Chapter 4

The Medium Access Control Sublayer

The contents may be based in part on “Computer Networks” by A. Tanenbaum, “, multiple standards and RFCS

MAC Sublayer

- We are dealing with broadcast and/or shared channels
- Broadcast channels are usually referred to as **multiple access channels**
- Many sources can use the channels concurrently, leading to chaos
- Need to determine who gets to use the channel
- The class of protocols that determine who accesses the channel is called **Medium Access Control** (MAC)
- When MAC exists in the datalink layer, it is called MAC sublayer

The Channel Allocation Problem

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

Static Channel Allocation

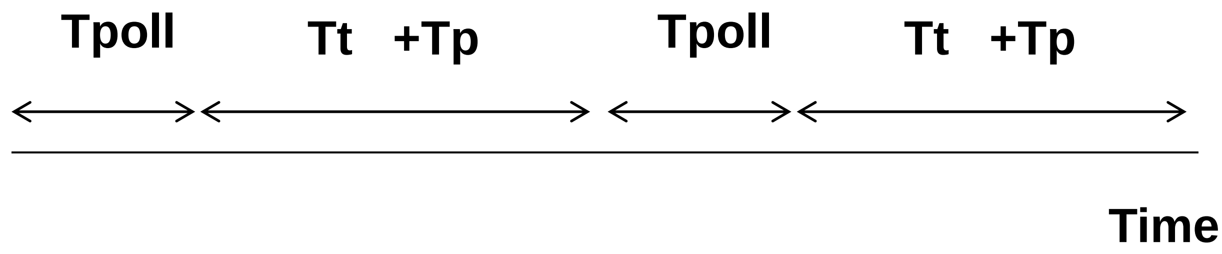
- Like dividing telephone trunk among N users
- Trunk with capacity *C* is divided using two major approaches
  - **Frequency Division Multiplexing (FDM)**
    - Divide *C* into N frequencies:
    - Each user gets a single bandwidth
    - User cannot use more than the allocated bandwidth even if channel is empty
    - If a user is not using the channel, the channel cannot be used by others
  - **Time Division Multiplexing (TDM)**
    - Divide time N time slots:
    - Each user gets to send traffic only every N^{th} slot using full capacity *C*
    - If user does not use time slot, the slot is wasted
- Problem if the number of users is greater than N
- Inefficiency if number of users is less than N
- Poor performance even if number of users is N (why?)

TDM Efficiency

- Efficiency = Useful time / Total time = Tt / Tt+Tp

  = 1 / 1+ a
- Example: Tt = 1 ms , Tp= 1ms
- Efficiency = 50%
- So what is the maximum number of users that can be connected to TDM, if each user needs 2kbps and channel Bandwidth is 4 Mbps
  - Effective bandwidth = 4Mbps * 50%= 2Mbps
  - Then Nmax * 2kbps = 2Mbps
  - **Nmax is 1000 users**

Enhancing TDM by Polling



- No slots is assigned
- Pick a station to transmit using a polling algorithm
  - Polling the stations to select the station that wants to transmit
- Efficiency = Tt / (Tpoll +Tt + Tp)
- Disadvantage: Polling time but solved the issue of static allocation.

Dynamic Channel Allocation in LANs and MANs Key Assumptions

1. Station Model.
   - *Independent stations*
   - Probability of a frame being generated in an interval of length Δt depends on $\lambda\Delta t$
     - λ is the rate of generation and is constant,.
     - But the generation process itself is *random*
   - Station is blocked until the frame has been successfully transmitted.
2. Single Channel Assumption.
   - All stations can send and receive from the channel
3. Collision Assumption.
   - When two stations transmit in *overlapping periods*, both frames are corrupted and both need to be re-transmitted
4. Time allocation

   (a) Continuous Time: Station can transmit any time.

   (b) Slotted Time:
   - Time divided into slots
   - Transmission starts at the beginning of a slot
   - Frame must fit a slot
   - Multiple frames can be transmitted in a slot
5. (a) Carrier Sense: Stations can tell if the channel is in use

   (b) No Carrier Sense: Stations cannot sense the channel

Dynamic 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

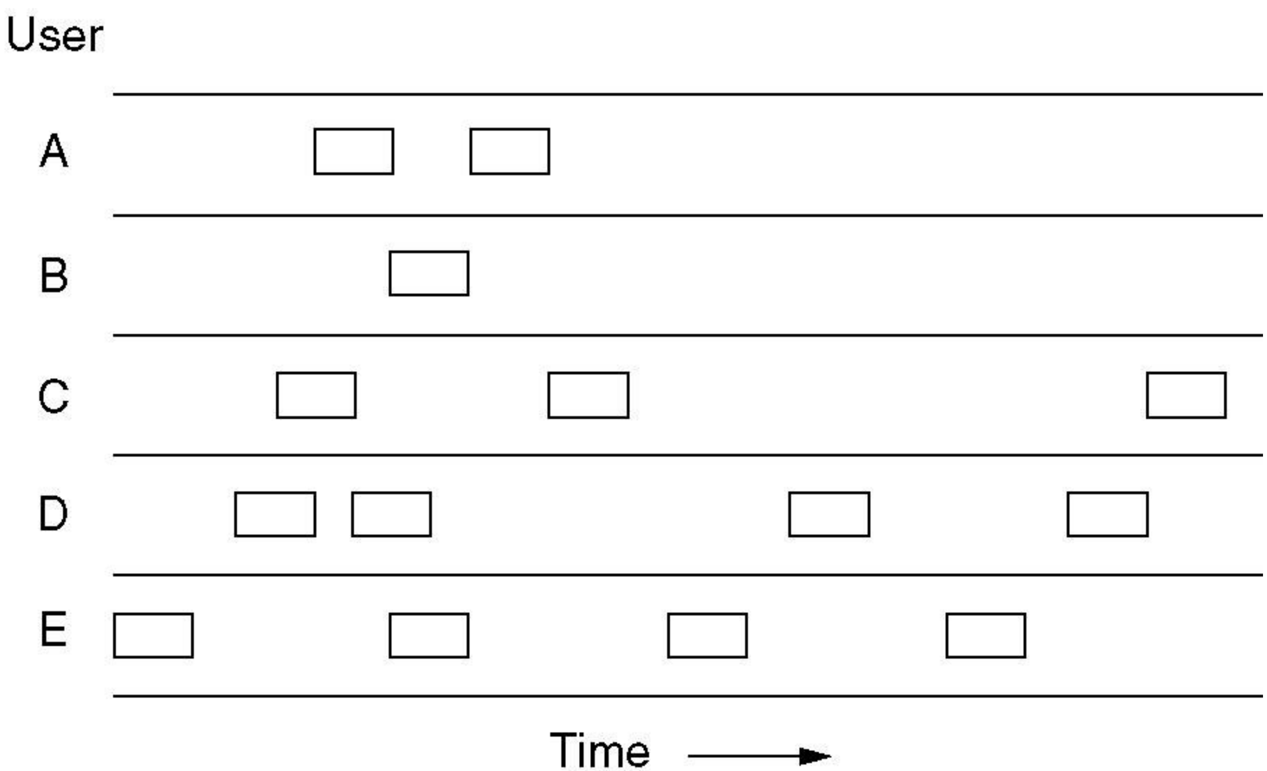
- Simple idea: Station does NOT listen to channel to check if other station is transmitting, so **Station transmits any time**
  - Station does **not** check if other station is already transmitting
- Detect collision, and **Retransmit** after random delay and a maximum number of times
- In many cases (wireless, coaxial cable,…, etc), a transmitter can listen to detect that its frame was received:
  – Almost immediate in LAN
  – Long delay in WAN and satellite (e.g 270 msec), Need ACK if listening while sending is impossible
- Old protocol, initially used in wireless, was rediscovered when cable internet was introduced
- Systems where multiple users use a common resource in a way leading to conflict are sometimes called **contention** systems

How a node to detect a Collision?

1. Feedback Property of Broadcast Channel, broadcast channel transmits the information to all nodes, if a node can hear multiple transmissions at the same time, the node will conclude that there is a collision
2. If Acknowledgment is received then no collision

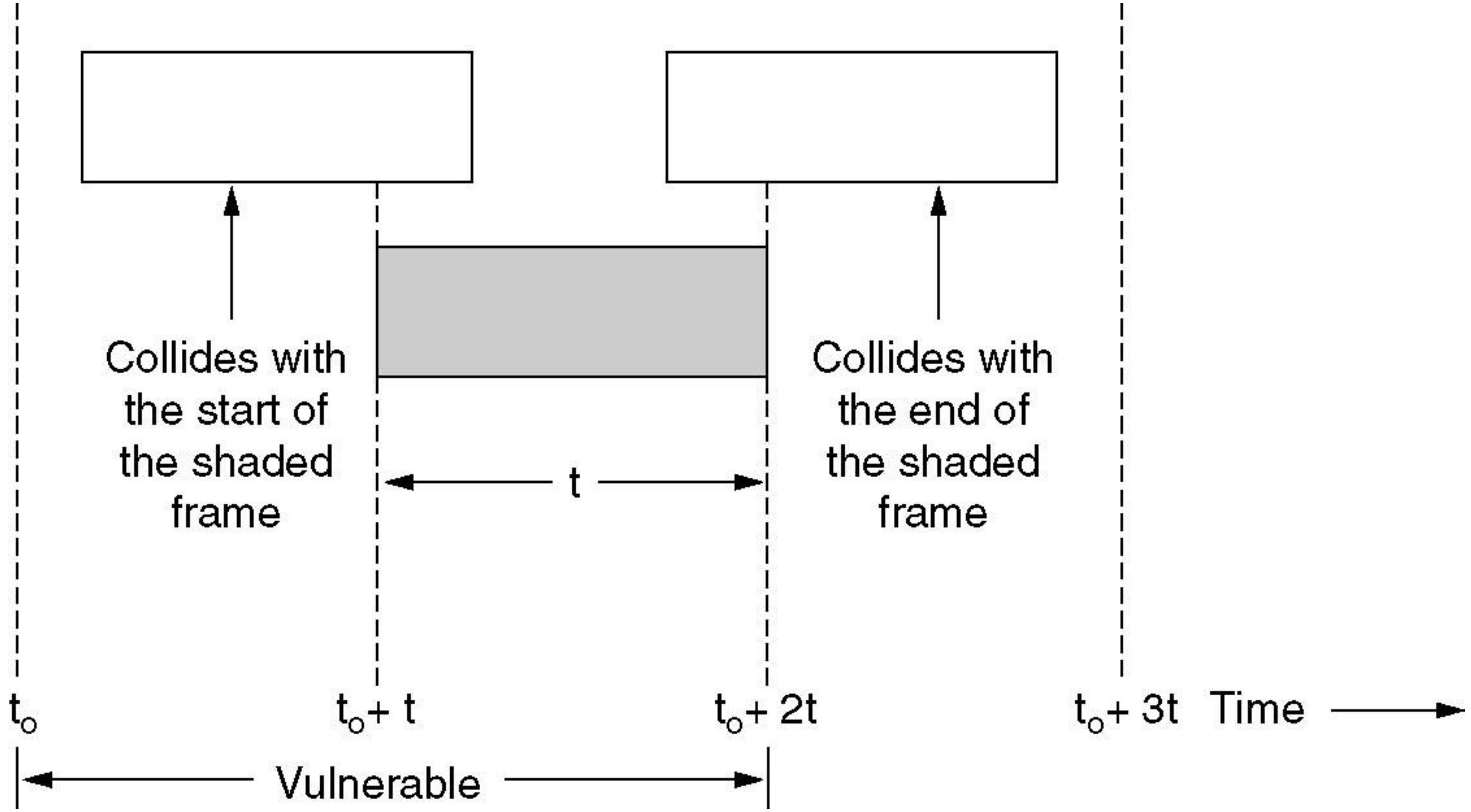
Pure ALOHA

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



Pure ALOHA: When does Collision Occur

Vulnerable period for the shaded frame.



Two possibilities of collision; either collision with a previous frame or a following frame, so no frame should be transferred during the time of two frame time

Remember that a station does **not** check if other station(s) are already transmitting before it transmits

How Good is Pure ALOHA

- We want to calculate the efficiency of Aloha
  - I.e. What fraction of all transmitted frames escape collision?
- Let all frames be fixed length of one time unit
- The unit of time is the time it takes to transmit *one frame*
  - i.e. $t = 1$ means the a single frame time
  - Rate of transmission is per frame time.
- Assume *infinite independent* users

- Offered Load is modeled by Poisson Distribution with rate G
  - Probability (k Packets are generated in t frame time) =

$$\frac{(t\,G)^{k} \; * \; e^{-tG}}{!K}$$

Pure Aloha Throughput

- Throughput: The rate of packets that get transmitted successfully
- Let P_0 be probability that a packet does *not* suffer collision
- Throughput = S = G $P_{(\text{ no collision})}$
  - S = G * (Probability that no other frame is transmitted in the vulnerable period)
  - S= G* (Probability that zero frame is transmitted in 2frame time)
  - K =0, t =2 $\Longrightarrow$ S = Ge^{-2G}
- To get maximum throughput differentiate w.r.t G and equate to zero
  - ➢ **G=0.5**
- Substitute with G=0.5 then **Smax = 18.4%**

Slotted ALOHA

- Time is divided into discrete slots, each of length one frame
- User transmits only at the beginning of the slot
  - Still does **<u>not</u>** check if other stations are transmitting before it transmits
- Need synchronization
  - E.g. special station transmit a clock
  - Central synchronization station and other schemes ….
  - In general, distributed synchronization is never 100% accurate

