Wired LANs
Ethernet (IEEE 802.3 Standard)

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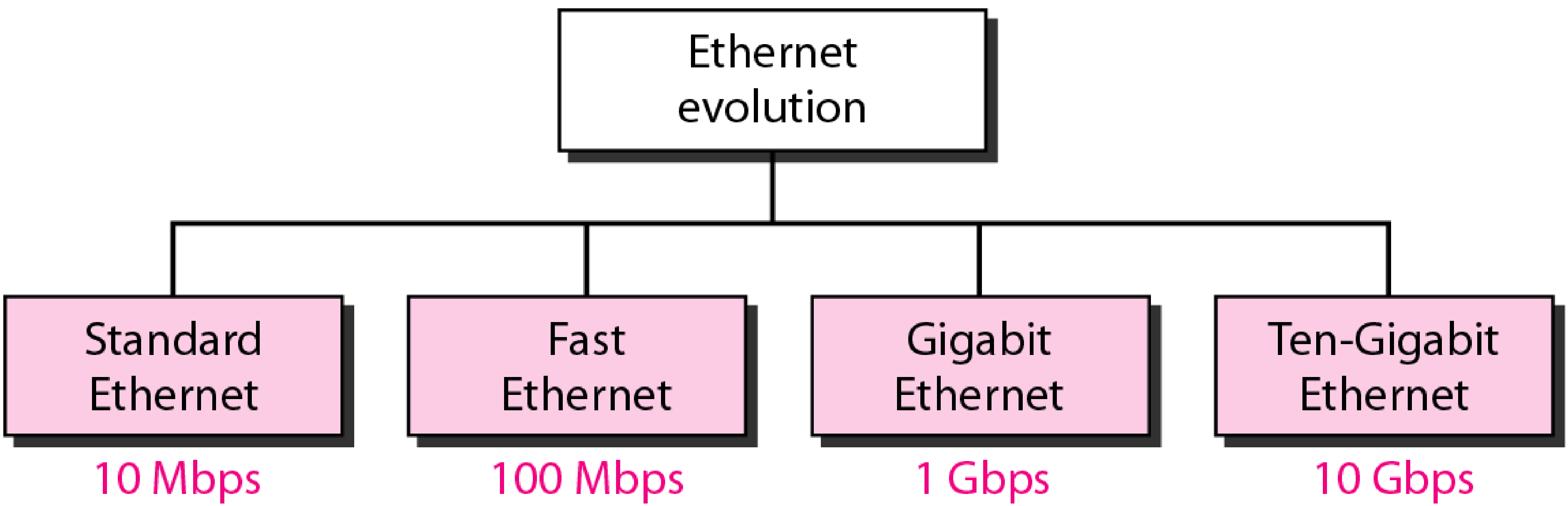
Reading Material

- DATA COMMUNICATIONS AND NETWORKING, Fourth Edition by Behrouz A. Forouzan, Tata McGraw-Hill
  - Chapter 13 Wired LANs, Topics 13.2, 13.4, 13.5

STANDARD ETHERNET

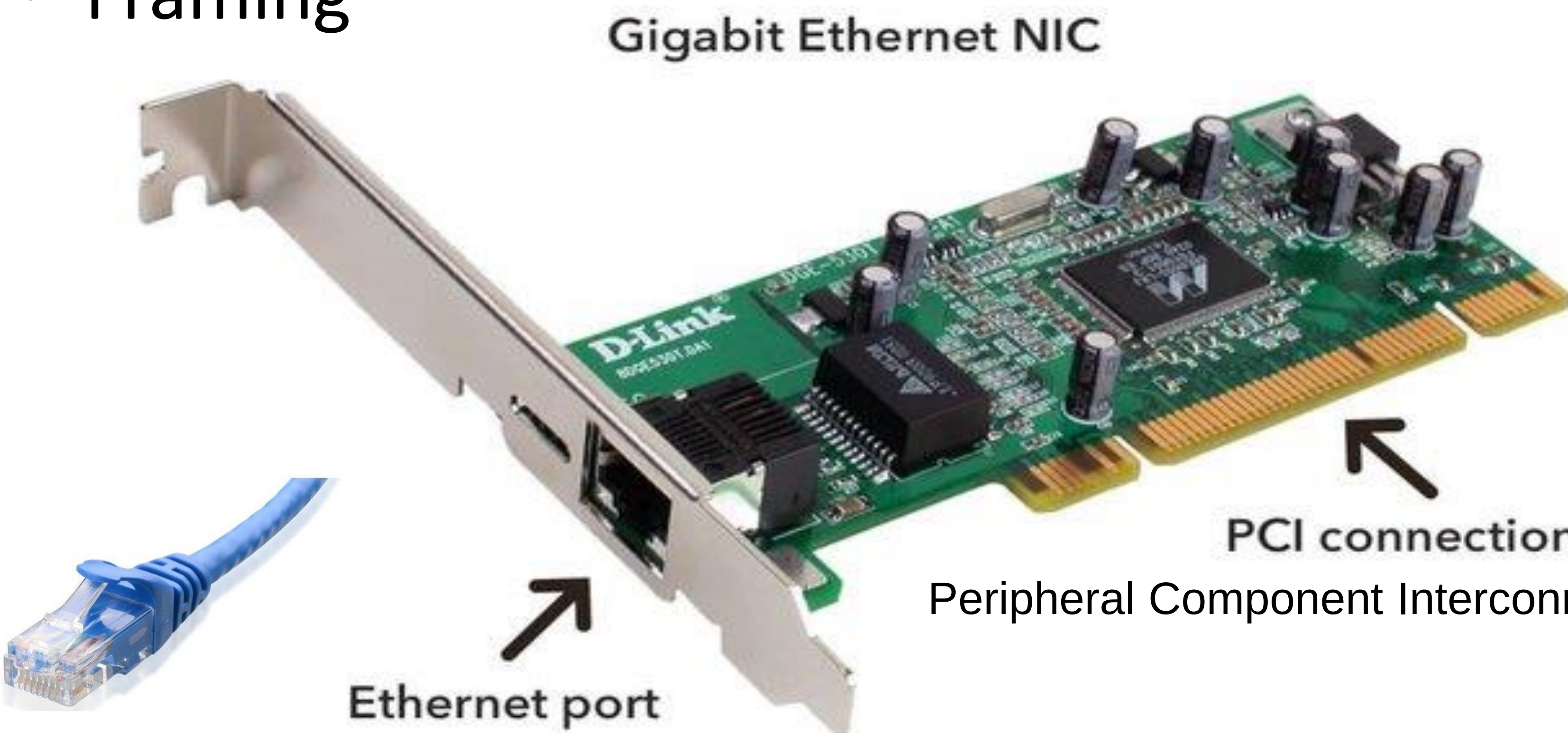
- For setting up a Wired Local Area Network
- In 1976 by Xerox's Palo Alto Research Center
- Defines – Data Link layer, Physical layer
- Now



Data link layer

- Medium Access Control
- Framing

Network Interface Card



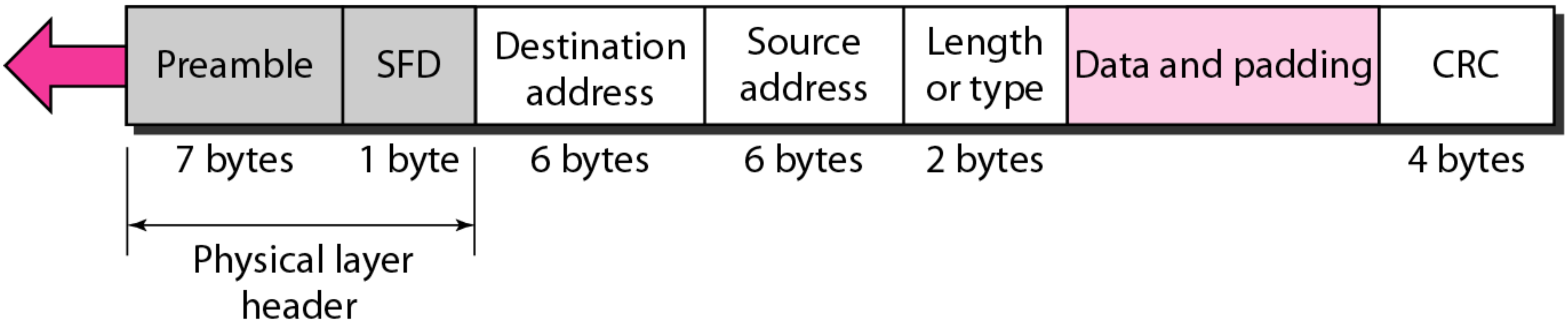
Peripheral Component Interconnect

Ethernet Shield for Arduino

Frame Format

Preamble: 56 bits of alternating 1s and 0s.

SFD: Start frame delimiter, flag (10101011)



Frame Fields - Preamble

- 7 bytes (56 bits) of alternating 0s and 1s
- alerts receiving system to the coming frame
- enables it to synchronize its input timing
- 56-bit pattern allows stations to miss some bits at the beginning of the frame
- added at physical layer and is not (formally) part of frame

Frame Fields - Start frame delimiter (SFD)

- 1 byte: 10101011
- signals beginning of frame
- warns station/stations that this is the last chance for synchronization
- last 2 bits is 11 to alert receiver that next field is destination address

Frame Fields - Destination address (DA) Source address (SA).

- Physical Address
- Destination address (DA).
  - 6 bytes
  - contains physical address of destination station or stations to receive the packet
- Source address (SA)
  - 6 bytes
  - contains physical address of sender of the packet

Physical Addressing

- Each station on Ethernet network (PC, workstation, printer) has its own network interface card (NIC)
- NIC provides station with a 6-byte (48 bits) physical address
- written in hexadecimal notation, with a colon between bytes

06 : 01 : 02 : 01 : 2C : 4B

6 bytes = 12 hex digits = 48 bits

How to find MAC/NIC/Physical address?

- getmac /v

Command Prompt

```
Microsoft Windows [Version 10.0.22000.978]
(c) Microsoft Corporation. All rights reserved.

C:\Users\EC-8>getmac /v

Connection Name Network Adapter Physical Address    Transport Name
=============== =============== =================== ==========================================================
Wi-Fi           Intel(R) Wi-Fi  8C-B8-7E-EC-C7-19   \Device\Tcpip_{B83CA907-E0C8-4844-BD9F-8F0285929D07}
Ethernet        Realtek PCIe Gb 88-A4-C2-A3-80-30   Media disconnected
```

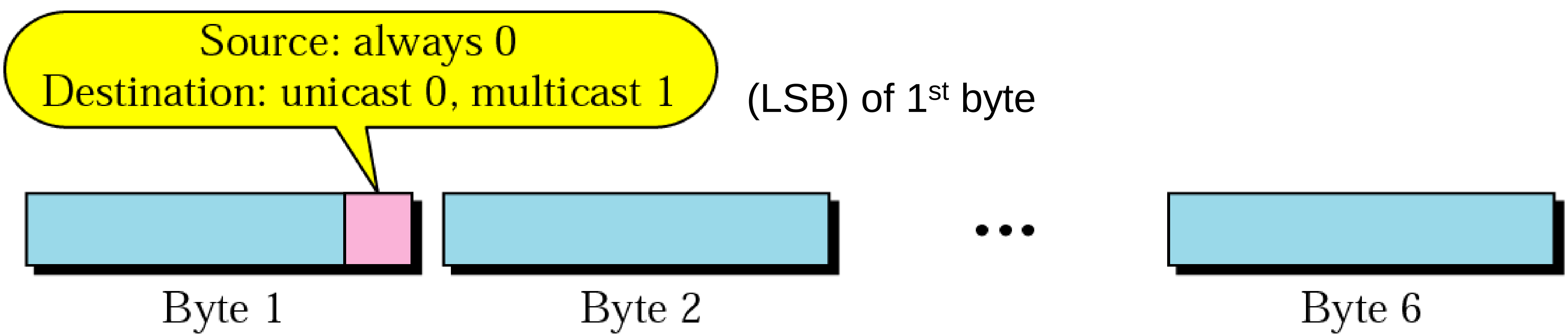
- ipconfig /all   Gigabit Ethernet (GbE)

```
Ethernet adapter Ethernet:

   Media State . . . . . . . . . . . : Media disconnected
   Connection-specific DNS Suffix  . :
   Description . . . . . . . . . . . : Realtek PCIe GbE Family Controller
   Physical Address. . . . . . . . . : 88-A4-C2-A3-80-30
   DHCP Enabled. . . . . . . . . . . : No
   Autoconfiguration Enabled . . . . : Yes
```

Unicast, Multicast, Broadcast

- Source address is always a unicast address
- Destination address
  - Least significant bit of first byte in a destination address = 0 → address is unicast
  - Otherwise, it is multicast
  - All bits = 1 → broadcast destination address



Example

Define type of following destination addresses:

a. 4A:30:10:21:10:1A ***b. 47:20:1B:2E:08:EE***

c. FF:FF:FF:FF:FF:FF

Solution

LSB of first byte (4A) tells type of address

If it is even number, in binary LSB = 0, address is unicast

If it is odd number, in binary LSB = 1, address is multicast

If all digits F's, address is broadcast

a. unicast address because A (10) in binary is 1010

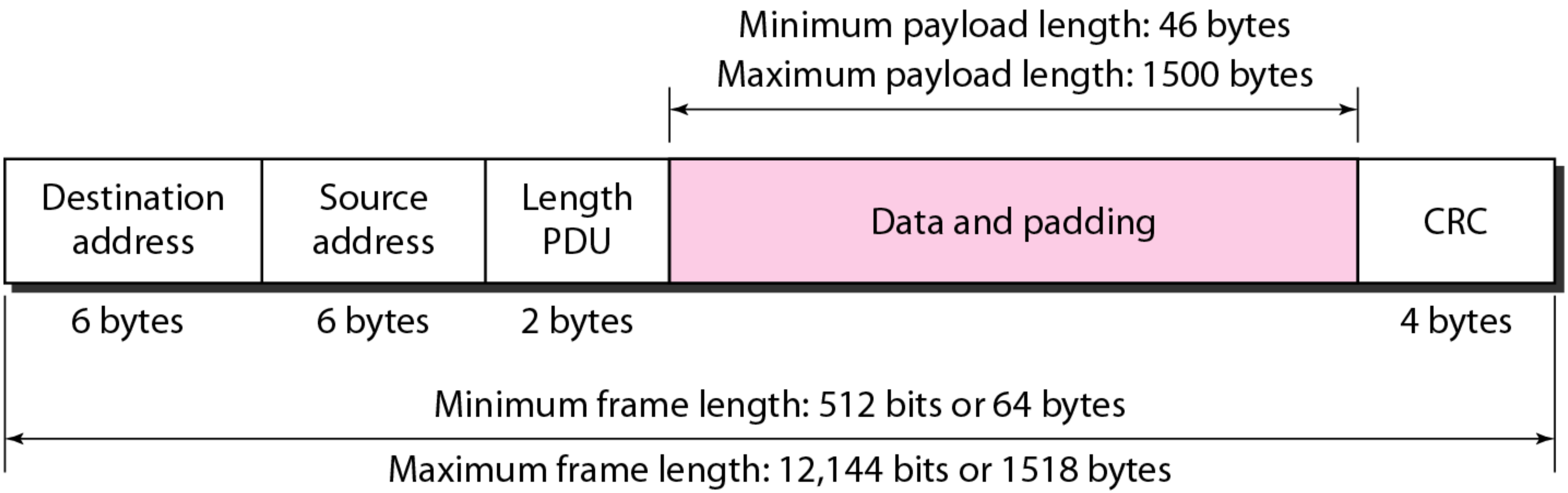
b. multicast address because 7 in binary is 0111

c. broadcast address because all digits are F's

Frame Fields - Length or Type

- Original Ethernet used to define upper-layer protocol using MAC frame (TYPE)
- IEEE standard used to define number of bytes in the data field (LENGTH)
- Both uses are common today

Minimum and Maximum frame length



- Reasons for maximum length restriction
- Memory was expensive when Ethernet was designed: a maximum length restriction helped to reduce size of buffer for frame storage
- Maximum length restriction prevents one station from monopolizing shared medium, blocking other stations that have data to send

Example

A network using CSMA/CD has a bandwidth of 10 Mbps. If maximum propagation time (including the delays in the devices) is 25.6 μs, what is minimum size of frame?

