding Schemes

Physical Layer	Coding	Modulation	Raw Bit Rate
Control (CPHY)	1/2 LDPC, 32× spreading	π/2-DBPSK	27.5 Mbps
Single carrier (SCPHY)	1/2 LDPC 1/2 LDPC, 5/8 LDPC 3/4 LDPC 13/16 LDPC	π/2-BPSK, π/2-QPSK, π 2-16QAM	385 Mbps to 4.62 Gbps
OFDM (OFDMPHY)	1/2 LDPC, 5/8 LDPC 3/4 LDPC 13/16 LDPC	OFDM-OQPSK OFDM-QPSK OFDM-16QAM OFDM-64QAM	693 Mbps to 6.76 Gbps
Low-power single carrier (LPSCPHY)	RS(224,208) + Block Code(16/12/9/8,8)	π/2-BPSK, π/2-QPSK	636 Mbps to 2.5 Gbps

BPSK = binary phase-shift keying
DBPSK = differential binary phase-shift keying
LDPC = low density parity check code
OFDM = orthogonal frequency-division multiplexing
OQPSK = offset quadrature phase-shift keying
QAM = quadrature amplitude modulation
QPSK = quadrature phase-shift keying
RS = Reed-Solomon