Computer Networks - I

- **Introduction and Data Communication Fundamentals**

  Goals of Networking

  Applications and Classification of networks

  Transmission media

  Functions of Networking Devices

  Pulse Code Modulation (PCM)

  Asynchronous and Synchronous Transmission, Multiplexing

  Circuit Switching Versus Packet Switching Techniques

- **Local Area Networks**

  Characteristics of Networks

  LAN topologies

  Introduction to the IEEE standard

  Ethernet

Computer Networks - I

- **Layered Protocols**

    Protocols, Protocol hierarchies

    Design issues for the layers

    The OSI reference model & TCP/IP reference model

    Protocols at different layers of the OSI reference model

    The Internet Protocol (IP), Subnets, Subnet Masks

    Transmission Control Protocol (TCP)

    User Datagram Protocol (UDP)

- **Domain Name Systems, Electronic Mail and World Wide Web**

    DNS, Resource records

    Electronic mail: Architecture and Services

    World Wide Web, Uniform Resource Locator and Cookies

Goals of Networking

- **Resource and Load sharing**
  – Several machines can share printer, scanner, DVD drive, etc.
  – Network resources are available to user of the network.
- **Reduced cost**
  – Mainframe Vs Desktop Computers
  – Cost of network printer, scanner & DVD drive is less.
- **High reliability**
  – If a one machine goes down, another machine can take over.
- **Remotely Access I/O Devices**
  – Access devices through the Internet.
- **Scalability**
  – As workload increase easily extent the network by adding more micro processors.
- **Powerful Communication**
  – A file that was updated or modified on a network can be seen by the other users on the network immediately.

- **Computer Networks**
  - "A network consists of two or more computers that are linked in order to share resources, exchange files, or allow electronic communications."
  - It is a collection of interconnected , but autonomous computers.
- **Distributed System**
  - A collection of independent computers that appear to the user of the system as single computer system.
- **Distributed System Vs Computer Networks**

– Computers are invisible to users	Computers are visible to users
– Login is not required	Login is required
– E.g. WWW	E.g. LAN

internet Vs Internet

- **internet or internetwork**
  - A collection of interconnected networks that function as a single network
  - Establish communication link between two or more networks.

Internetworking = Interconnectivity + Interoperability

  - **Interconnectivity** – the ease and ability of connecting networks
  - **Interoperability** – the methodology applied to make data understand to computers that uses different OSs and Languages.

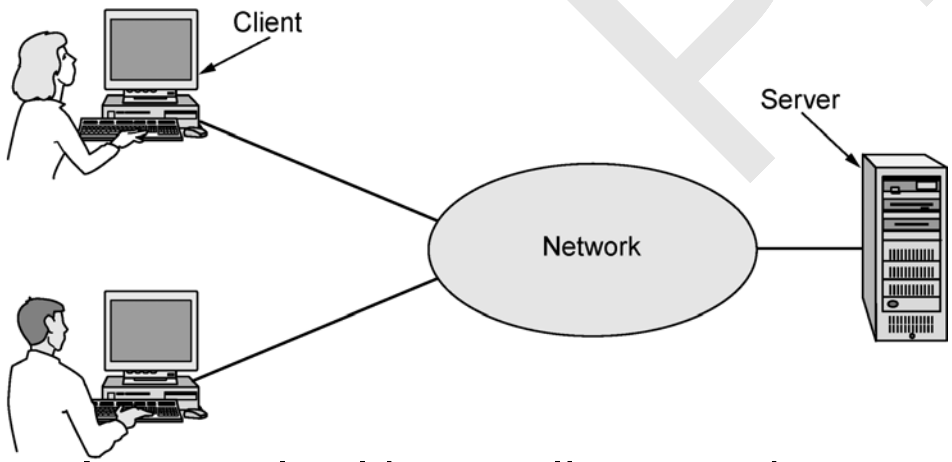
- **Internet**
  - A Network of networks
  - Used to connect universities, government offices, Banks etc.

Historical Perspective

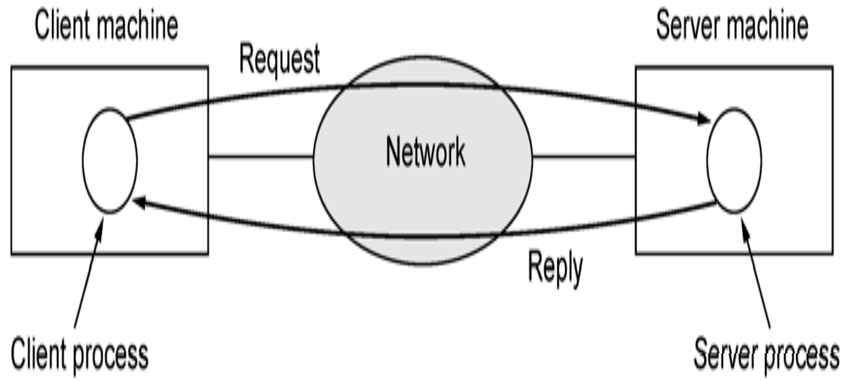
- 1967: ARPAnet –Advanced Research Projects Agency Network
- 1970: ALOHA (Additive Links On-line Hawaii Area) network in Hawaii
- 1973: Ethernet used in LAN
- 1983: TCP/IP
- 1990: WWW (Http)
- 2000: Ipv6
- 2005 : Social Networks
- 2007: Smartphone
- 2010: Broadband & Mobile Internet
- 2011: Cloud Computing
- 2014 : WiFi with higher speed
- 2016 : Internet of Things

Networks Applications

- **Business Applications**
  - All programs, Data and Devices available to anyone on the network.
  - Connect individual network or host at different physical location through the VPN (Virtual Private Network)
  - Client – Server Model is used for network usage.



A network with two clients and one server.



The client-server model involves requests and replies.

Networks Applications

- **Business Applications**
  - E-mail, FTP, Messenger
  - IP Telephone or Voice over IP (VoIP)
  - Audio & Video Conferencing
  - Desktop sharing
  - E-commerce

Networks Applications

- **Home Application**
  - Access to remote Information
    - Home shopping
    - Pay the bills
    - Manage bank account
    - Surfing for business, health, govt., news etc
  - Person to Person Communication
    - Email , Messenger, Audio / Video conference
  - Interactive Entertainment
    - Internet Radio, Video on demand, Youtube , Playing game
  - Social network
    - Face book, Twitter, LinkedIn

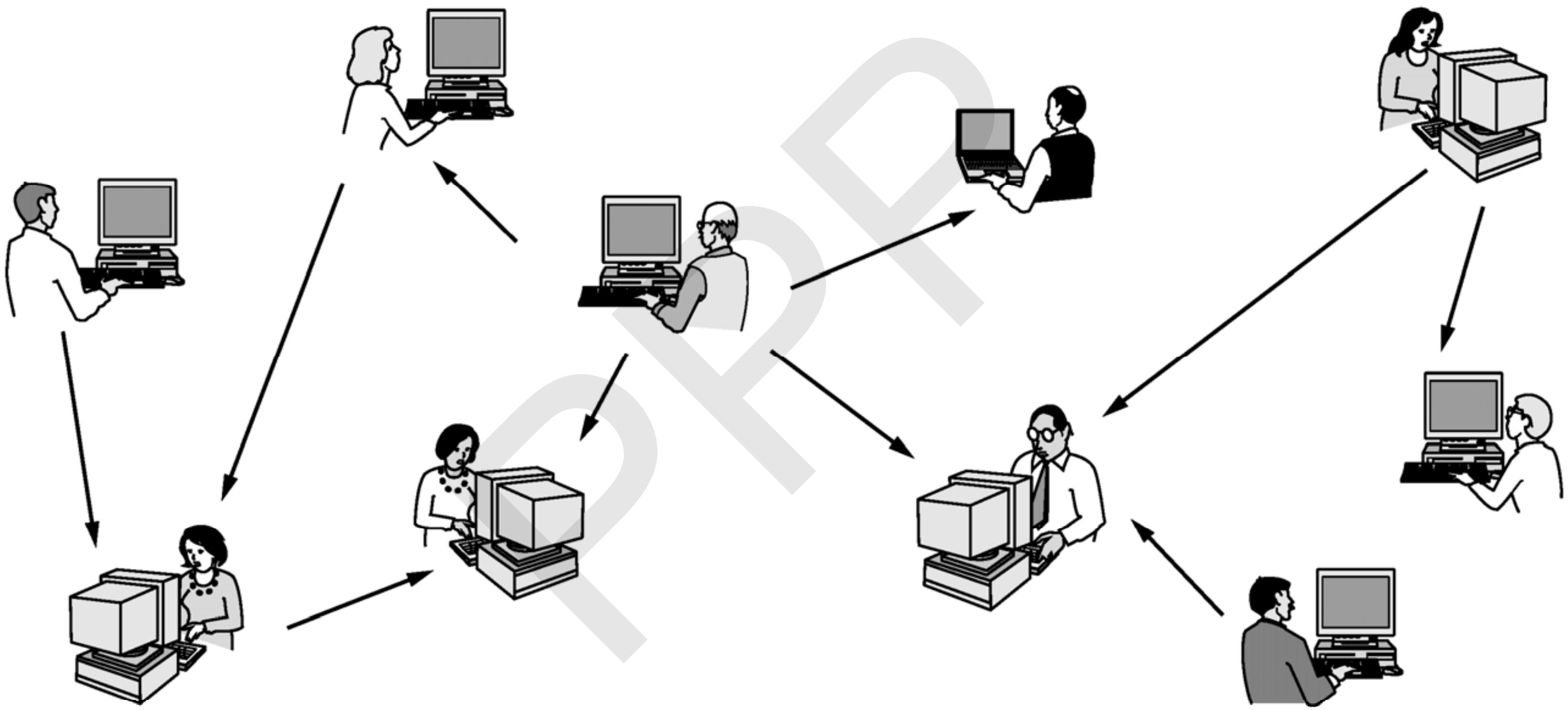
Networks Applications

Home Application

- Door and Window Sensors
- Electricity, Gas & Water meter
- Smoke Detector
- Shower may record water usage
- Refrigerator reminds about buying vegetables
- Babysitter is sleeping
- Electric bulb tells us if it is going down
- Lamp dims itself when you are asleep
- Night lamp automatically switches on and off
- Smart Keys
- A phone receiver transfers the call automatically
- Control house via Internet or phone
- RFID (Radio Frequency Identification)

Networks Applications

Home Application:



In a peer-to-peer system there are no fixed clients and servers.

Networks Applications

Some forms of e-commerce.

Tag	Full name	Example
B2C	Business-to-consumer	Ordering books online
B2B	Business-to-business	Car manufacturer ordering tires from supplier
G2C	Government-to-consumer	Government distributing tax forms electronically
C2C	Consumer-to-consumer	Auctioning second-hand products online
P2P	Peer-to-peer	Music sharing

Networks Applications

Mobile Users

Wireless	Mobile	Typical applications
No	No	Desktop computers in offices
No	Yes	A notebook computer used in a hotel room
Yes	No	Networks in unwired buildings
Yes	Yes	Store inventory with a handheld computer

Combinations of wireless networks and mobile computing.

Networks Applications

Mobile Users

- PDA with built in printer
- PDA with Barcode
- Vending Machine
- University Campus
- Military
- Conferences
- Location Dependent Services
- Electronic wallet
- SMS (Short Message Service)
- Taxi Drivers are independent businessman
- M-commerce

Types of Transmission

- **Broadcasting**:
  - **Single communication channel that is shared by all the machines on the network.**
  - **Every machine gets the packet but the machine for which it is broadcast only that machine accept other will reject it.**
- **Multicasting**:
  - **Transmission to subset of the machines.**
- **Point-To-Point**:
  - **Many connections between individual pairs of machines.**
  - **Packet may have to visit one or more intermediate machine.**

Types of Broadcasting

- **Static Broadcasting**
  - **To divide the time into discrete intervals and use round robin algo. which allowing each machine to broadcast only when its time slot comes up.**
  - **Problem :: Idle slot when machine has nothing to say.**
- **Dynamic Broadcasting**
  - **Centralize**
    - **Single entity determines who goes next**
  - **Decentralize**
    - **Each machine must decide for itself whether to transmit or not.**

Transmission Mode

To define the direction of signal flow between linked devices.

- Simplex : Signal flow only in one direction.
- Half-Duplex : Signal flow in both direction but at a time in only one direction.
- Full-Duplex : Signal flow in both direction at the same time.

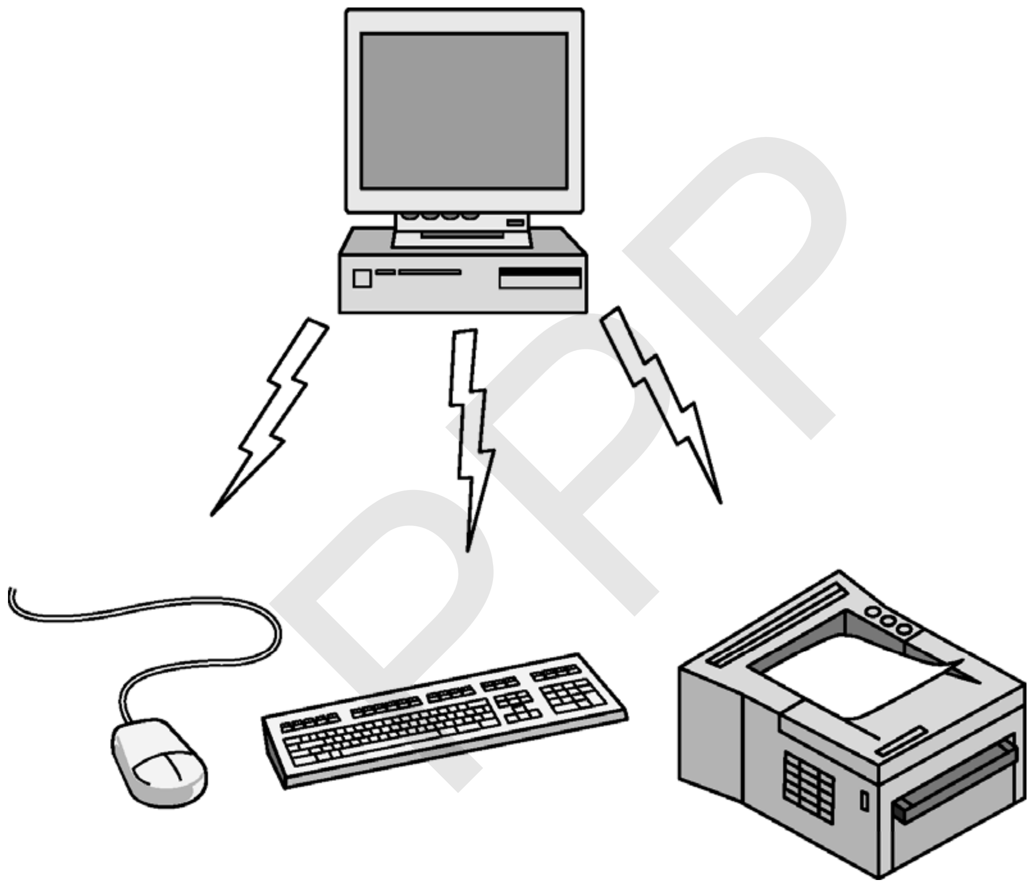
Classification of Networks

- Scale :
  - According the distance covered by network.
- Connection Method :
  - Types of connection in network
- Functional Relationship
  - Relationship between technology of network.
- Network Topology
  - The way the network devices are physically or logically connected.

Classification of Networks

Scale	Connection Method	Functional Relationship	Network Topology
Personal Area Network (PNA)	Ethernet	Client Server	Bus Network
Local Area Network (LAN)	Fiber Optics	Peer to Peer	Ring Network
Metropolitan Area Network (MAN)	Wireless Network		Star Network
Wide Area Network (WAN)	Satellite Network		Tree Network
			Mesh Network

Personal Area Network



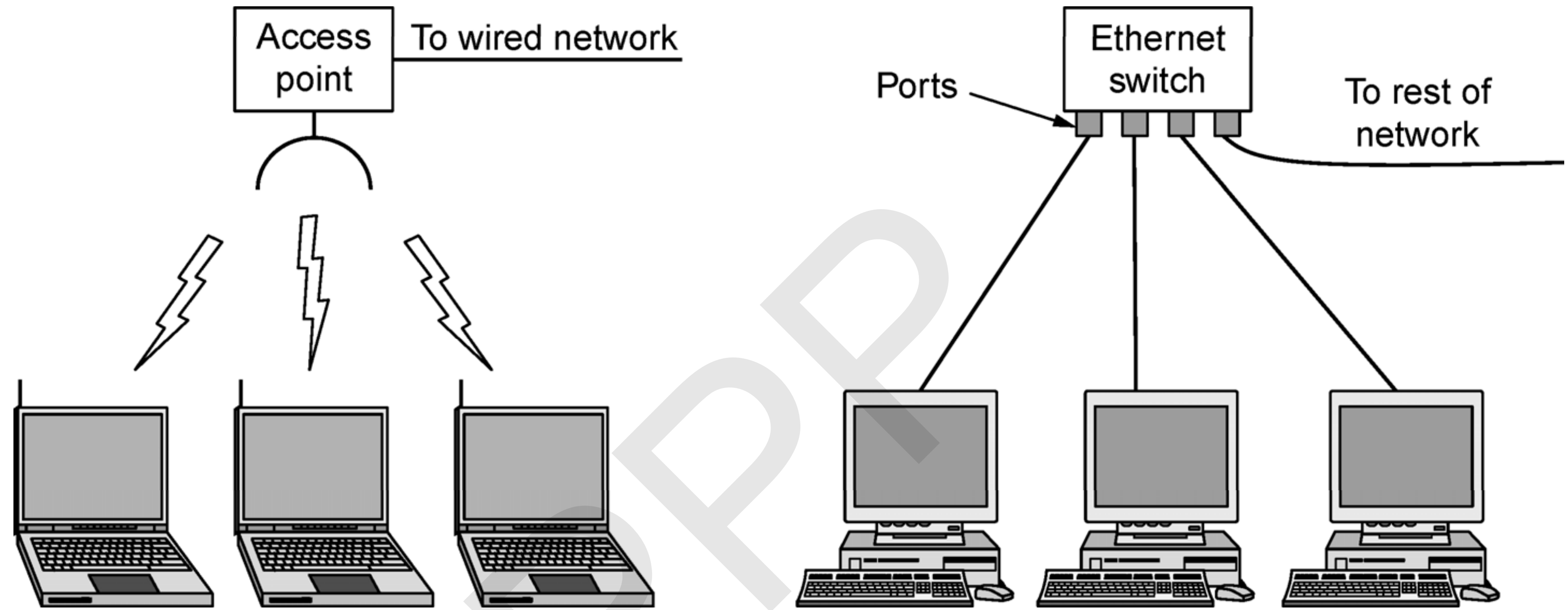
Bluetooth PAN configuration.

- Short range signals
- Master Slave concept

Local Area Network (LAN)

- Enterprise network
- Wi-Fi network
- Switch & Port
- Switched Ethernet (Broadcast)
- Classic Ethernet (Collision Resolution)

Wireless Network & Ethernet Network



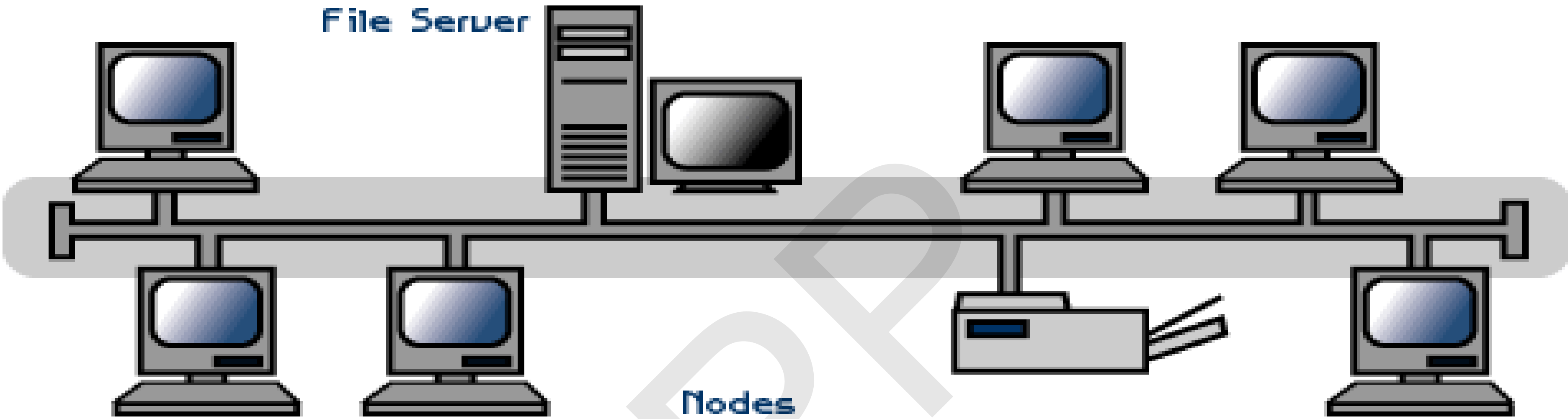
Wireless and wired LANs. (a) 802.11. (b) Switched Ethernet.

Topology

Configuration of cables, computers, and other peripherals

- Bus
- Ring
- Star
- Mesh
- Tree

Bus Topology



Advantages

Simple , reliable in very small networks

Least amount of cable

Less expensive

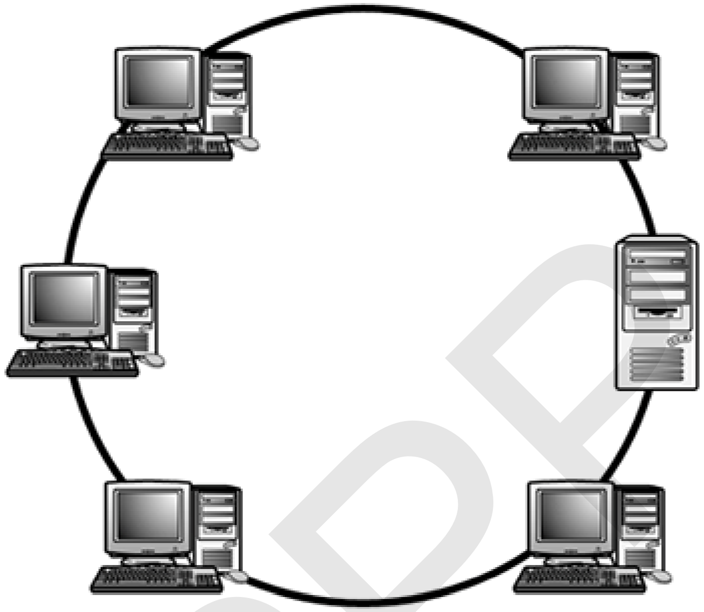
Easy to extend

Disadvantages

Heavy network traffic

Difficult to fault isolation

Ring Topology



Advantages

Every computer is given equal access to the token

Fault isolation is simplified

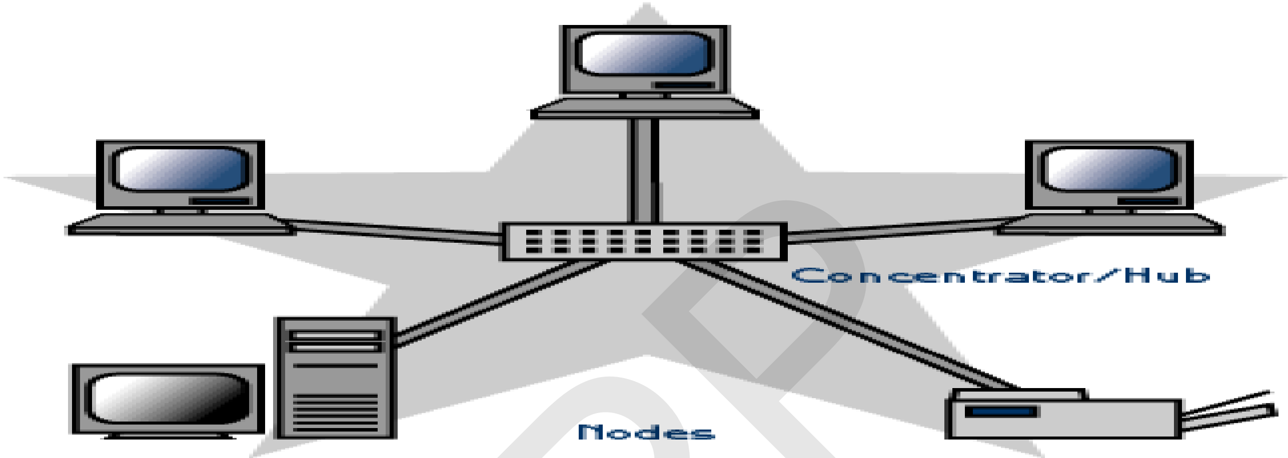
Easy to add or remove device

Disadvantages

Unidirectional traffic

Failure of one computer on the ring can affect the whole network.