Solution

- ***The frame transmission time is $T_{fr} = 2 \times T_p = 51.2$ μs.***
- ***This means, in worst case, a station needs to transmit for a period of 51.2 μs to detect collision.***
- ***Transmission time=Message size/BW***
- ***Minimum size of frame = 10 Mbps × 51.2 μs = 512 bits or 64 bytes***
- ***This is frame size of Ethernet***

Frame Fields – Data and CRC

- Data
  - data encapsulated from upper-layer protocols
  - It is a minimum of 46 and a maximum of 1500 bytes
- CRC
  - Contains error detection information, CRC-32 algorithm

No Acknowledgement

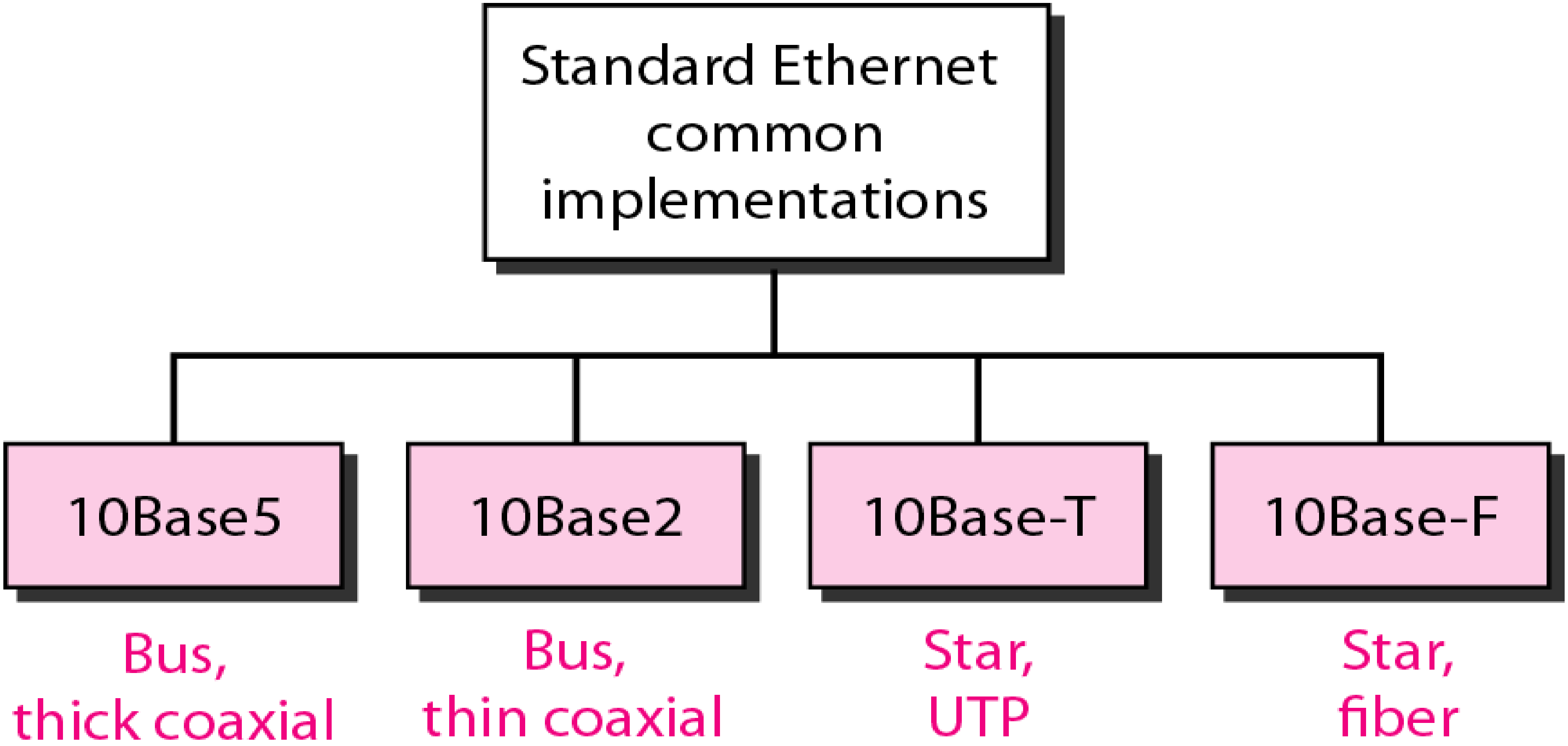
- Ethernet does not provide any mechanism for acknowledging received frames
- Less needed as it’s a wired media not wireless
- Acknowledgments must be implemented at the higher layers

Access Method: CSMA/CD

- Standard Ethernet uses 1-persistent CSMA/CD

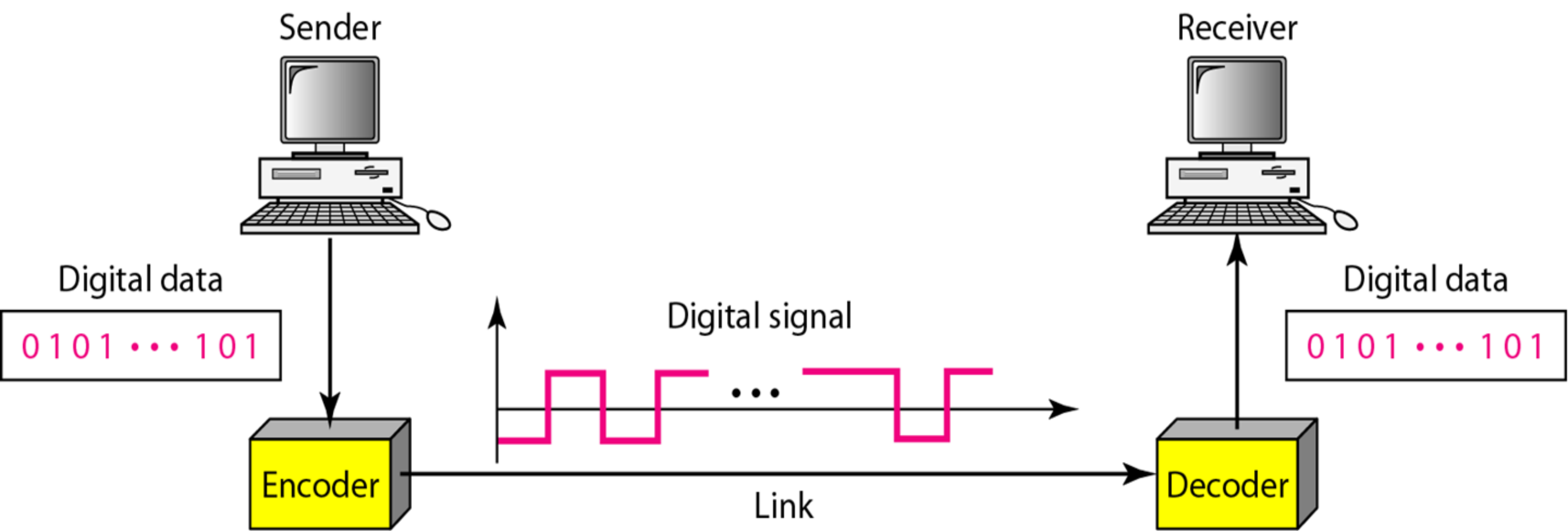
Physical Layer

- Several physical layer implementations
- Most common are



Digital To Digital Conversion

- Line coding converts digital data to digital signals
- Data (text, number, image, video) in computer memory as 1s/0s → Line Coding→ converted to digital signals (+V, 0, -V)
- At sender, digital data are encoded into a digital signal
- At receiver, digital signal decoded to get back digital

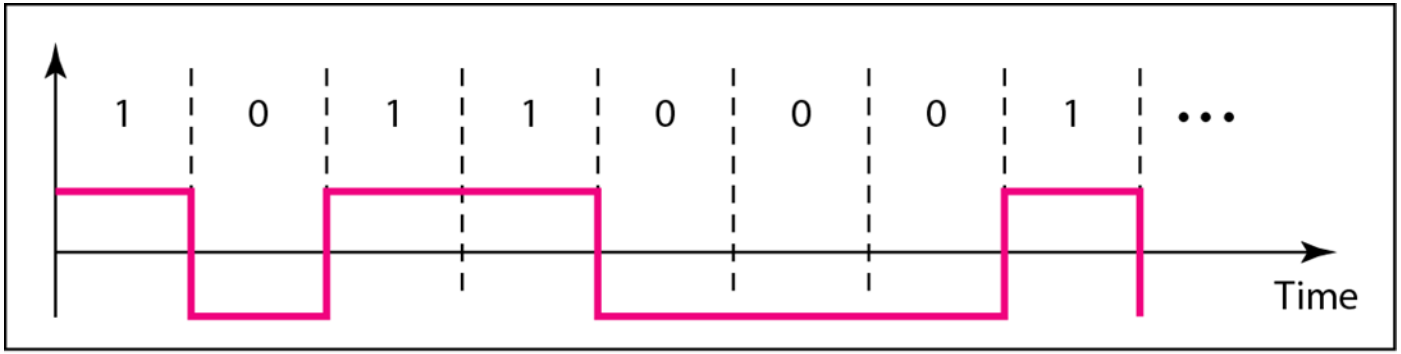


Synchronization

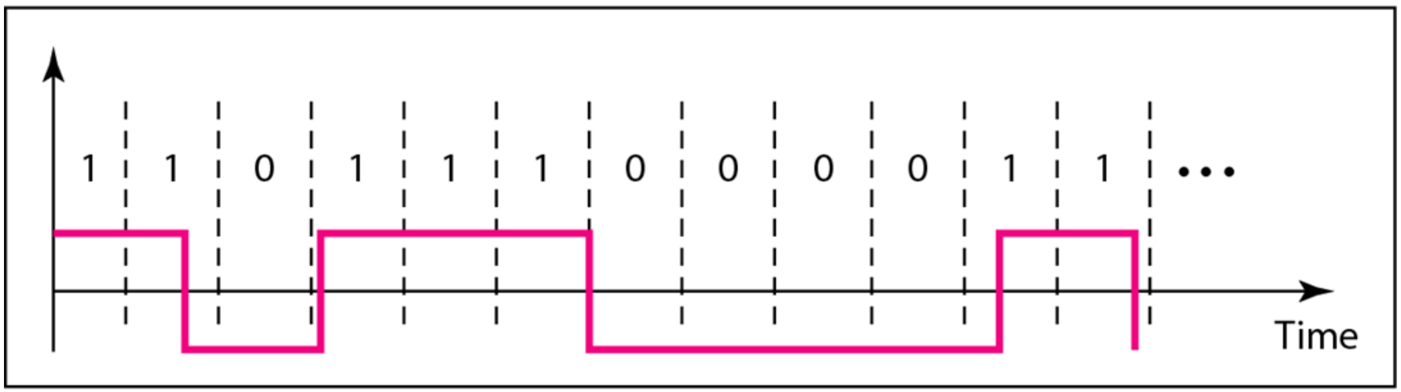
- To correctly interpret signals received from sender, receiver's bit intervals must correspond exactly to sender's bit intervals
- If receiver clock is faster or slower, bit intervals are not matched and receiver might misinterpret signals

Problem if there is no Synchronization

- Eg. Receiver has a shorter bit duration



a. Sent

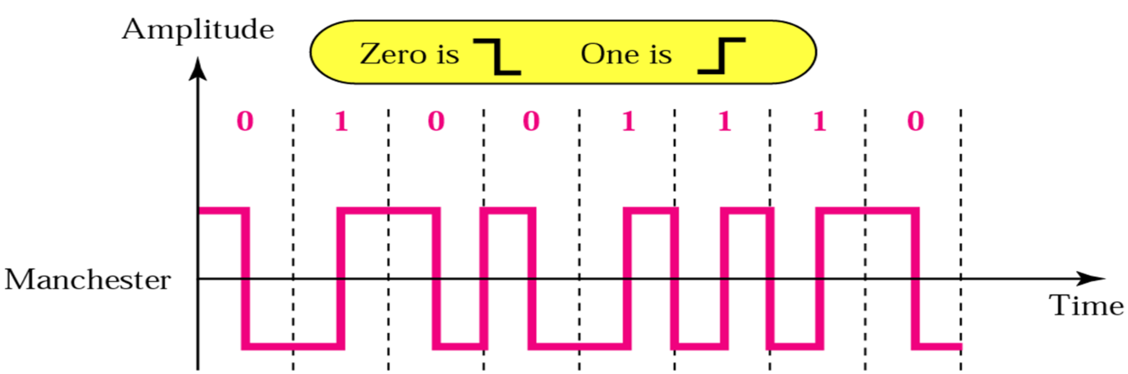


b. Received

- sender sends 10110001
- receiver receives 110111000011

Self-synchronization

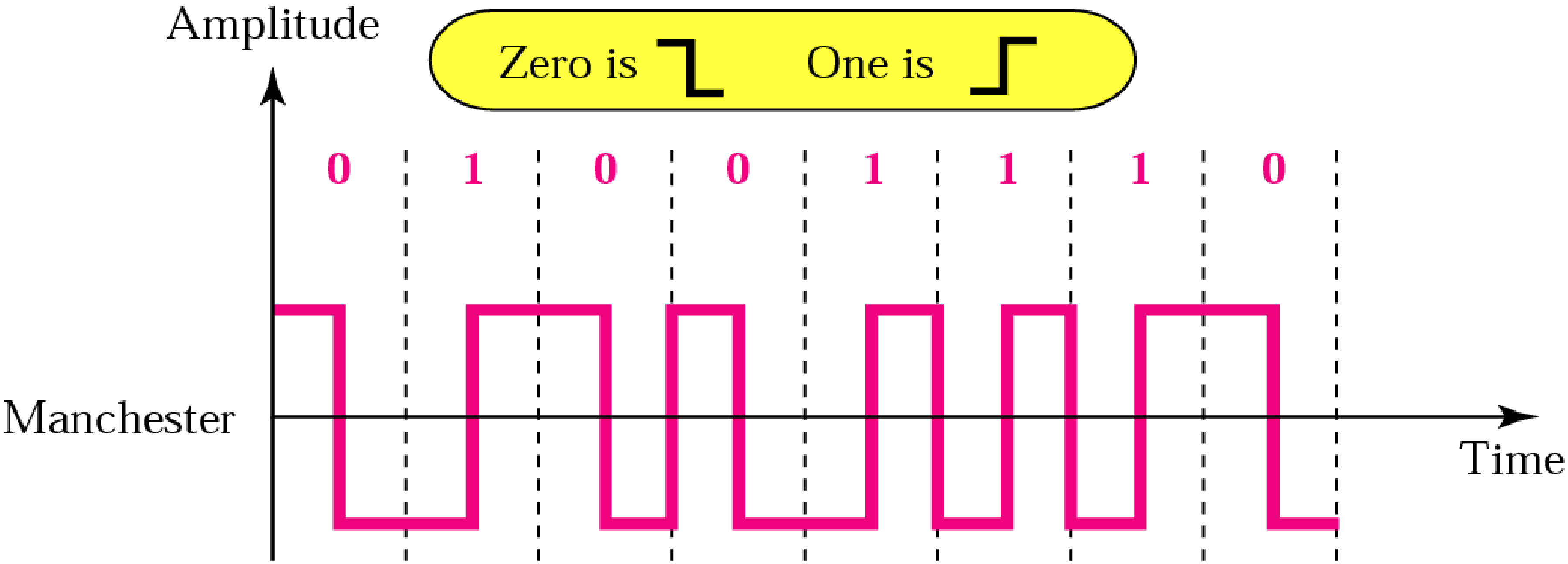
- A self-synchronizing digital signal includes timing information in data being transmitted
- Can happen if there are transitions in signal that alert receiver to beginning, middle, or end of pulse
- If receiver's clock is out of synchronization, these points can reset the clock
- Manchester encoding is self-synchronous