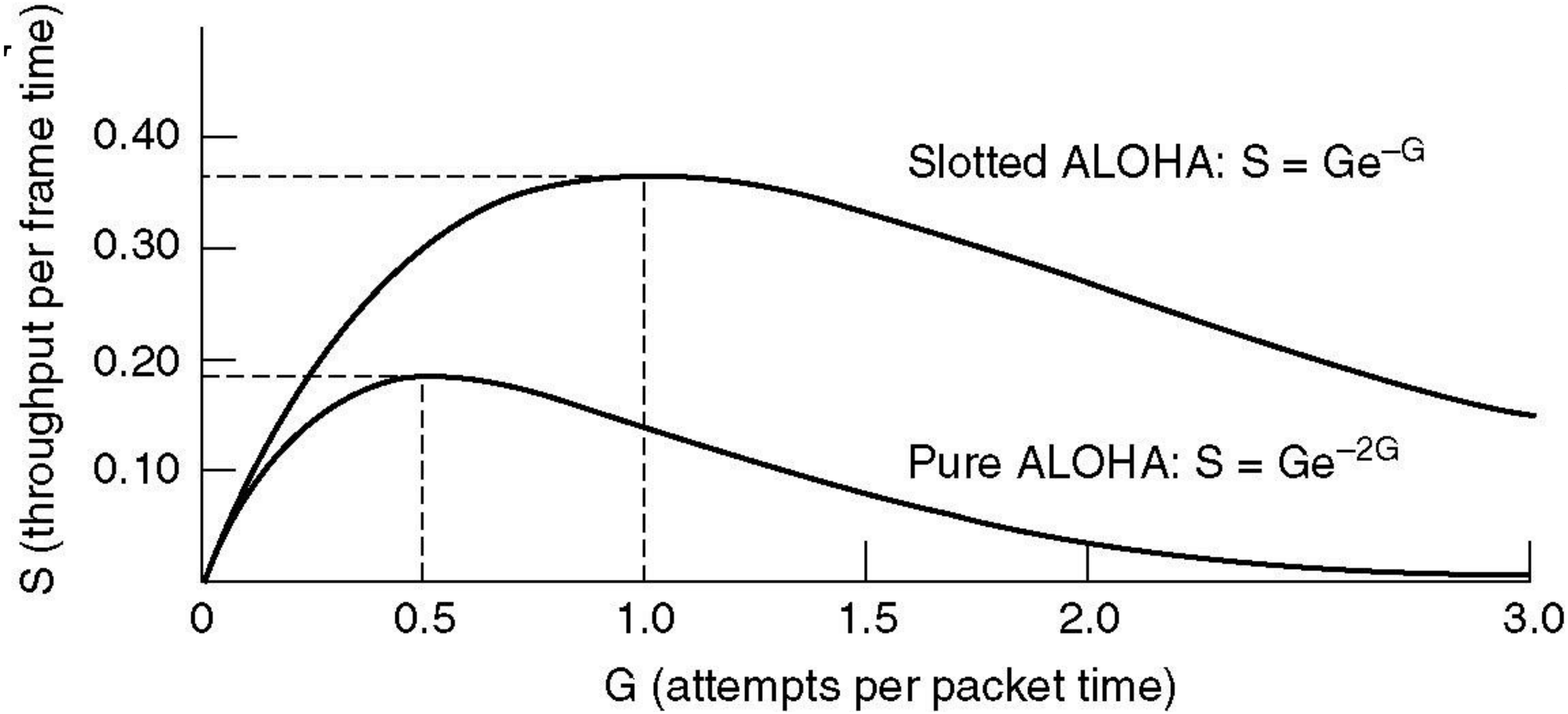
- **Slotted ALOHA makes vulnerable period <u>half</u> of pure ALOHA**

- **Vulnerable time is t not 2t as in pure ALOHA**

$$S = G\, e^{-G}$$

- **Maximum at G=1 , and S is 36.8%**

Pure vs Slotted ALOHA



CSMA (Carrier Sense Multiple Access)

- ALOHA:
  - bad performance because there is no co-ordination
  - many collisions ⇒ poor utilization (*1/e*)
- In LANs, a station can detect what other stations are doing
- Carrier Sense Protocols are protocols in which **a station *listens* for a carrier** and *acts* accordingly
- We will study few types
  - **Persistent CSMA**
  - **Non-persistent CSMA**
  - **CSMA/CD**

CSMA and Propagation Delay

- Important factor in performance
- A station starts
- Second station starts before signal of the first station arrives
- Longer the propagation delay ⇒ more collisions
- Collision can also happen even in case of zero delay. E.g.
  - Two stations become ready while 3rd station is transmitting
  - As soon as the 3rd station stops, both start sending ⇒ collision

1-Persistent CSMA

1. Listen to the channel
2. Channel Free: Transmit
3. Channel Busy: Wait while **<u>continuously</u>** listening
   - **Transmit** <u>as soon as</u> the channel becomes free
4. On collision:
   - waits a random period
   - Start all over again

Non-persistent CSMA

1. Listens to the channel
2. Channel Free: Transmit
3. Channel busy:
    - **<u>Wait for a random period</u>** instead of continuously listening
    - Repeats steps again
4. On collision:
    - waits a random period
    - Start all over again

- Less greedy
- Better utilization

p- persistent CSMA

- Works with ***slotted channels***
- When the station is ready to send, it applies the following steps

1. Listens to channel
2. Channel is busy:
   - Wait till the next slot
   - Repeat again starting from step (1)
3. Channel is free
   - **Transmit** with **probability p** OR **Wait** for the next slot with **probability q** = 1-p
   - If **Transmit**

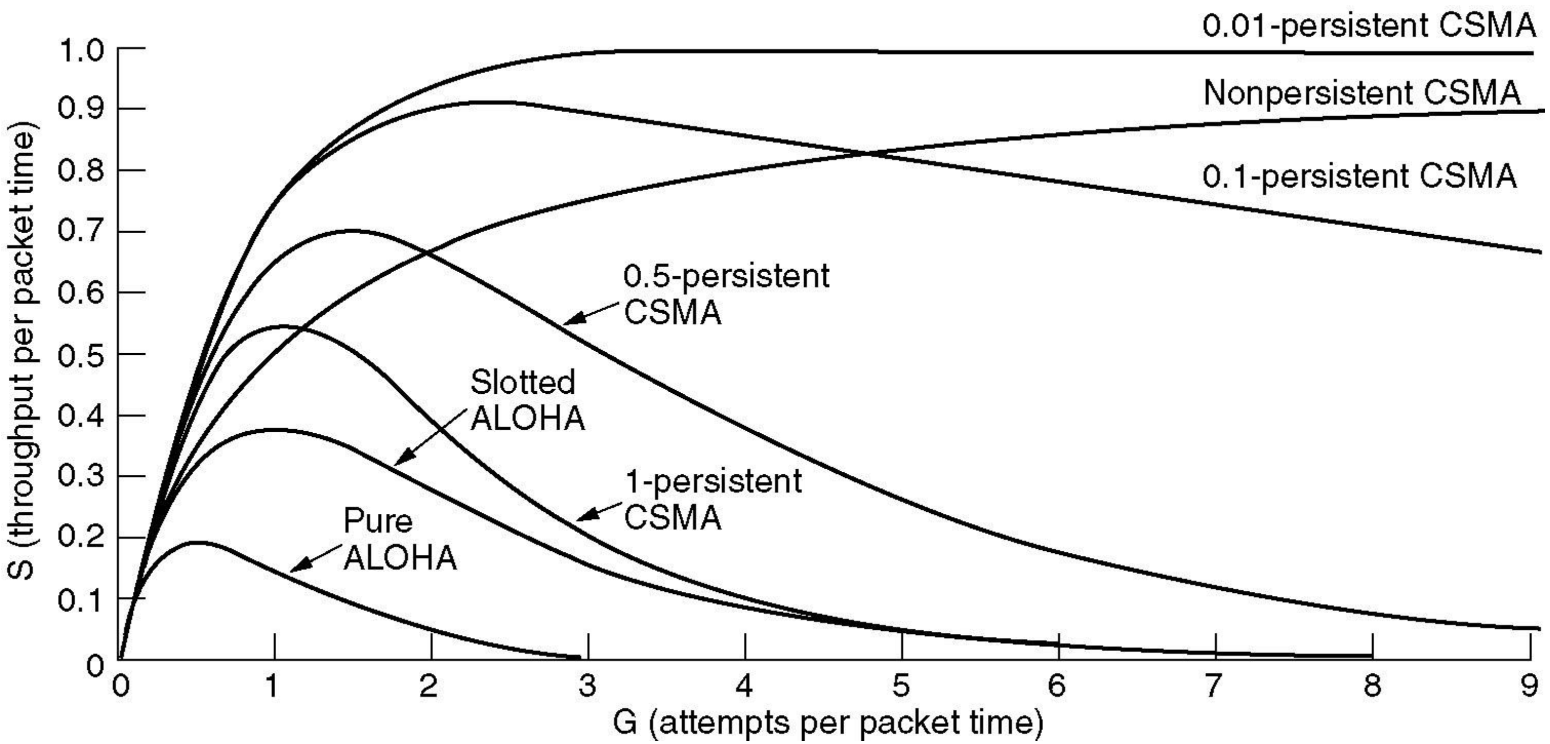
     If transmission is successful → Terminate

     Else Go to step (1)
   - If **Wait**
     - wait till next slot
     - Listen to channel
     - If the channel is ***busy*** or there is ***collision***
       - Wait for *random period*
       - Repeat again from step (1)
     - Else (channel is free)
       - Go to step (3)

As p is smaller:
- Better utilization
- But longer waiting time for stations

Persistent and Nonpersistent CSMA

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



CSMA with Collision Detection CSMA/CD

- Abort as soon as collision is detected
- If two stations start simultaneously, collision is detected almost immediately
- Save time and BW because the rest of the transmission time is not wasted on bits that can never be recovered
- Allows the remaining portion to be used by other stations
- Widely used in MAC sub-layers of LANs, particularly Ethernet
- CSMA/CD is inherently *half duplex*

CSMA/CD

- Station listens to channel
- If busy, continuously listen or wait for a random period
- Start transmission when the channel is free
- On Collision Detection
  - **Aborts immediately**
  - Waits for random period of time
  - Repeats steps

- This means that the transmission pattern consists of alternating *contention and transmission* periods with idle periods when the stations are not sending (e.g. station has nothing to send)
- The time the station takes to detect collision is very important
  - Minimum time is the propagation delay between the two stations

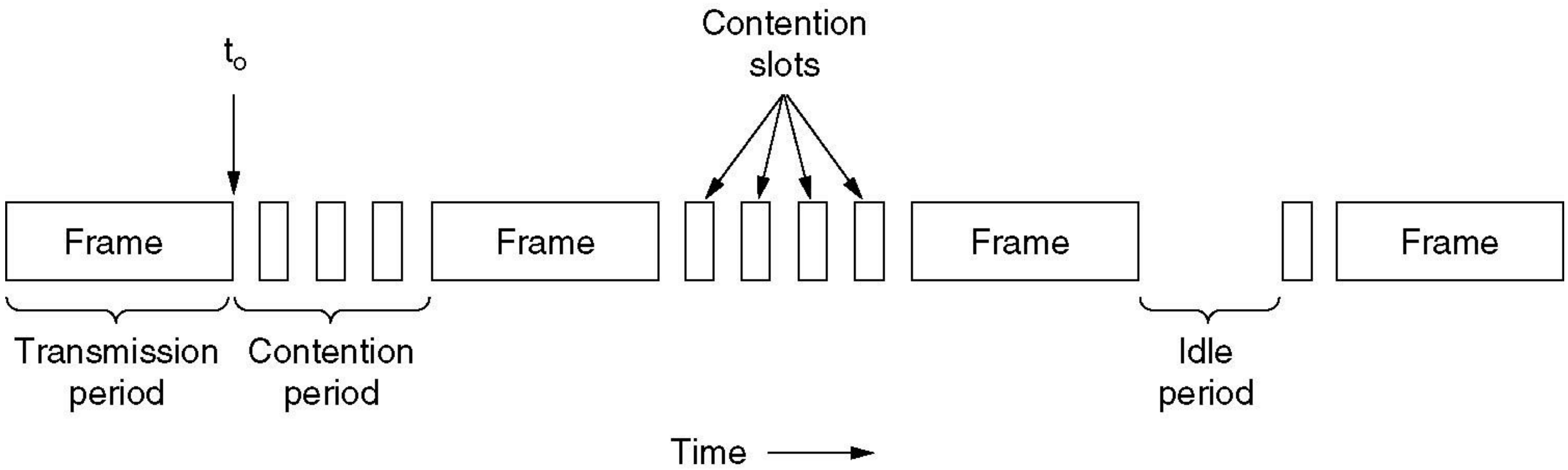
Collision Detection

- Station may detect collision by
  - Comparing received signal /pulse with the transmitted signal

- When there is data waiting to be sent, each transmitting NIC also monitors its own transmission. If it observes a collision (excess current above what it is generating, i.e. > 24 mA for coaxial Ethernet), Collisions can be spotted since they are generally higher in signal amplitude than normal signals.

- The station stops transmission immediately and instead transmits a 32-bit jam sequence.