Star Topology



Advantages

Easy to add and remove computers

Easy to fault isolation

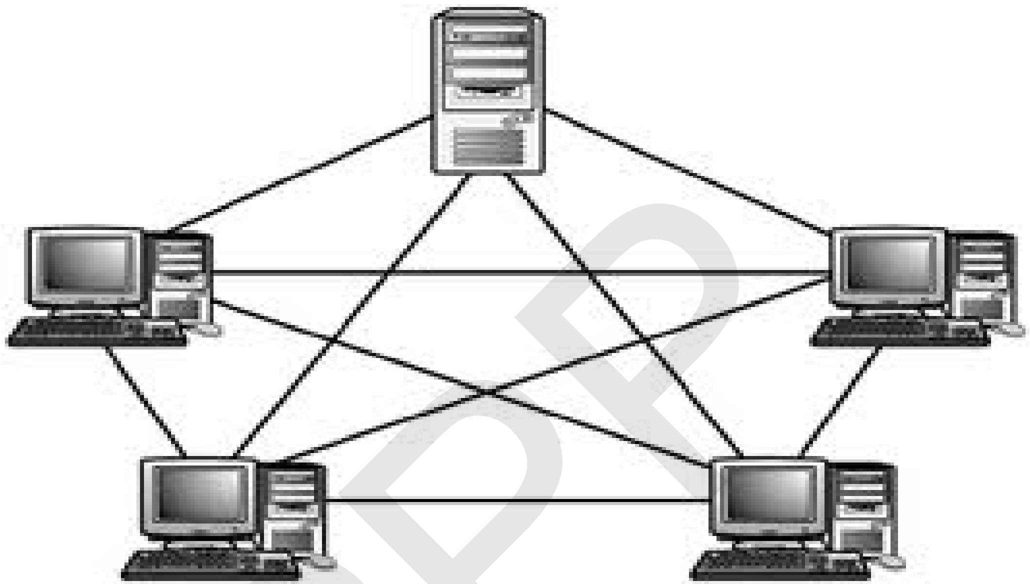
Single computer failure do not bring down the whole star network.

Disadvantages

If the central hub fails , the whole network fails to operate

More cable require

Mesh Topology



Advantages

No traffic problem

Robust

Privacy or Security

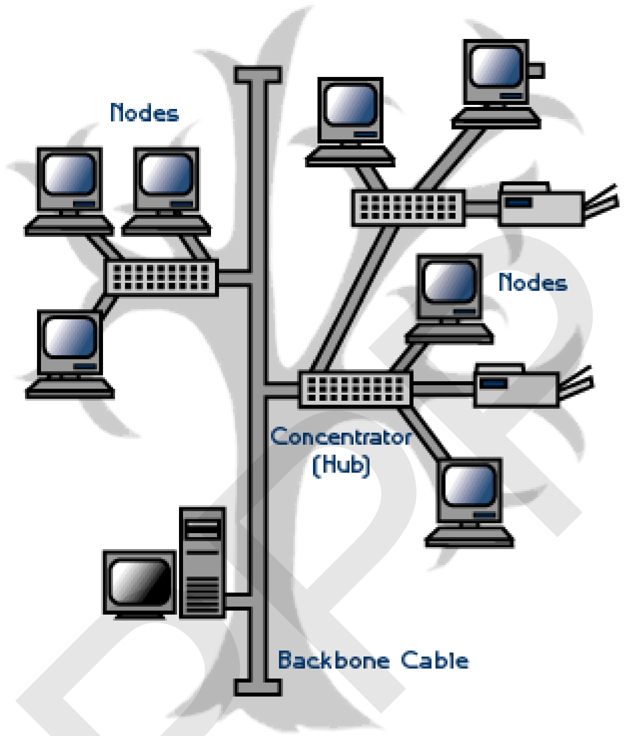
Easy fault identification and fault isolation

Disadvantages

More cabling and number of I/O ports required

More expensive

Tree Topology



Advantages

It allows the network to isolate and prioritize communications from different computers

It allows more devices to be attached to a single central hub

Disadvantages

If the backbone line breaks, the entire segment goes down.

- **Network Architecture**
  - A set of layers and protocols

- **Protocol**
  - It is an agreement between the communicating parties on how communication is to proceed.

- **Layer**
  - Most networks are organized as a stack of layers
  - The number of layers , name of each layers and function of each layers differ from network to network.

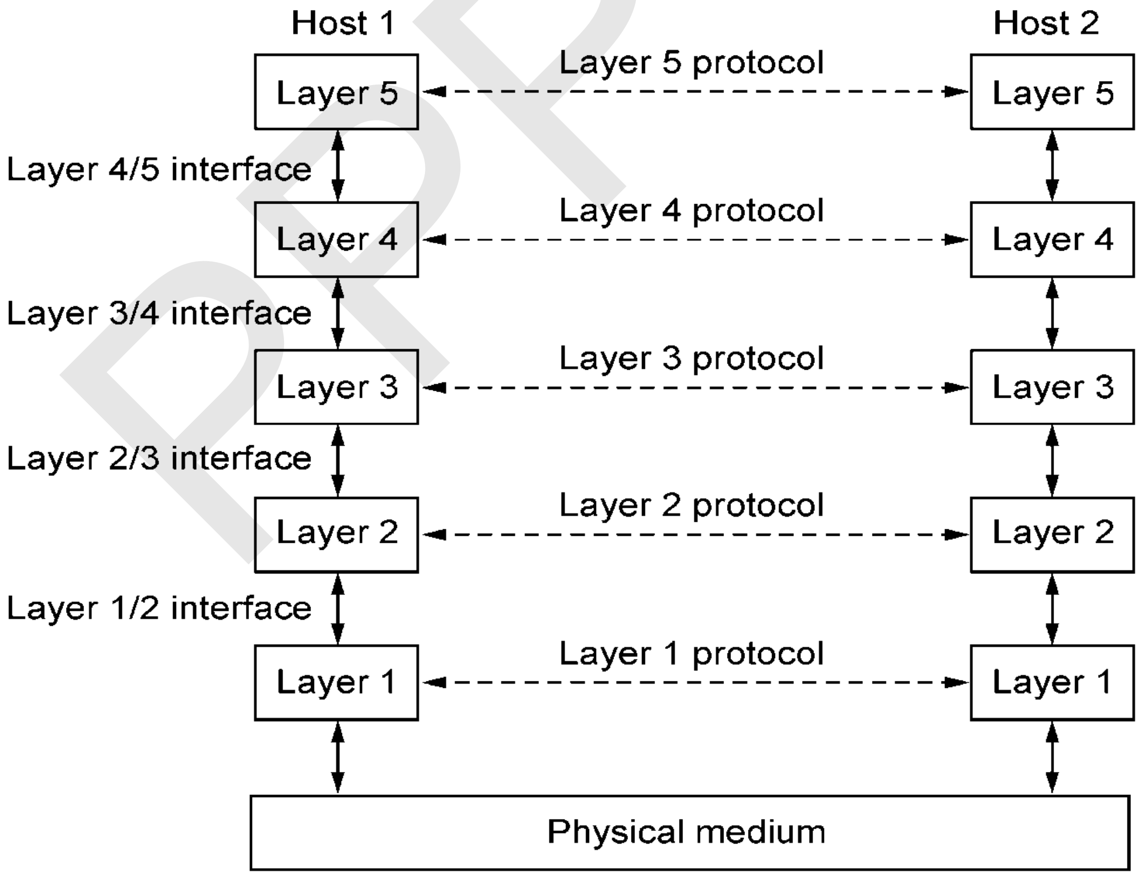
- **Interface**
  - Between each pair of adjacent layers is an interface.
  - It defines which primitive operations and services the lower layer makes available to the upper one.

- **Entity**
  - Active element (h/w or s/w) in each layer are called entity
  - Entities in the same layer on different machines are called peer entities.

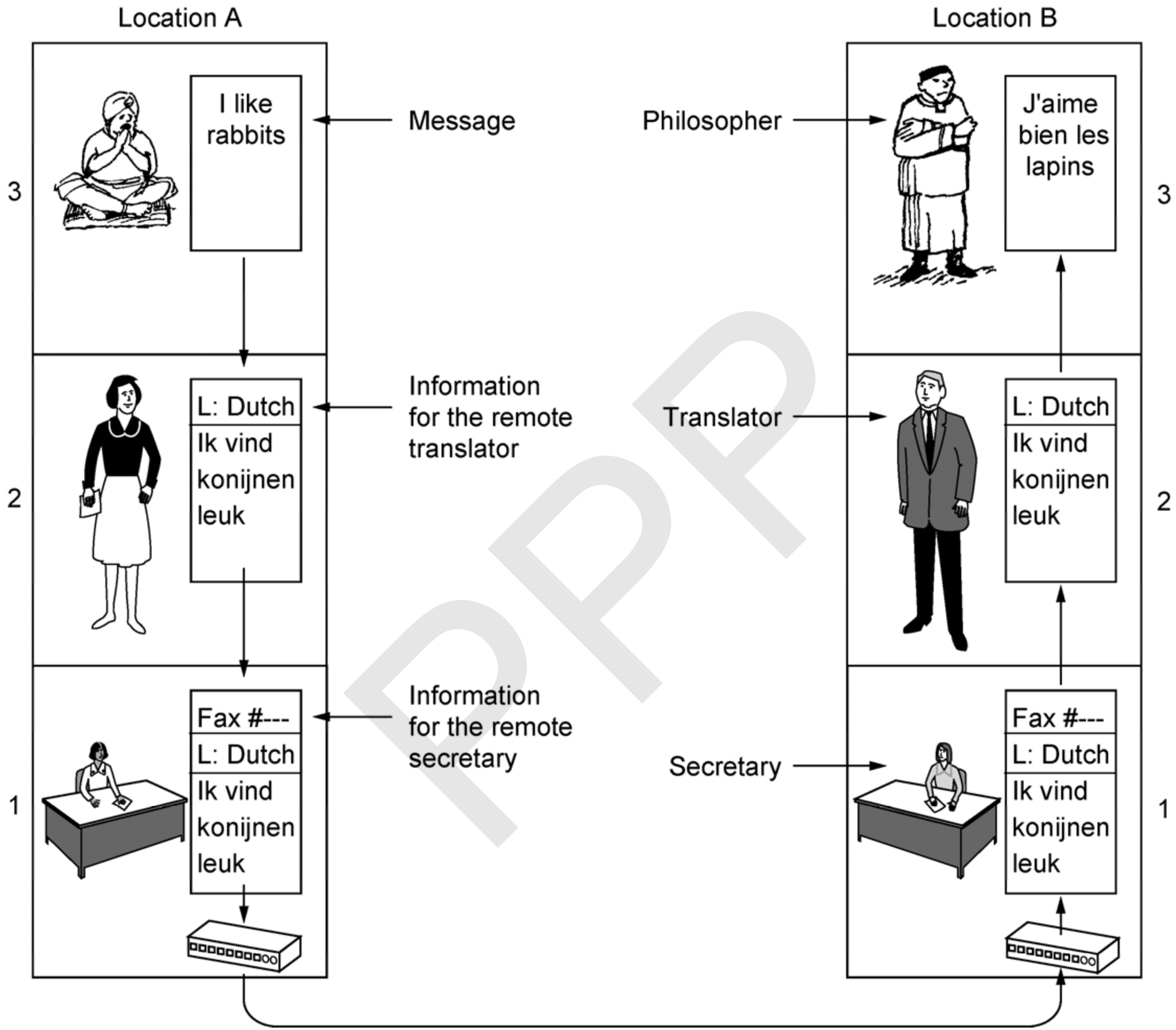
Protocol Layers

Protocol layering is the main structuring method used to divide up network functionality.

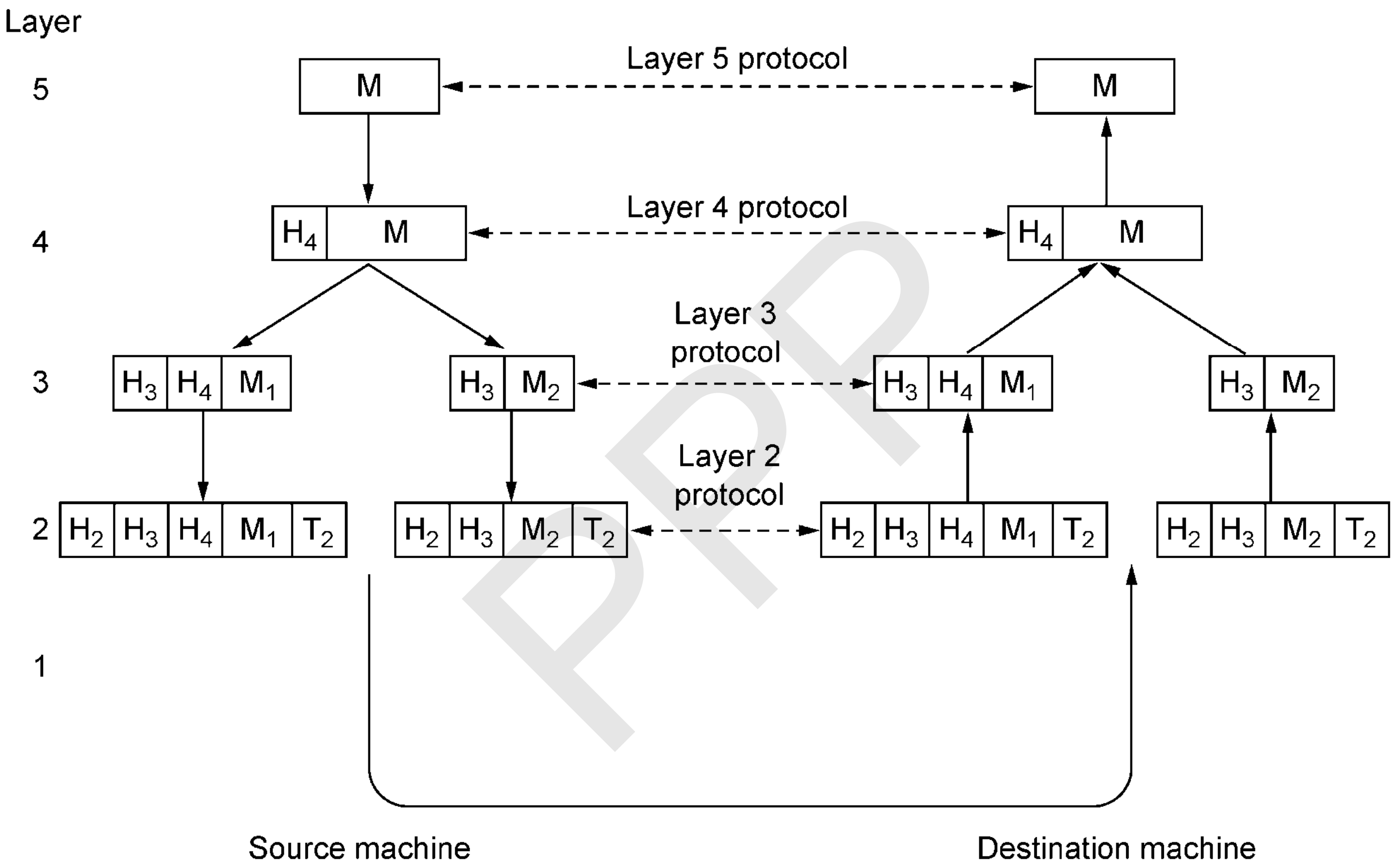
- Each protocol instance talks virtually to its peer
- Each layer communicates only by using the one below
- Lower layer services are accessed by an interface
- At bottom, messages are carried by the medium



Layers, protocols, and interfaces.



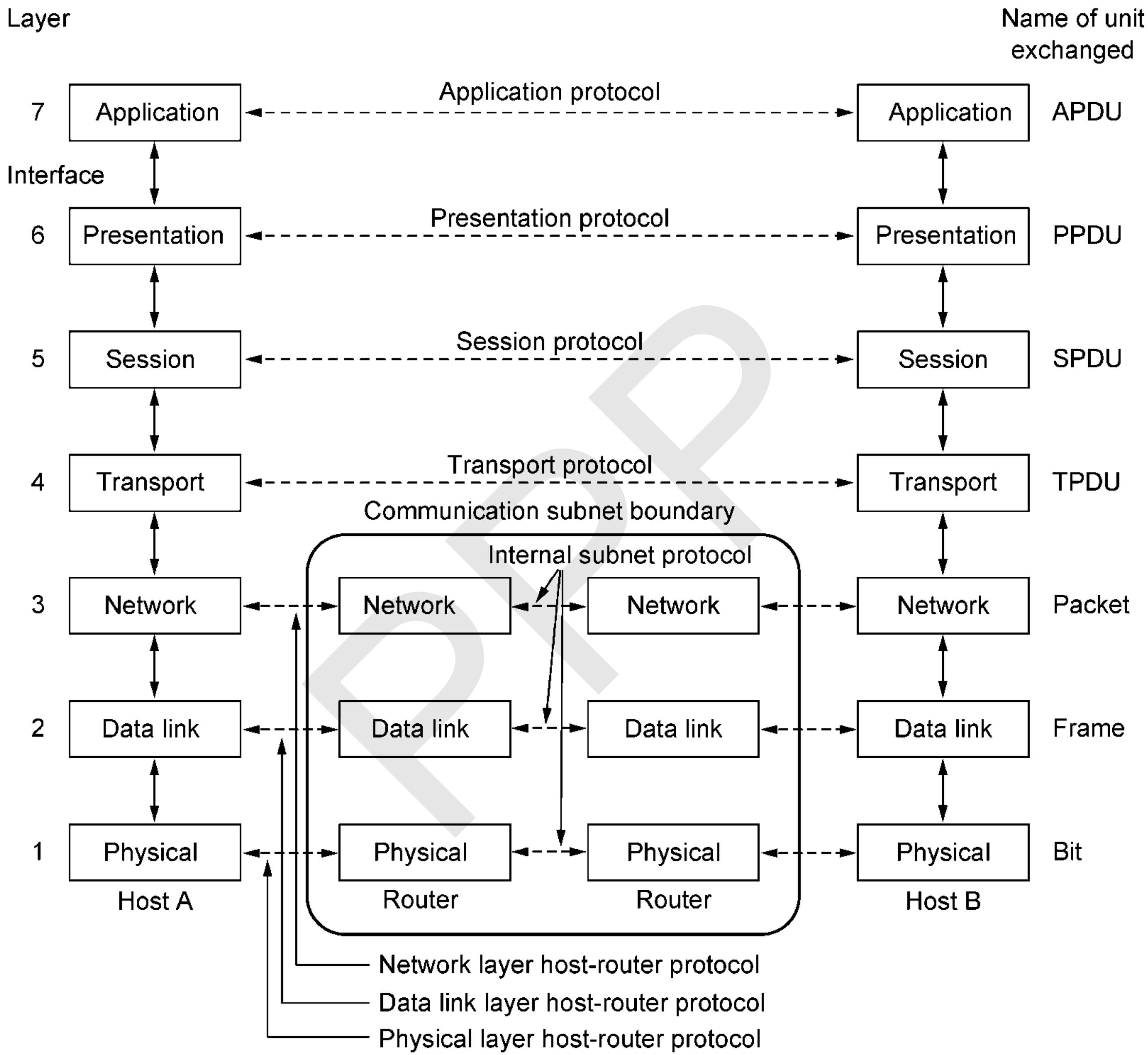
The philosopher-translator-secretary architecture.



Example information flow supporting virtual communication in layer 5.

Two important network architecture

- **OSI** (Open System Interconnection) reference model
  - Developed by ISO (International Standard Organization)
  - It is open system because , it deals with connecting open system.
  - Systems that are open for communication with other systems.
- **TCP / IP** reference model
  - It used in ARPANET and its successor , the world wide internet.
  - Two primary protocols : TCP & IP



The OSI reference model.