Encoding and Decoding

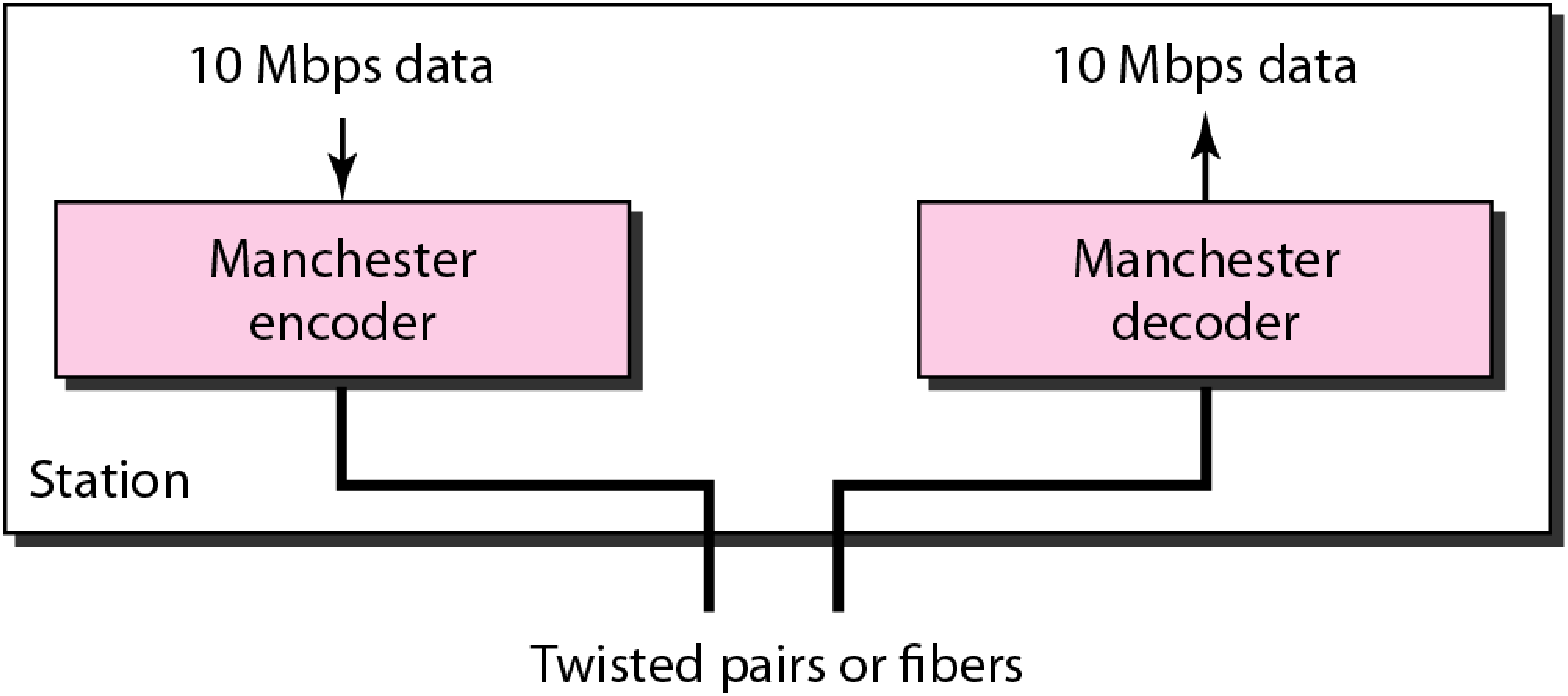
- All standard implementations use digital signaling (baseband) at 10 Mbps
- Baseband signaling means no modulation is done, signal transmitted in its original form
- At sender, data converted to a digital signal using Manchester scheme
- At the receiver, received signal is interpreted as Manchester and decoded into data

Manchester encoding



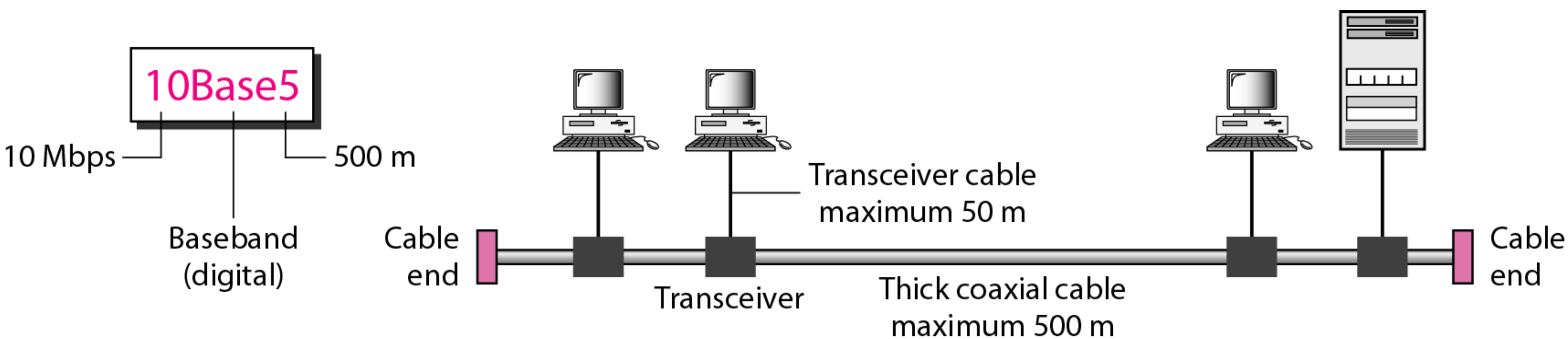
- Transition at middle of the bit is used for both synchronization and bit representation
- Manchester encoding is self-synchronous

Encoding in a Standard Ethernet implementation

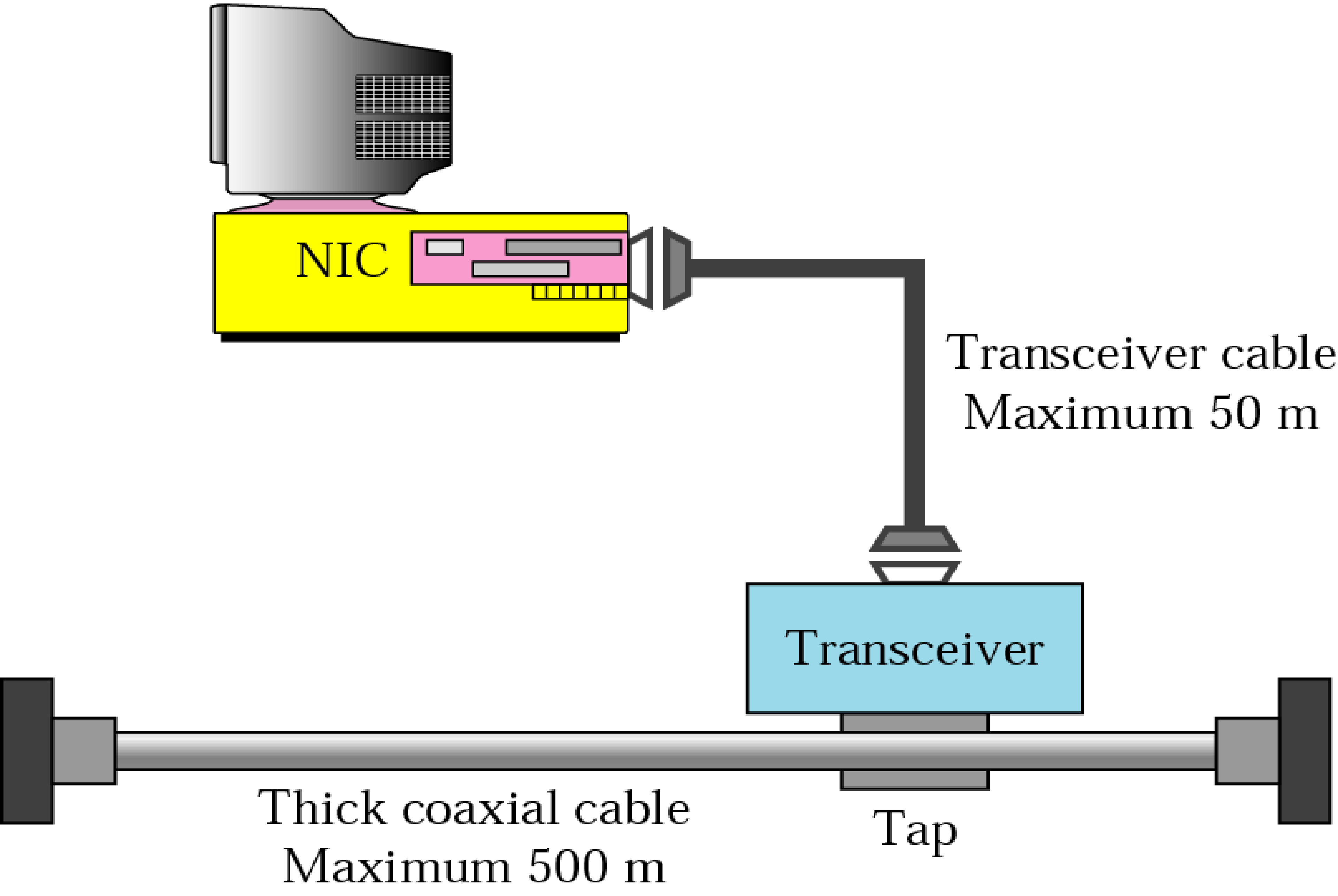


10Base5: Thick Ethernet

- First implementation is called 10Base5, thick Ethernet, Thicknet.
- Nickname due to size of cable, roughly size of a garden hose, too stiff to bend with hands.
- Uses bus topology with external transceiver connected via a tap to a thick coaxial cable.



Connection of a station to medium using 10Base5



10Base5 implementation

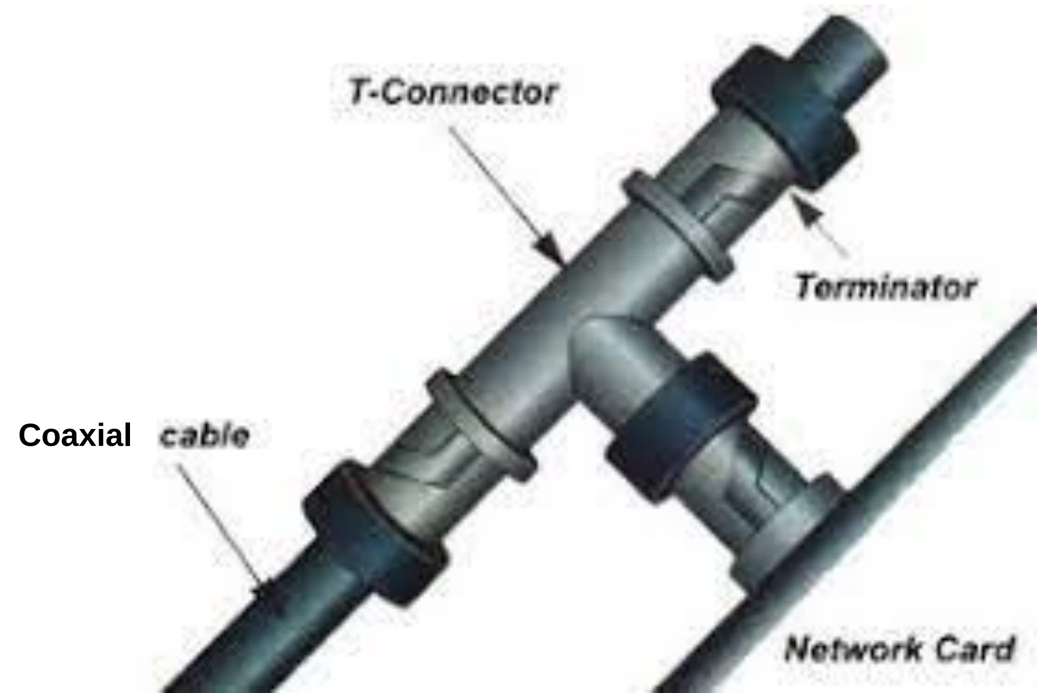
- Transceiver is responsible for transmitting, receiving, detecting collisions.
- Transceiver connected to station via a transceiver cable that provides separate paths for sending and receiving
- Thus collision can only happen in coaxial cable.
- Maximum length of coaxial cable must not exceed 500 m
- Otherwise, there is excessive degradation of signal.
- If a length of > 500 mtr is needed repeaters are required
- Can go up to 5 segments, each a maximum of 500 mtr