CSMA with Collision Detection



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

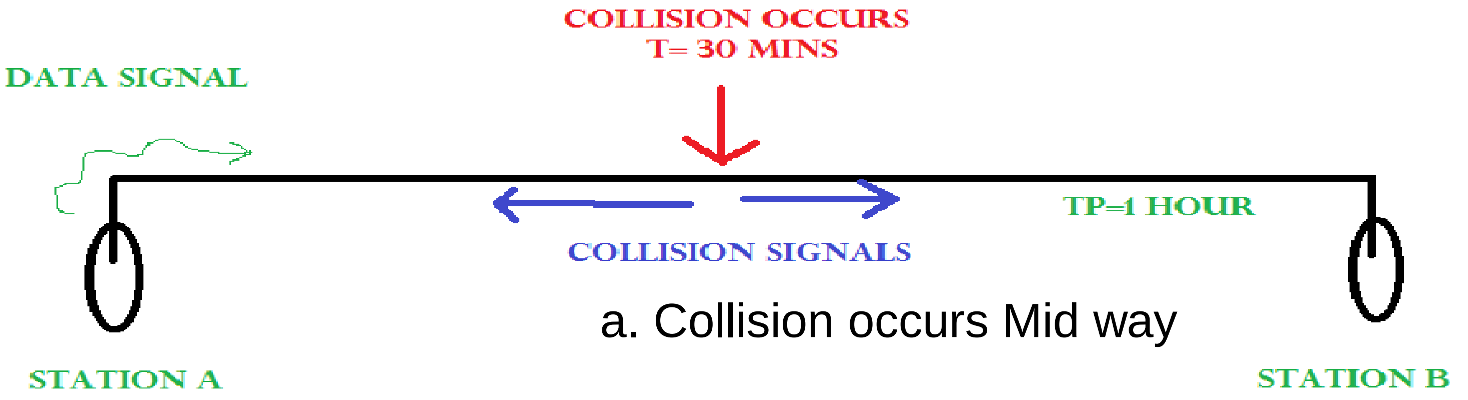
CSMA with Collision Detection

- If the signal takes τ to traverse the entire cable, then a station is sure that it successfully sent the data after 2τ
- Collision detection is an analog process
  - Encoding must allow for collision detection
- If a collision has occurred, the signals will corrupt each other and the communication medium’s state will be different from what the station is transmitting
- easy in wired LANs: measure signal strengths, compare transmitted, received signals
- difficult in wireless LANs: received signal strength overwhelmed by local transmission strength

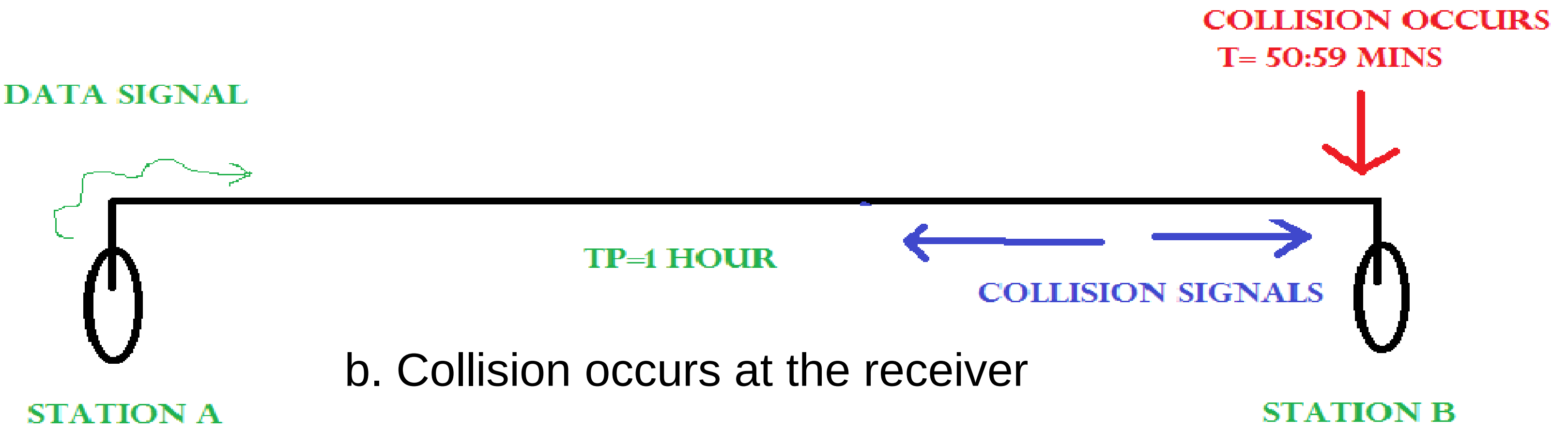
Collision Detection
Transmission Time Tt

- Two stations, A & B, Propagation Time: Tp = 1 hr (Signal takes 1 hr to go from A to B)
- (a) At time t=0, A transmits its data. At t= 30 mins Collision occurs. After collision occurs, a collision signal is generated and sent to both A & B to inform the stations about collision. Since the collision happened midway, the collision signal also takes 30 minutes to reach A & B.
- Therefore, at t=1 hr: A & B receive collision signals.
- **Transmission time (Tt) should be > Propagation Time (Tp)**
- Devices involved in the collision keep transmitting for a short period of time, to make sure all devices on the network see the collision (also referred to as the jamming signal)

Collision Scenarios



a. Collision occurs Mid way



b. Collision occurs at the receiver

Collision Detection
Collision Detection time / Frame Length

- (B) Maximum collision time to detect that a system can take to detect if the collision was of its own data.
  - **Tt > = 2 * Tp condition for collision detection**
- **What should be the minimum length of packet to be transmitted?**

  Transmission Time = Tt = Length of the packet/ Bandwidth of the link

  [Number of bits transmitted by sender per second]

  Substituting above, we get,

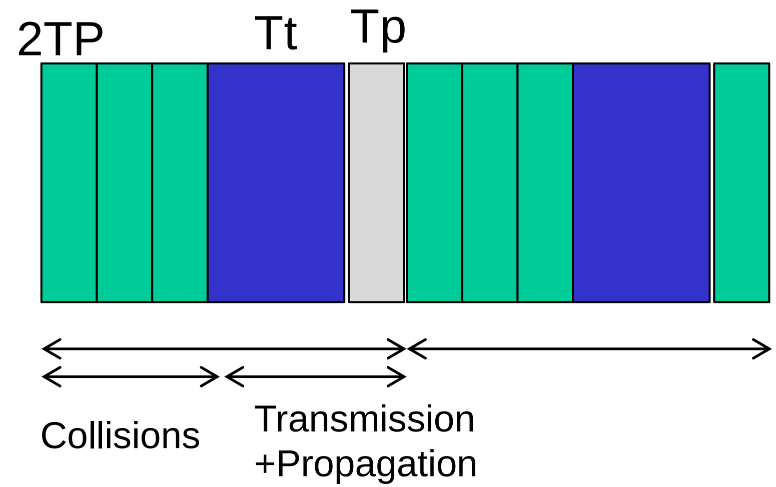
  Minimum Length of the packet/ Bandwidth of the link>= 2 * Tp
  - **L >= 2 * Tp * Bandwidth of the link**

Frame Length

- The reason for having a lower bound on the frame length is to prevent a computer from completing the transmission of a short frame before the first bit of the frame has reached the far end of the cable, where it may collide with another frame

L >= 2 * Tp * Bandwidth of the link

Efficiency of CSMA/CD (1/2)



1. **Efficiency** =

   Tt / (C*2*Tp + Tt + Tp)

   Tt → transmission time,

   Tp → propagation time ,

   C → number of collisions

2. **Maximum Probability of Success:**
   - Assume N stations are connected and every station wants to send the data with a probability p
   - For success transmission, only 1 station should transmit while others shouldn't.
   - Let p be the probability to transmit data successfully

     P(success) = $^{n}C_{1} * p * (1-p)^{n-1}$ (using Binomial distribution)
   - To get Pmax we differentiate w.r.t. **p** and equate to 0, d(Psuccess)/dp =0
   - Then p=1/n

     Pmax= $n * 1/n * (1-1/n)^{n-1} = (1-1/n)^{n-1}$

     If n → infinity and take the limit then **Pmax = 1/e**

Efficiency of CSMA/CD (2/2)

3. How many times should I try before getting the first success ?
   - It is 1/Pmax = 1/1/e = e **(binomial distribution)**
   - Then **the number of collisions before the first success = e**
   - So we have e collisions before success transmit

$$\textbf{Efficiency} = \frac{T_t}{2 \cdot \mathbf{e} \cdot T_p + T_t + T_p} = \frac{1}{1 + 6.44\,a}$$

$a = T_p/T_t$, $T_p = d/v$ $T_t = L/B$

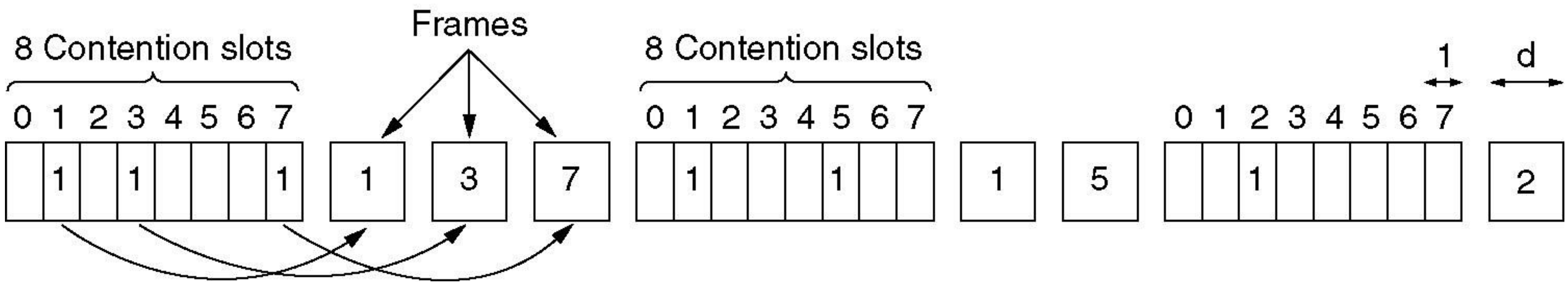
– If distance increases ⟹ efficiency decreases so CSMA/CD is useful for LANs not WANs

– For Bigger Packets ⟹ better efficiency

Collision-Free Protocols

- CSMA/CD reduces collisions, but there is still contention periods
- We want protocol with no collision at all
- Not widely used like CSMA
- Assumptions
  - *N* stations, each with address *0* to *N-1*
  - Propagation delay is <u>negligible</u>
- Two schemes
  - Bit-map protocol
  - Binary count down

Collision-Free Protocols
1. Bitmap Protocol



- Alternate between contention period and transmission period
- Contention period has *N* 1-bit slots
- If station *j* that has a frame queued, it inserts *1* in slot *j*
- At the end of the contention slots, all stations know who wants to send
- Stations that inserted bits in the contention slots transmit in order
- If a station has a packet queued right after its bit passes in the contention period, it has to wait for next contention period
- Protocols that announce its intention to send before sending are called ***reservation protocols.***

Collision-Free Protocols
How good is Bitmap Protocol

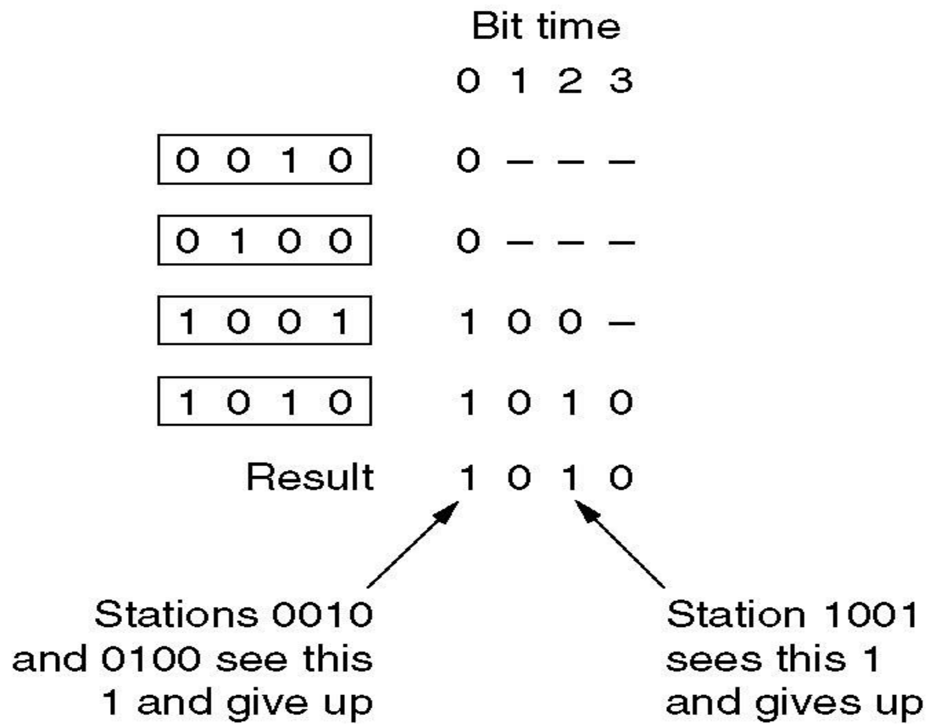
- Lets assume that a frame has *d* bits.
- For a channel with *low* load conditions N bits frame (reservation frame) will keep turning
  - To send a d-bits frame we need approximately $(N+d)$ bits
  - Efficiency $\approx d/(N+d)$

- For channels with a *high* load condition (1 bit per frame)
  - To send a *d*-bits frame we need approximately $(d+1)$ bits
  - Efficiency $\approx d/(1+d)$
- Does not scale well with large N (thousands)

Collision-Free Protocols 2. Binary Countdown

- Fundamental assumption: delay is negligible
  - A station sees the bit of the transmitting station *instantaneously*
- Each station has a *binary* ID
- When a station wants to transmit, it announces its address, starting with the *higher order bit first*
- Each station *bitwise ORs* the bit at position j from all stations
- A station receiving address announcement for bit position *j* containing *ORed value* of "1" while its address has "0" in bit position *j* goes out of the competition
- Eventually, the station whose ID has the *highest numerical value* wins.
- Inherently gives *priority* to station with *higher ID*

Collision-Free Protocols
Binary Countdown



- Efficiency is $d/(d+\ log_2N)$
- If the address of the station must be prepended to the frame, then the log_2N bits are not wasted

Ethernet

1. Ethernet Types
2. Classic Ethernet MAC Sublayer Protocol
3. Ethernet Encoding
4. Wireless LANS
5. Data Link Layer Switching

1. Ethernet Types

a. Classic Ethernet
b. Switched/Fast Ethernet
c. Gigabit/10 Gigabit Ethernet

a. Classical Ethernet

Classical Ethernet Types:

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

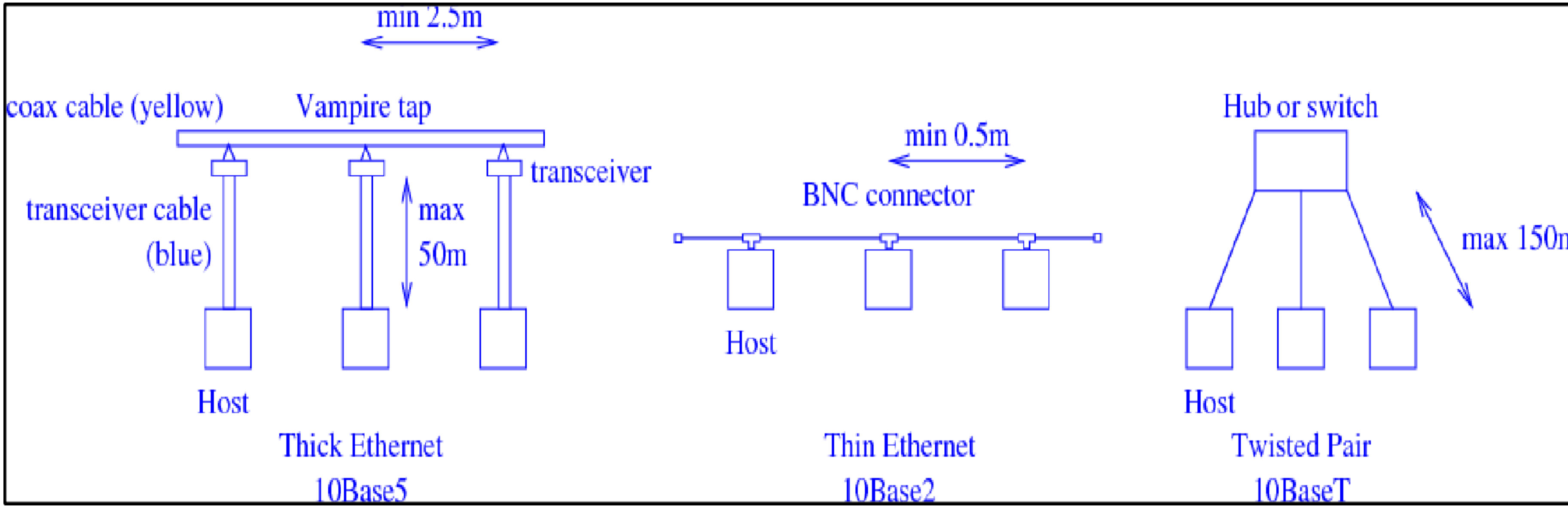
RJ-45

Optical Fiber Connector

FIGURE 36. BNC connectors

BNC Connector
coaxial cable

Ethernet Cabling

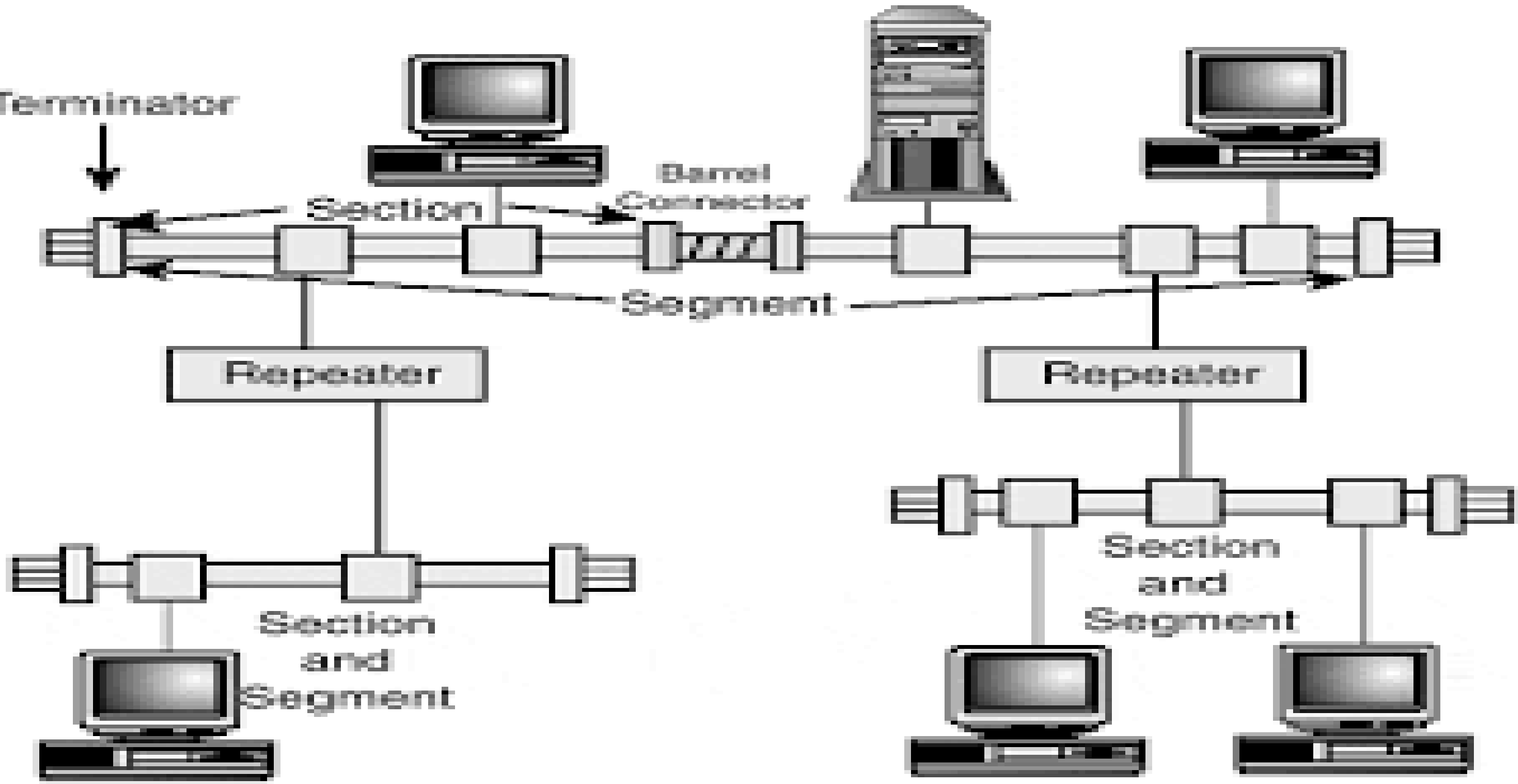


(a) 10Base5, (b) 10Base2, (c) 10Base-T

Coaxial Ethernet 5-4-3 rule

- You can have up to **five** segments, connected by **four** repeaters, with no more than **three** of these segments being mixing segments.
- In the days of coaxial cable networks, this meant that you could have up to three mixing segments of 500 or 185 meters each (for 10Base5 and 10Base2, respectively) populated with multiple computers and connected by two repeaters.
- You could also add two additional repeaters to extend the network with another two cable segments of 500 or 185 meters each, as long as these were link segments connected directly to the next repeater in line, with no intervening computers

Ethernet LAN with 3 segments



Network Repeater

- A repeater is an electronic device that relays a transmitted signal. It receives a signal on a specific frequency, then amplifies and rebroadcasts it. By amplifying the signal, a repeater increases the transmission range of the original signal.

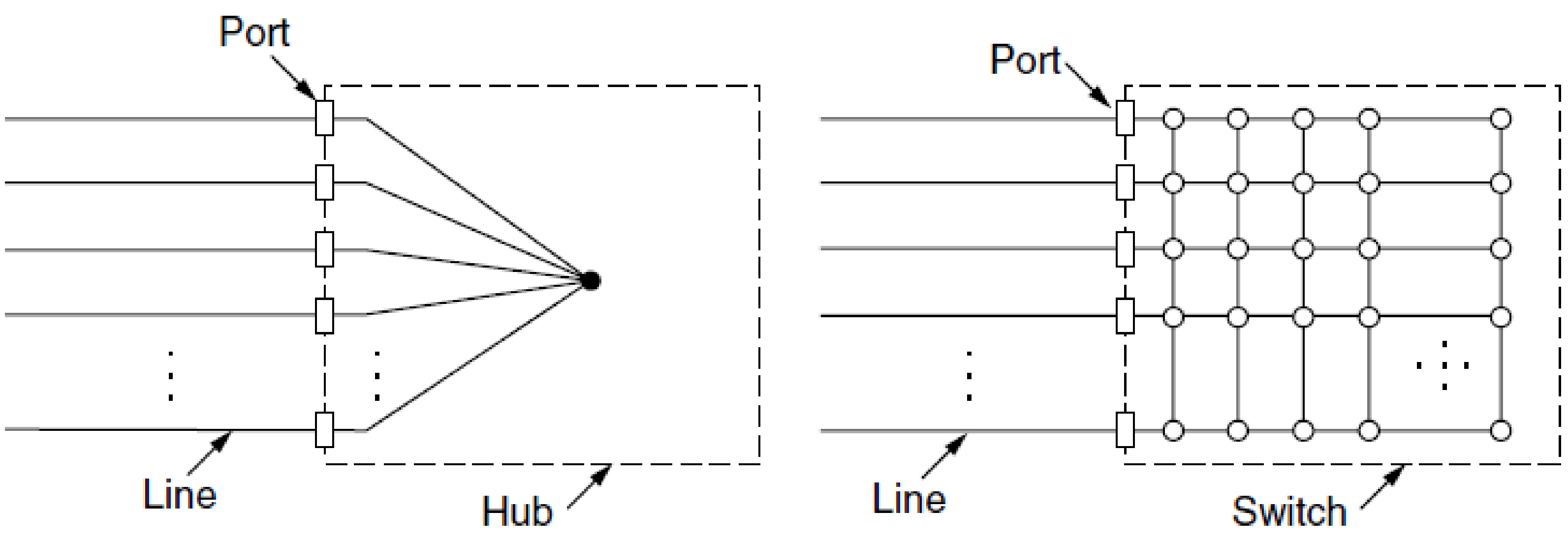
b. Fast Ethernet

Fast Ethernet cabling.

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

Fast Ethernet Implementations

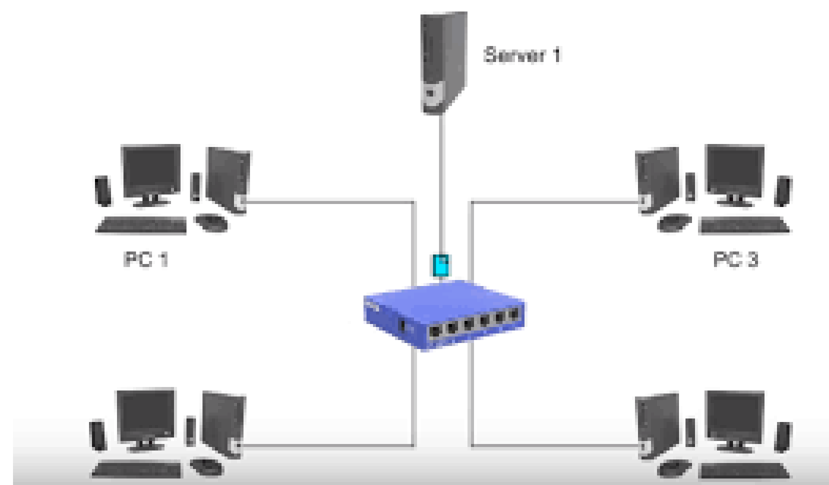
- Implemented using Hub or Switch
- Hubs wire all lines into a single CSMA/CD domain
- Switches isolate each port to a separate domain
  - Much greater throughput for multiple ports



Network Hub

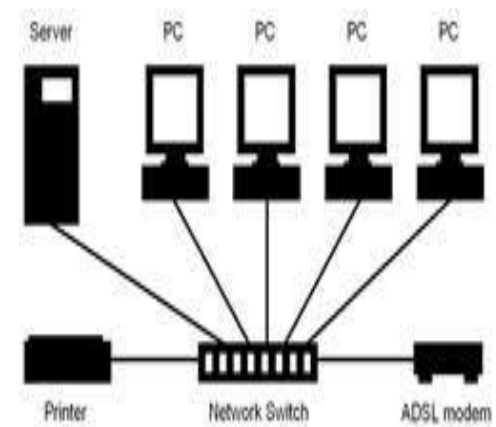
- A network hub is a device that allows multiple computers to communicate with each other over a network.
- A hub simply echoes all inputs to all outputs
- Provides a **single collision** domain
- The available bandwidth shared between all the hosts

Hub



Network Switch

- A switch is a high-speed device that receives incoming data packets and redirects them to their destination on a local area network (LAN).
- A switch understands the link layer and forwards a packet to the appropriate single output
- Each output cable is now a **separate collision domain, i.e.** The full bandwidth available on each output
- **Collisions only if two hosts send to the same destination simultaneously**



Example 1: A wired client-server network

Hub vs. Switch

- Switches are similar to hubs, only smarter.
- A hub simply connects all the nodes on the network -- communication is essentially in a haphazard manner with any device trying to communicate at any time, resulting in many collisions.
- A switch, on the other hand, creates an electronic tunnel between source and destination ports for a split second that no other traffic can enter. This results in communication without collisions.

c. Gigabit / 10 Gigabit Ethernet

- Gigabit Ethernet is commonly run over twisted pair

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 is being deployed where needed

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

- 40/100 Gigabit Ethernet is under development

Summary of Ethernet Types (1)

Designation	Supported Media	Maximum Segment Length	Transfer Speed	Topology
10Base-5	Coaxial	500m	10Mbps	Bus
10Base-2	ThinCoaxial (RG-58 A/U)	185m	10Mbps	Bus
10Base-T	Category3 or above unshielded twisted-pair (UTP)	100m	10Mbps	Star,using either simple repeater hubs or Ethernet switches
1Base-5	Category3 UTP, or above	100m	1Mbps	Star,using simple repeater hubs
10Broad-36	Coaxial(RG-58 A/U CATV type)	3600m	10Mbps	Bus(often only point-to-point)
10Base-FL	Fiber-optic- two strands of multimode 62.5/125 fiber	2000m (full-duplex)	10Mbps	Star(often only point-to-point)

Summary of Ethernet Types (2)

Designation	Supported Media	Maximum Segment Length	Transfer Speed	Topology
100Base-TX	Category5 UTP	100m	100Mbps	Star,using either simple repeater hubs or Ethernet switches
100Base-FX	Fiber-optic- two strands of multimode 62.5/125 fiber	412 meters (Half-Duplex), 2000 m (full-duplex)	100 Mbps, (200 Mb/s full-duplex mode)	Star(often only point-to-point)
1000Base-SX	Fiber-optic- two strands of multimode 62.5/125 fiber	260m	1Gbps	Star,using buffered distributor hub (or point-to-point)
1000Base-LX	Fiber-optic- two strands of multimode 62.5/125 fiber or monomode fiber	440m (multimode) 5000 m (singlemode)	1Gbps	Star,using buffered distributor hub (or point-to-point)
1000Base-CX	Twinax,150-Ohm-balanced, shielded, specialty cable	25m	1Gbps	Star(or point-to-point)
1000Base-T	Category5	100m	1Gbps	Star