Functions of OSI Layers

Physical Layer

->Row bit transmission
->Decide which voltages use for 0 as well as 1 bit
->Data rate
->Which medium is used and how many wires are there
->How communication is possible (Simplex , Half-Duplex , Full-Duplex)

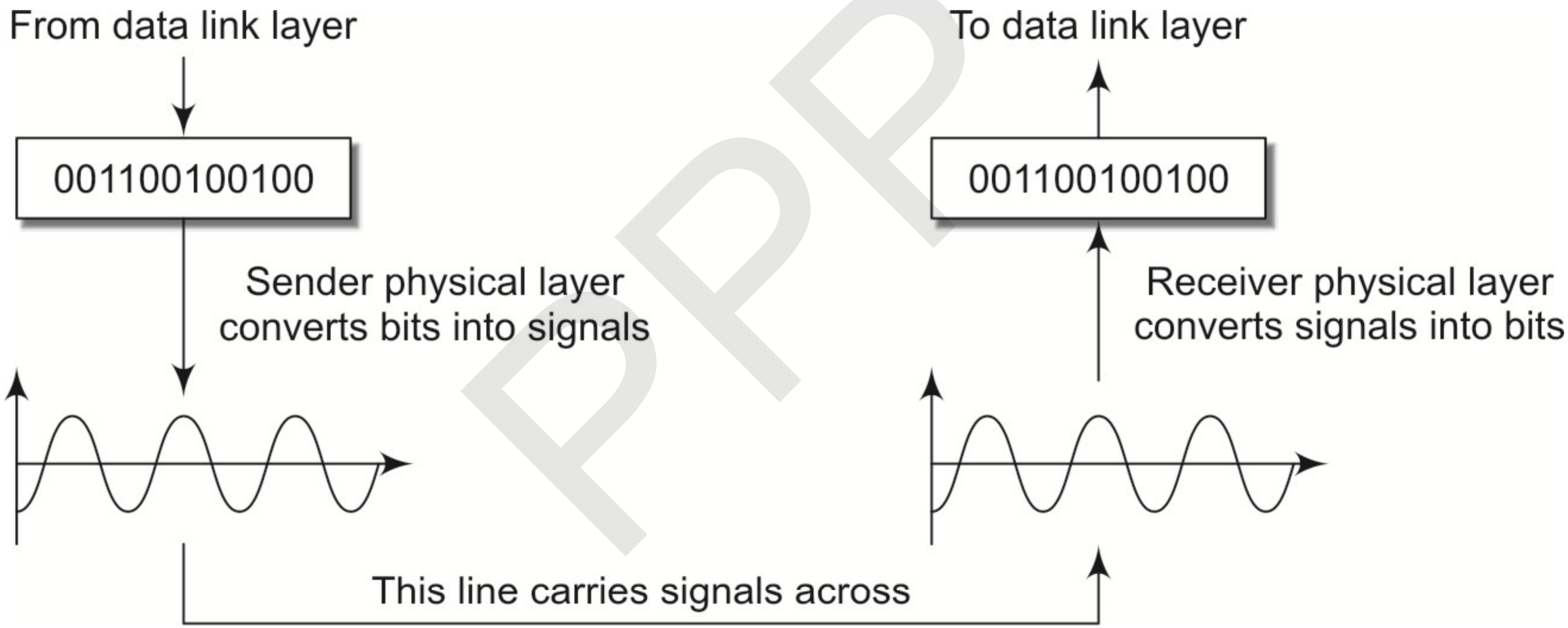
Data link Layer

->Convert the row bit into frame
->special bit or byte for the boundary of the frame
->Flow Control
->Error Control
->Solve the problem occurs by damage , lost , duplication of frame

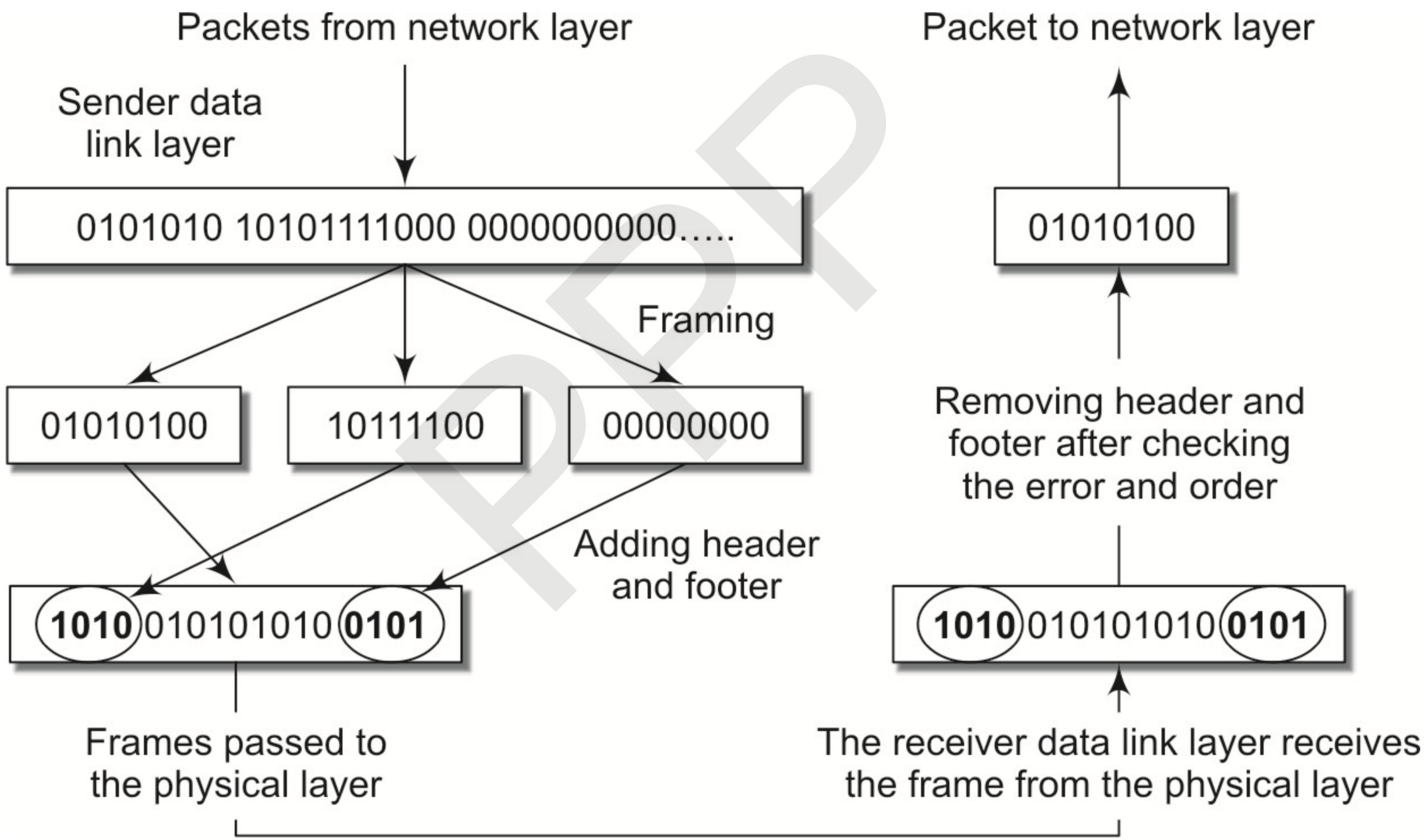
Network Layer

->Decide the route for the packet
->Congestion Control

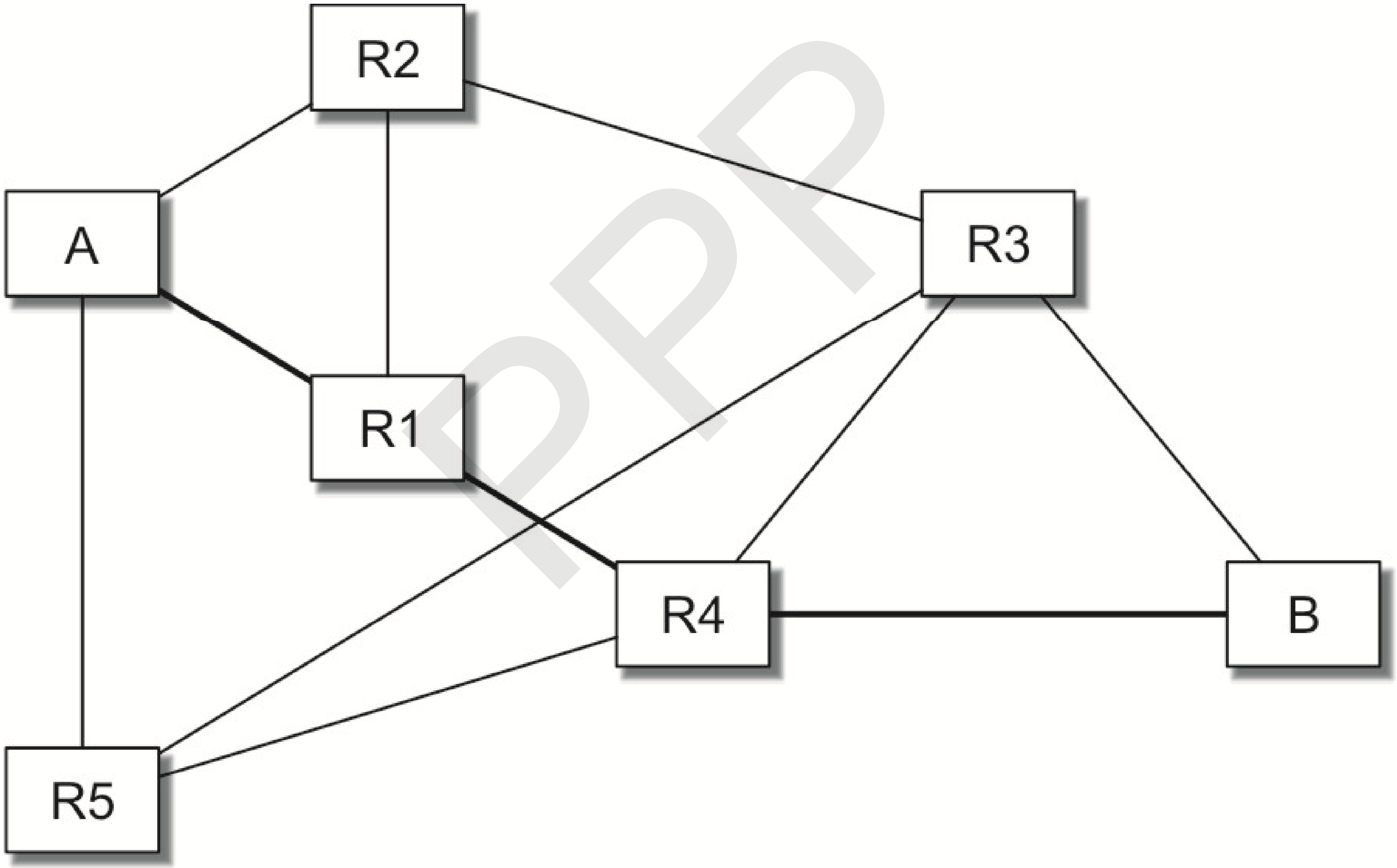
The Physical Layer



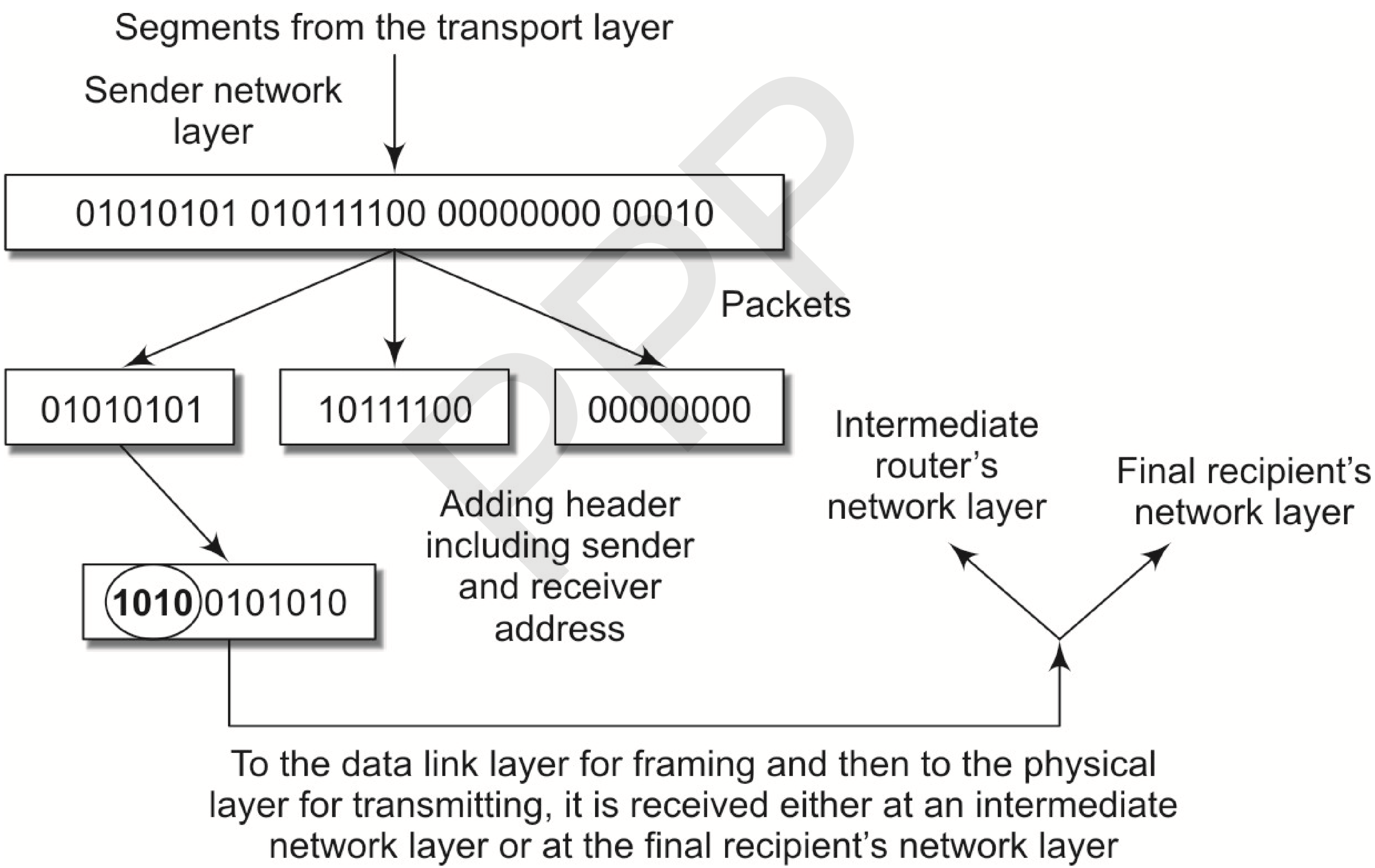
The Data Link Layer



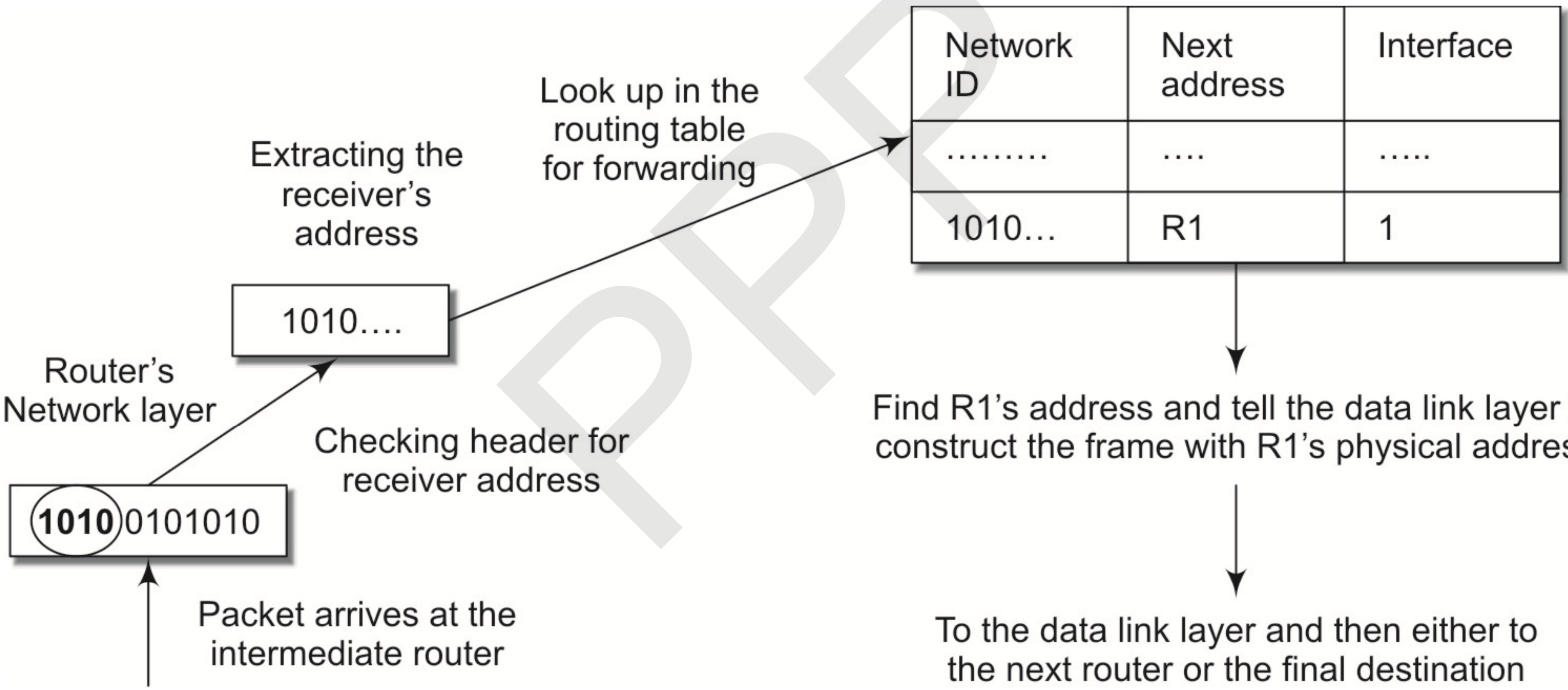
The Network Layer



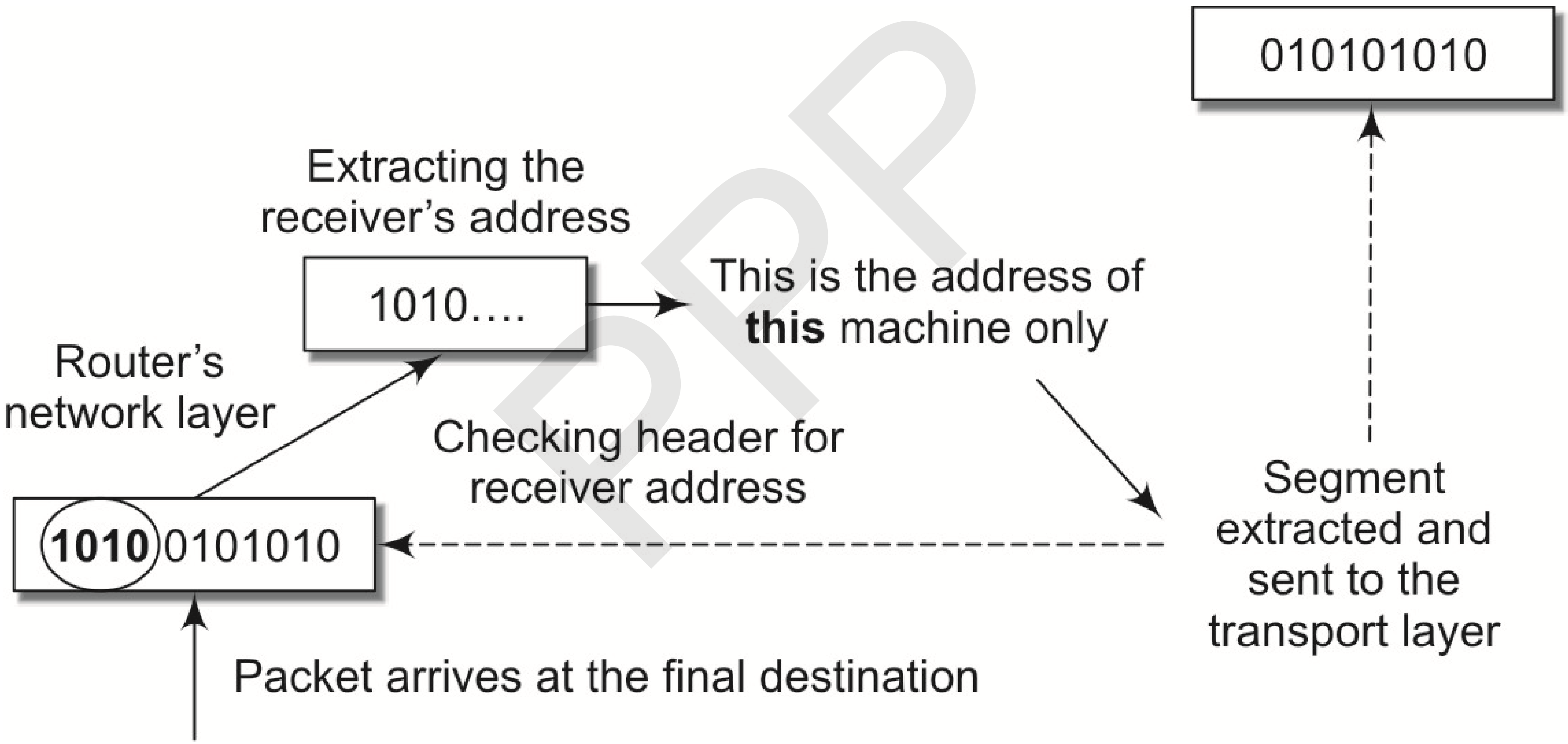
Network Layer Functioning



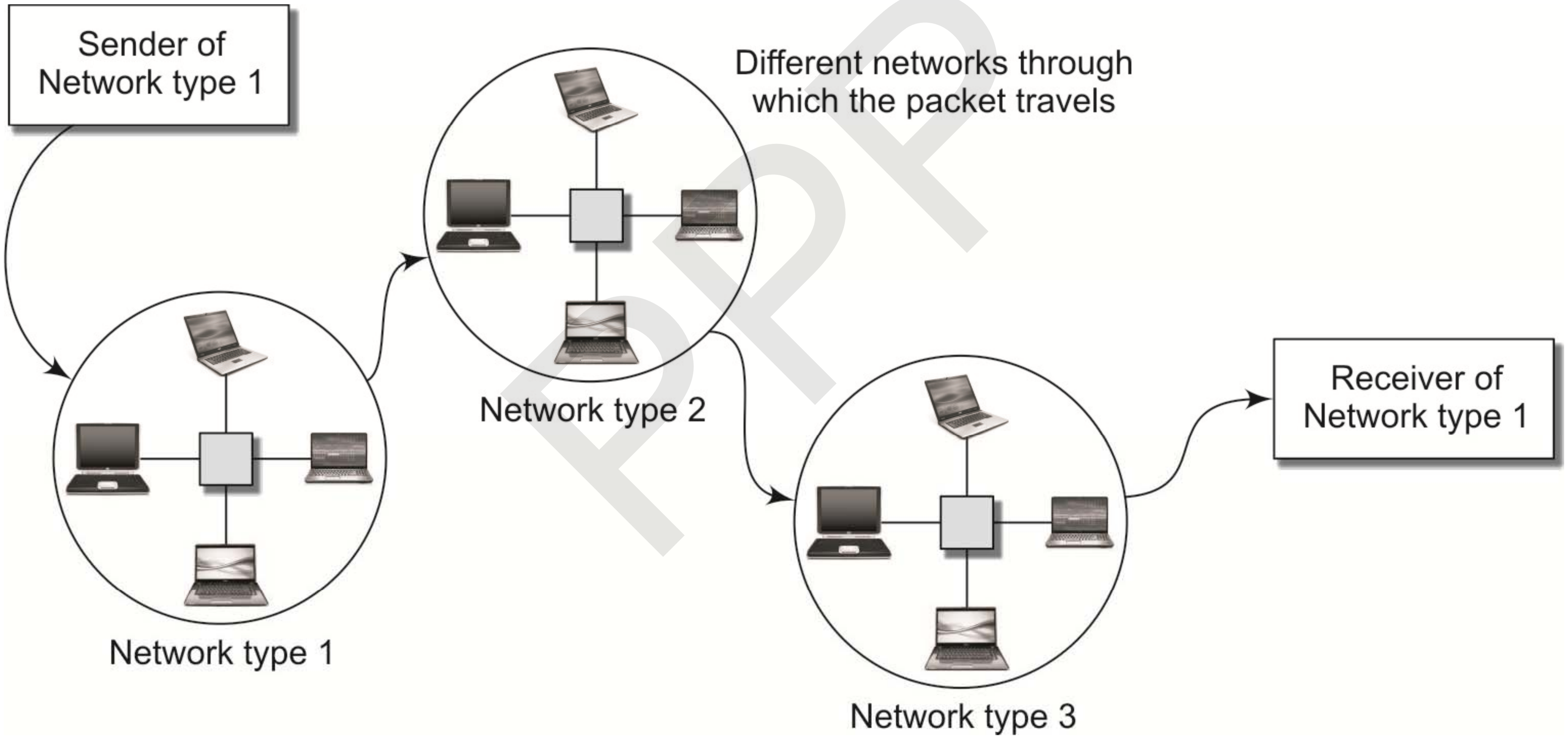
Routing At Network Layer



Extracting Prefix



Routing Between Different Networks



Functions of OSI Layers

Transport Layer

->Break data it receive from session layer and transfer to N/W Layer
->Segmentation & Reassembly
->Service Point Addressing
->Flow Control

Session Layer

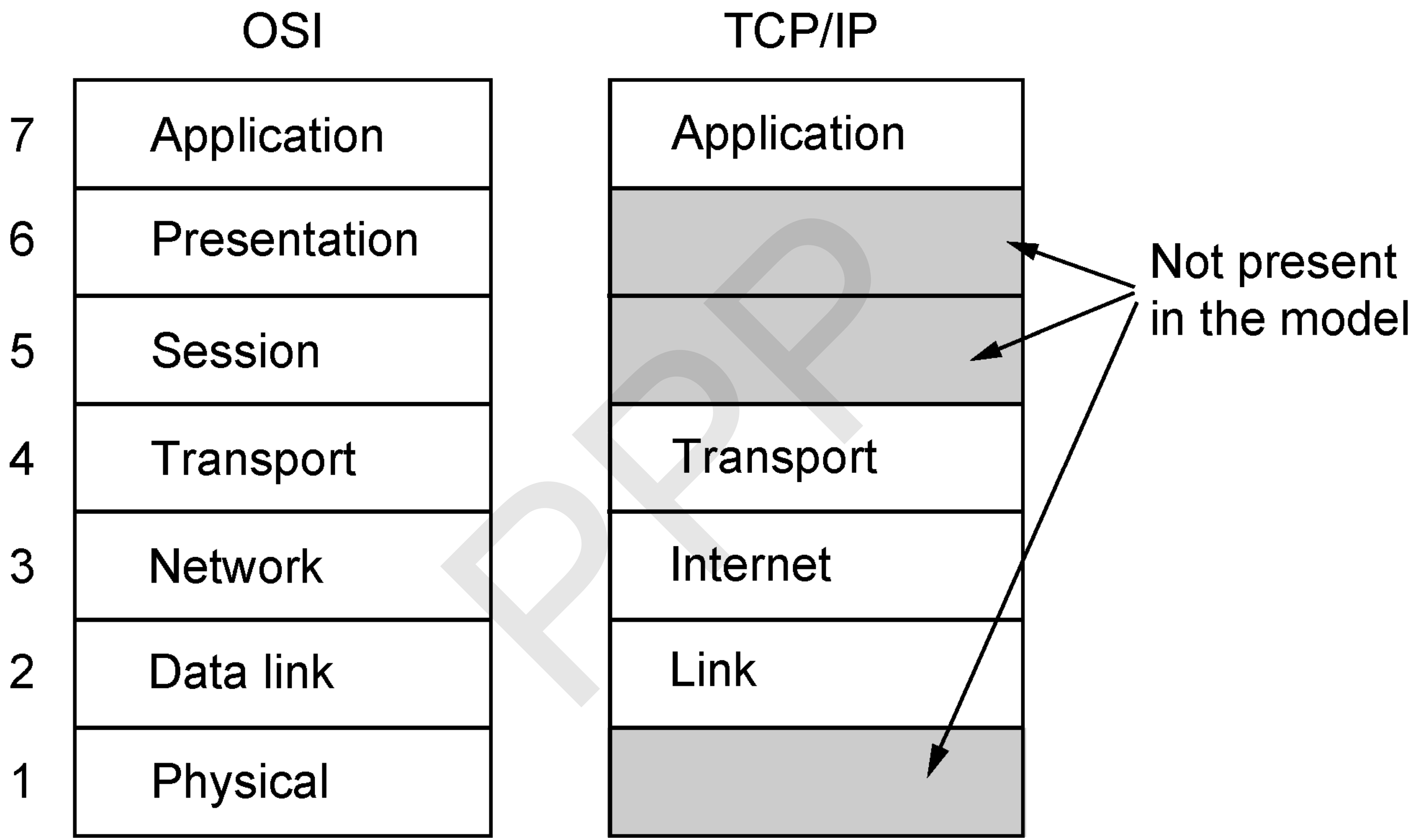
->Keeping track which session's turn to transmit.
->Synchronization

Presentation Layer

->Translation
->Encrypted
->Encoded
->Compressed

Application Layer

->Application that develop for use across the internet
->Contain the protocol that are commonly needed by user (HTTP)



The TCP/IP reference model.