10Base2: Thin Ethernet

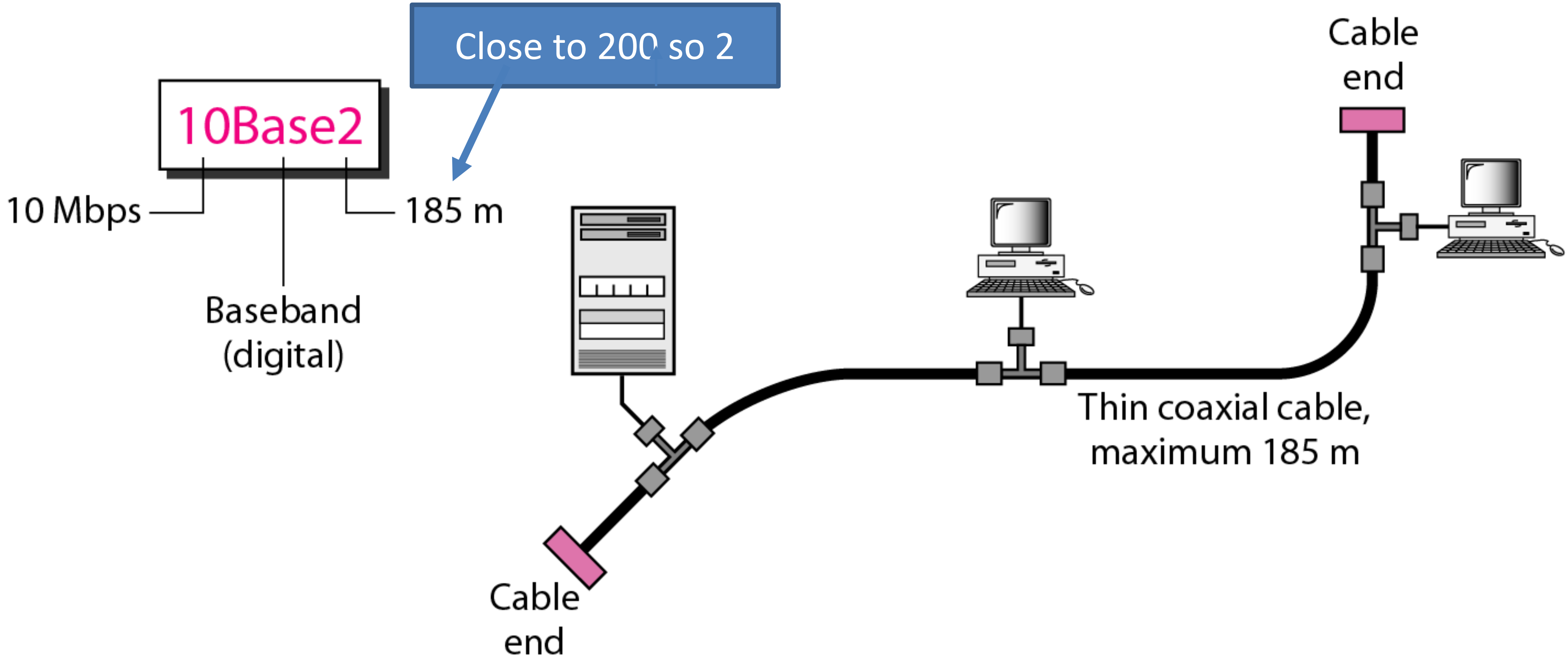
- 10Base2, Thin Ethernet, Cheapernet
- Uses a bus topology
- Cable is much thinner and more flexible
- Cable can be bent to pass very close to stations
  - Installation is easy
- Transceiver is part of network interface card (NIC), which is installed inside the station

10Base2: Thin Ethernet

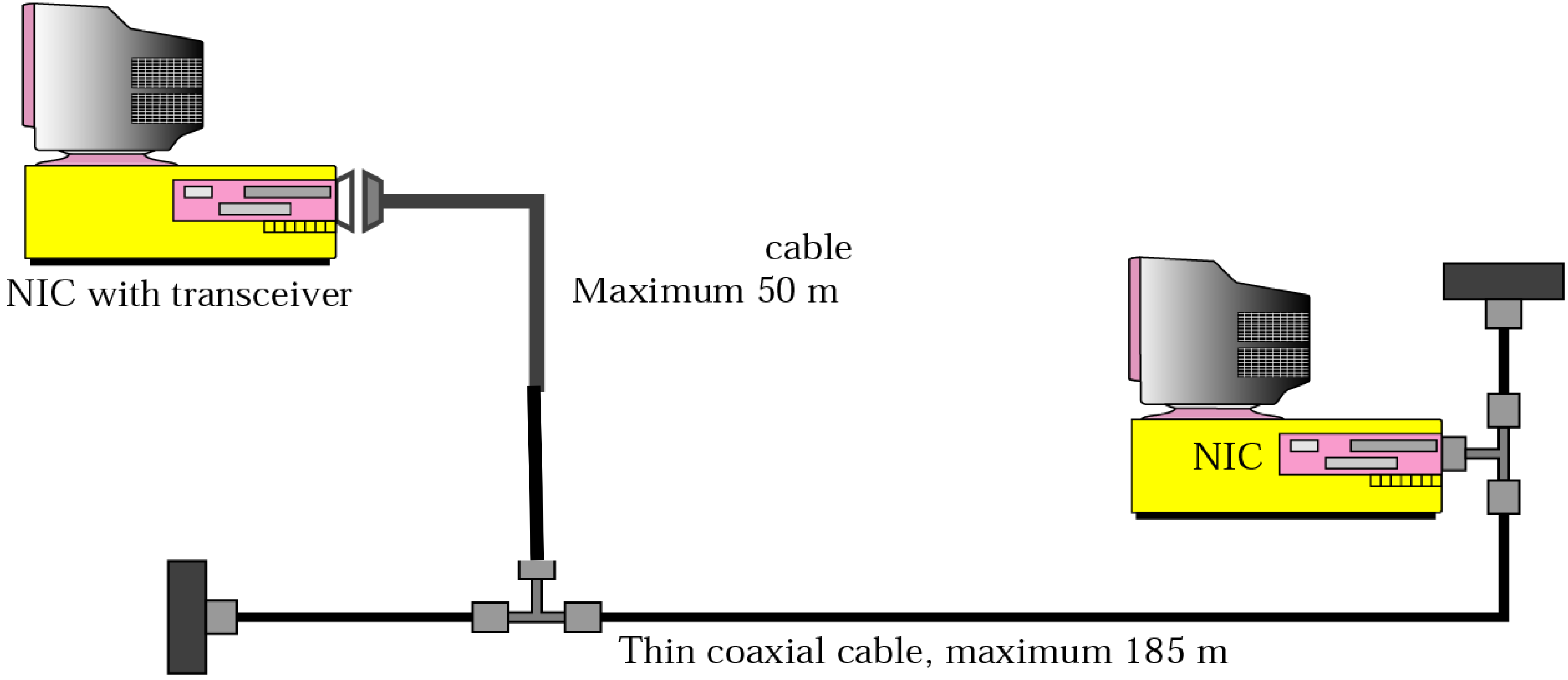
- Collision occurs in thin coaxial cable
- Cable is less expensive than thick coaxial
- Tee connections are cheaper than taps
- Length of each segment cannot exceed 185 m due to attenuation in thin coaxial cable



10Base2 implementation



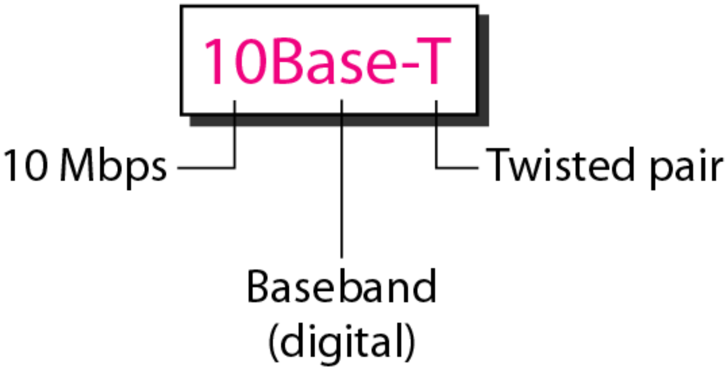
Connection of stations to medium using 10Base2

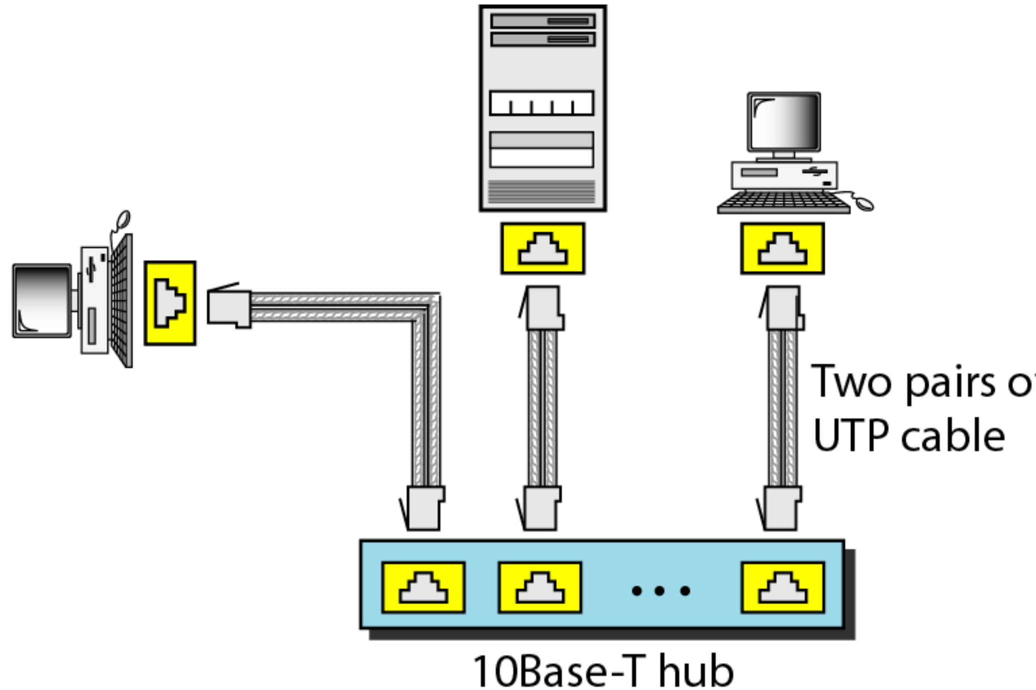


10Base- T Twisted-Pair Ethernet

- Uses star topology
- Stations are connected to hub via two pairs of twisted cable
- 2 pairs of twisted cable create 2 paths (one for sending, one for receiving) between station and hub
- Collision here happens in hub
- Maximum length of cable=100 mtr to minimize effect of attenuation in cable

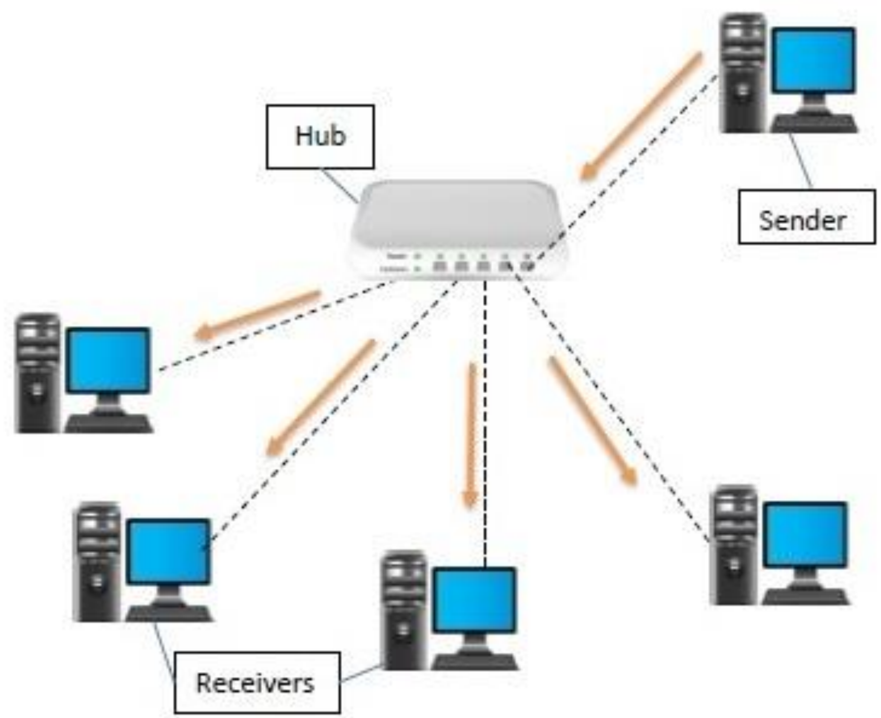
10Base-T implementation





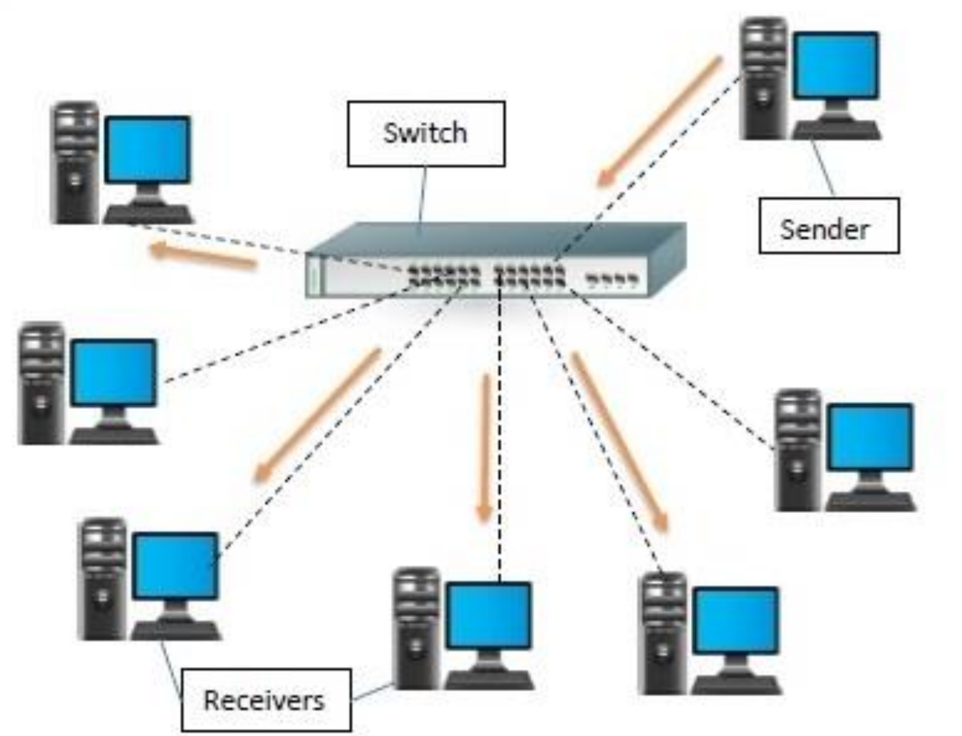
Hub

- Physical layer device
- Multiport repeater
- A data frame received at a port, is repeated and broadcasted to every other port