2. Ethernet MAC Sublayer Protocol

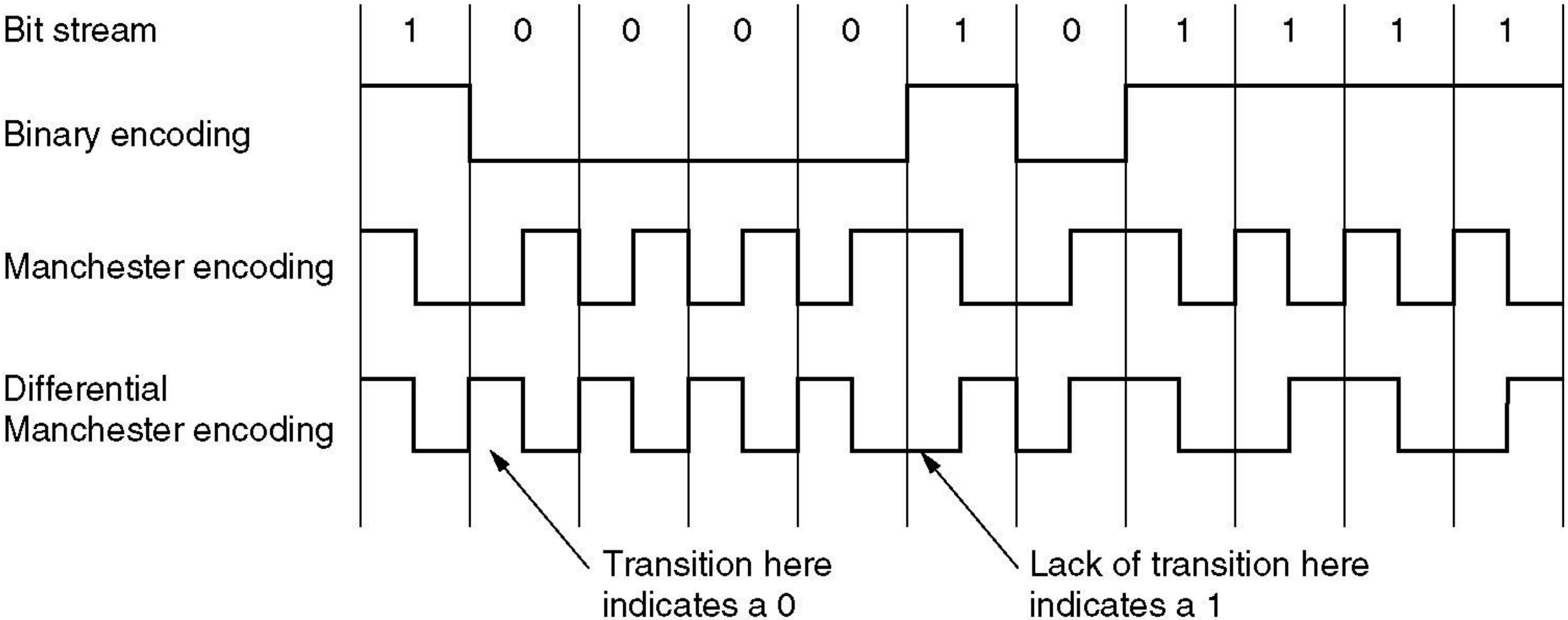
- MAC protocol is 1-persistent CSMA/CD with Binary Exponential Back off
- Random delay (backoff) after collision is computed with BEB (Binary Exponential Backoff) : after i collisions, a random number between 0 and 2i − 1 is chosen, and that number of slots is skipped

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) Ethernet DIX, (b) IEEE 802.3.

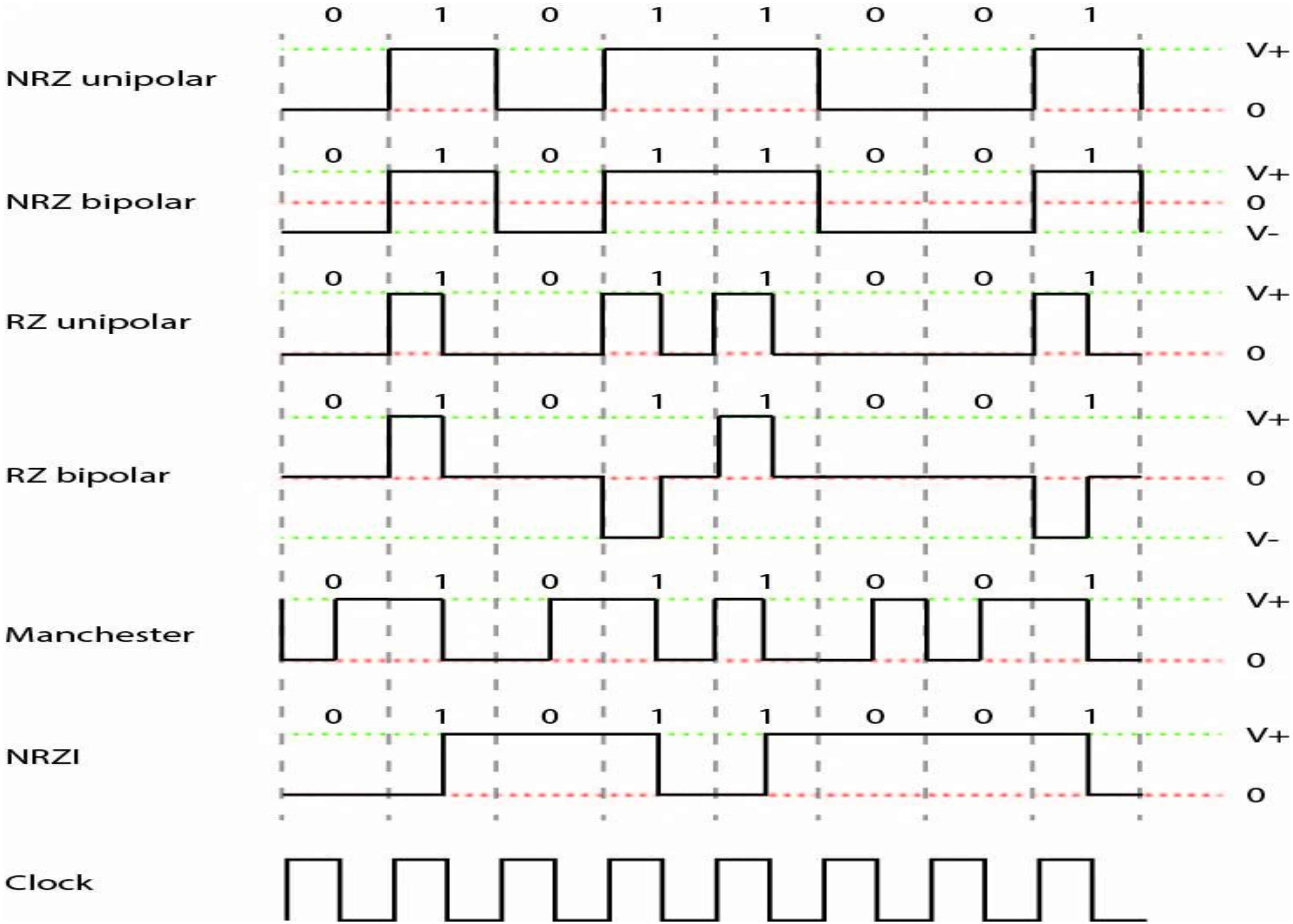
3. Encoding

Classical Ethernet uses Manchester Encoding



- Manchester encoding use voltage *transitions*, instead of voltage *levels*, to represent ones and zeros
- Diff Manchester : a zero bit is indicated by a transition at the beginning of the bit-time

More on Encoding

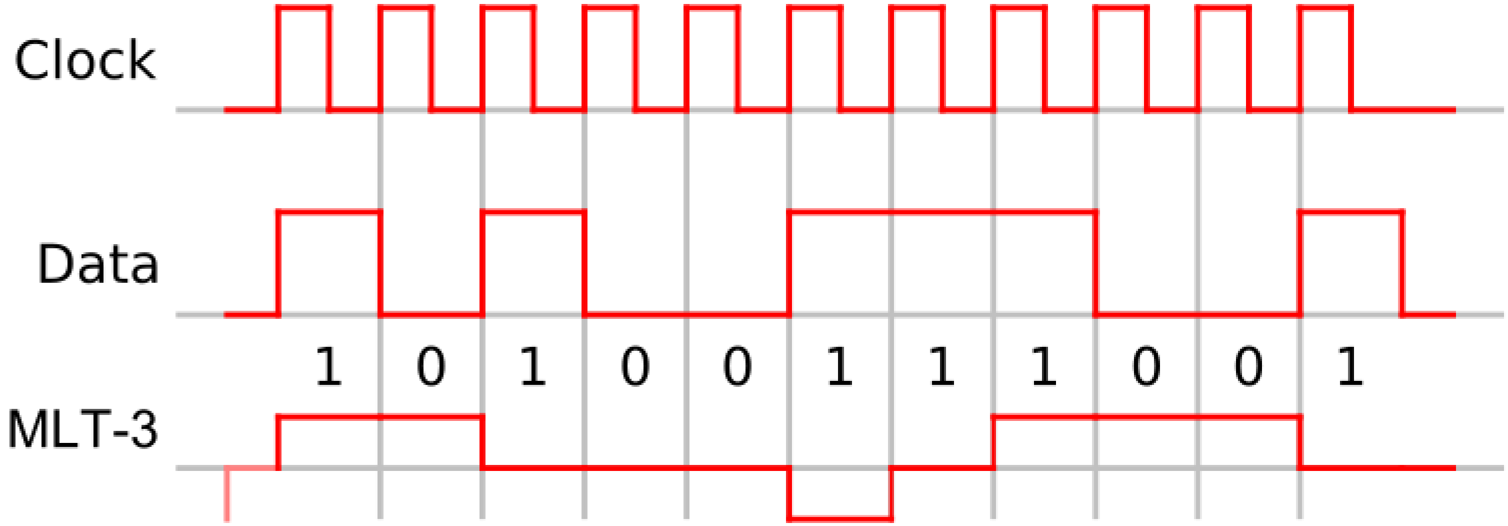


MLT-3 Encoding (Multi Level Transmit)

MLT-3 encoding uses three levels (+V, 0, -V) and three transition rules to move between levels:

- If the next bit is zero ('0'), there is no transition.
- If the next bit is one ('1) and current level is not zero '0', the next level is 0.
- If the next bit is one ('1) and current level is zero ('0'), the next level is the opposite of the last nonzero level.

MLT-3 Encoding (Multi Level Transmit)



pattern **1, 0, -1, 0**.

MLT-3 Encoding provides 100Mbps out of a 31.25MHz signal (1/4 of 125 MHz)

4bit/5bit Encoding

- 4B/5B encoding is a type of 'Block coding'. This processes groups of bits rather than outputting a signal for each individual bit (as in Manchester encoding).

- A group of 4 bits is encoded so that an extra 5th bit is added. Since the input data is taken 4-bits at a time, there are 2^4, or 16 different bit patterns.

- The encoded bits use 5-bit, and hence have 2^5 or 32 different bit patterns. As a result, the 5-bit patterns can always have two '1's in them even if the data is all '0's a translation occurs to another of the bit patterns.

- This enables clock synchronizations required for reliable data transfer

4B/5B Table

Input	4B/5B	Input	4B/5B
0000	11110	1000	10010
0001	01001	1001	10011
0010	10100	1010	10110
0011	10101	1011	10111
0100	01010	1100	11010
0101	01011	1101	11011
0110	01110	1110	11100
0111	01111	1111	11101

- Non data codes are used for control signals

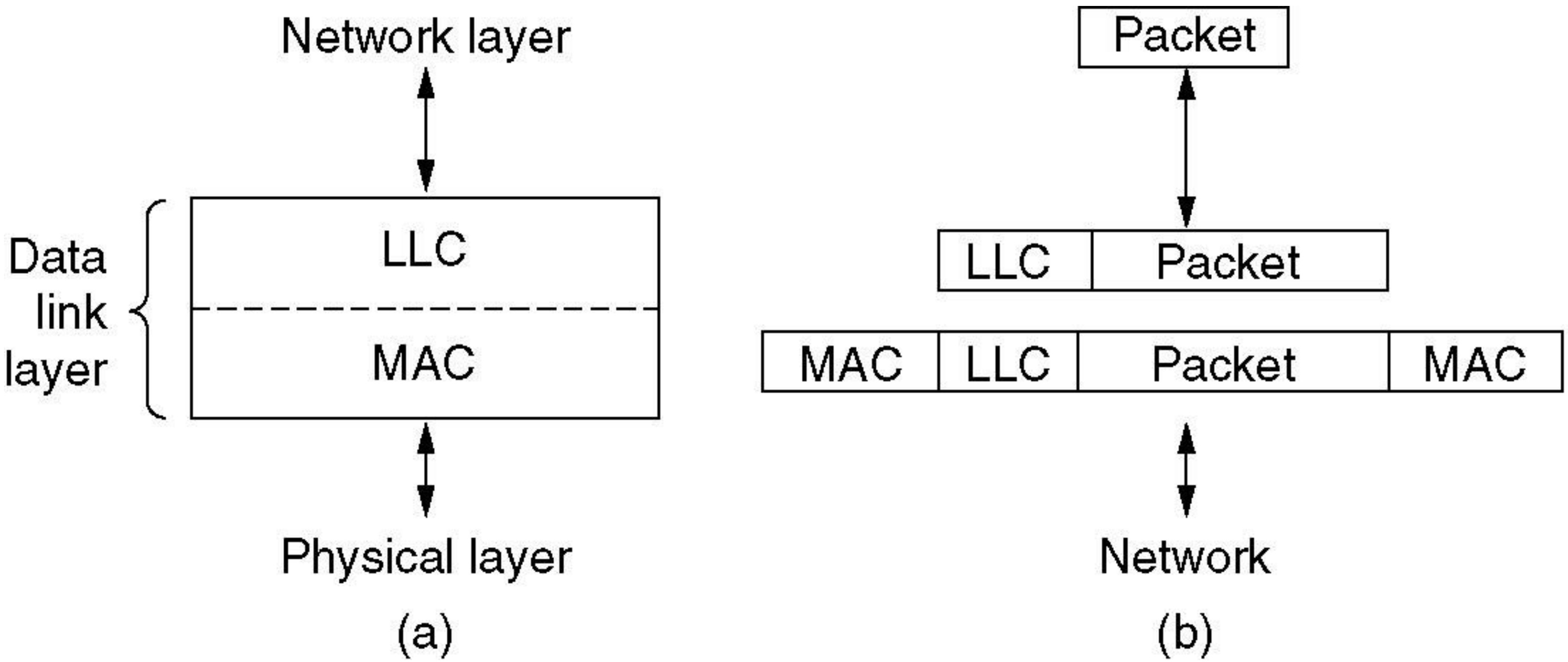
Ex: IDLE 11111; QUIET 00000 ; HALT 00100; etc.