Difference between OSI and TCP/IP Model

	OSI	TCP/IP
1.	Open System Interconnection	Transmission control protocol / Internet protocol
2.	7 layers	4 layers
3.	Models was devised first	Protocols came first
4.	N/W layer provide connection oriented and connection less service.	N/W layer provides only connectionless service.
5.	Transport layer provides only and connection less service.	Transport layer provides connection oriented Connection less service.

Design Issues for the Layers

Each layer solves a particular problem but must include mechanisms to address a set of recurring design issues.

Issue	Example mechanisms at different layers
Reliability despite failure	Codes for error detection / correction Routing around failure
Network growth and evaluation	Addressing & Naming protocol layering
Allocation of resources like bandwidth	Multiple access & Congestion control
Security against various	Confidentiality of message

Networking Devices

• Amplifier	(Physical Layer)
• Repeater	(Physical Layer)
• Hub	(Physical Layer)
• Bridge	(Data Link Layer)
• Switch	(Data Link Layer)
• Router	(Network Layer)
• Gateway	(Application Layer)

Networking Devices

- **NIC (Network Interface Card)**
  - It is a hardware device that connect a computer with the network.
  - It is installed on the mother board.
  - It is responsible for developing a physical connection between the network and the computer.
  - Computer data is translated into electrical signals send to the network via Network Interface Cards.
  - Manage data-conversion function. It is software configured.

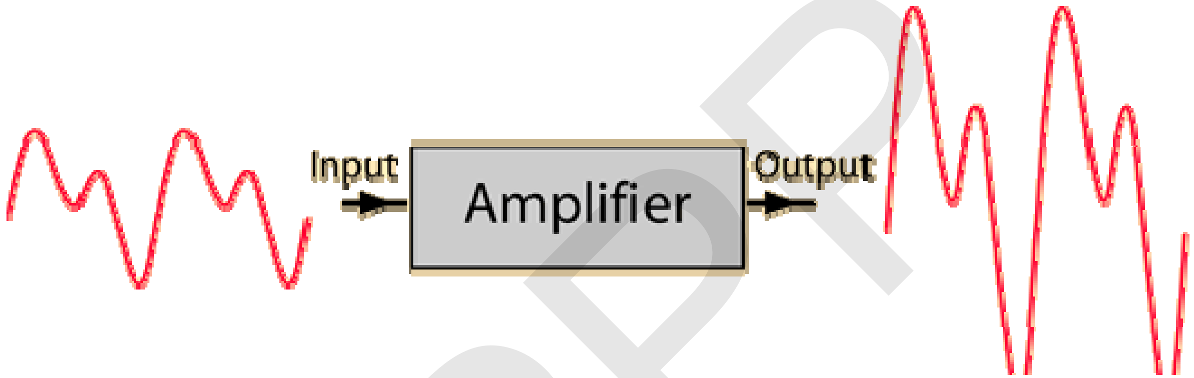
Networking Devices

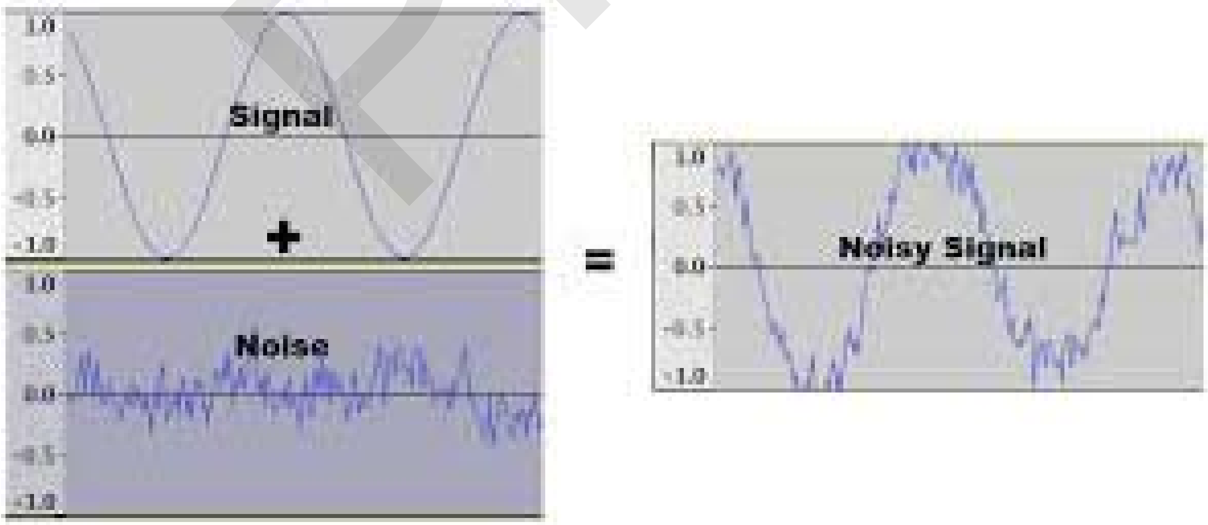
- **Amplifier**
  - A signal containing some information and after travelling some distance, signal get weakened (attenuated) due to energy loss in the medium. Therefore, it should be improved (or amplified). Amplifier is the circuit which magnifies the weak signal to a signal with more power.
  - An electronic device that can increase the power of a signal (a time-varying voltage or current). An amplifier functions by taking power from a power supply and controlling the output to match the input signal shape but with a larger amplitude.
  - Amplifies both signal and noise

Networking Devices

Amplifier

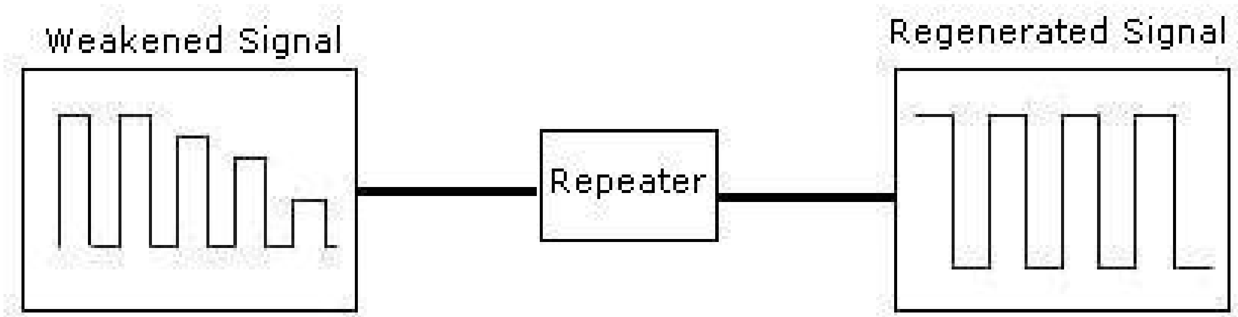
• An amplifier is an electronic device that increases the voltage, current, or power of a signal.
• Amplifiers are used in wireless communications and broadcasting, and in audio equipment of all kinds.





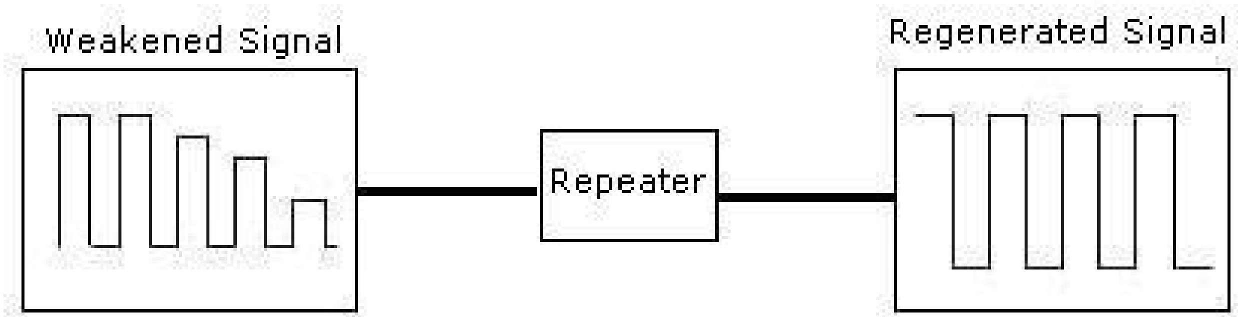
Networking Devices

- **Repeater**
  - An electronic device that regenerate the signal to maintain the strength of a signal up to long distance.
  - Used to increase the length of the network by removing the affect of attenuation on the signal.
  - It connects two segments of the same network, overcoming the distance limitations of the transmission media.
  - It just forward the frames it has no filtering capability.



Networking Devices

- **Repeater**
  - Most telecommunications cables are now fiber optic cables which use optical repeaters.
  - Submarine cable repeater used in underwater submarine telecommunications cables.
  - To extend the coverage of a radio or television broadcasting stations.
  - Cellular repeater to receive the signals at base station from nearest cell tower and rebroadcast to nearby cell phones.



Difference Between Amplifier and Repeater

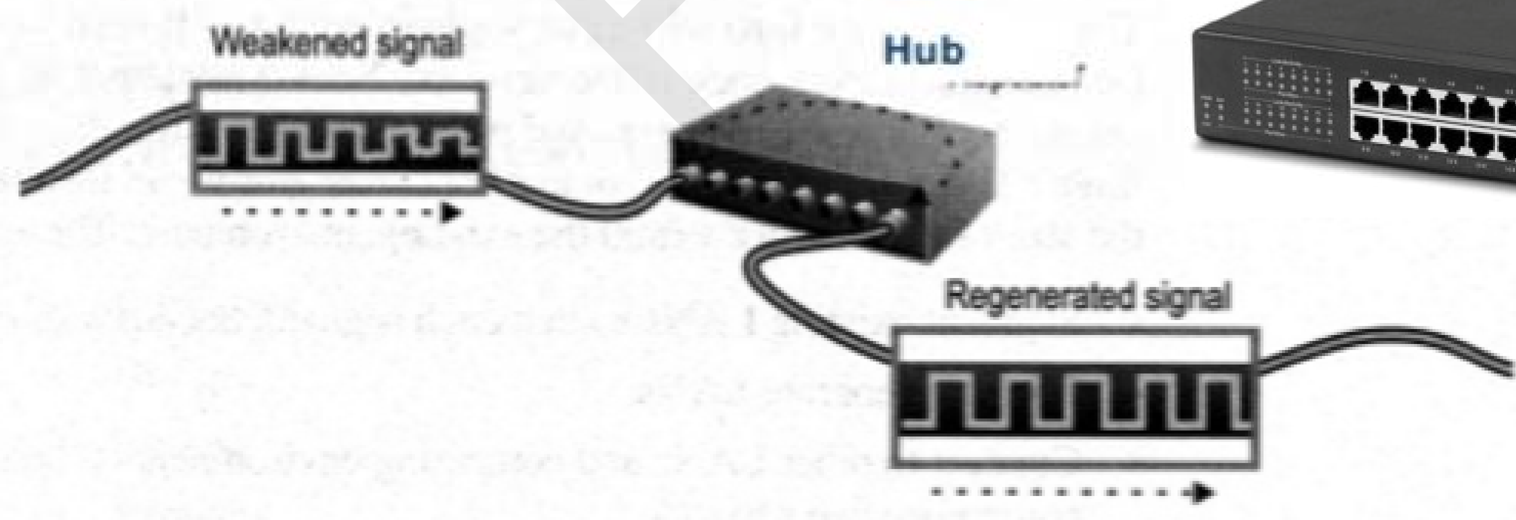
- Amplifier is used to magnify a signal, whereas repeater is used to receive and retransmit a signal with a power gain.

- Repeater has an amplifier as a part of it.

- Sometimes, amplifiers introduce some noise to the signal, whereas repeaters contain noise eliminating parts.

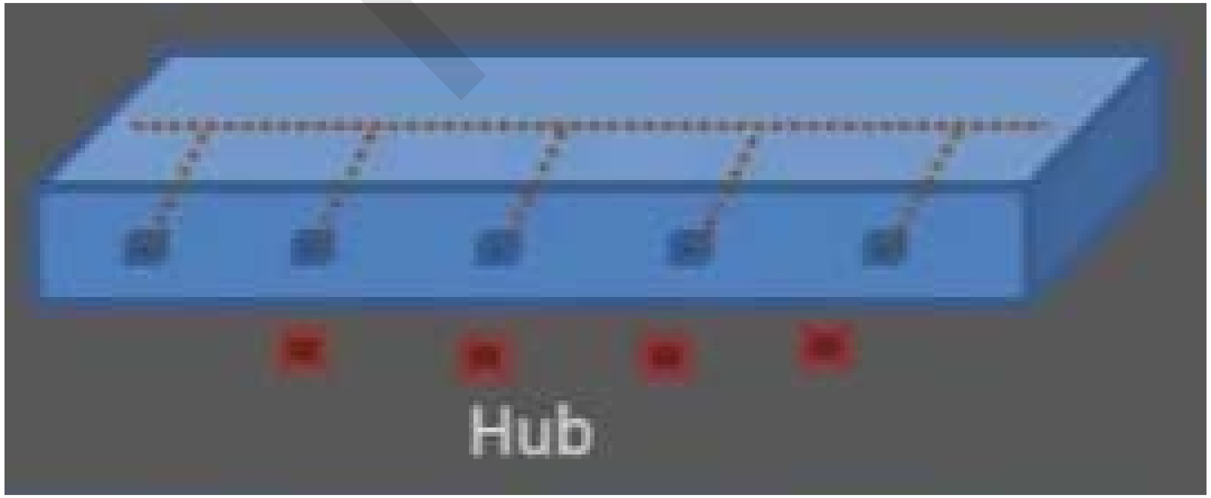
Networking Devices

- **Hub**
  - It regenerate data and broadcasts them to all ports.
  - When a frames arrives at one port, it is copied to the other ports so that all segments of the LAN can see all packets.
  - Network devices like printer, scanner, pc, server connected to the ports on hub.
  - **Passive hub** just pass the signal without amplify or regeneration.
  - **Active hub** pass the signal with amplify or regeneration.
  - All information broadcast to multiple ports can be a security risk.
  - Can not handle large data traffic.



Difference between Repeater and Hub

- **Repeater :** A repeater is a device that has single input and single output port. (Bus Topology)
- **Hub :** A repeater with multiple input and multiple output ports. (Star Topology)

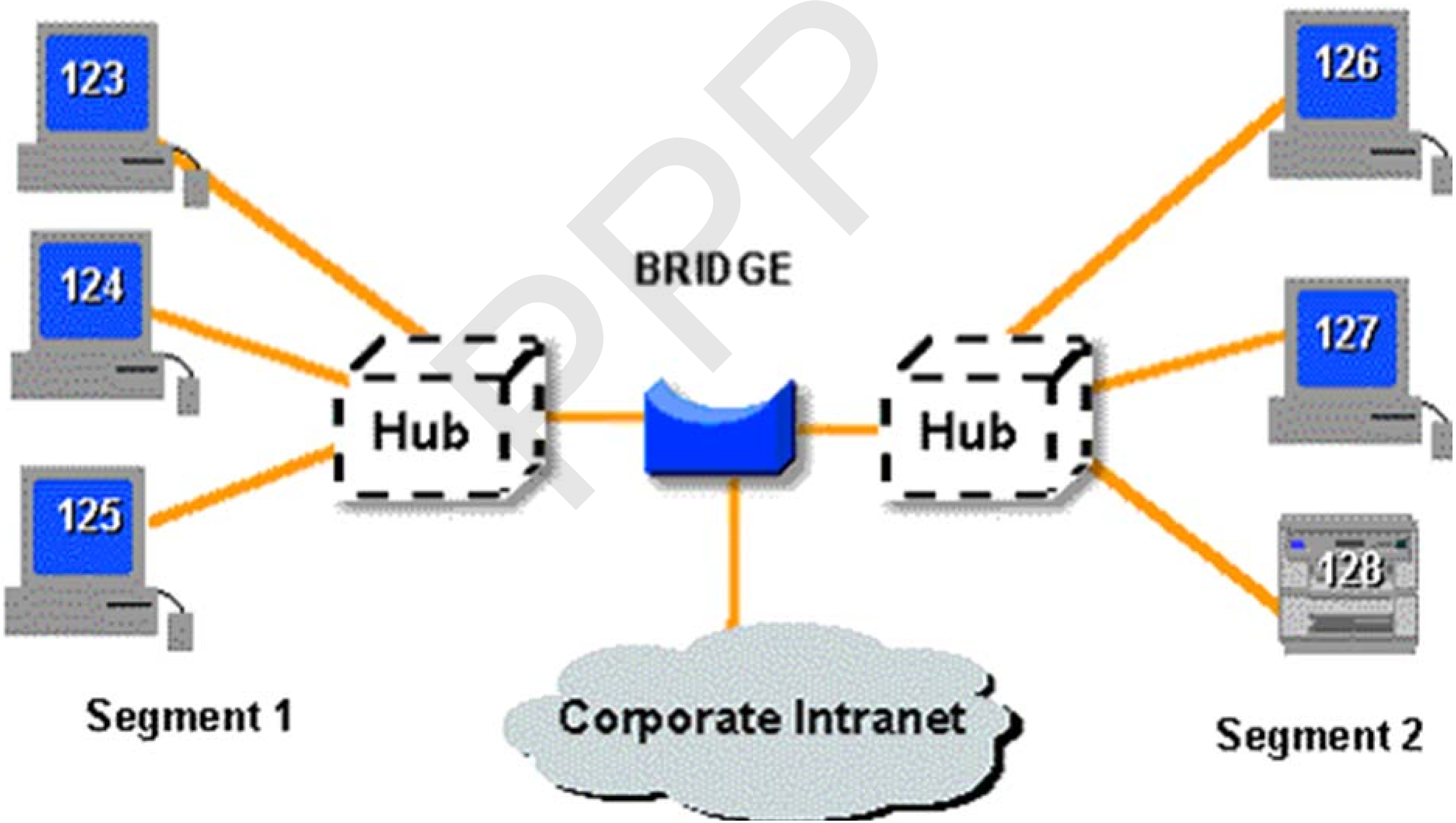


Networking Devices

Bridge

- A bridge is a computer networking device that builds the connection with the other bridge networks which use the same protocol.
- It works at the Data Link layer of the OSI Model and connects the different networks together and develops communication between them.
- It connects two local-area networks; two physical LANs into larger logical LAN or two *segments* of the same LAN that use the same protocol.

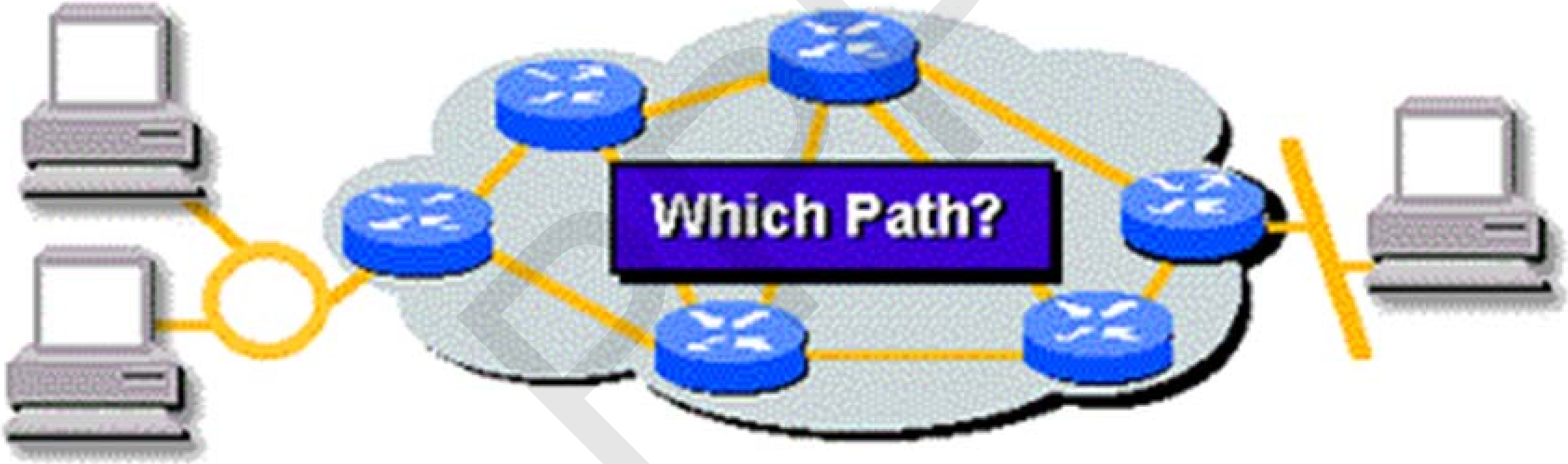
Bridge Example



Networking Devices

- **Switch**
  - It is a more intelligent form of Bridge. It referred as multiport bridge.
  - No collision occurs in full-duplex switch.
  - L2 Switch (Frame) & L3 Switch (Packet)
  - Speed 1 Mbps, 10 Mbps, 100 Mbps, 1 Gbps
  - A **switch** transfers data only to that port which is connected to the destination device.
  - In this switching environment the entire packet is received and checked before being forwarded ahead.