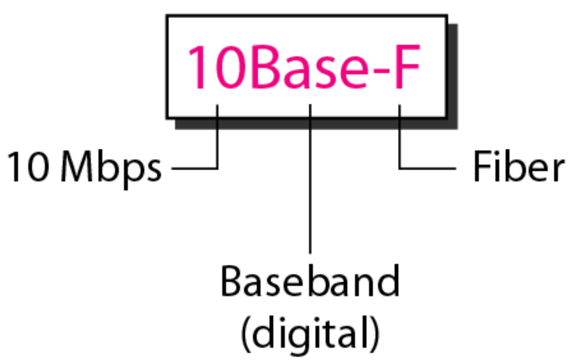
Two layer Switch

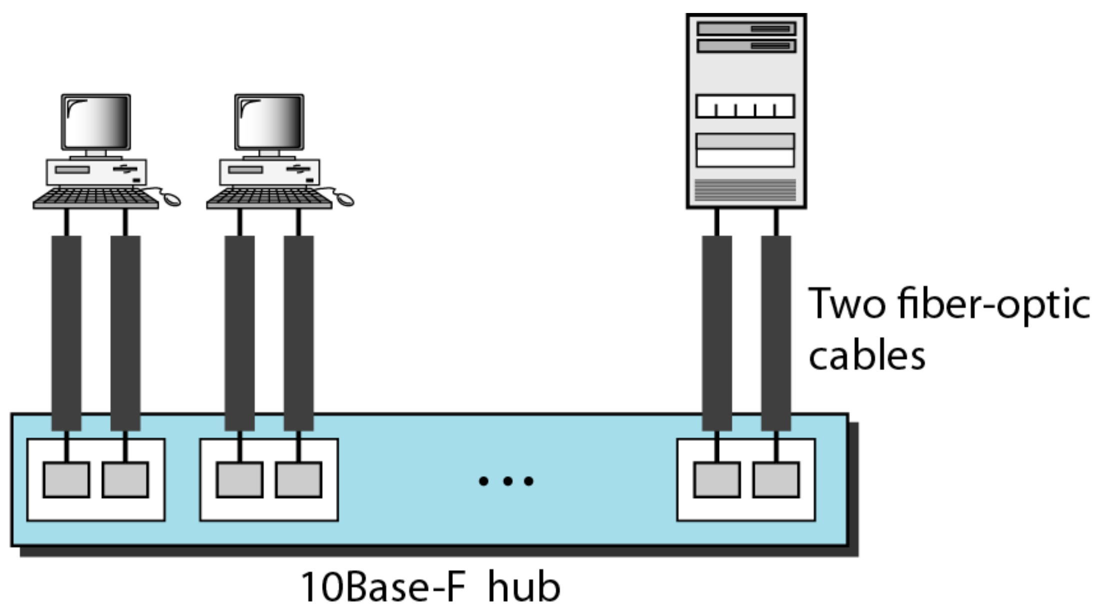
- Physical and data link layer device
- Makes a filtering decision based on MAC address of frame it received
- Can have a buffer to hold frames for processing



10Base-F: Fiber Ethernet

- Uses star topology to connect stations to a hub.
- Stations are connected to hub using two fiber-optic cables





Summary of Standard Ethernet implementations

Characteristics	*10Base5*	*10Base2*	*10Base-T*	*10Base-F*
Media	Thick coaxial cable	Thin coaxial cable	2 UTP	2 Fiber
Maximum length	500 m	185 m	100 m	2000 m
Line encoding	Manchester	Manchester	Manchester	Manchester

FAST ETHERNET

- IEEE 802.3u
- backward-compatible with Standard Ethernet
- can transmit data 10 times faster at a rate of 100 Mbps

Goals of Fast Ethernet

1. Upgrade data rate to 100 Mbps.
2. Make it compatible with Standard Ethernet.
3. Keep the same 48-bit address
4. Keep the same frame format.
5. Keep the same minimum and maximum frame lengths.

MAC Sublayer

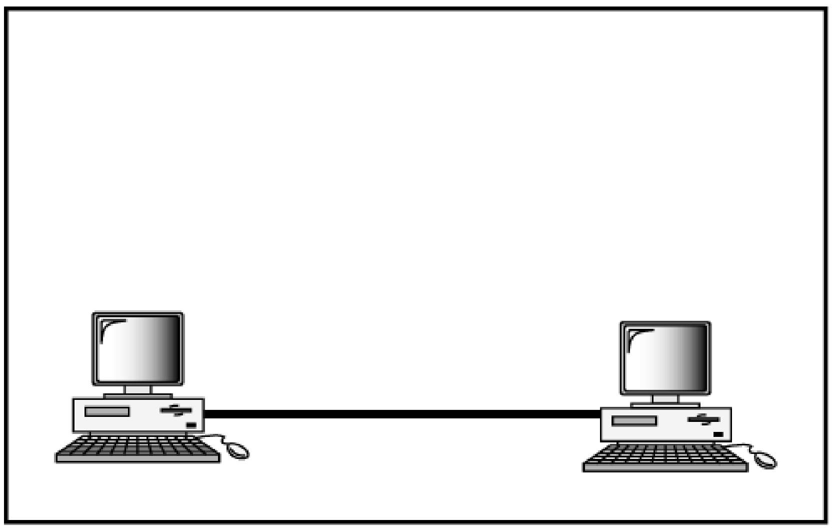
- Main consideration - Keep the MAC sublayer untouched
- Keep only the star topology
- For star topology, there are two choices
  - In half-duplex approach, stations are connected via a hub
  - In full-duplex approach, connection is made via a switch with buffers at each port
- Access method is CSMA/CD

Autonegotiation

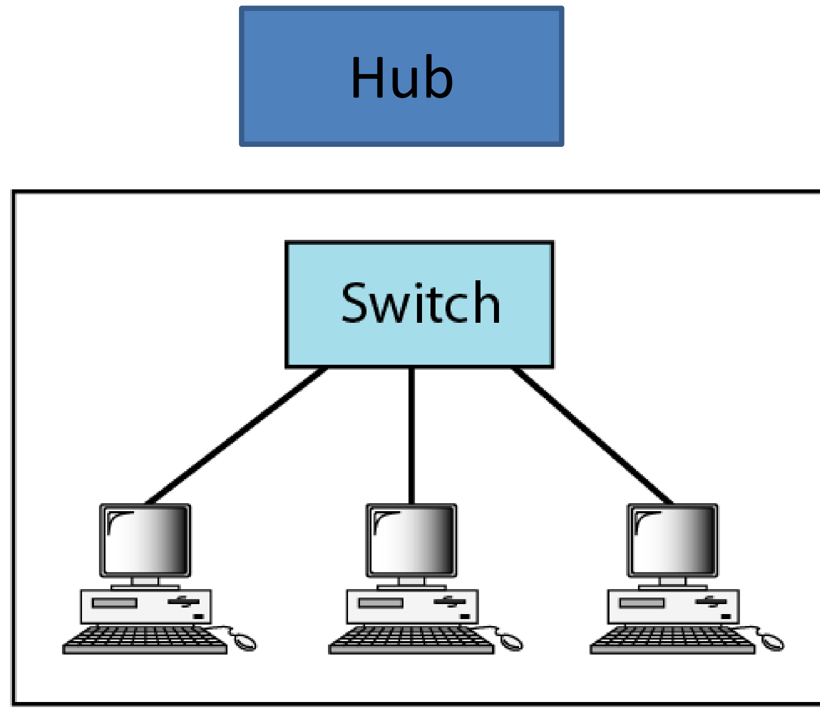
- It allows a station or a hub a range of capabilities.
- Allows two devices to negotiate the mode (half/full duplex) or data rate of operation.
- Allows incompatible devices to connect to one another
  - eg. A device with capacity of 10 Mbps can communicate with a device with a 100 Mbps capacity (but can work at a lower rate)
- To allow one device to have multiple capabilities (encoding)
- To allow a station to check a hub's capabilities (ports etc.)

Physical Layer

- Topology

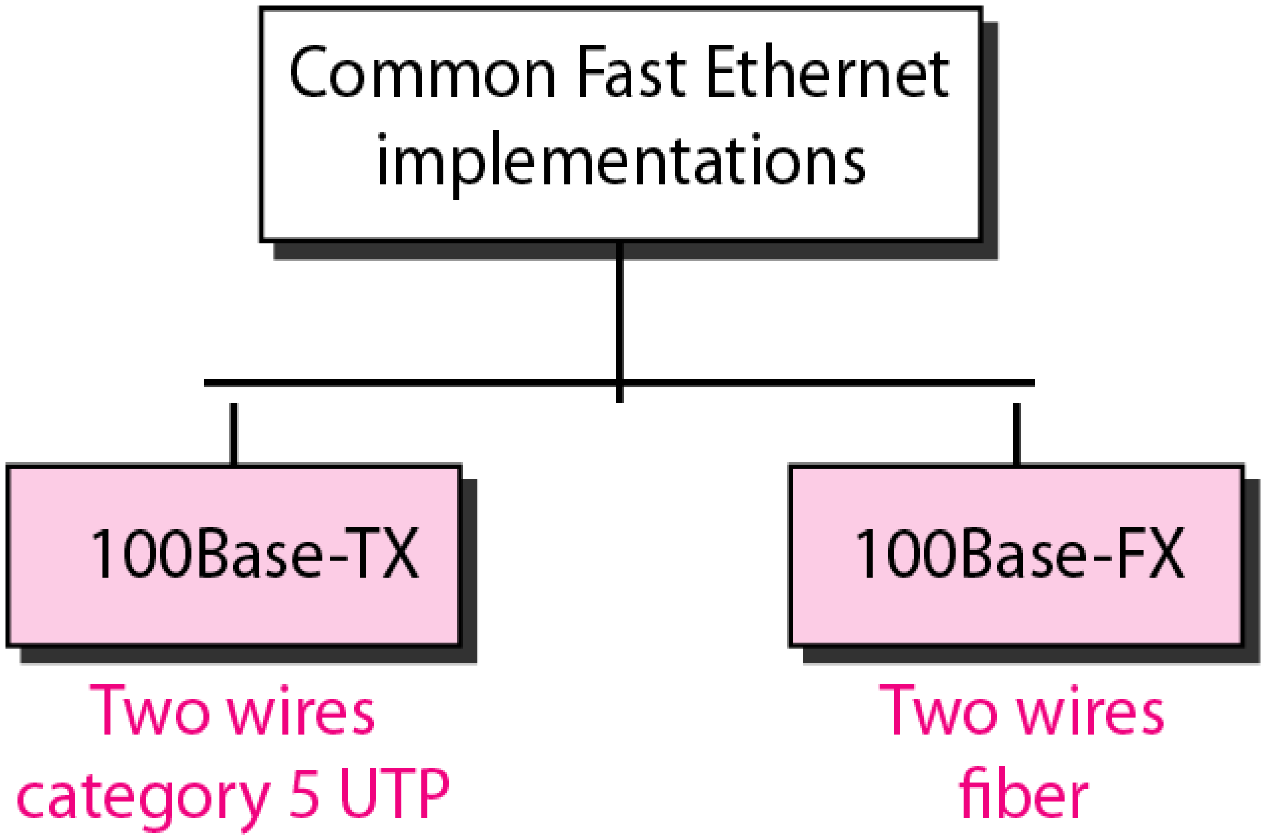


a. Point-to-point



b. Star

Fast Ethernet implementations

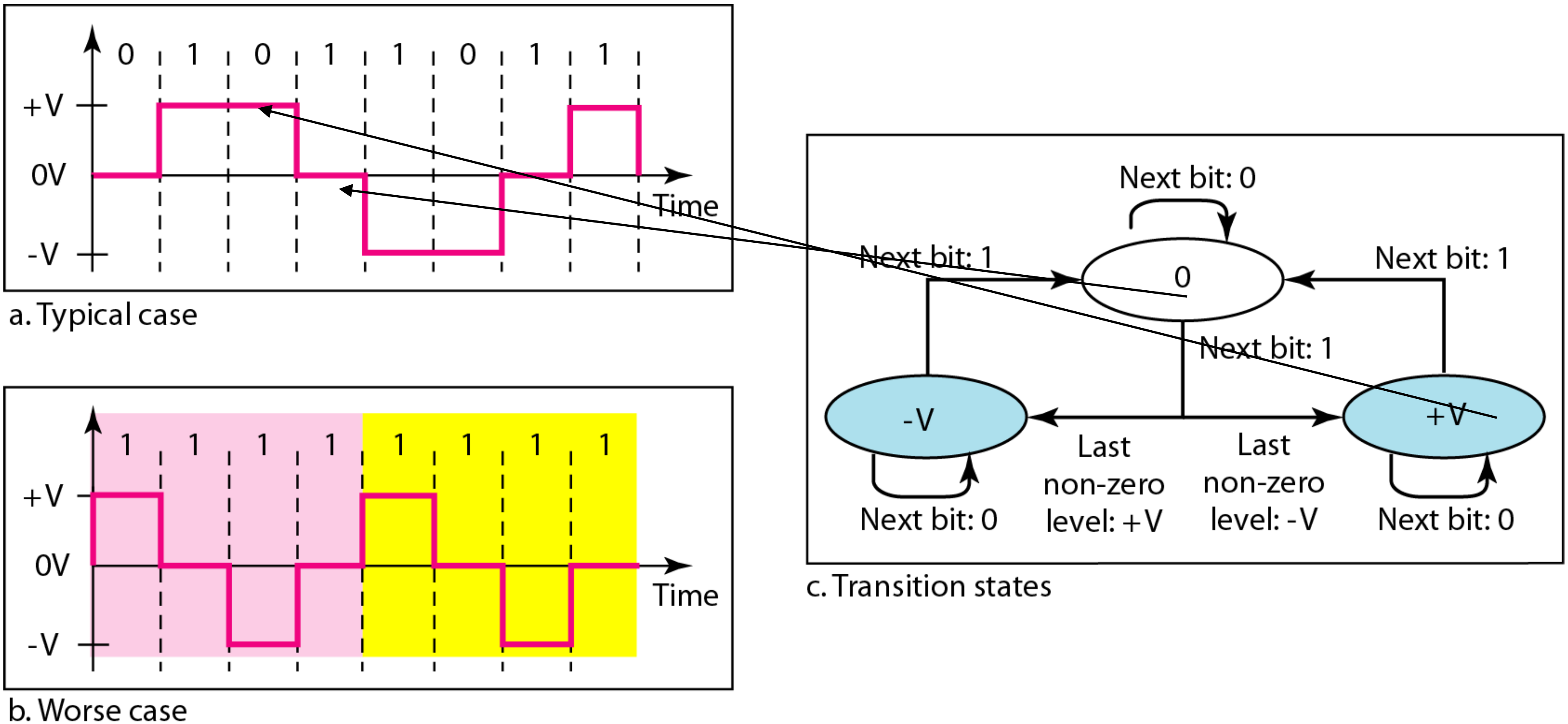


100Base-TX

- Uses 2 pairs of twisted-pair cable (category 5 UTP or STP)
- Multiline transmission, three level (MLT-3) scheme is used for encoding
- It uses 3 levels (+V, 0, - V) and 3 transition rules to move between levels

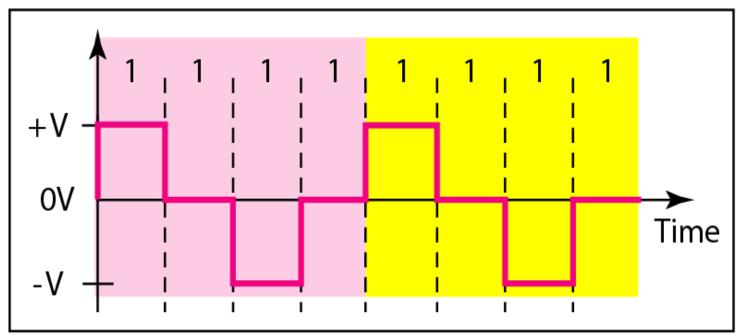
1. If next bit is 0, there is no transition.
2. If next bit is 1 and current V level is not 0, next level is 0.
3. If next bit is 1 and current V level is 0, next level is opposite of last nonzero level

Multitransition: MLT-3 scheme



Why MLT-3 is used in 100Base-TX?