- Overhead is only 25%, one extra bit
- The clock frequency is 125MHz. The reason for this is due to the A 100MHz signal would not have been enough to give us 100Mbps, we need a 125MHz clock

4. Wireless LANs

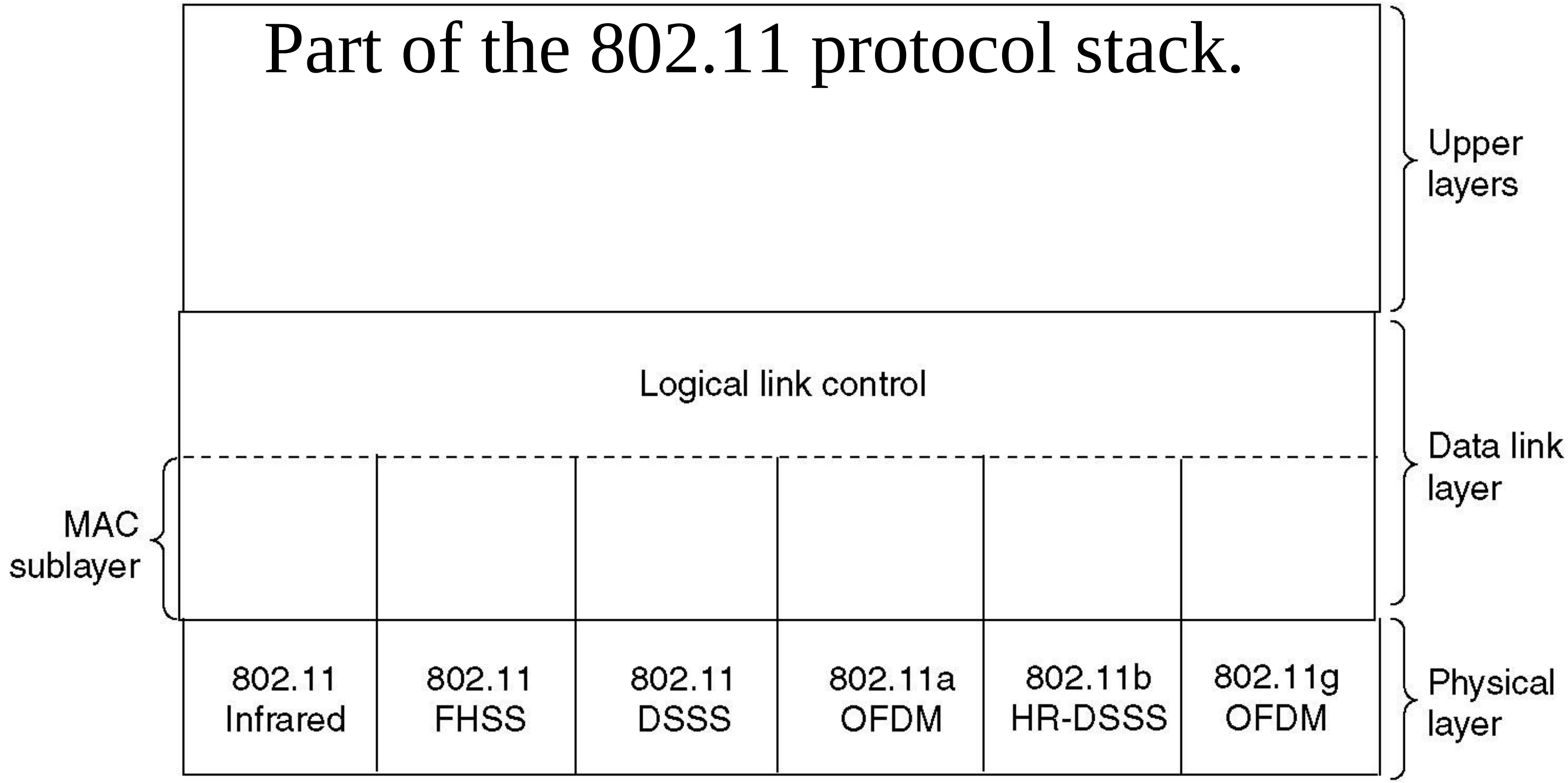
- 802.11 Protocol
- 802.16 Protocol for Broadband Wireless LAN

IEEE 802.2: Logical Link Control



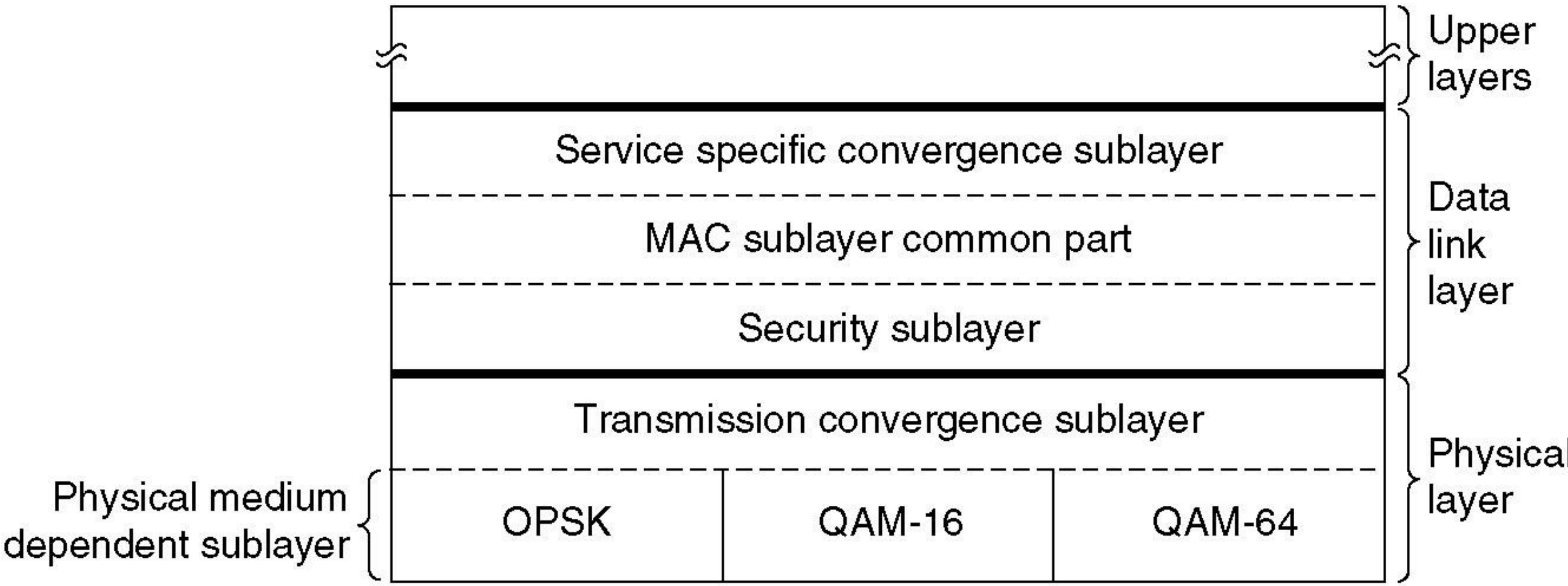
(a) Position of LLC. (b) Protocol formats.

The 802.11 Protocol Stack



Part of the 802.11 protocol stack.