Network Layer: Path Determination



- Layer 3 functions to find the best path through the internetwork

Networking Devices

- **<u>Router</u>**
  - Routers are network layer devices and are particularly identified as Layer- 3 devices of the OSI Model.
  - They process *logical* addressing (IP Address) information in the header of a packet.
  - It has the ability to connect dissimilar LANs on the same protocol.
  - A router has more than one network interface and routing software.
  - When a router receives the data, it determines the destination address by reading the header of the packet. Once the address is determined, it searches in its **routing table** to get know how to reach the destination and then forwards the packet to the next router on the path.

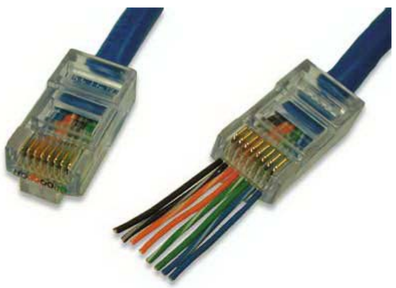
Networking Devices

- **Gateway**
  – It is operate in all seven layers of OSI model.
  – Capable of converting frame and network protocols into the format needed by another network.
  – It is used to connect two different network systems.
  – It is a software installed in a router.
  – Transport gateway to connect two networks at transport layer.
  – Application gateway to connect two networks at application layer.
  – Both the computers of Internet users and the computers that serve pages to users are host nodes, while the nodes that connect the networks in between are gateways.

Networking Devices

- **Modem**
  - A modem is a computer peripheral that allows to connect and communicate with other computers through telephone lines.
  - Modem stands for Modulation & Demodulation.
  - Modulation : Convert binary signals into analog signals (Sender Side)
  - Demodulation : Convert analog signals into binary signals (Receiver Side)
  - Types of Modem : Internal & External

- **RJ-45 Connector**
  - RJ stands for Registered Jack.
  - It is 8 wire connector used to connect computers on LAN



Transmission Media

- Two types of transmission media
  - Guided Transmission Media
  - Unguided Transmission Media (Wireless Transmission)
- Guided Media
  - Magnetic media
  - Twisted Pairs
  - Coaxial Cable
  - Power lines
  - Fiber Optics
- Wireless Transmission
  - E-M Spectrum
  - Radio Transmission
  - Microwave Transmission
  - Infrared Transmission
  - Light Transmission

Magnetic Media

Magn. Tape or removable media(DVD)

Storage Capacity :

4.7 GB on single-layer/single-sided media of data

9.4GB on single-layer/double-sided discs.

In future 17GB DVD writing will become a reality.

Ultrium tape can store 800 Gegabytes.

Box 60*60*60 cm can hold 1000 tapes.

So total capacity 800 terabytes or 800 * 8 = 6400 terabits or 6.4 petabits

Federal Express and other Companies delivered it anywhere in US 24 hrs

So 6400 / 24 * 60 * 60 = 70 Gbps (Gigabits / sec).

If dest. Is only hour away by road

6400 / 24 = 1700 Gbps(Gigabits / sec)

Magnetic Media

Useful for a bank with many Gigabytes of data to be backed up daily.

Cost : $40 if purchase in bulk. Tape can be reused atleast 10 times.

So cost may be $4000 per box per usage + $1000 for shipping

Total = $5000 to ship 800terabytes.

B.W. :: 70 Gbps (gigabits/sec)

Cost : $5000 to ship 800terabytes.

Application : Banking

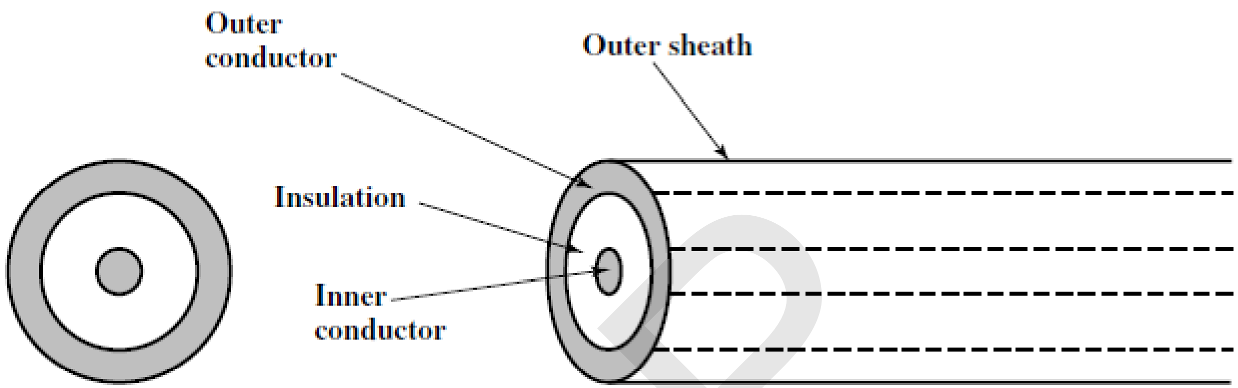
Delay : 1hr to 24 hr. (Disadvantage)

UTP advantages

(a) Twisted pair

- Twists help cancel out crosstalk result in better quality of signal for longer distance.
- Inexpensive (Rs. 2 to 5 per meter)
- Possible to bend the UTP
- Same technology used in Telephone networks
- There is less attenuation in UTP cables
- Cat-3 (25 Mbps), Cat-5 (100 Mbps Or 1 Gbps)
- Cat-6 (10 Gbps) Cat-7 (10 – 100 Gbps)

Co-Axial Cable



- Diameter of from 1 to 2.5 cm.
- Used over longer distances
- Using FDM, A coaxial cable can carry over 10,000 voice channels simultaneously.
- Application:
  - Television distribution
  - Long-distance telephone transmission

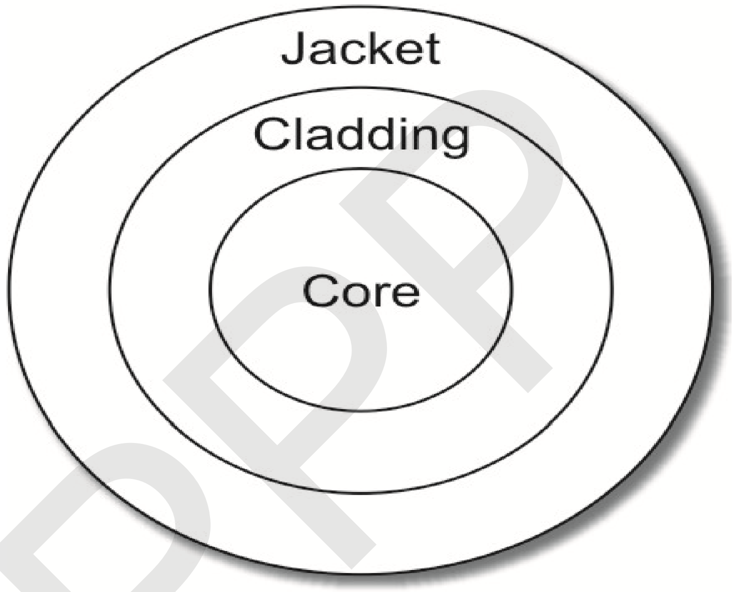
Fiber Optics

- It is made up of pure glass (Higher Dense)
- Easily bent without breaking
- Least resistance to the light passing through it
- Light

  A form of electromagnetic energy , travels at 300 m/sec in a vacuum.
- Refraction

  If a ray of light traveling through one substance suddenly enters another substance, its speed changes abruptly, causing the ray to change direction. This change is called refraction.

Fiber cable structure



- Core made up of pure glass
- Cladding is made up of a glass with lower refractive index than core.
- Interface bet’n core & cladding is responsible for refracting the light back into cable.
- Jacket shields the cladding and core to protect against noise signal

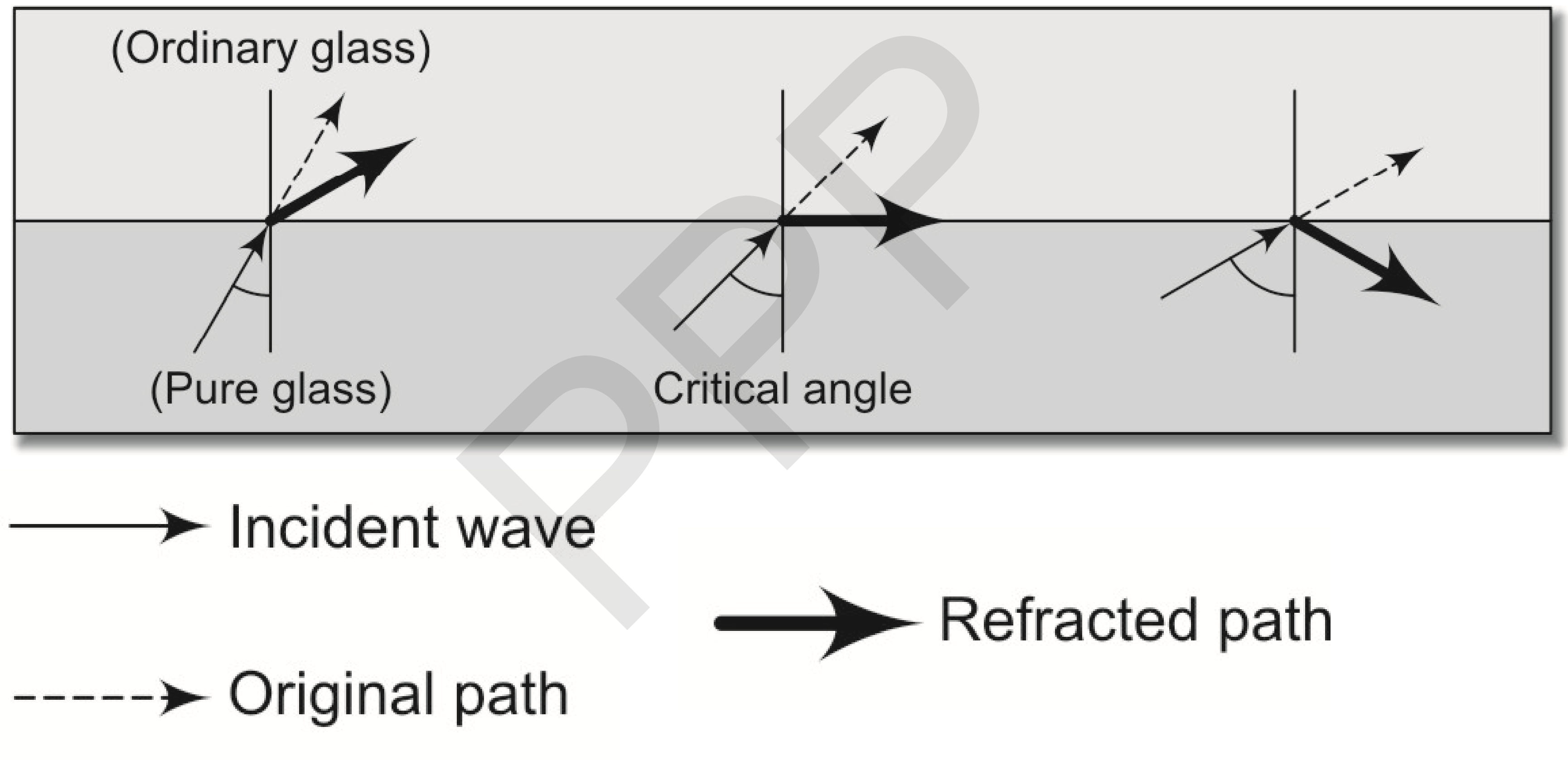
Incidence , Refracted , Critical & Reflected Angle

- The two angles made by the beam of light in relation to the vertical axis are called I , for **incident** , and R , for **refracted**.

- The incident angle at which the refracted angle becomes 90 is known as **critical angle**.

- When the angle of incidence becomes greater than the critical angle , a new phenomenon occurs called **reflection**.

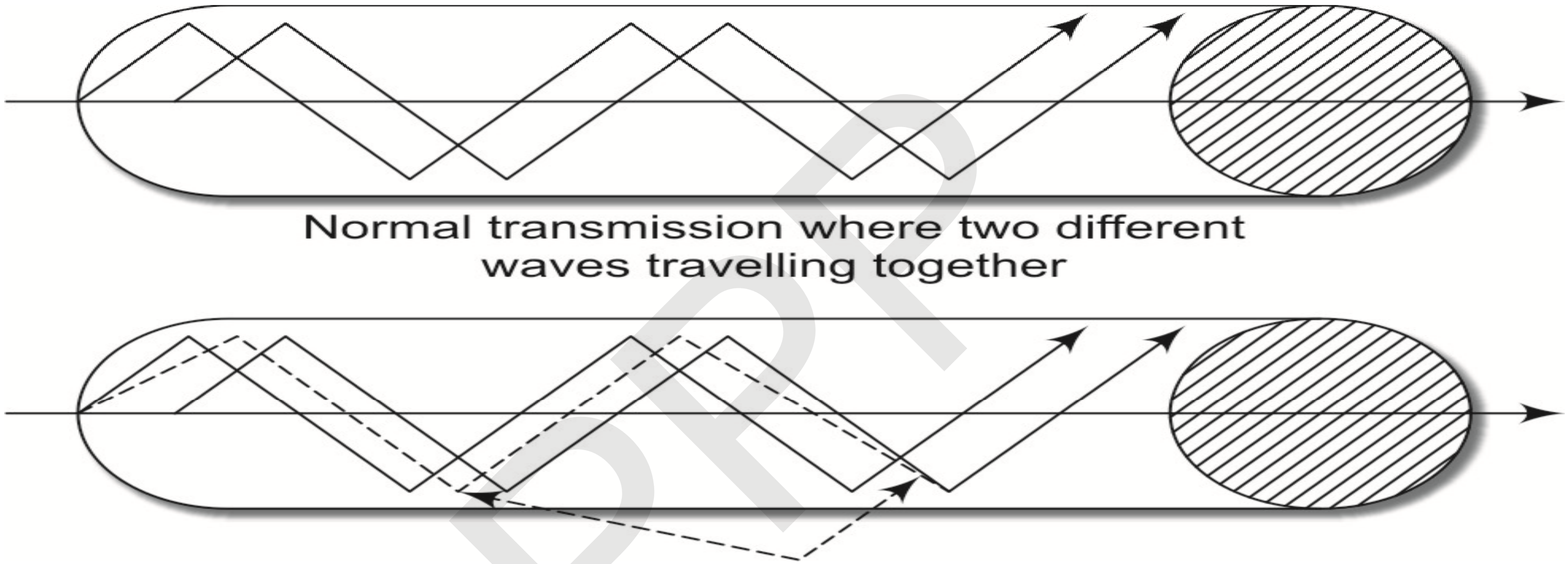
Total Internal Reflection



Pure Glass: More Dense

Ordinary glass : Less Dense

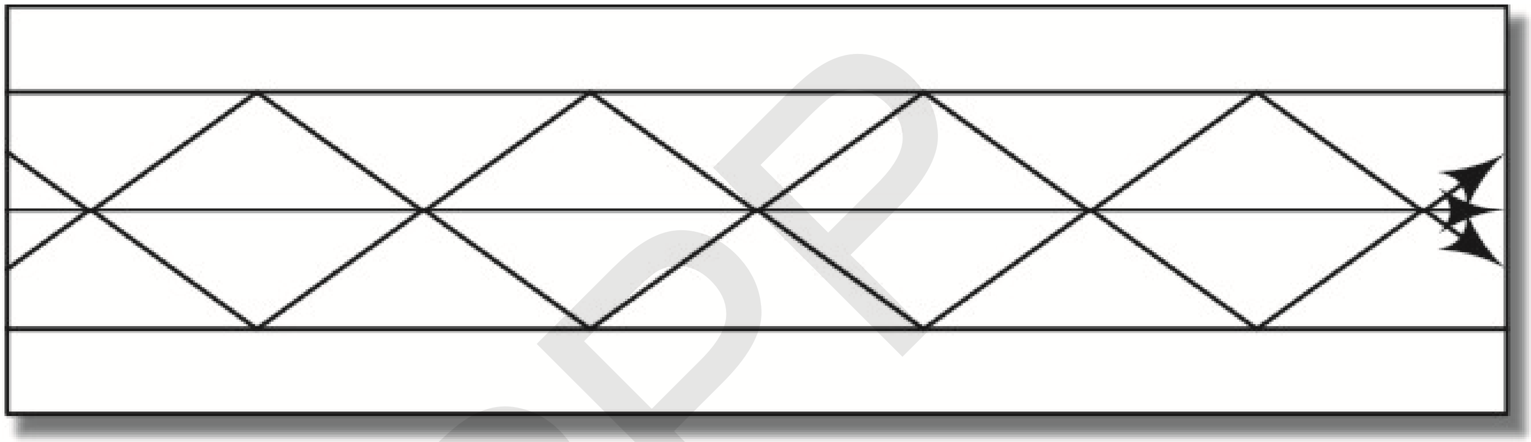
Dispersion in fiber optic



Dispersion first wave merged with second wave.

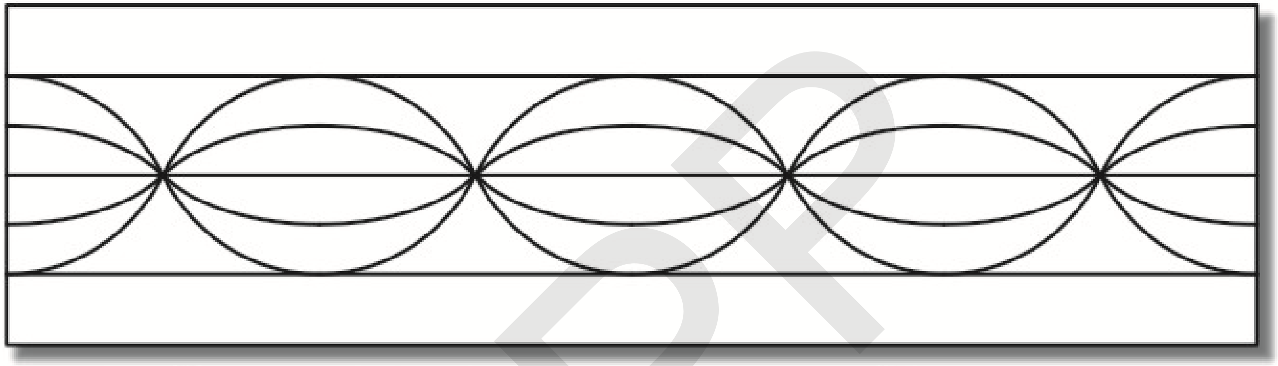
Solution: Increase the distance between waves

Multimode - 1



a. Single step index multimode fiber

Multimode - 2



b. Graded index multimode fiber

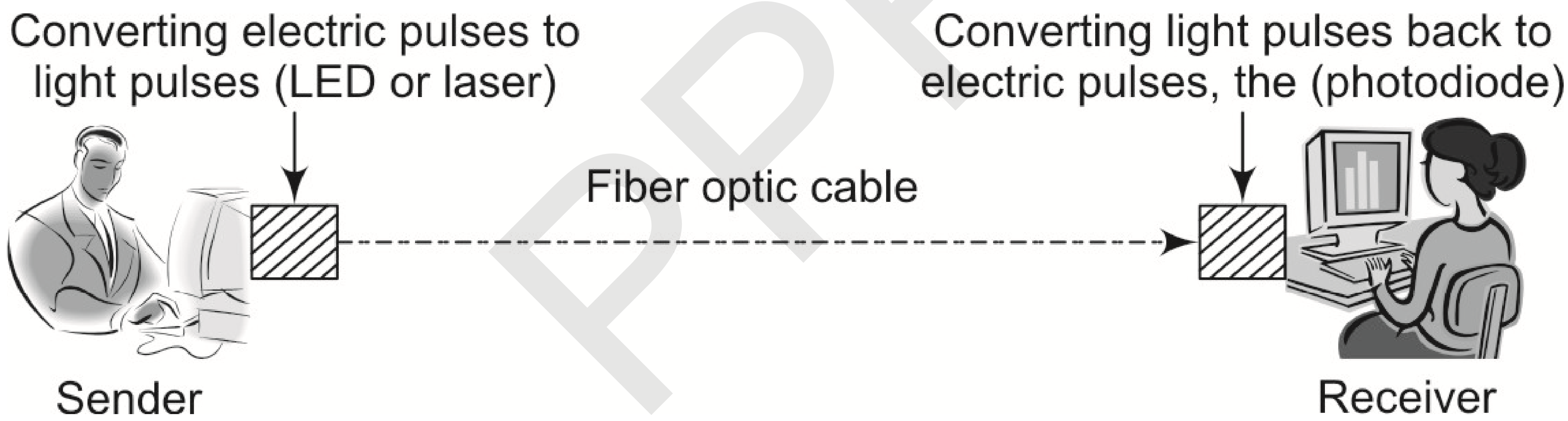
In graded index multimode fiber, the refractive index of the glass reduces gradually as we move from the core towards the cladding.

Single Mode

c. Single mode

Speed of 50 Gbps upto 100 km
Laser signals

Sending and receiving devices



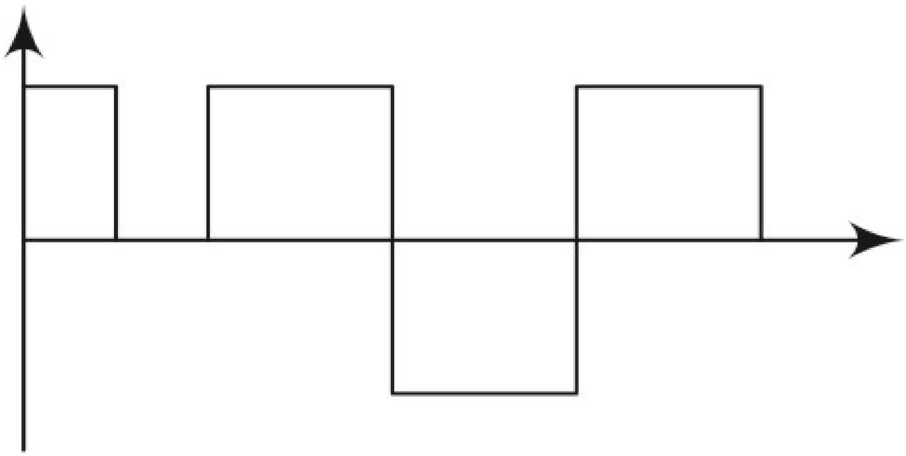
A comparison of semiconductor diodes and LEDs as light sources.

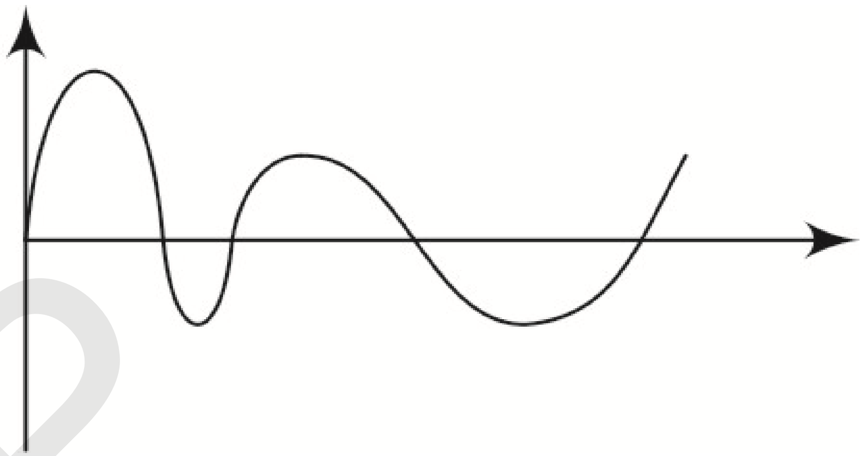
Item	LED	Semiconductor laser
Data rate	Low	High
Fiber type	Multi-mode	Multi-mode or single-mode
Distance	Short	Long
Lifetime	Long life	Short life
Temperature sensitivity	Minor	Substantial
Cost	Low cost	Expensive

Comparison: UTP vs. FO

- Thickness
- Weight
- Photons vs. electrons
- Attenuation
- Effect of EM interference
- Leaking
- Bandwidth
- Cost
- Need for skilled engineer

Digital and analog wave





▪<u>Signal</u>

It is an electric current or electromagnetic field used to convey data from one place to another.