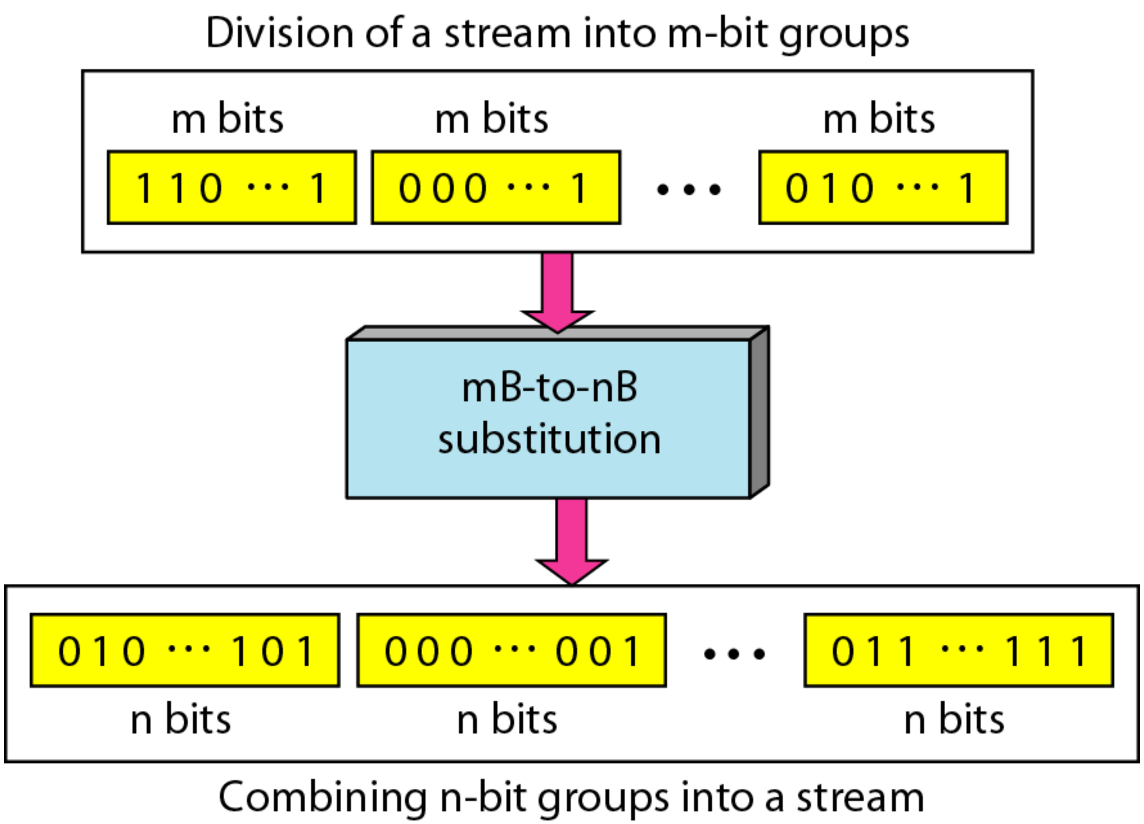
- Shape of signal in MLT-3 helps to reduce required bandwidth
- Worst-case scenario is a sequence of 1s
- Signal element pattern +V,0,- V,0 is repeated every 4 bits
- Nonperiodic signal has changed to a periodic signal with the period equal to 4 times the bit duration
- This can be simulated as an analog signal with a frequency one-fourth of bit rate
- i.e Signal rate for MLT-3 = One-fourth bit rate
- For 100 Mbps, Signal rate = ¼ x 100 = 25 MHz
- Copper wire cannot support more than 32 MHz (frequencies above this level create electromagnetic emissions)
- MLT-3 is not a self-synchronous line coding scheme



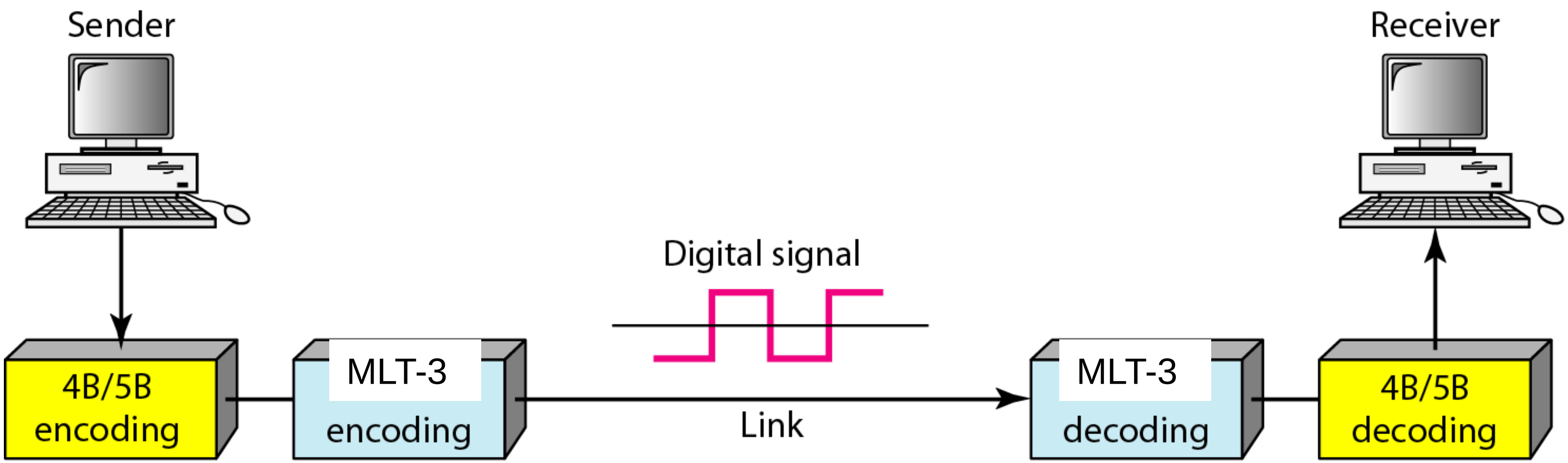
b. Worse case

Block Coding

- Put redundancy to ensure synchronization and to provide some kind of inherent error detecting
- Block coding gives redundancy and improves performance of line coding
- Block (mB/nB) coding replaces each m-bit group with an n-bit group



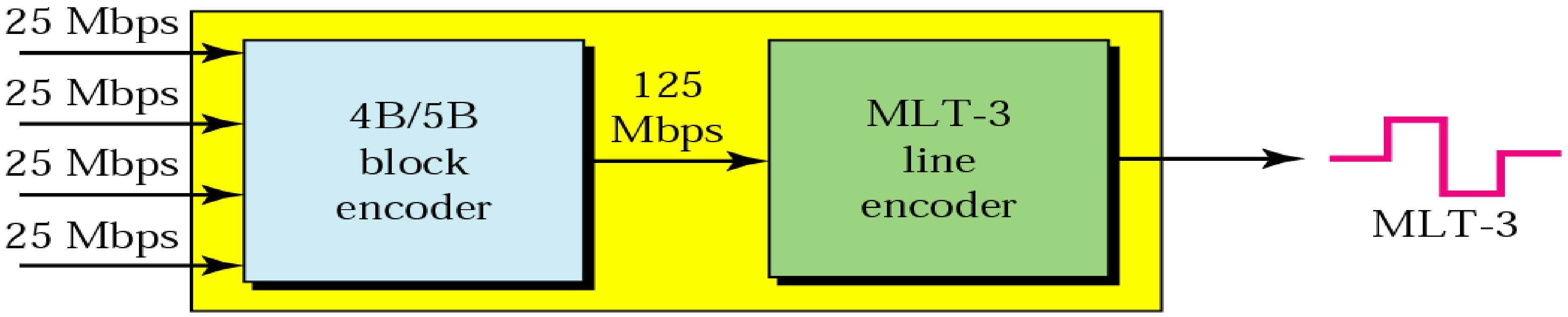
Block coding 4B/5B with MLT-3 line coding



- MLT-3 is not a self-synchronous line coding scheme
- 4B/5B block coding is used to provide bit synchronization by preventing occurrence of a long sequence of 0 s and 1 s
- Every 4 bits are replaced by 5 bits and it is assured that there are no consecutive 0s or 1s
- This creates a data rate of 125 Mbps, which is fed into MLT-3 for encoding

Encoding and decoding in 100Base-TX

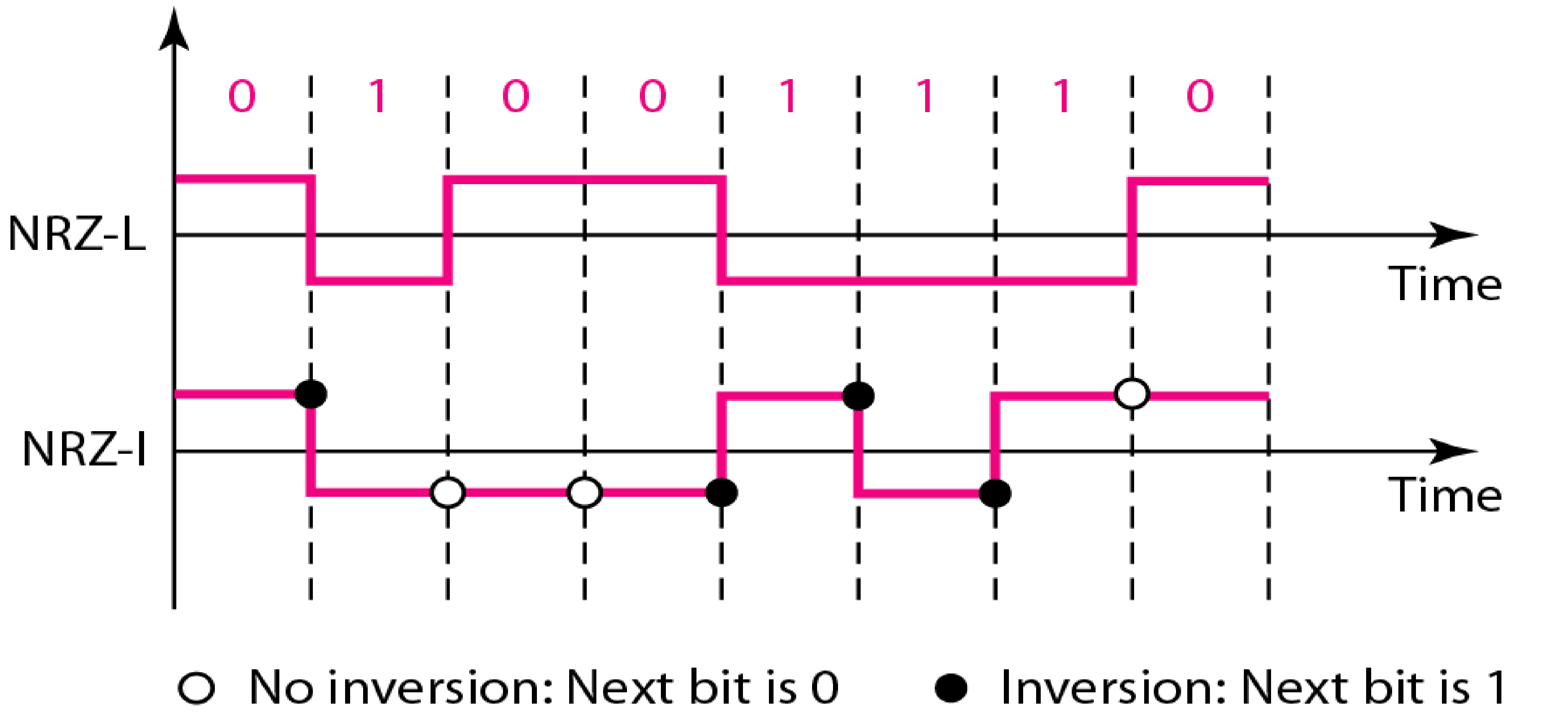
2 pairs of twisted-pair cable



100Base-FX

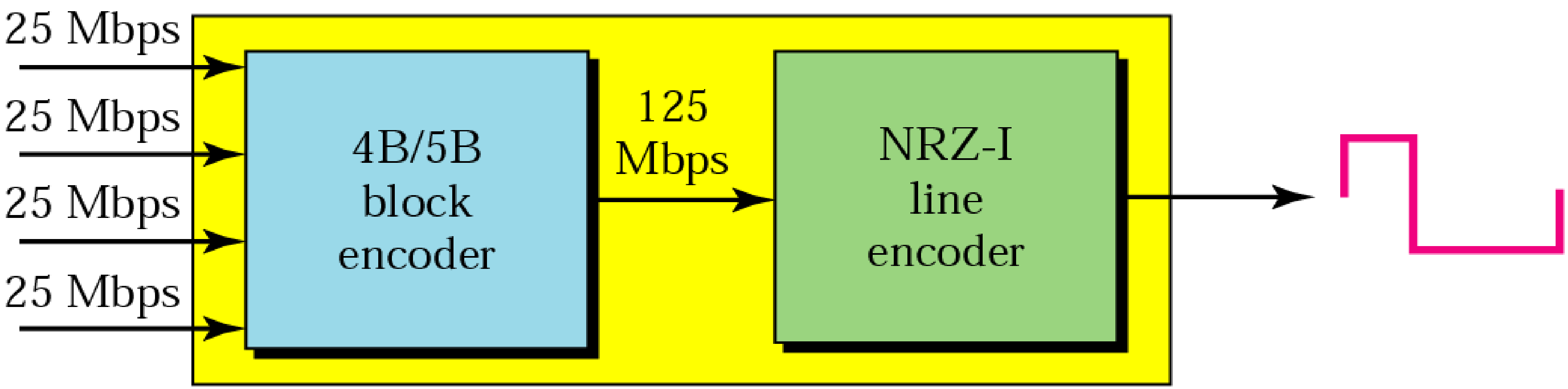
- uses two pairs of fiber-optic cables
- NRZ-I encoding scheme is used
- NRZ-I has a bit synchronization problem for long sequences of 0s or 1 s
- A long sequence of 0s can make the receiver clock lose synchronization.
- To overcome this problem, 4B/5B block encoding is used
- The block-coded stream does not have more that three consecutive 0s
- The block encoding increases the bit rate from 100 to 125 Mbps, which can easily be handled by fiber-optic cable

NRZ-L and NRZ-I schemes



In NRZ-L the level of the voltage determines the value of the bit.
In NRZ-I the inversion (for 1) or the lack of inversion (for 0) determines value of bit.