The 802.16 Protocol Stack

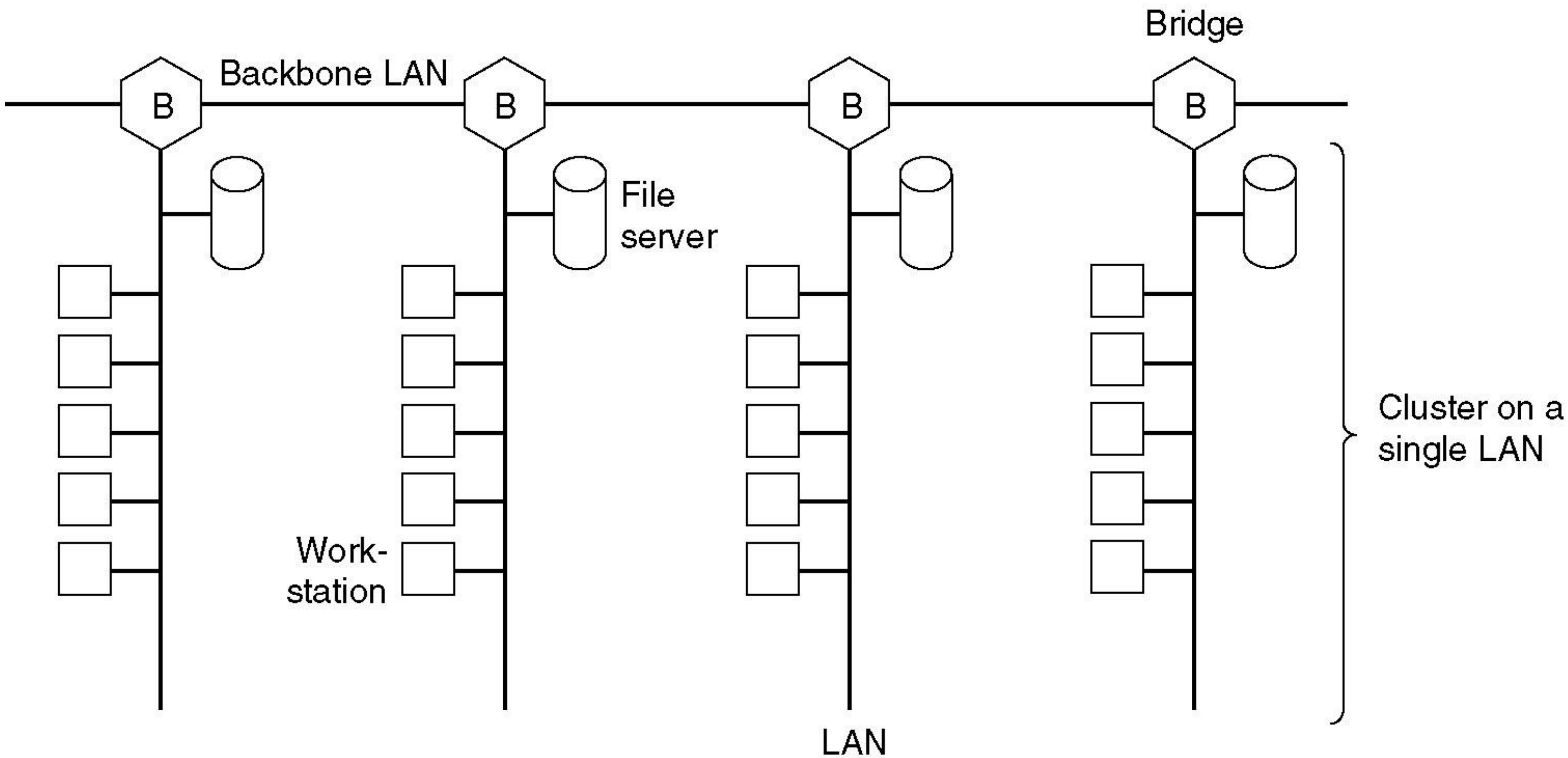


5. Data Link Layer Switching

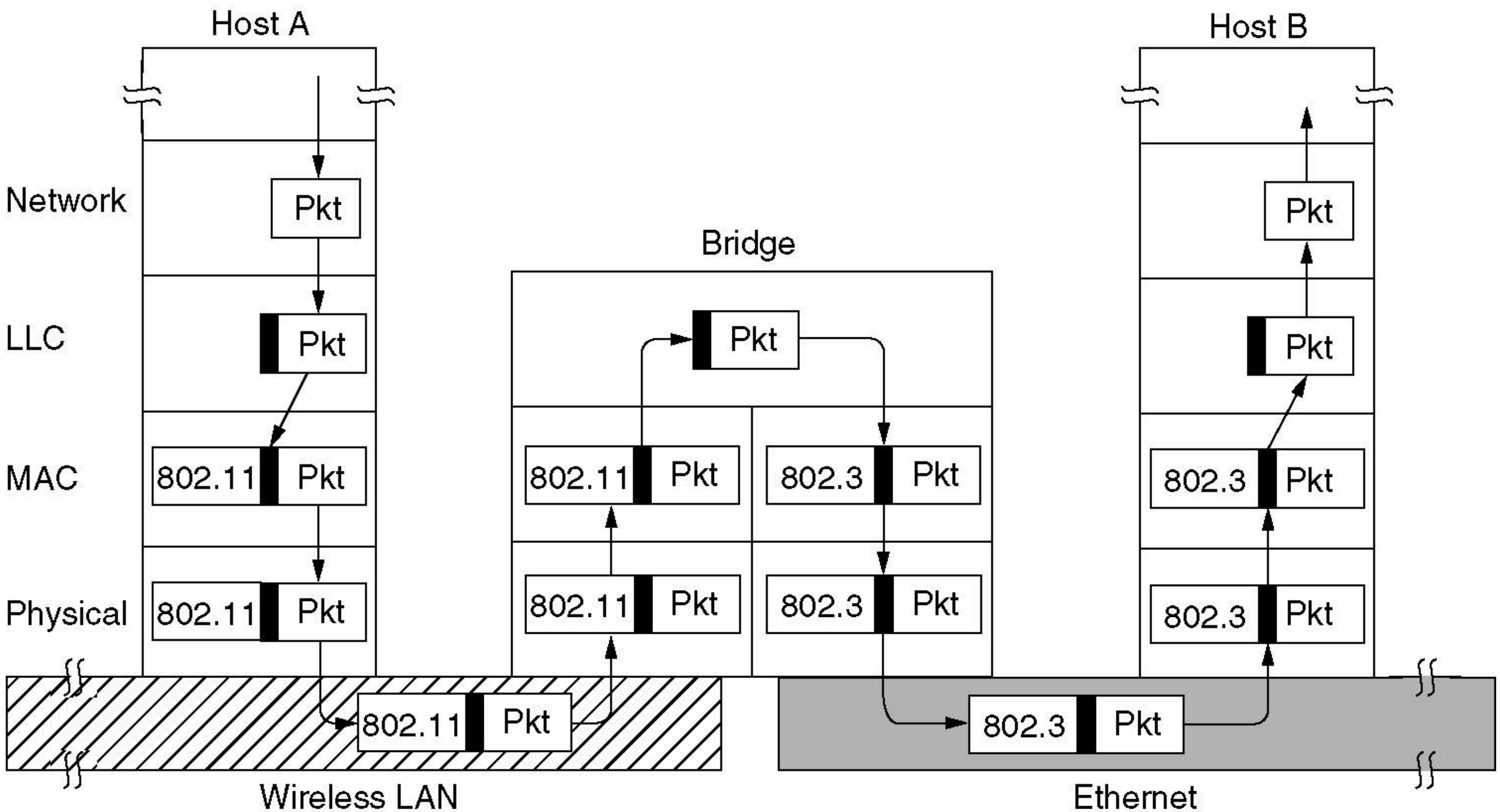
- Bridges from 802.x to 802.y
- Local Internetworking
- Remote Bridges
- Repeaters, Hubs, Bridges, Switches, Routers, Gateways
- Virtual LANs

Data Link Layer Switching

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

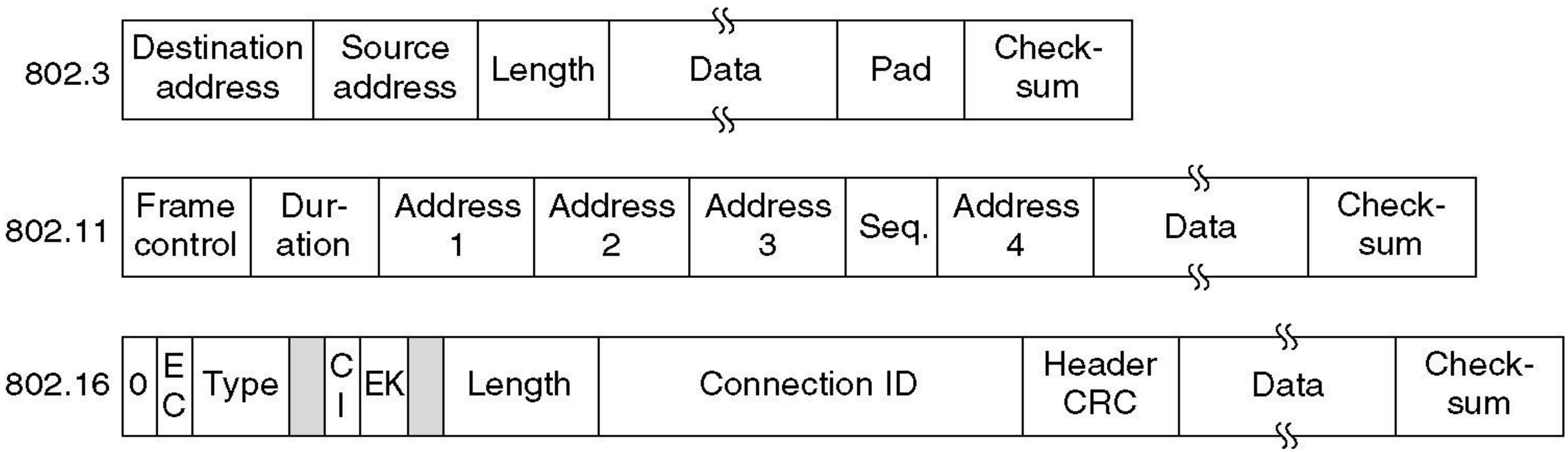


Bridges from 802.x to 802.y



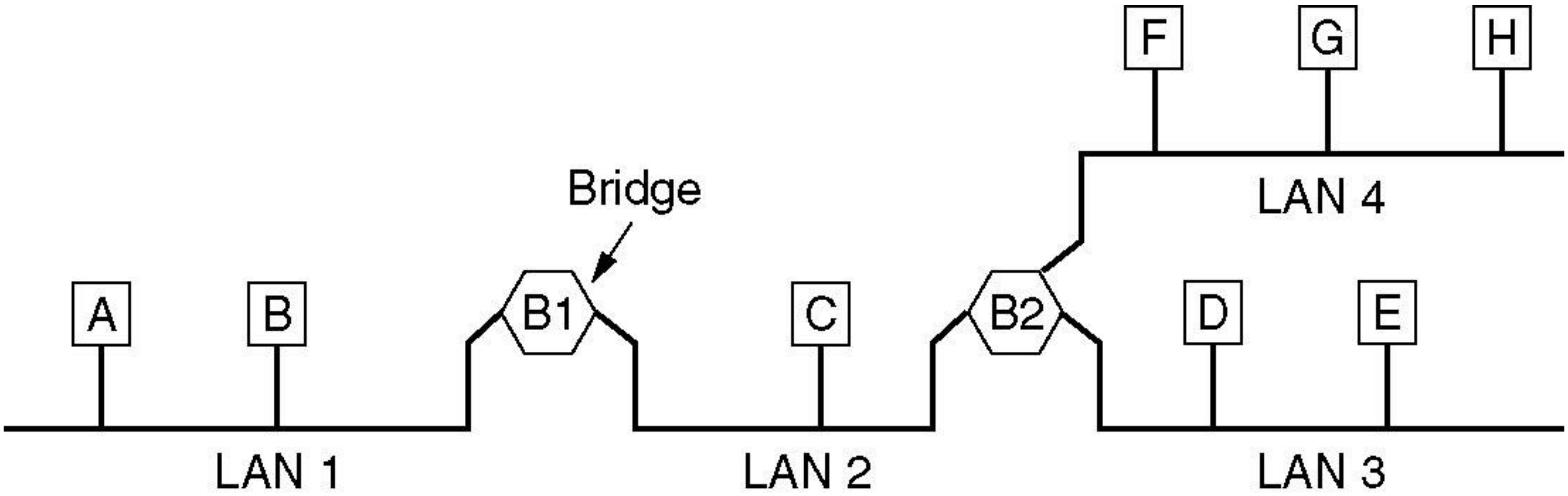
Bridges from 802.x to 802.y (2)

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



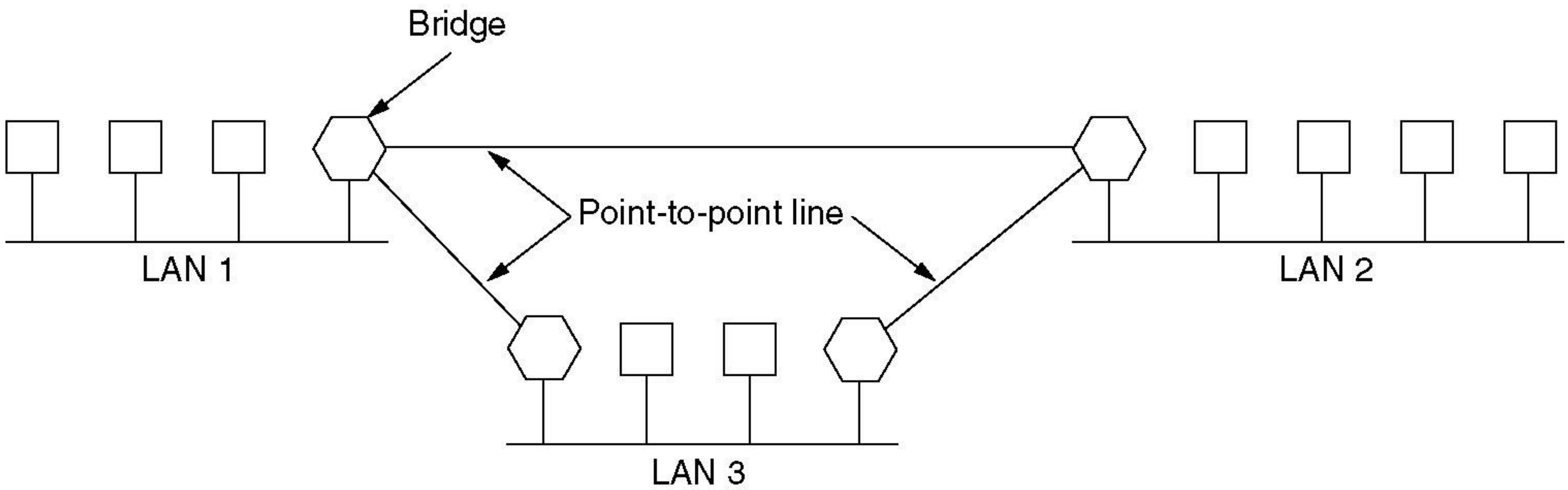
Local Internetworking

A configuration with four LANs and two bridges.

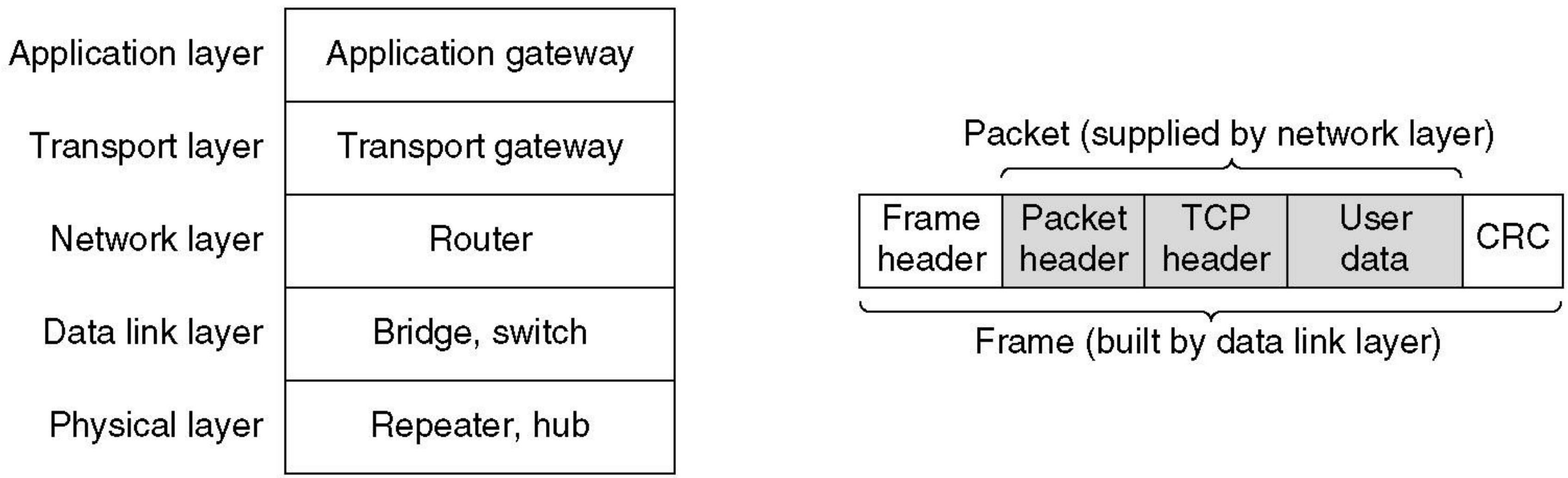


Remote Bridges

Remote bridges can be used to interconnect distant LANs.



Repeaters, Hubs, Bridges, Switches, Routers and Gateways



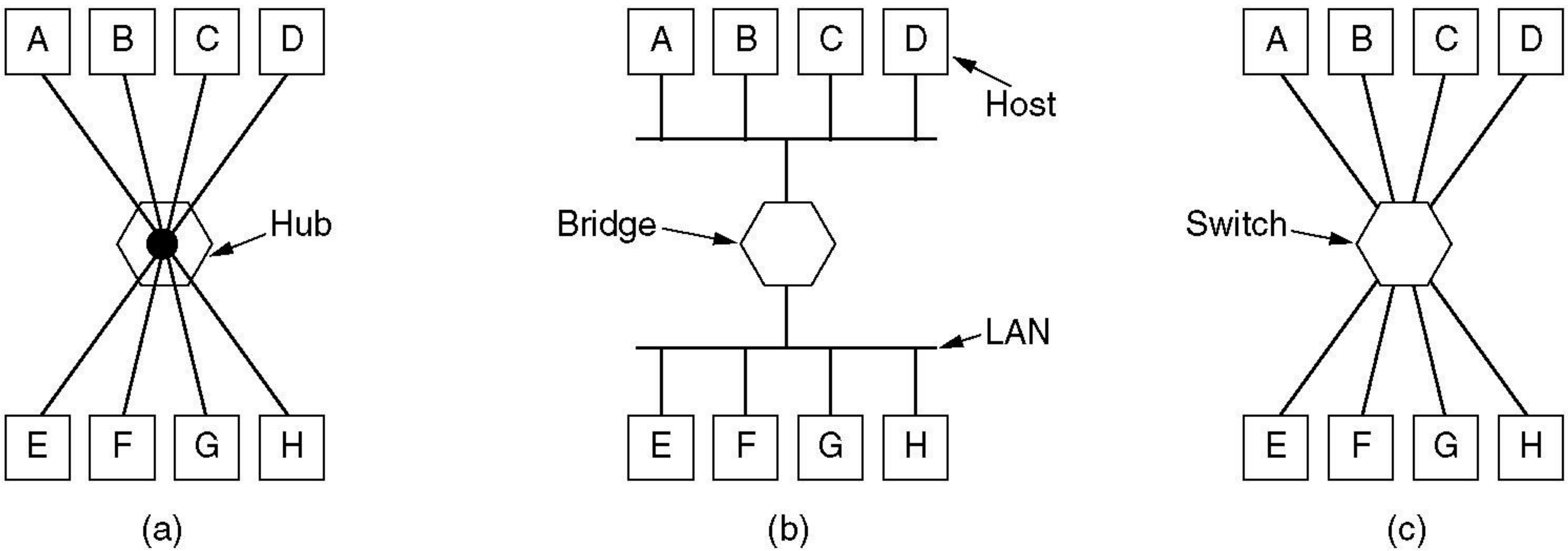
(a) (b)

(a) Which device is in which layer.