▪<u>Analog Signal</u>

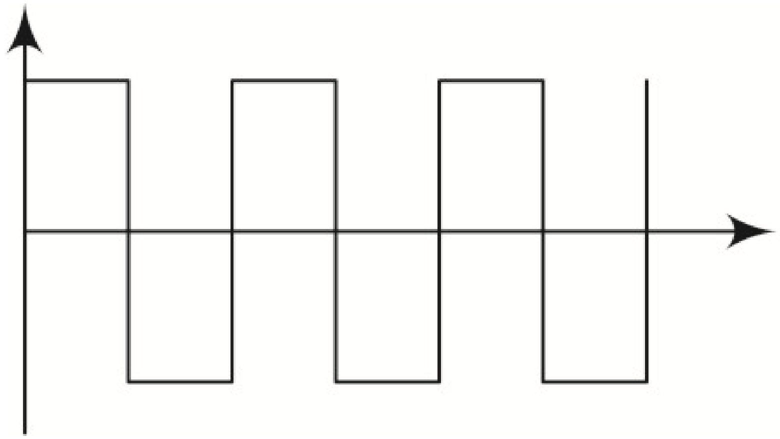
It is continuous wave form that changes smoothly over time.

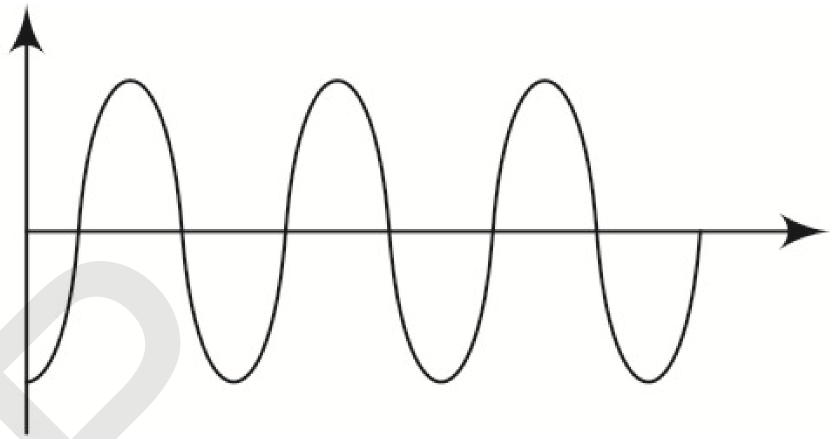
▪<u>Digital Signal</u>

It is discrete. It has only limited values 1 and 0.

The transition of a signal from value to value is instantaneously

Periodic waves, digital and analog





•<u>Cycle</u>

Completion of one full pattern is called a cycle.

•<u>Period</u>

Require time to complete one cycle.

•<u>Periodic Signal</u>

It completes a pattern within a period & repeats that pattern.

Analog signal characteristics.

- Amplitude

  Value of a signal at any point on the wave.

  Measured in volts, Amperes, Watts

- Frequency

  Number of periods in one second.

  Number of cycles per second. F = 1 / T

  Electric power distribute in India at 50 Hz while US having 60 Hz

  Aircraft often uses 400 Hz as the fundamental frequency

  Voltage in India for AC signal is 220 While US having 120

  Unit of period : s , ms , □μs , ns , ps

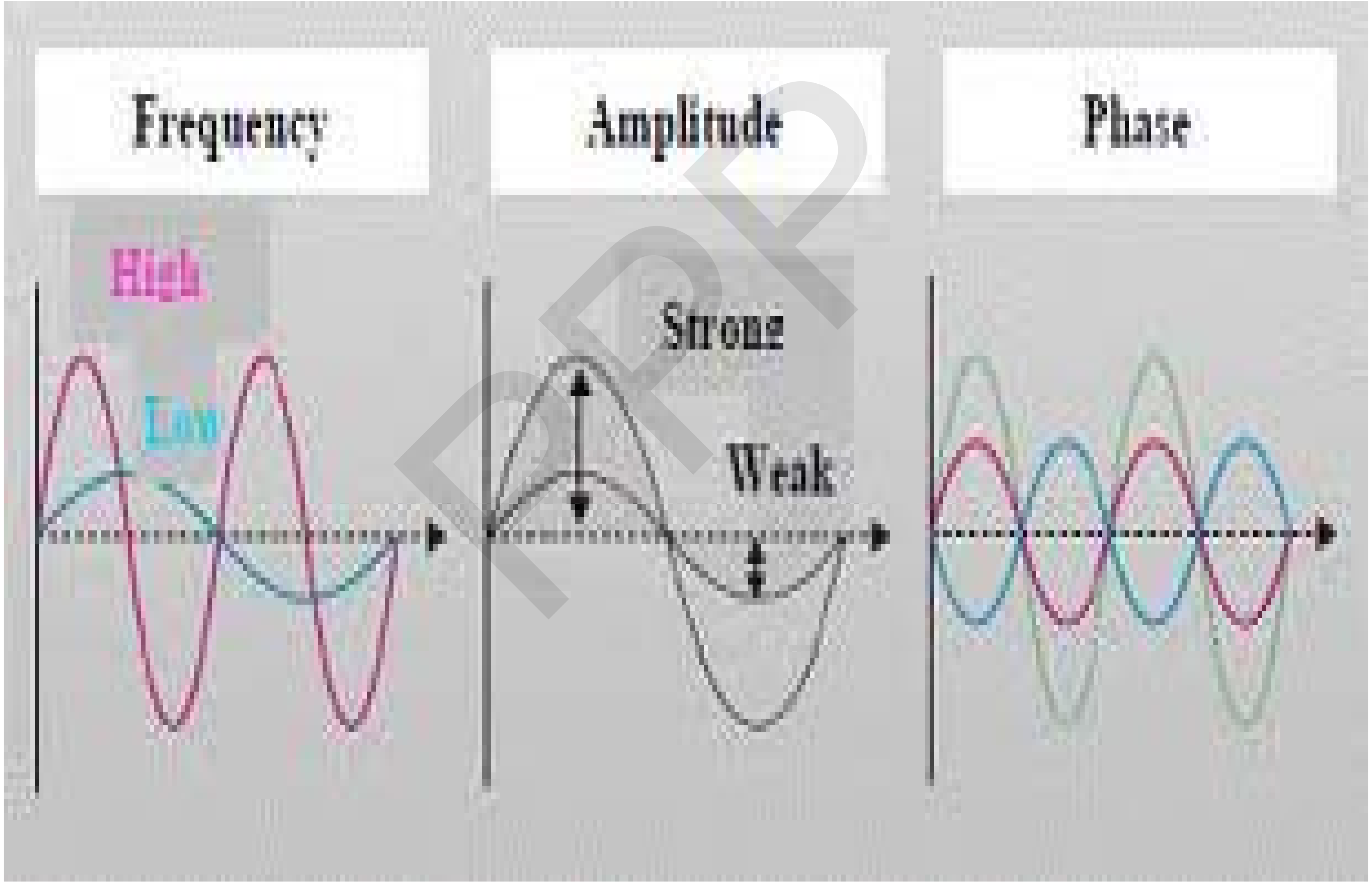
  Unit of frequency : Hz, KHz , MHz , GHz , THz

- Phase

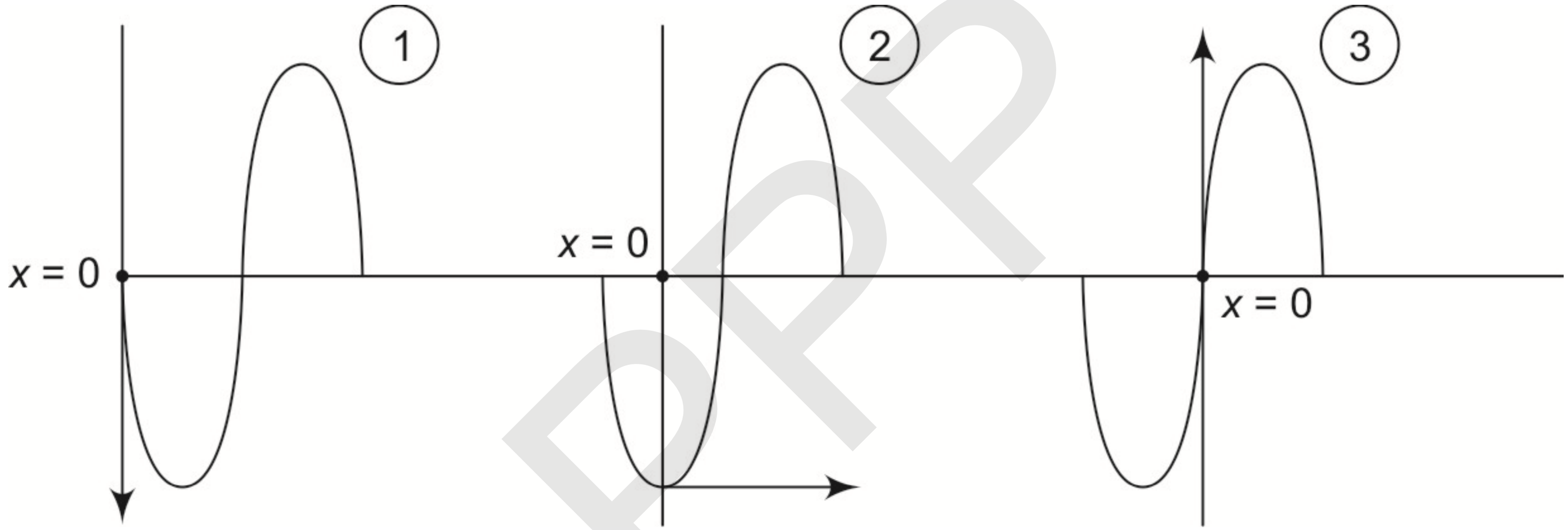
  Position of the waveform relative to the zero.

  It measured in degrees or radians

Analog signal characteristics.



Phase

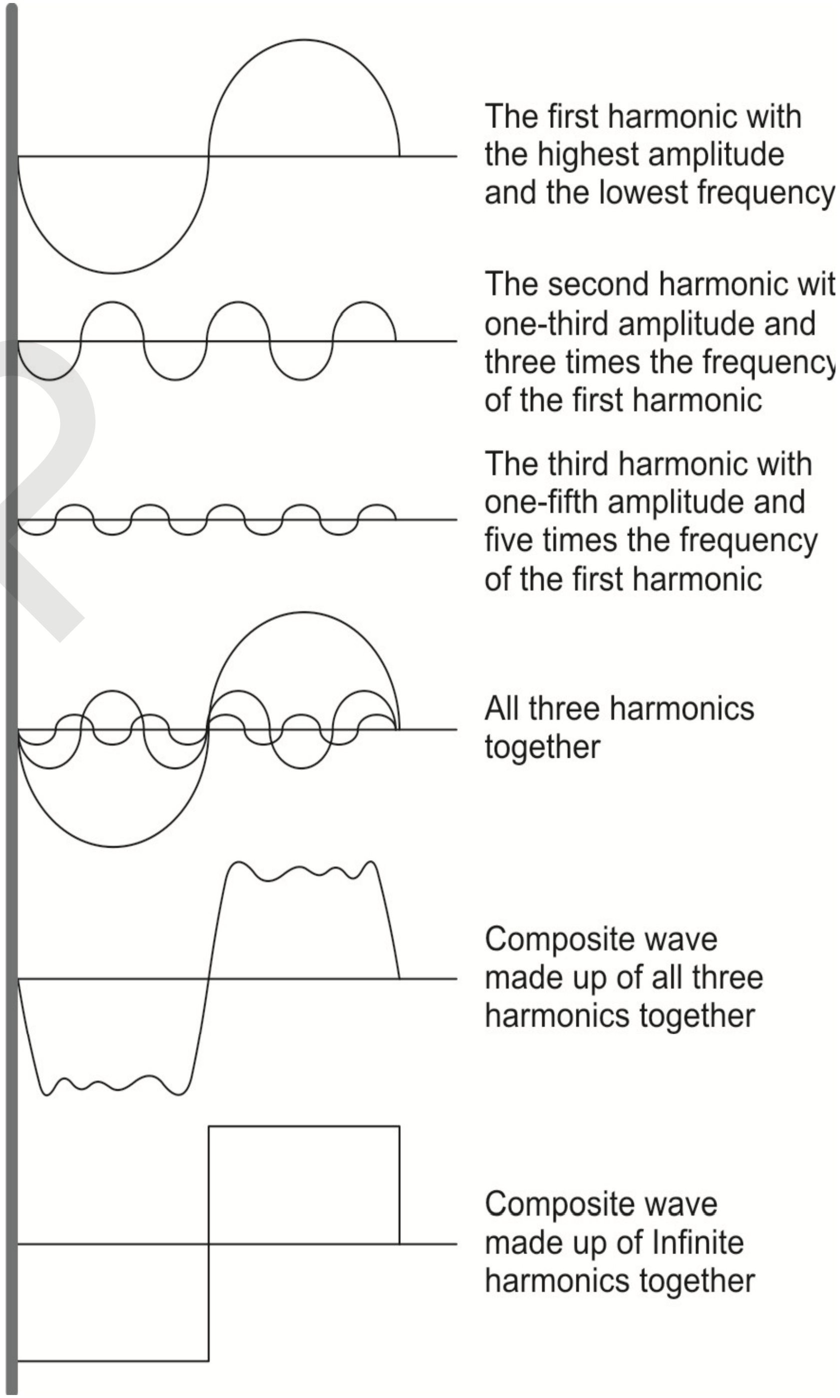


0 Degree **90 Degree** **180 Degree**

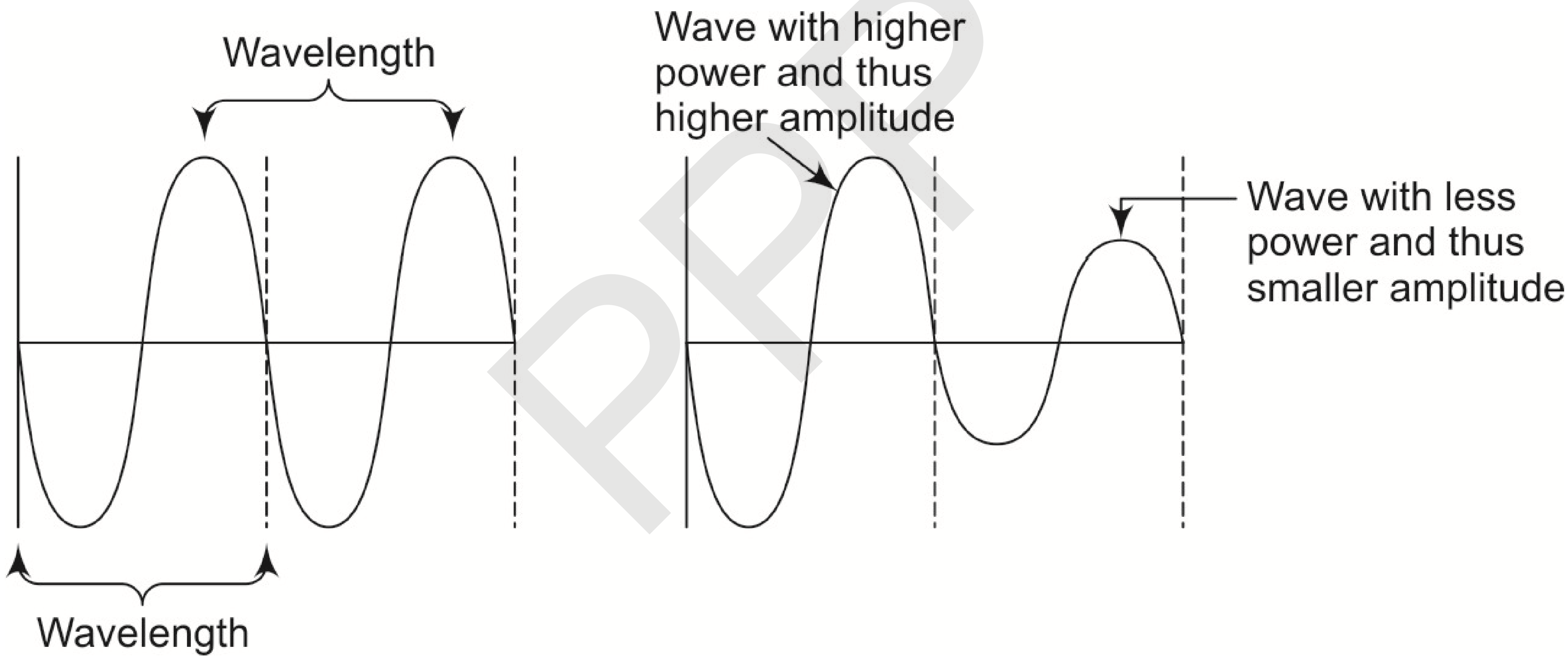
Harmonic and composite wave

Harmonic:
A sine wave component of a periodic wave

Composite signal
A signal contains multiple frequencies



Wavelength


Wavelength
Wave with higher
power and thus
higher amplitude
Wave with less
power and thus
smaller amplitude
Wavelength

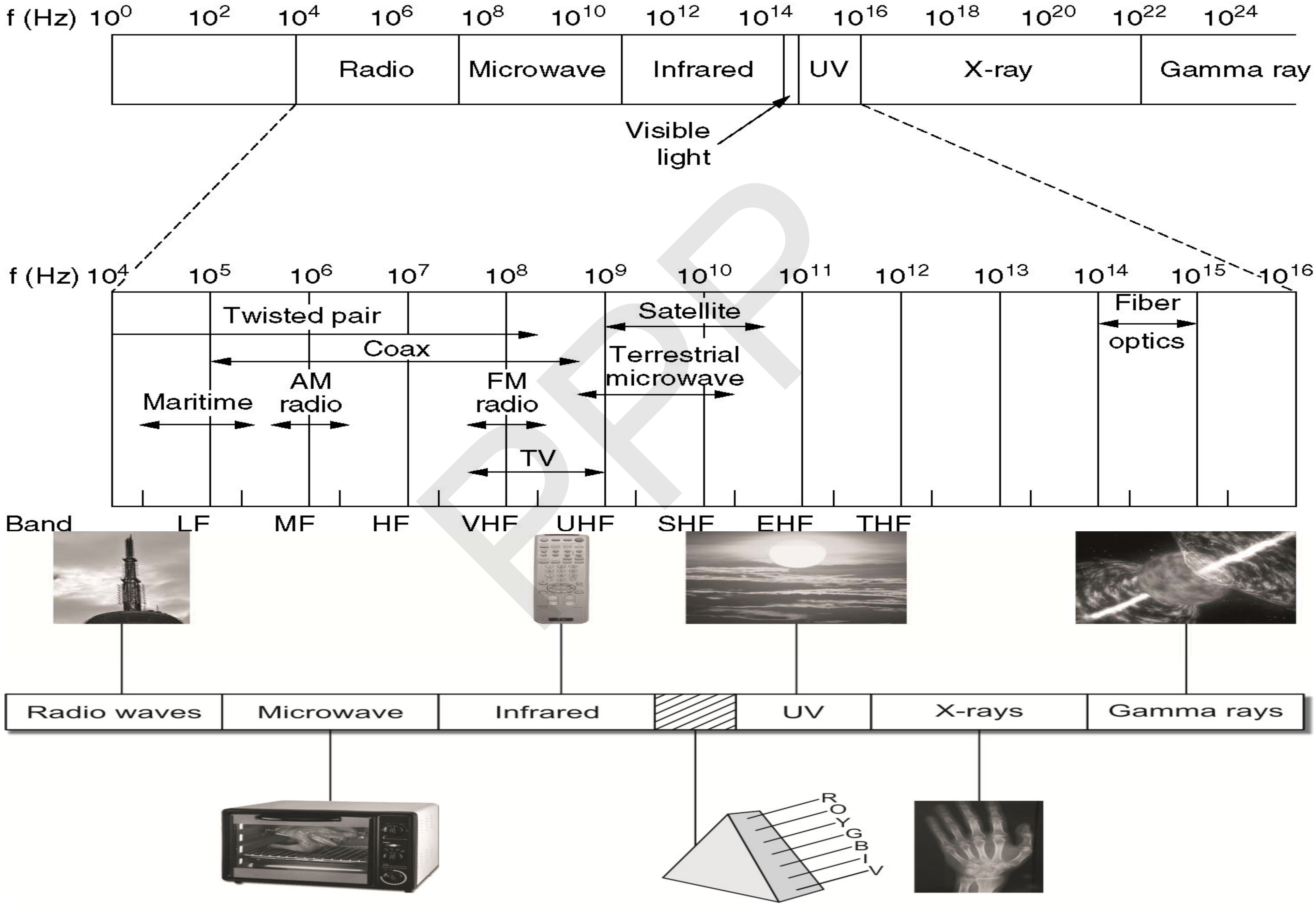
Relation between f & λ

- (f) Frequency :
  - No. of oscillations / Sec
  - Measured in Hz.
- (w or λ) Wave Length :
  - Distance between Two maxims or Two minims
  - It is measured in meters.
- $C = f * \lambda$
  - c= velocity of light = $3 * 10^8$ m/sec
- E.g.
  - waves with f = 100 MHz are 3 meters long.
  - waves with f = 1000 MHz are 0.3 meters long.
  - waves with f = 30 KHz are 10 km long.
  - waves with f = 300 KHz are 1 km long.