Encoding and decoding in 100Base-FX



At the receiver, the NRZ-I encoded digital signal is first decoded into a stream of bits and then decoded to remove the redundancy.

Summary of Fast Ethernet implementations

Characteristics	*100Base-TX*	*100Base-FX*
Media	Cat 5 UTP or STP	Fiber
Number of wires	2	2
Maximum length	100 m	100 m
Block encoding	4B/5B	4B/5B
Line encoding	MLT-3	NRZ-I

GIGABIT ETHERNET (802.3z)

1. Upgrade data rate to 1 Gbps.
2. Make it compatible with Standard or Fast Ethernet.
3. Use same 48-bit address.
4. Use same frame format.
5. Keep same minimum and maximum frame lengths.
6. To support autonegotiation as defined in Fast Ethernet.

Gigabit Ethernet - MAC Sublayer

- Full-duplex mode
- Switch connected to computers/other switches
- Each switch has buffers for each input port to store data until they are transmitted
- Thus no collision and CSMA/CD is not used
- Lack of collision implies
  - maximum length of cable is determined by signal attenuation in cable, not by CD process (Slot time rule is not required here)

Gigabit Ethernet - MAC Sublayer

- Half-Duplex Mode
- To have it compatible with previous generations Ethernet
- Switch replaced by a hub, which acts as common cable in which a collision might occur
- Uses CSMA/CD – brings slot time rule

Slot Time and Minimum Frame Size

- Slot time = minimum time a station must transmit a single frame for
- This means a frame cannot be too small or a station would not be able to transmit for long enough to abide by slot-time rule
- The reason a station has to transmit continuously for a particular length of time is (slot time rule):

Slot time rule

- Suppose station is transmitting frame and collision occurs at the far end of network
- Transmitting station will only be able to detect collision when collision wave has propagated back again
- This takes time
- If sending station finishes transmitting before collision wave makes it back to it, then it will not realize a collision has occurred
- Slot time rule makes sure a transmitting station transmits for a long enough period of time, so it can detect any returning collision wave

Slot time for 10/100 Mbps Ethernet

- For 10/100 Mbps Ethernet networks, slot time is 512 bit times
- A bit time is time it takes for a transmitter to send a single bit out onto the medium
- Gigabit Ethernet can send out bits at a faster rate than 10/100 Mbps Ethernet
- If slot time for Gigabit Ethernet was also 512 bit times, then transmission time period would not be long enough for a station to detect collision waves
- So the slot time for Gigabit Ethernet is 4096 bit times

Slot time for 10/100 Mbps Ethernet

- To think about what slot and bit time means, consider Ethernet frame
- If a transmitter has to transmit 512 bits of data to satisfy slot time, how many bytes is that?
- Which frame fields below must be transmitted to satisfy slot time rule?

Slot time and Frame Size in 10/100 Mbps Ethernet

Ethernet II Frame

preamble	destination	source	type	data/pad	FCS
8	6	6	2	46 - 1500	4

- For 512 bits (64 bytes), transmitter must send out destination source, type, FCS fields (6+6+2+4=18 bytes)
- Preamble is not part of frame so not considered
- To satisfy slot time (64 bytes), a transmitter must send out at least 46 (64-18) more bytes of data
- This is why there is 46 byte minimum size for the data/pad field of a frame - to ensure that slot time is satisfied
- Station is not allowed to transmit a frame shorter in length than this

Slot time and Frame Size in Gigabit Ethernet

- Gigabit Ethernet has problem with 512 bit slot time used on 10/100 Mbps Ethernet
- It can transmit 512 bits on medium so quickly, that signal would travel less than 100 mts before station stopped transmitting
- Thus station would have stopped transmitting way before any collision wave made its way back along a 100 m of cable.

Slot time and Frame Size in Gigabit Ethernet

- So, slot time for Gigabit Ethernet was increased to 4096 bit times - this is 512 bytes of data
- If a short frame is to be transmitted that meets the minimum data/pad field length of an Ethernet frame (46 bytes) but is too short to meet slot time requirements (512 bytes), then an “carrier extension field" is added to the frame
- The extension field helps bring the total transmission size up to the required 512 bytes.
- Any extension field is discarded by the receiving station

Carrier Extension

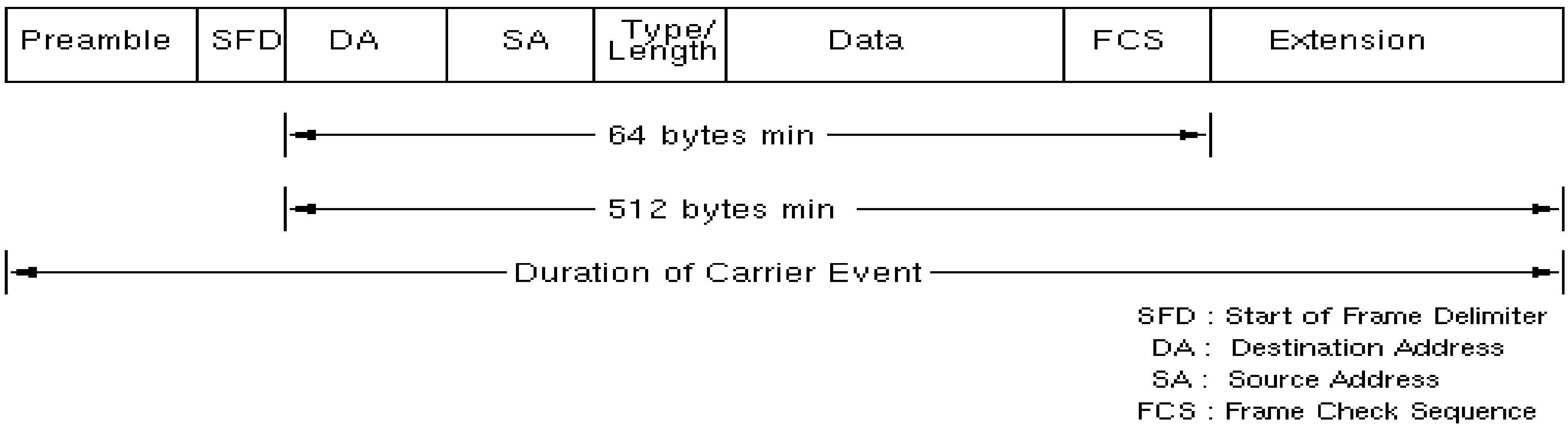
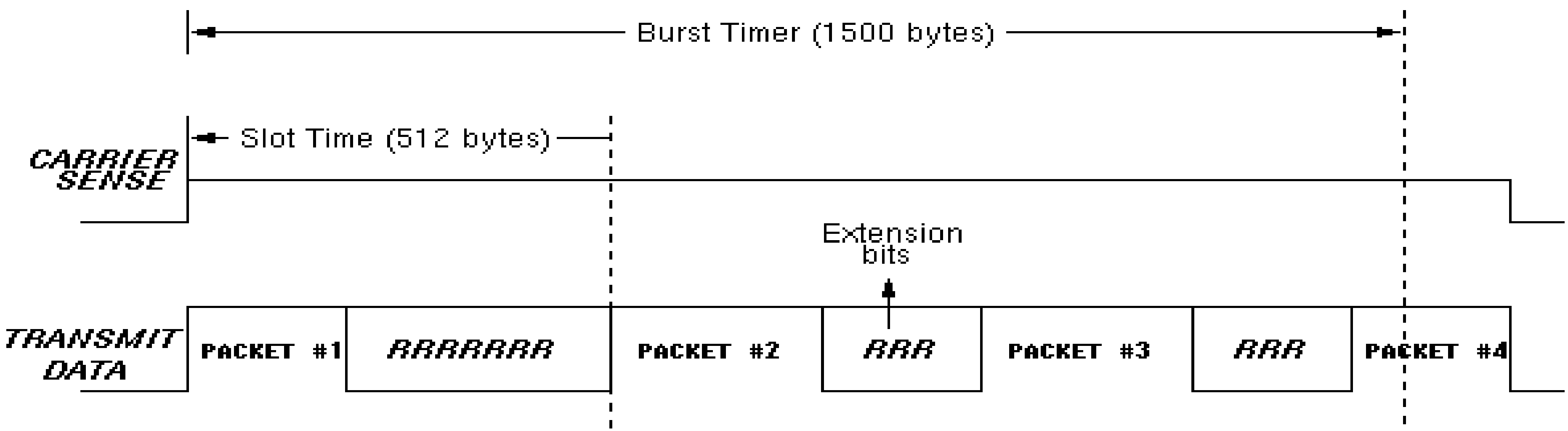


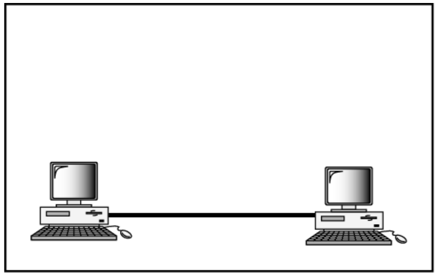
Fig 1. Ethernet Frame Format with Carrier Extension

Frame Bursting

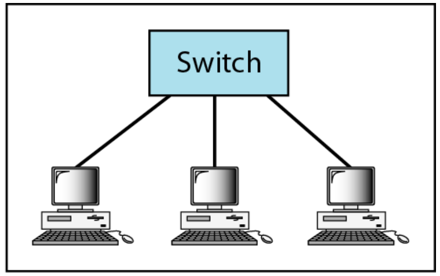
- Carrier Extension wastes bandwidth as up to 448 padding bytes may be sent for small packets (64 bytes size)
- Frame Bursting is "Carrier Extension plus a burst of packets“
- When a station has a number of packets to transmit, first packet is padded to slot time using carrier extension.
- Subsequent packets are transmitted back to back, with minimum Inter-packet gap (IPG) until a burst timer (of 1500 bytes) expires (the maximum payload is 1500 bytes offered by ethernet frame)