(b) Frames, packets, and headers.

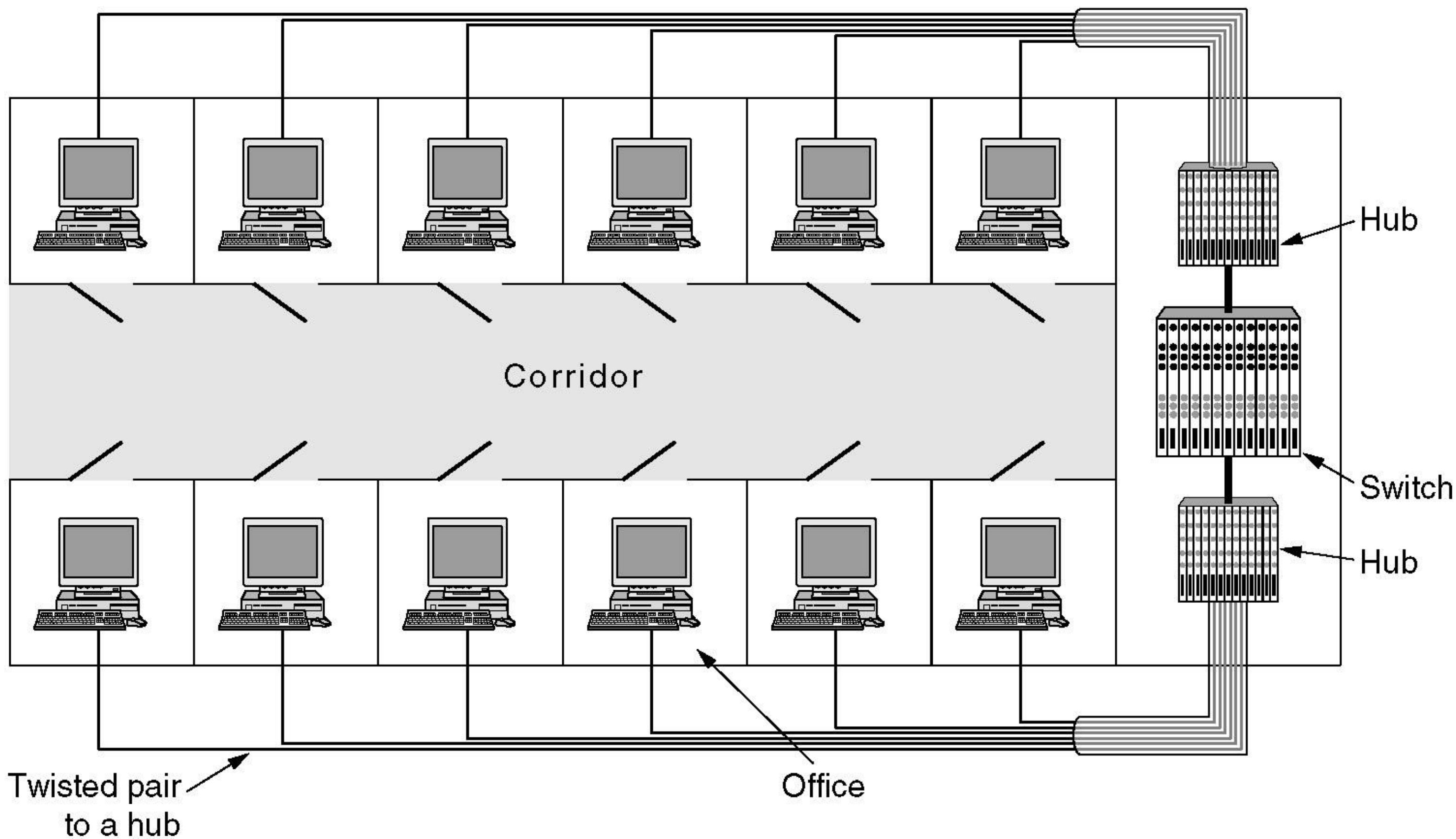
Repeaters, Hubs, Bridges, Switches, Routers and Gateways (2)

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

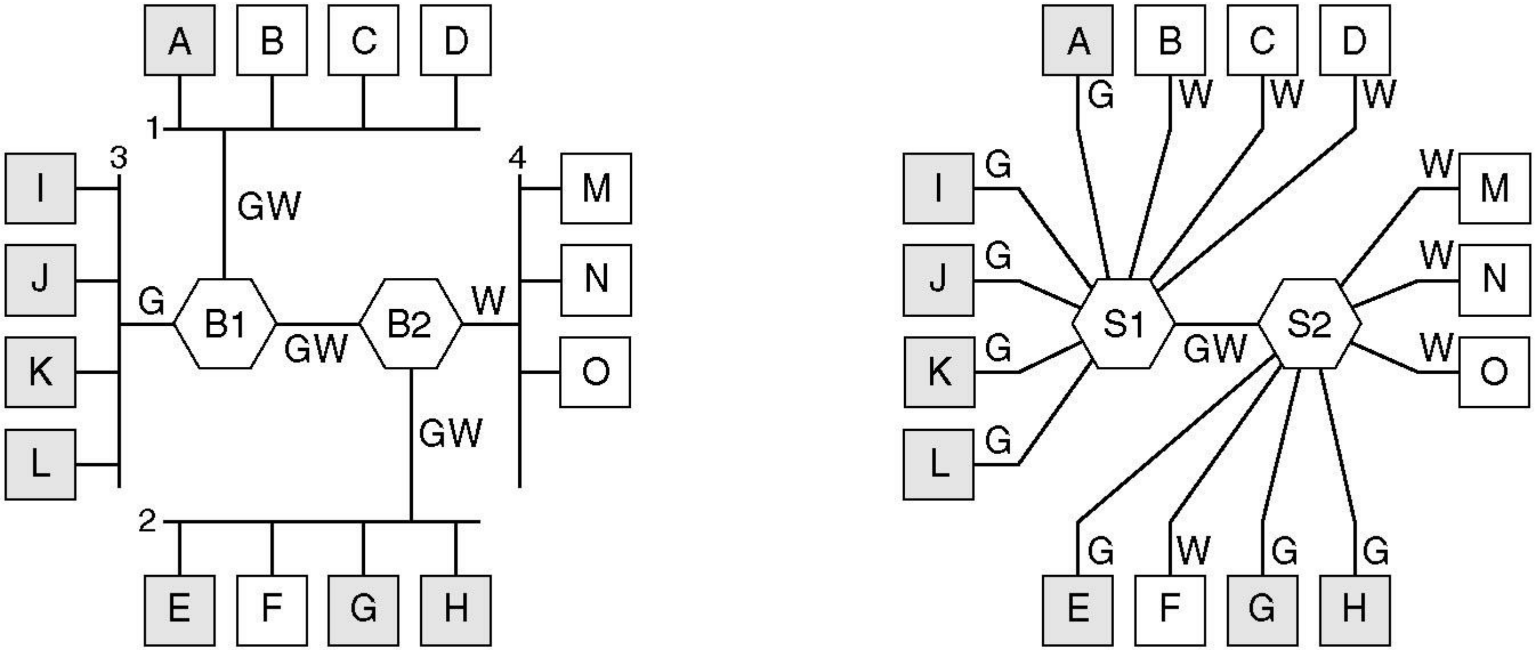


Virtual LANs

A building with centralized wiring using hubs and a switch.



Virtual LANs (2)

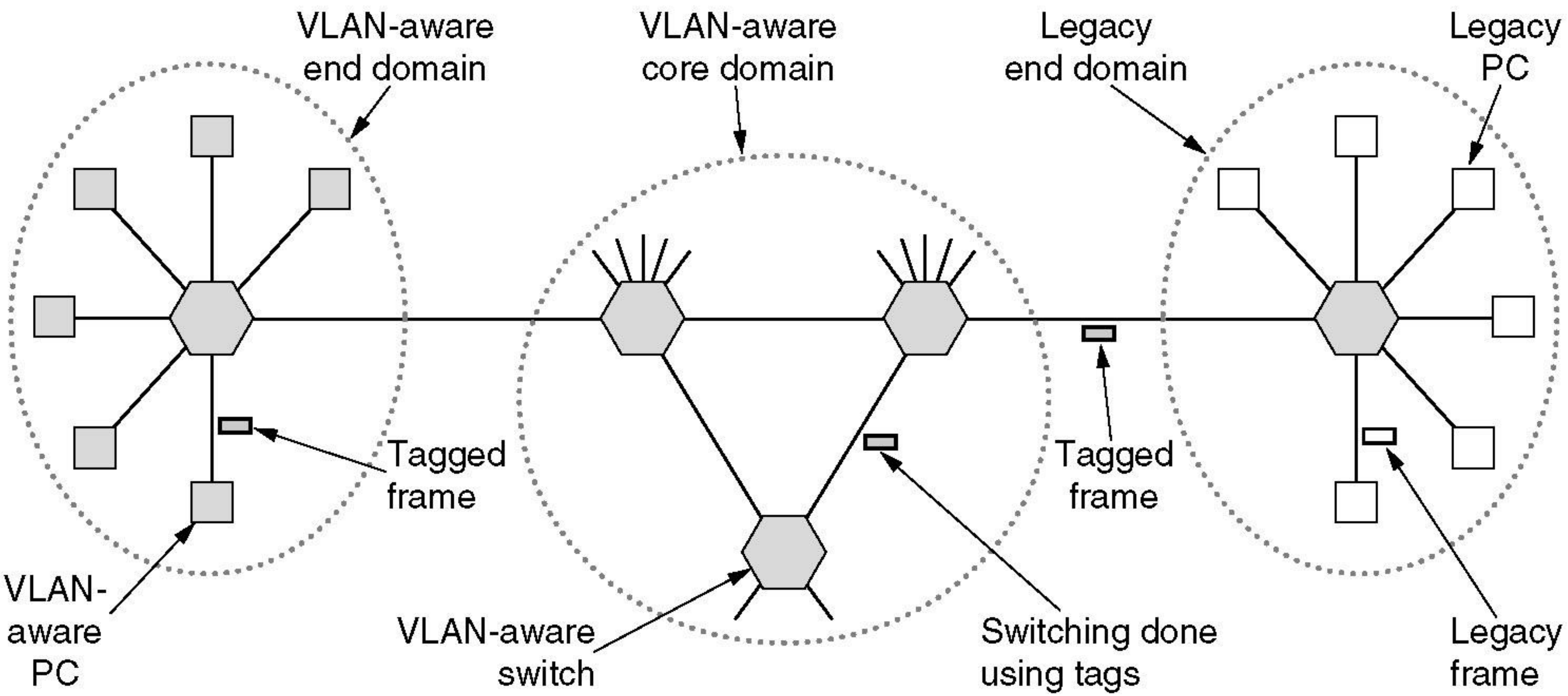


(a) (b)

(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.

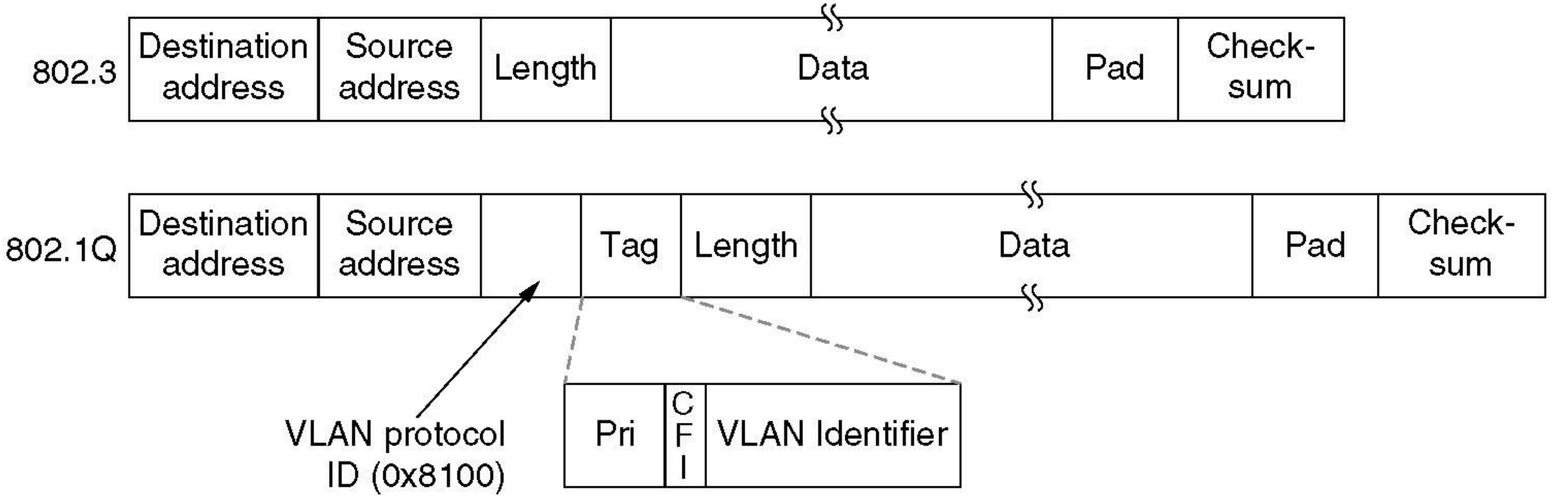
The IEEE 802.1Q Standard

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.