The Electromagnetic Spectrum

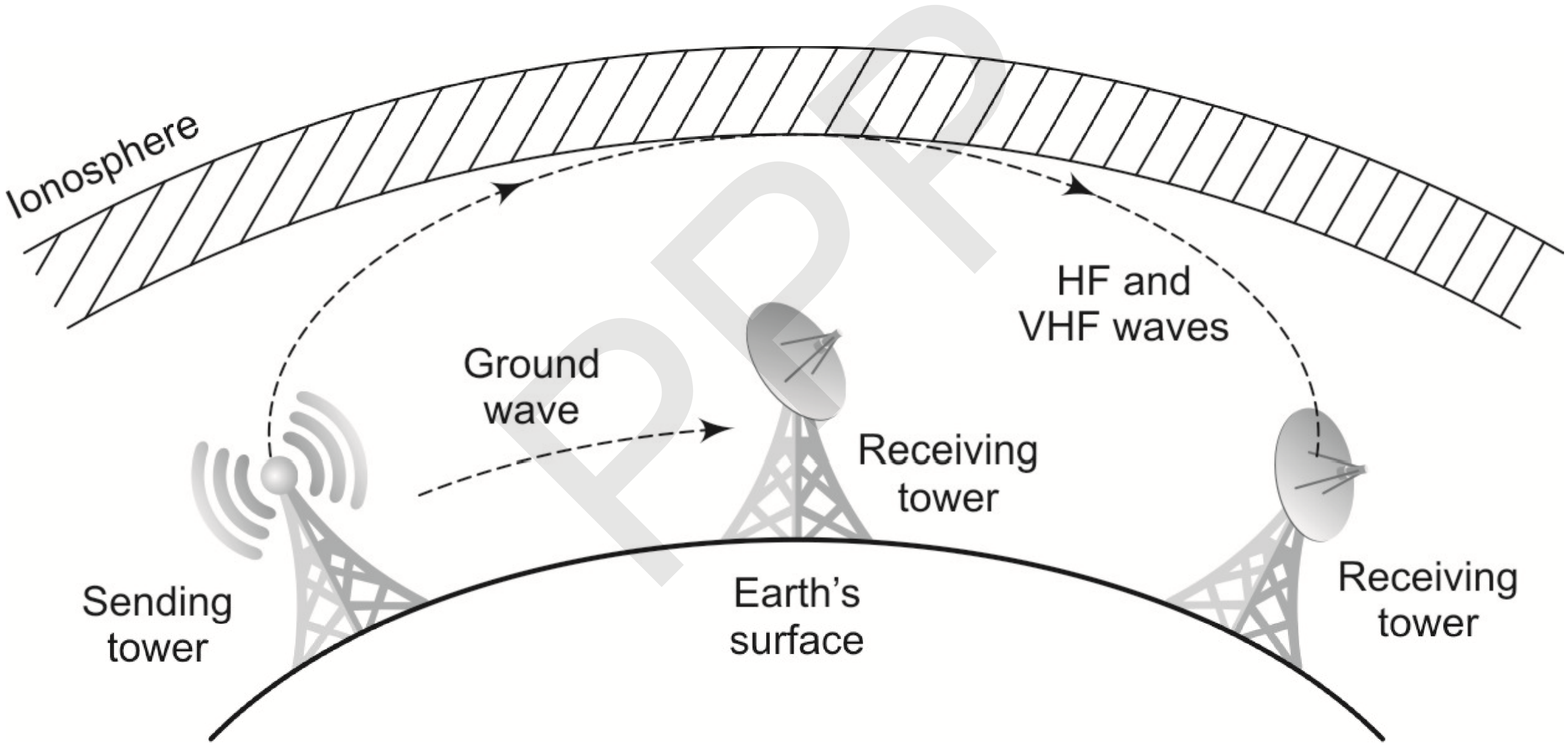
- Radio Waves
- Microwaves
- Infrared and Millimeter Waves
- The ISM Bands
- The optical light

E-M Spectrum



f (Hz) 10^0 10^2 10^4 10^6 10^8 10^10 10^12 10^14 10^16 10^18 10^20 10^22 10^24
Radio
Microwave
Infrared
UV
X-ray
Gamma ray
Visible light
f (Hz) 10^4 10^5 10^6 10^7 10^8 10^9 10^10 10^11 10^12 10^13 10^14 10^15 10^16
Twisted pair
Coax
Satellite
Terrestrial microwave
Fiber optics
Maritime
AM radio
FM radio
TV
Band LF MF HF VHF UHF SHF EHF THF
Radio waves
Microwave
Infrared
UV
X-rays
Gamma rays
R
O
Y
G
B
I
V

Radio Waves


Ionosphere
HF and
VHF waves
Ground
wave
Receiving
tower
Receiving
tower
Sending
tower
Earth's
surface

Radio Waves

- 10^4 to 10^8 Hz
- Frequency is less and waves are long
- Travel in all directions (omnidirectional)
- Passing through obstacles
- Travels a long distance
- Poor for data transmissions

Radio Waves

- Subdivided into VLF, LF, MF , HF , and VHF
- VLF, LF, and MF waves are known as ground waves
- HF and VHF travel in straight line
- HF and VHF refracted back by ionosphere

Microwaves

- 10^8 to 10^{11} Hz
- Travel straighter and not in all directions
- The *line of sight (LoS) requirement*.
- Get more and more focused as the wavelength decreases

Microwaves

- Parabolic antennas
- Do not penetrate through the walls; have a tendency to bounce off the obstacles
- Waves above 4 GHz absorbed by raindrops.
- *multipath fading*
- No wiring between the sender and receiver
- Repeaters at 50 to 60 KM

Microwaves

- Relatively inexpensive
- Licensing is required
- FCC (Federal Communications Commission) in US does this job. In India, this is done by DoT (Department of Telecommunications)

Infrared & Millimeter waves

- Infrared (TV remote control)
- Millimeter waves
  - Easy to produce and use
  - Travel straight and cannot pass through obstacles.
  - Cannot work outdoors
  - License is not required
  - Short range devices (Toys, VCRS, Stereos)

Other part of the spectrum

- **ISM bands**

– **902 to 928 MHz**	**2.4 to 2.48 GHz**	**5.736 to 5.860 GHz**
– Garage door openers	802.11b (home N/W) (11 Mbps)	802.11a (Bus. N/W) (54 Mbps)
– Cordless phones	802.11g (54 Mbps)	
– Wireless mouse	microwave ovens	
– Toys Remote Control		

  - Only restriction is the range of power.

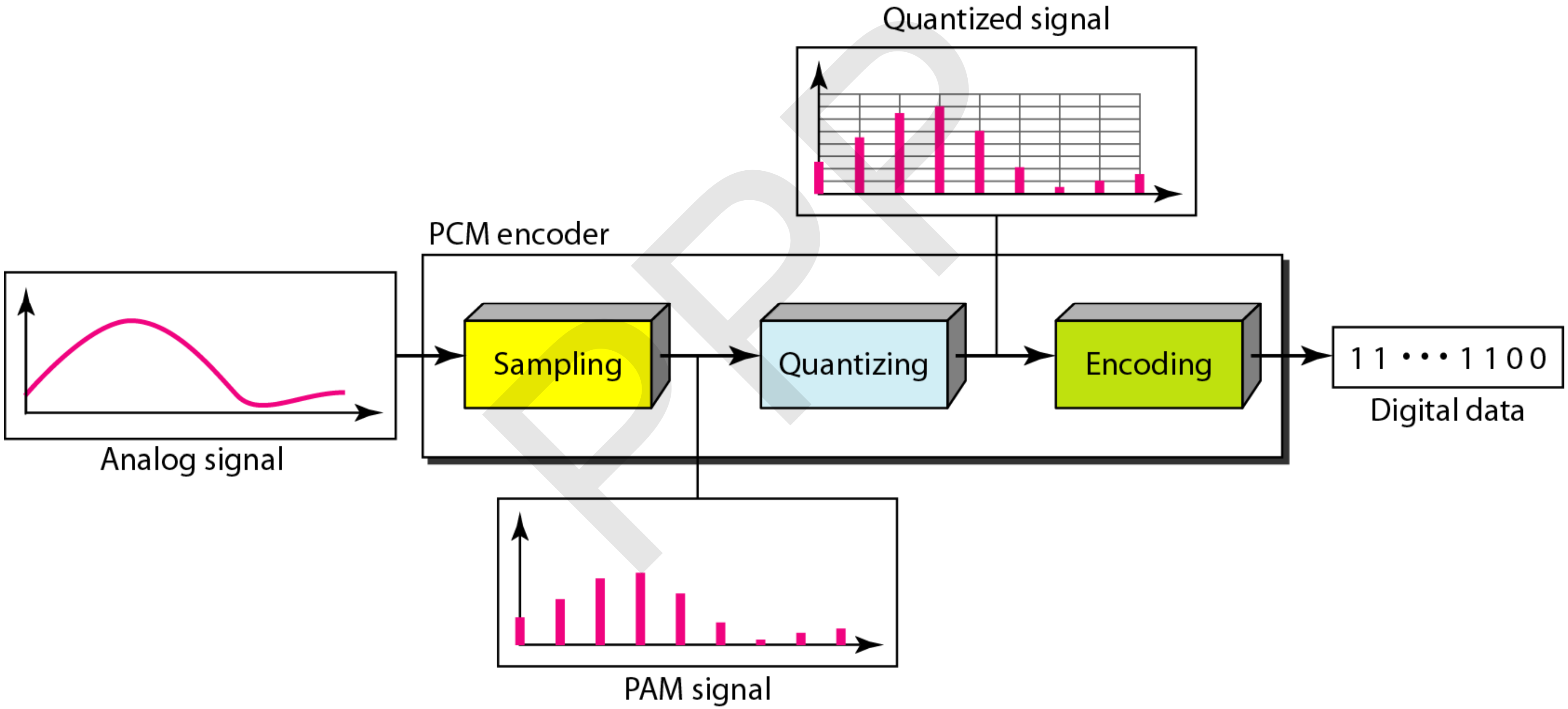
- **Free Space Optics (FSO) using visible light**
  - Communication in outer space (**1Gbps up to 2 KM**)
  - Communication between spacecrafts.
  - Aircraft to communicate with satellites
  - Atmospheric condition affect the quality of FSO (Rain, Fog, Heat, Dust)

PCM (Pulse Code Modulation)

- ***A digital signal is superior to an analog signal because it is more robust to noise and can easily be recovered, corrected and amplified. For this reason, the tendency today is to change an analog signal to digital data.***

- PCM consists of four steps to digitize an analog signal:
  1. Sampling
  2. Quantization
  3. Binary encoding
  4. Line Coding

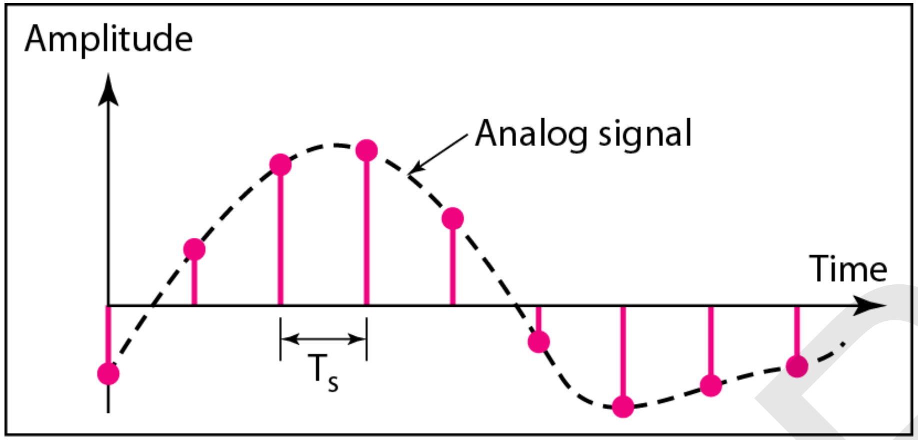
Components of PCM encoder



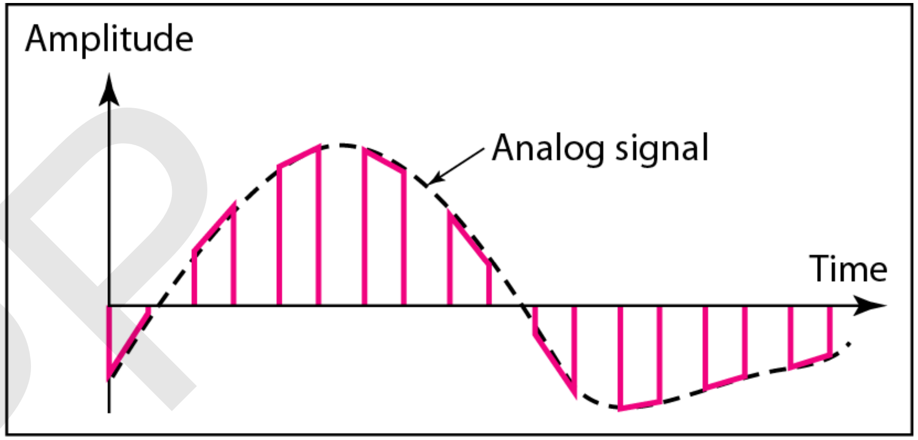
Sampling

- Analog signal is sampled every T_S secs.
- T_s is referred to as the sampling interval.
- $f_s = 1/T_s$ is called the sampling rate or sampling frequency.
- There are 3 sampling methods:
  - Ideal - an impulse at each sampling instant
  - Natural - a pulse of short width with varying amplitude
  - Flattop - sample and hold, like natural but with single amplitude value
- The process is referred to as pulse amplitude modulation PAM and the outcome is a signal with analog (non integer) values

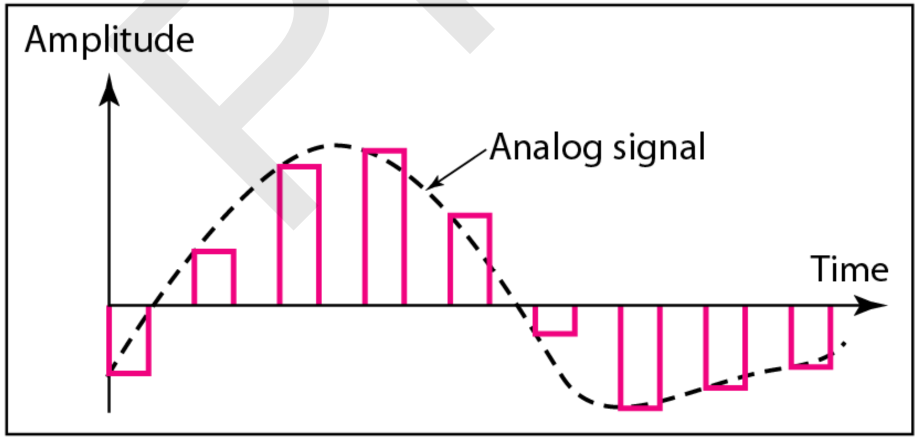
Three different sampling methods for PCM



a. Ideal sampling



b. Natural sampling

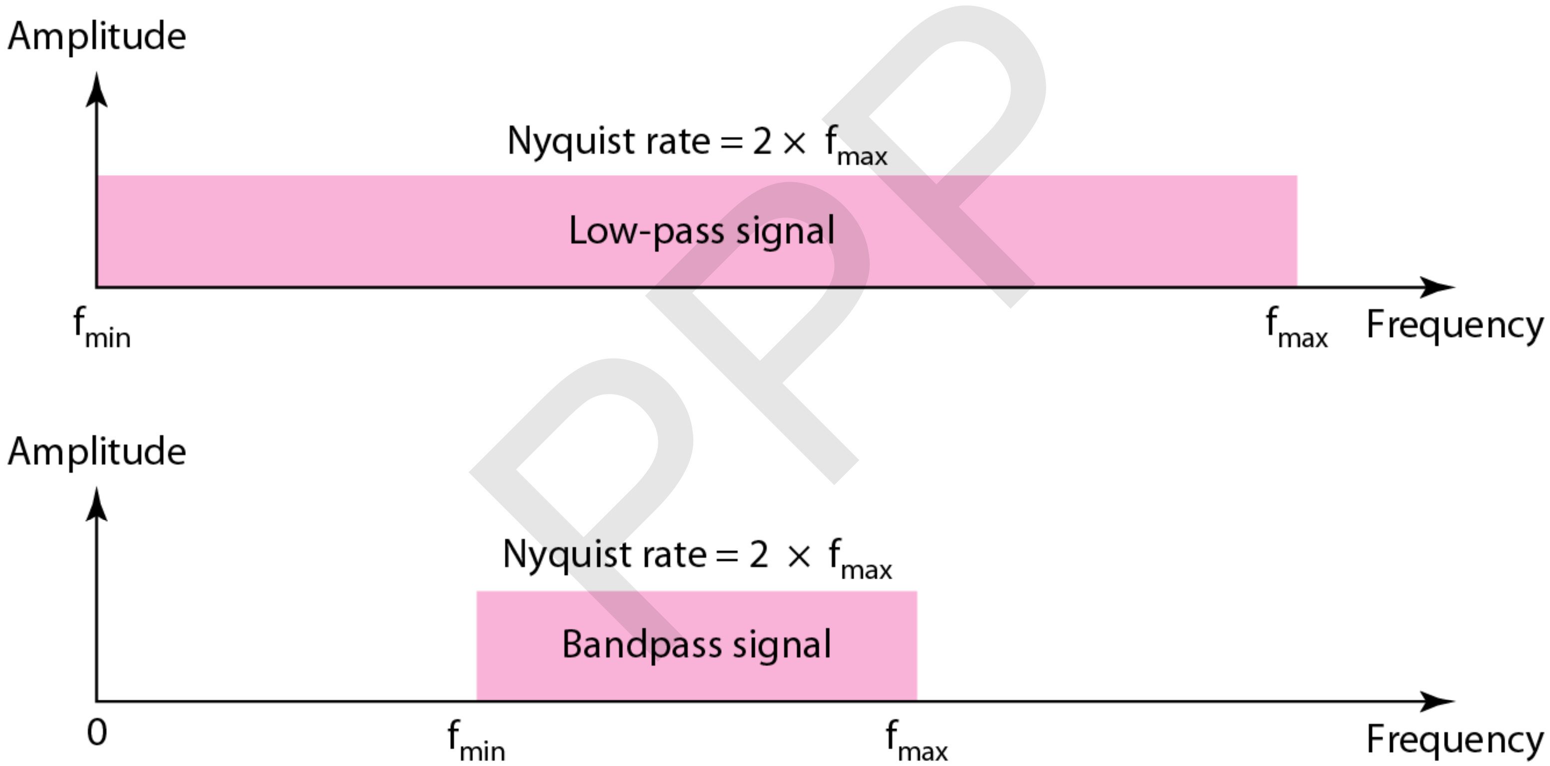


c. Flat-top sampling

Nyquist Theorem

The sampling rate must be at least 2 times the highest frequency contained in the signal.

Nyquist sampling rate for low-pass and bandpass signals



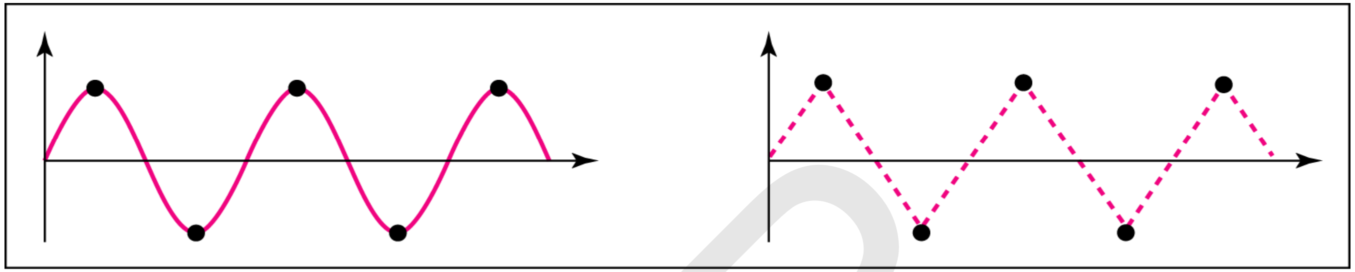
Proof of Nyquist Theorem

For example of the Nyquist theorem,

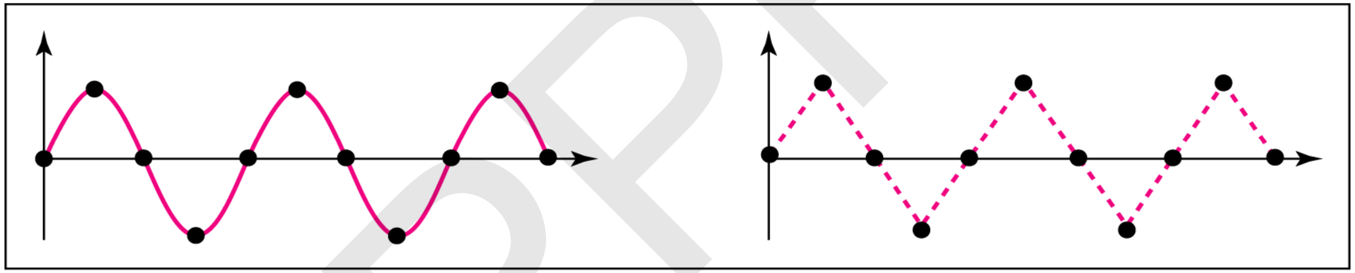
let us sample a simple sine wave at three sampling rates:

$f_s = 4f$ ***(2 times the Nyquist rate),***
$f_s = 2f$ ***(Nyquist rate), &***
$f_s = f$ ***(one-half the Nyquist rate).***

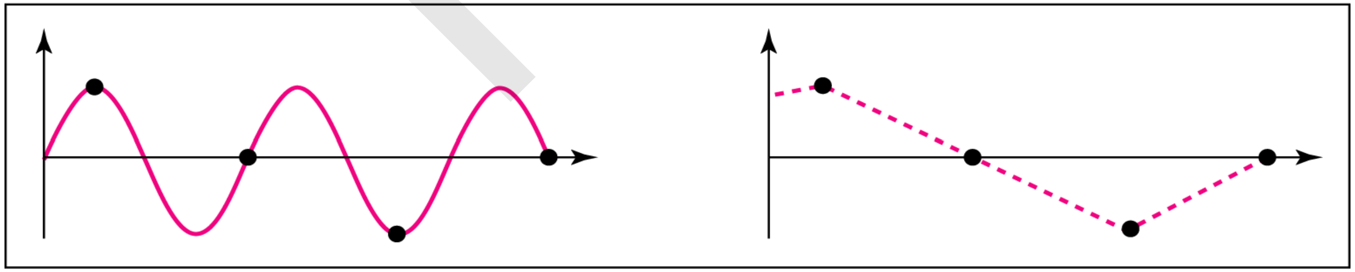
Sampled sine wave for different sampling rates