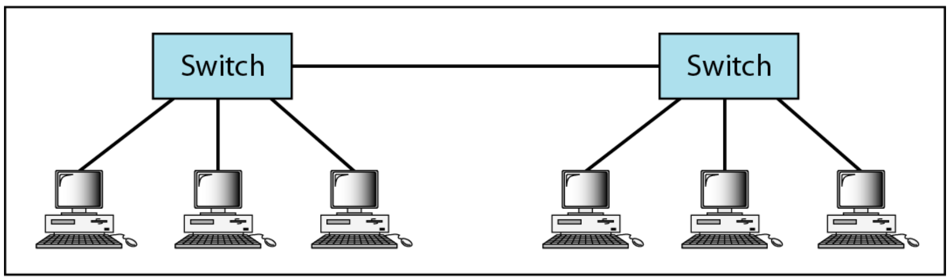
Gigabit Ethernet - Physical Layer



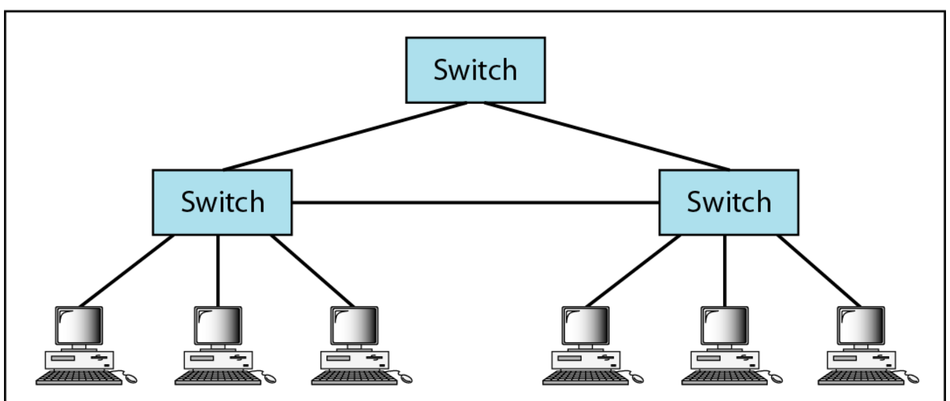
a. Point-to-point



b. Star

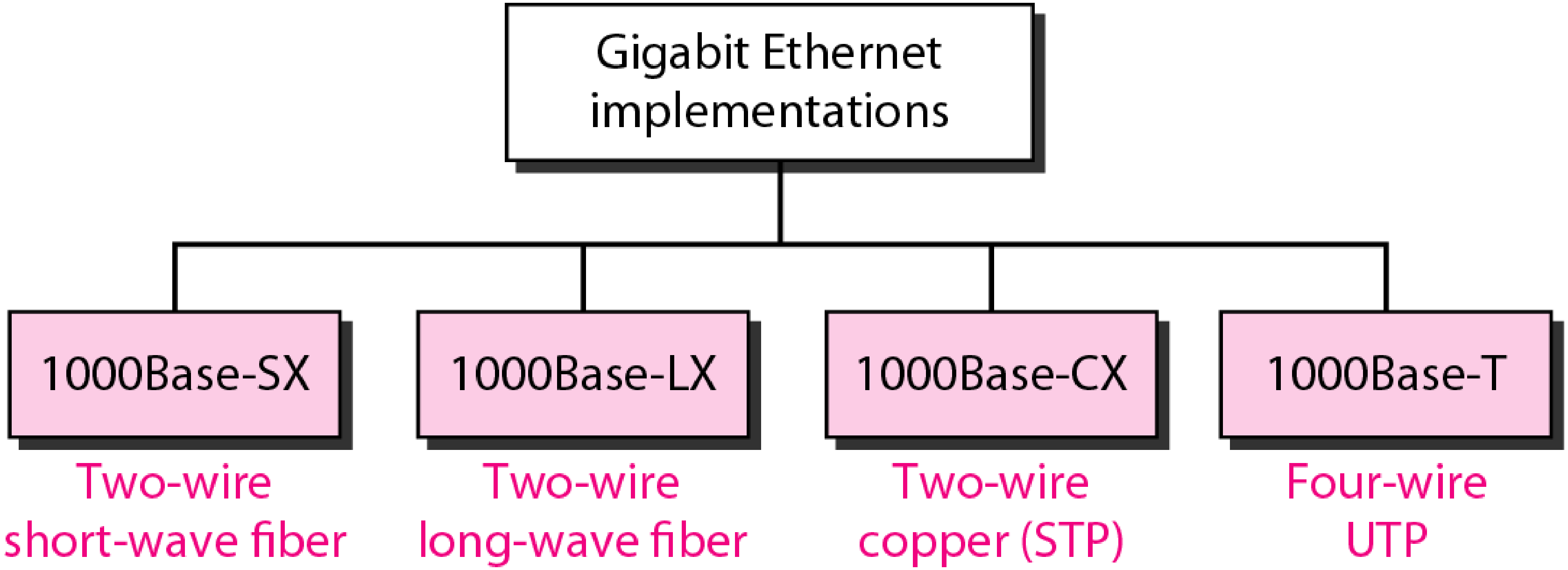


c. Two stars



d. Hierarchy of stars

- Topology
- Can be Hub or Switch

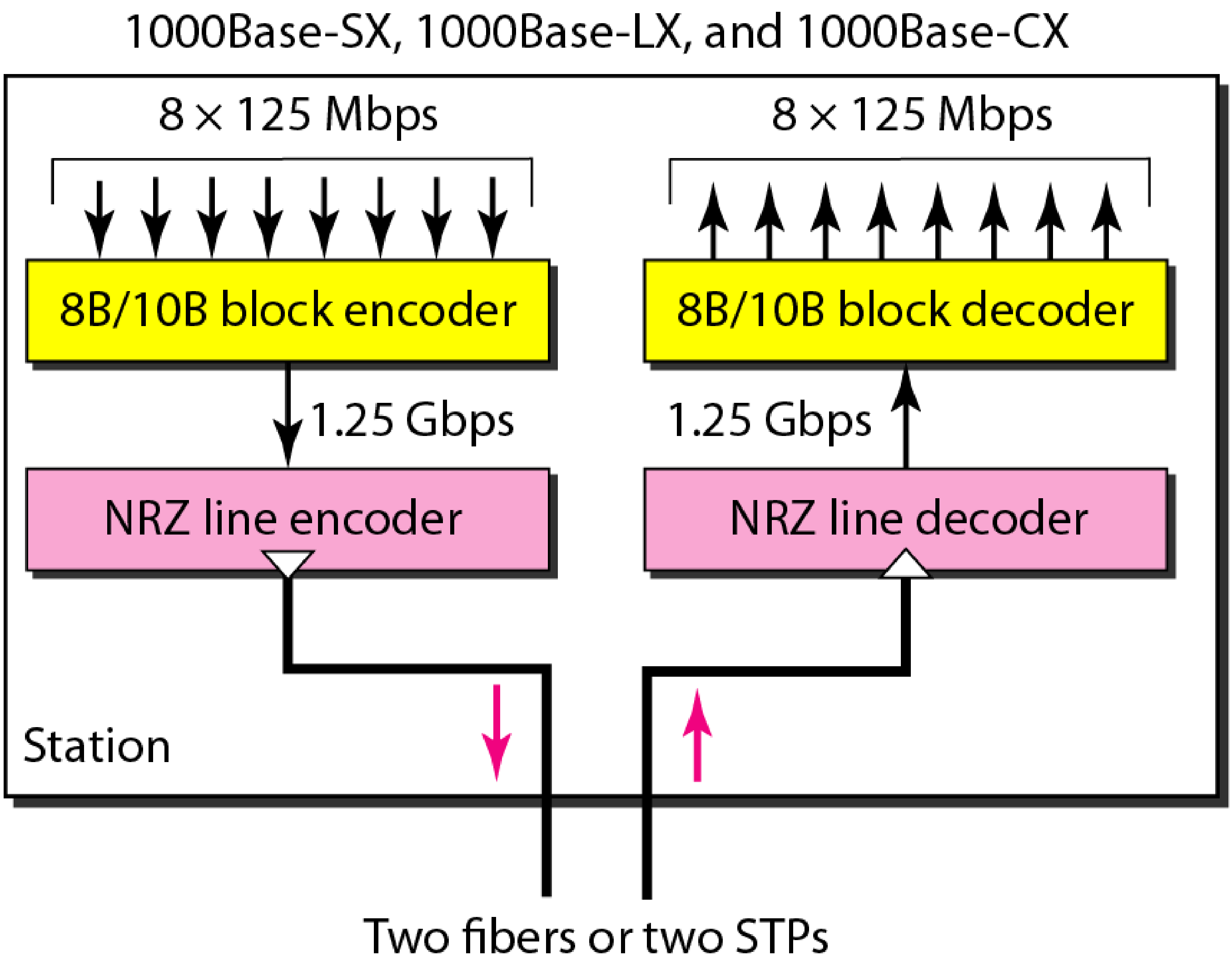

Gigabit Ethernet implementations
1000Base-SX
1000Base-LX
1000Base-CX
1000Base-T
Two-wire short-wave fiber
Two-wire long-wave fiber
Two-wire copper (STP)
Four-wire UTP

- Cat-5 cable

Encoding in Gigabit Ethernet Two wire case

- 1000BaseSX, 1000BaseLX
- Two wire – one fiber for sending and one for receiving
- Two-wire implementations uses NRZ scheme
- NRZ does not self-synchronize properly
- To synchronize bits, at this high data rate, 8B/10B block encoding is used.
- It prevents long sequences of 0s or 1s in the stream, the resulting stream is 1.25 Gbps

Encoding in Gigabit Ethernet



Encoding in Gigabit Ethernet Four wire case

1000BaseT

UTP cables used

Four wire implementation

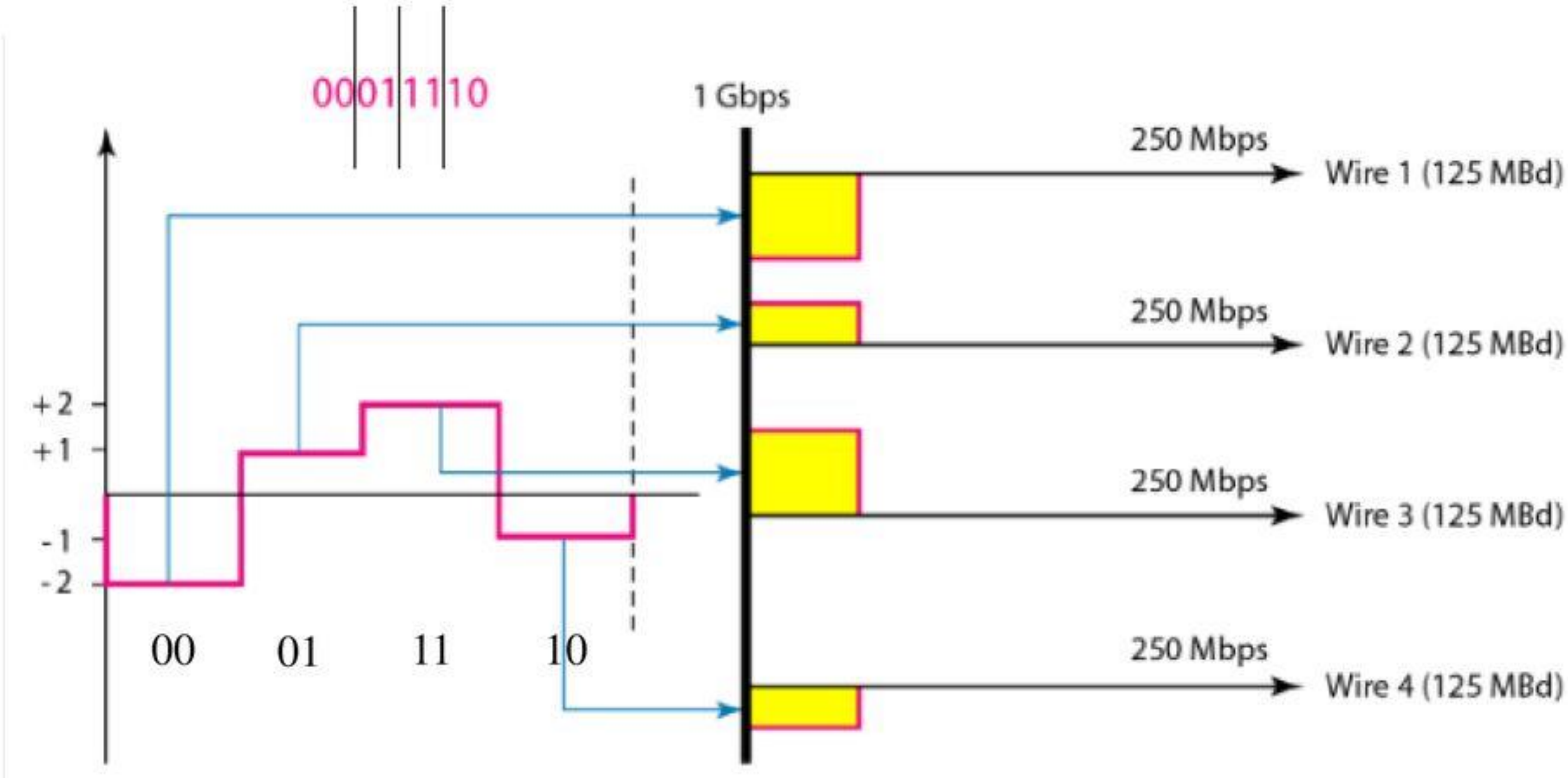
- All four wires are involved in input/output each carries 250 Mbps (capacity of Cat-5 UTP)
- 4D-PAM5 encoding is used to reduce BW and bring it to that offered by UTP

4D-PAM5 encoding

- 4 dimensional 5 level pulse amplitude modulation
- data transmitted over four wires simultaneously
- 5 voltage levels are used to represent these data viz. -2, -1, 0, 1 and 2
- Level '0' is used for forward error detection
- All 8 bits are fed into wire simultaneously and are transmitted using one signal element

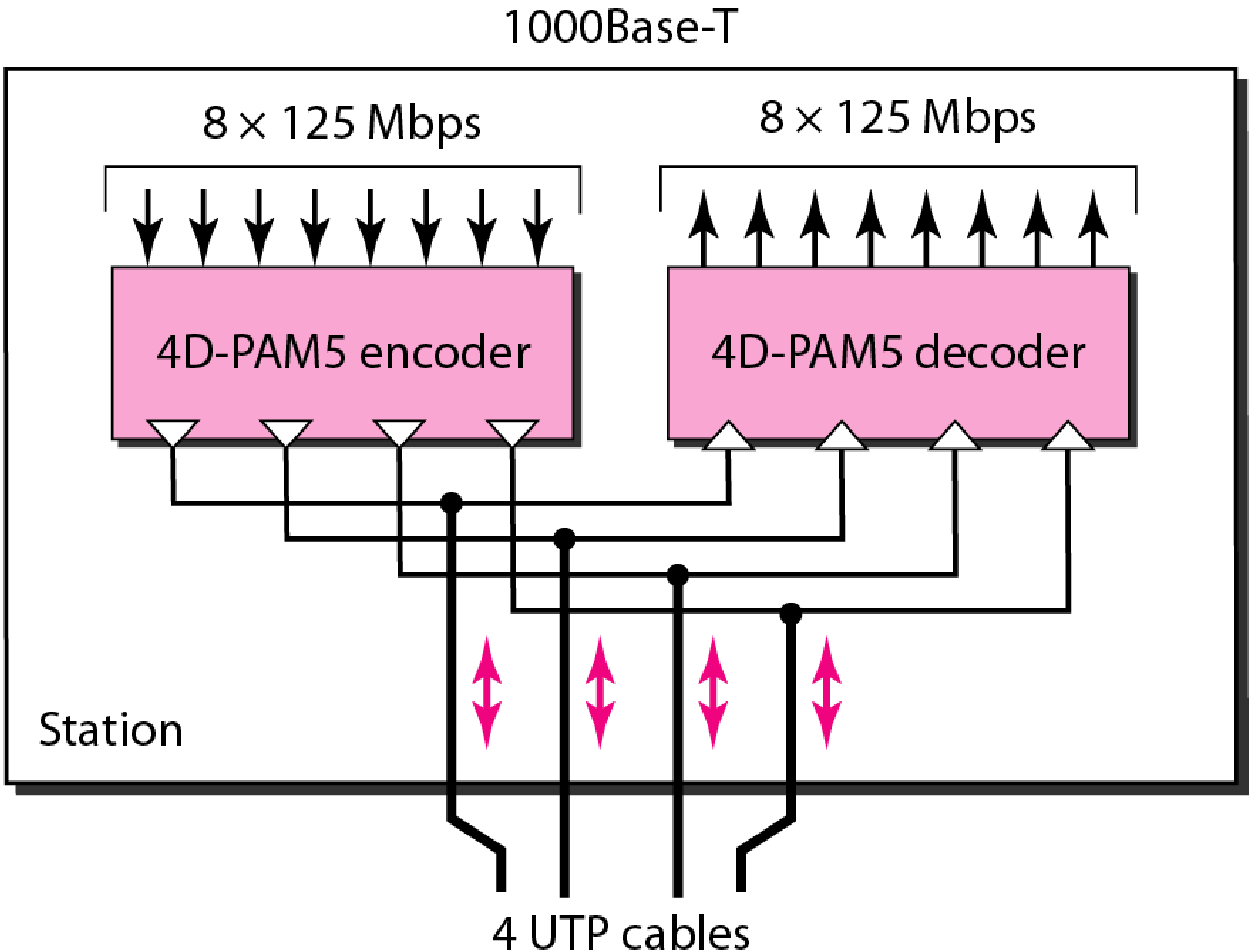
4D-PAM5: Gigabit Ethernet: 1000Base-T

(Four-Dimensional Five-level Pulse Amplitude Modulation)



1 voltage level = 2 bits

Encoding in Gigabit Ethernet



Summary of Gigabit Ethernet implementations

Characteristics	*1000Base-SX*	*1000Base-LX*	*1000Base-CX*	*1000Base-T*
Media	Fiber short-wave	Fiber long-wave	STP	Cat 5 UTP
Number of wires	2	2	2	4
Maximum length	550 m	5000 m	25 m	100 m
Block encoding	8B/10B	8B/10B	8B/10B	
Line encoding	NRZ	NRZ	NRZ	4D-PAM5

Ten-Gigabit Ethernet (802.3ae)

- Goals
  - Upgrade the data rate to 10 Gbps.
  - Make it compatible with Standard, Fast, Gigabit Ethernet.
  - Use same 48-bit address.
  - Use same frame format.
  - Keep same minimum and maximum frame lengths.
  - Allow interconnection of existing LANs into MAN/WAN
  - Make Ethernet compatible with technologies such as Frame Relay and ATM

Ten-Gigabit-MAC Sublayer

- Operates in full duplex mode which means there is no need for contention
- CSMA/CD is not used

Ten-Gigabit-Physical Layer

- for using fiber-optic cable over long distances

Characteristics	*10GBase-S*	*10GBase-L*	*10GBase-E*
Media	Short-wave 850-nm multimode	Long-wave 1310-nm single mode	Extended 1550-mm single mode
Maximum length	300 m	10 km	40 km

Thank You!