a. Nyquist rate sampling: $f_s = 2\,f$

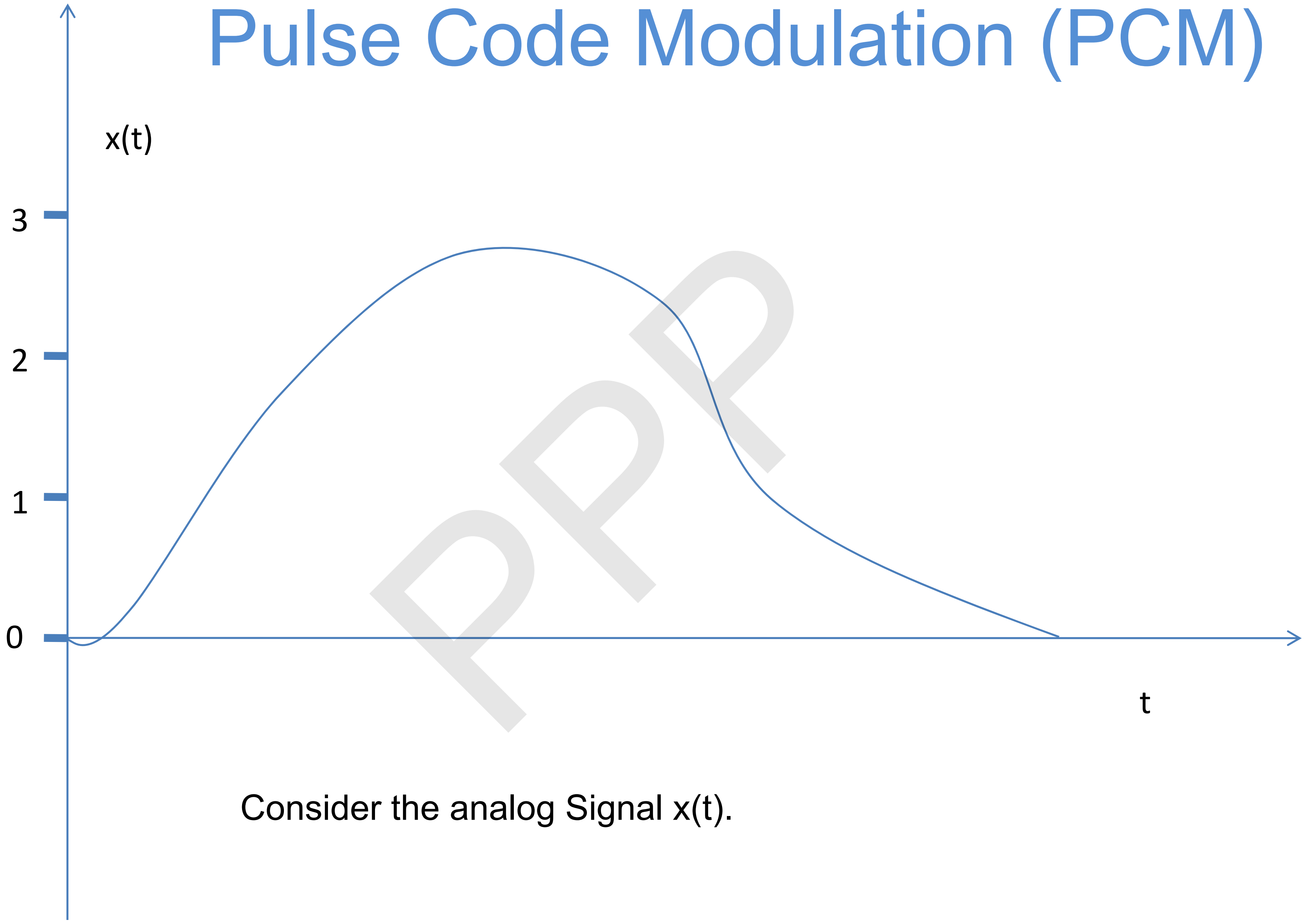


b. Oversampling: $f_s = 4\,f$



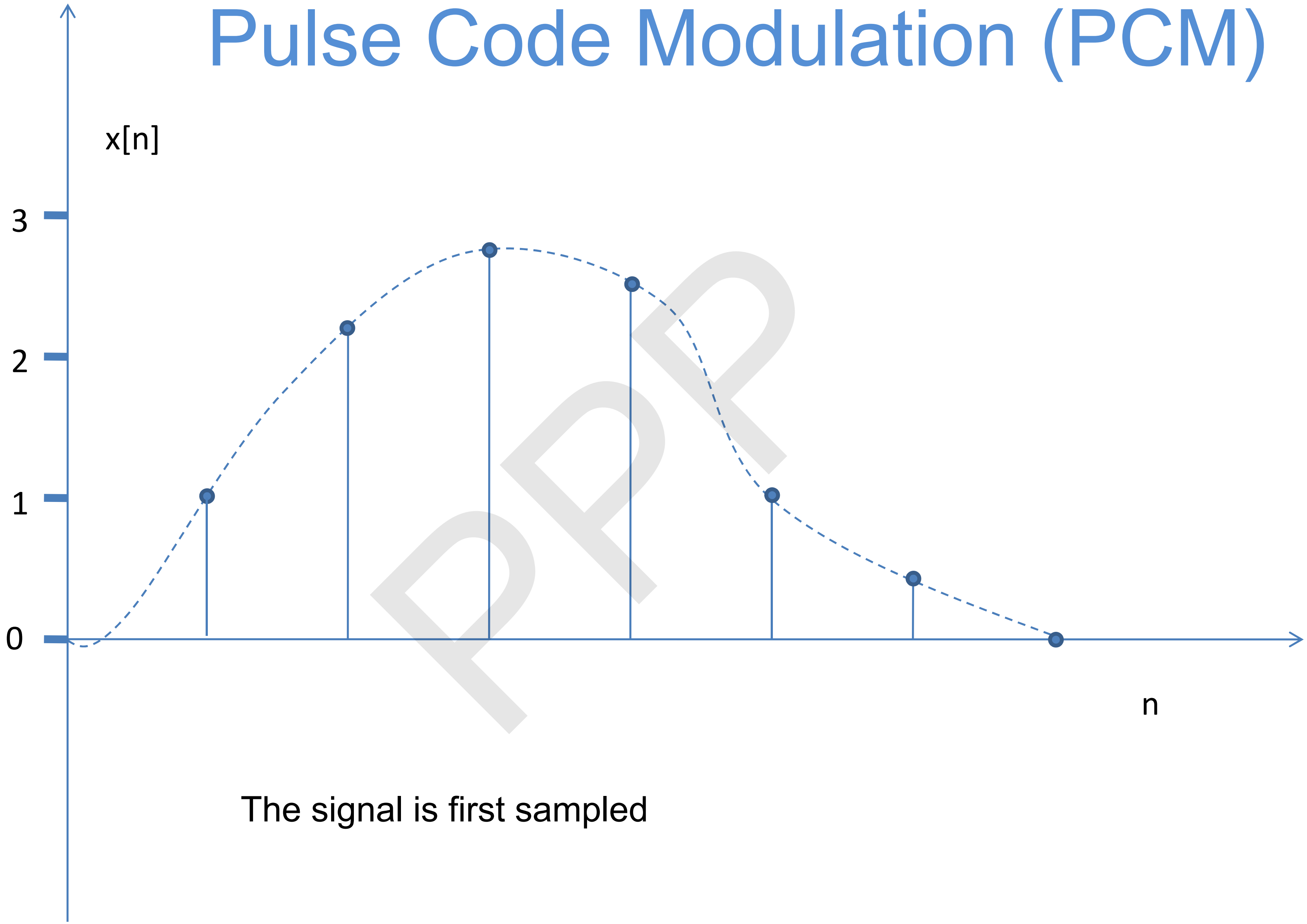
c. Undersampling: $f_s = f$

Pulse Code Modulation (PCM)



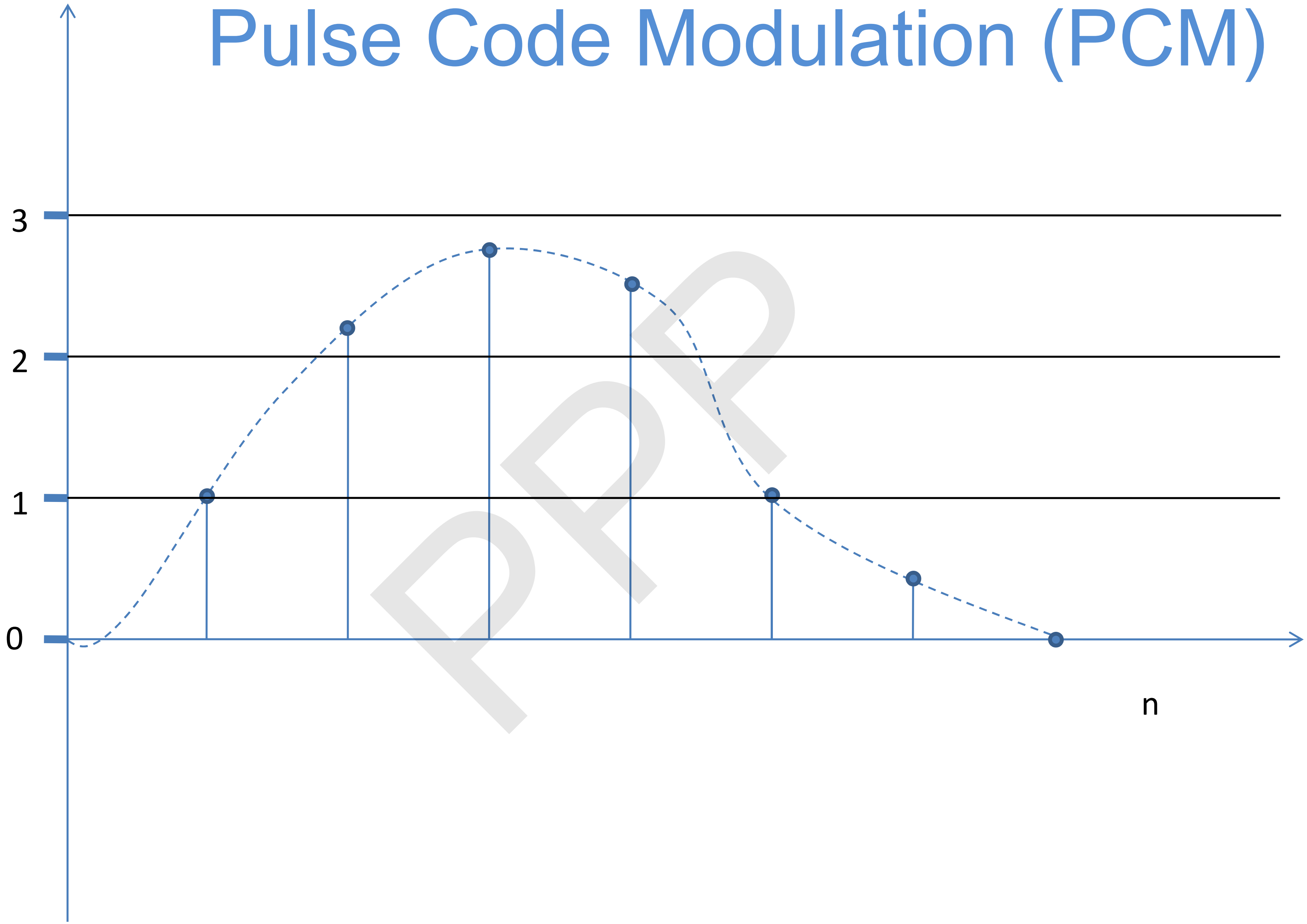
Consider the analog Signal x(t).

Pulse Code Modulation (PCM)

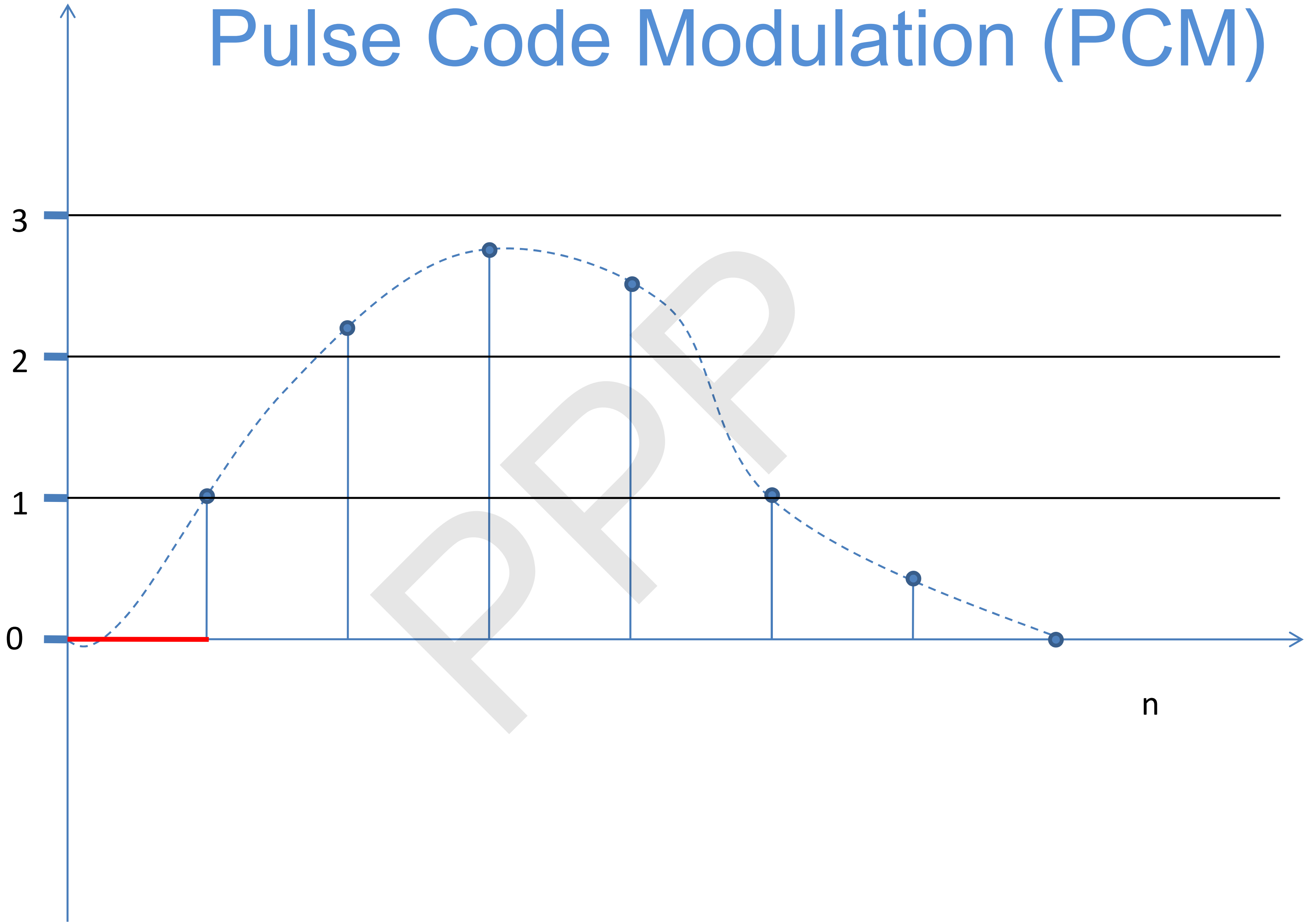


The signal is first sampled

Pulse Code Modulation (PCM)



Pulse Code Modulation (PCM)



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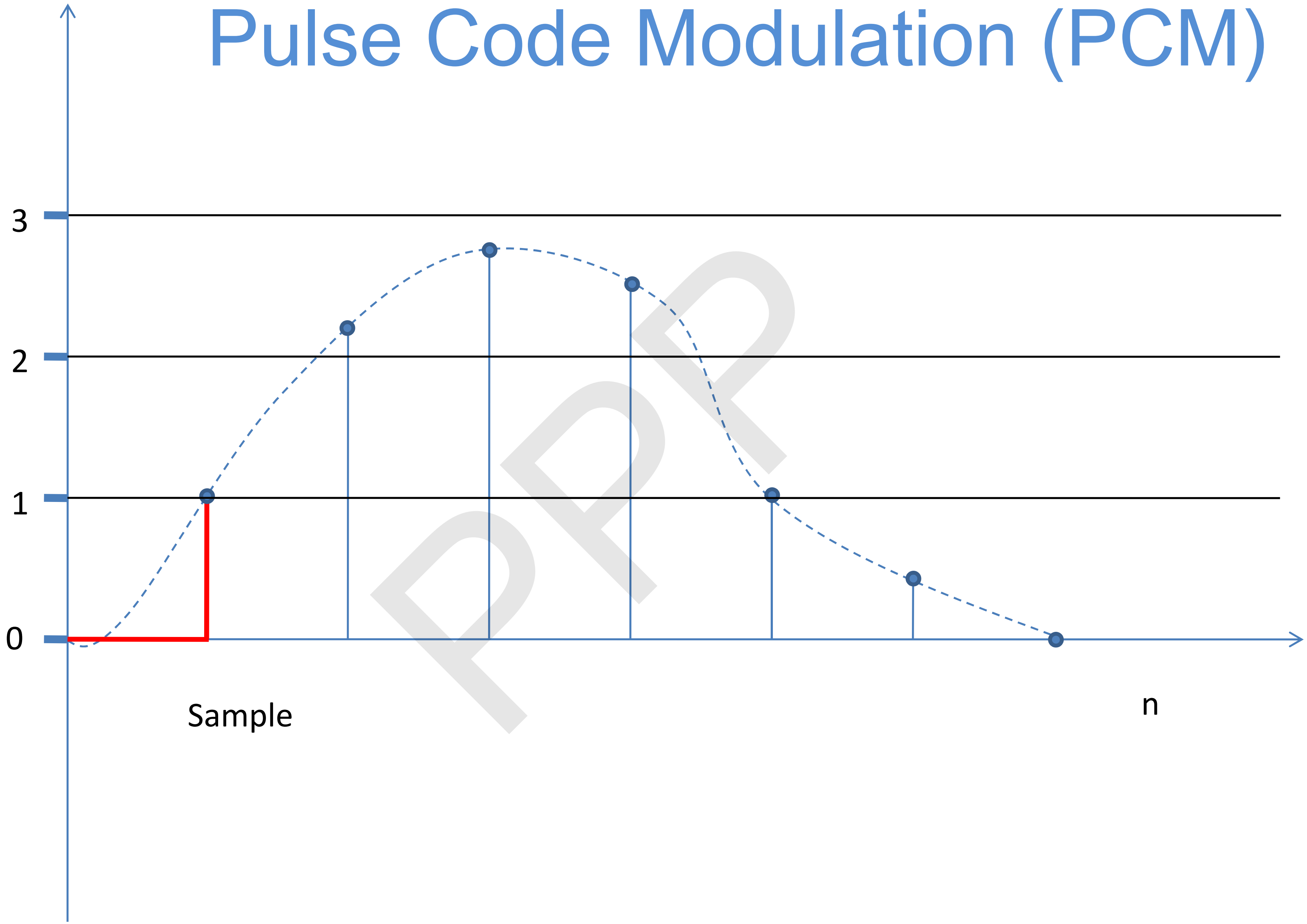

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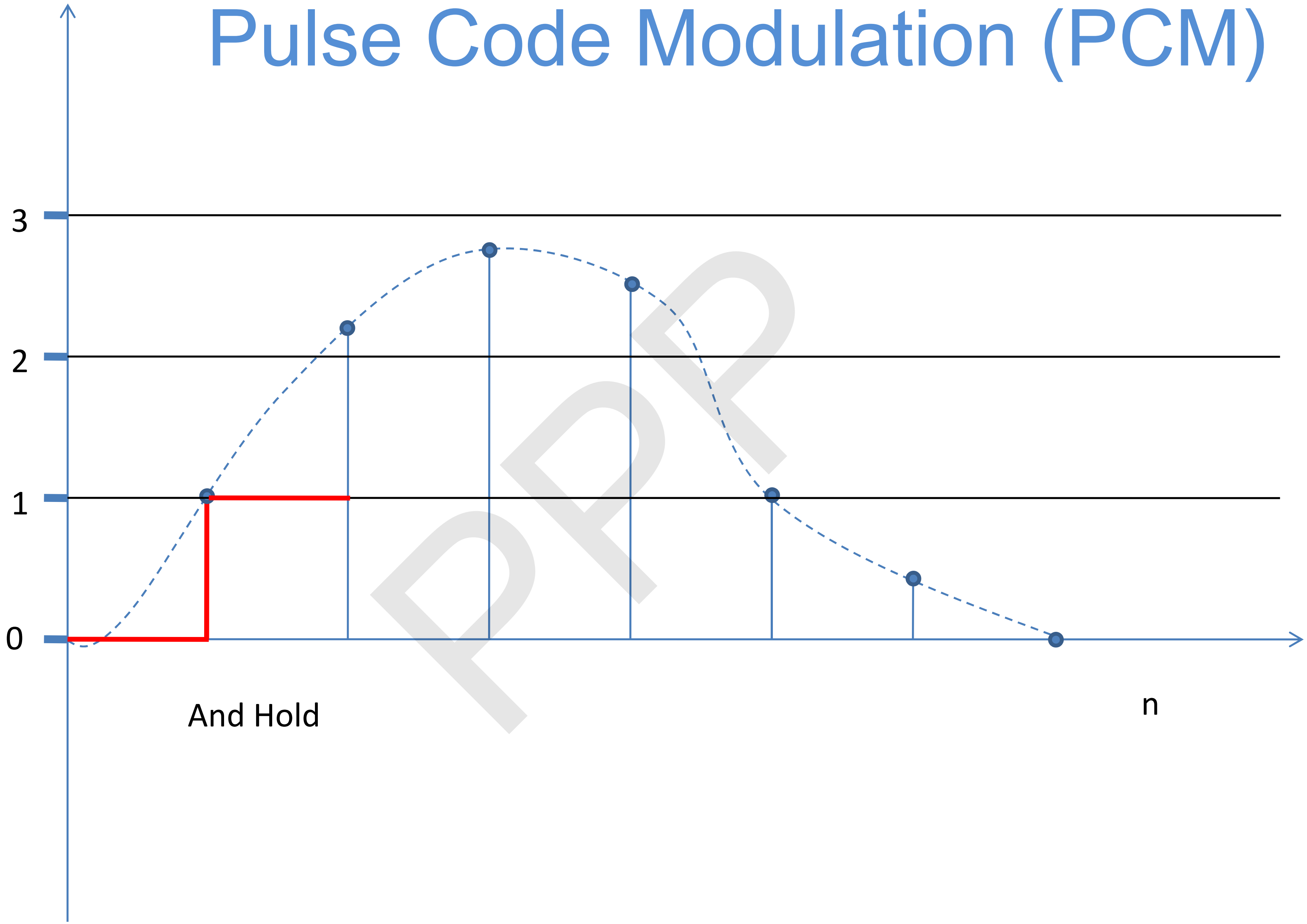

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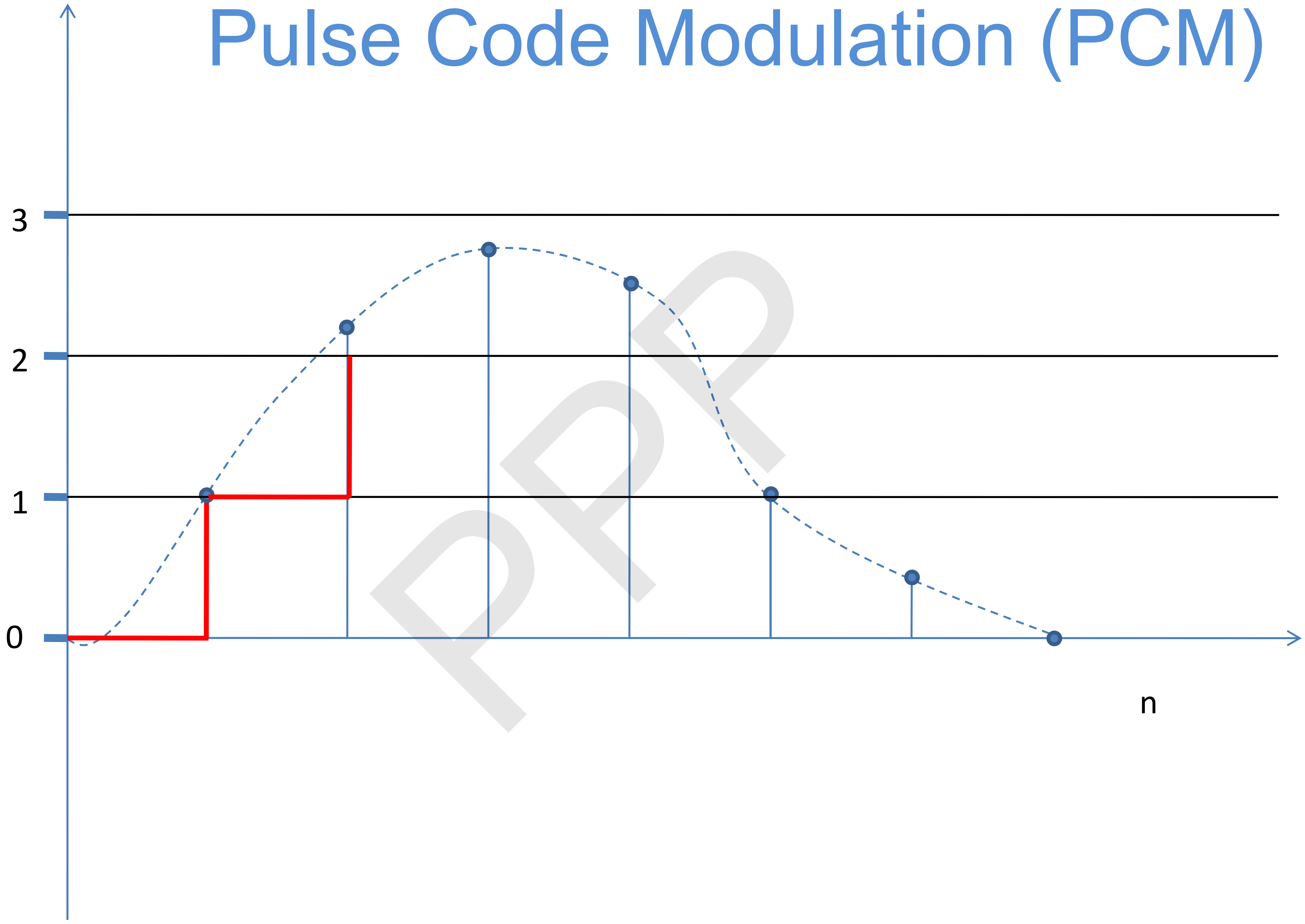

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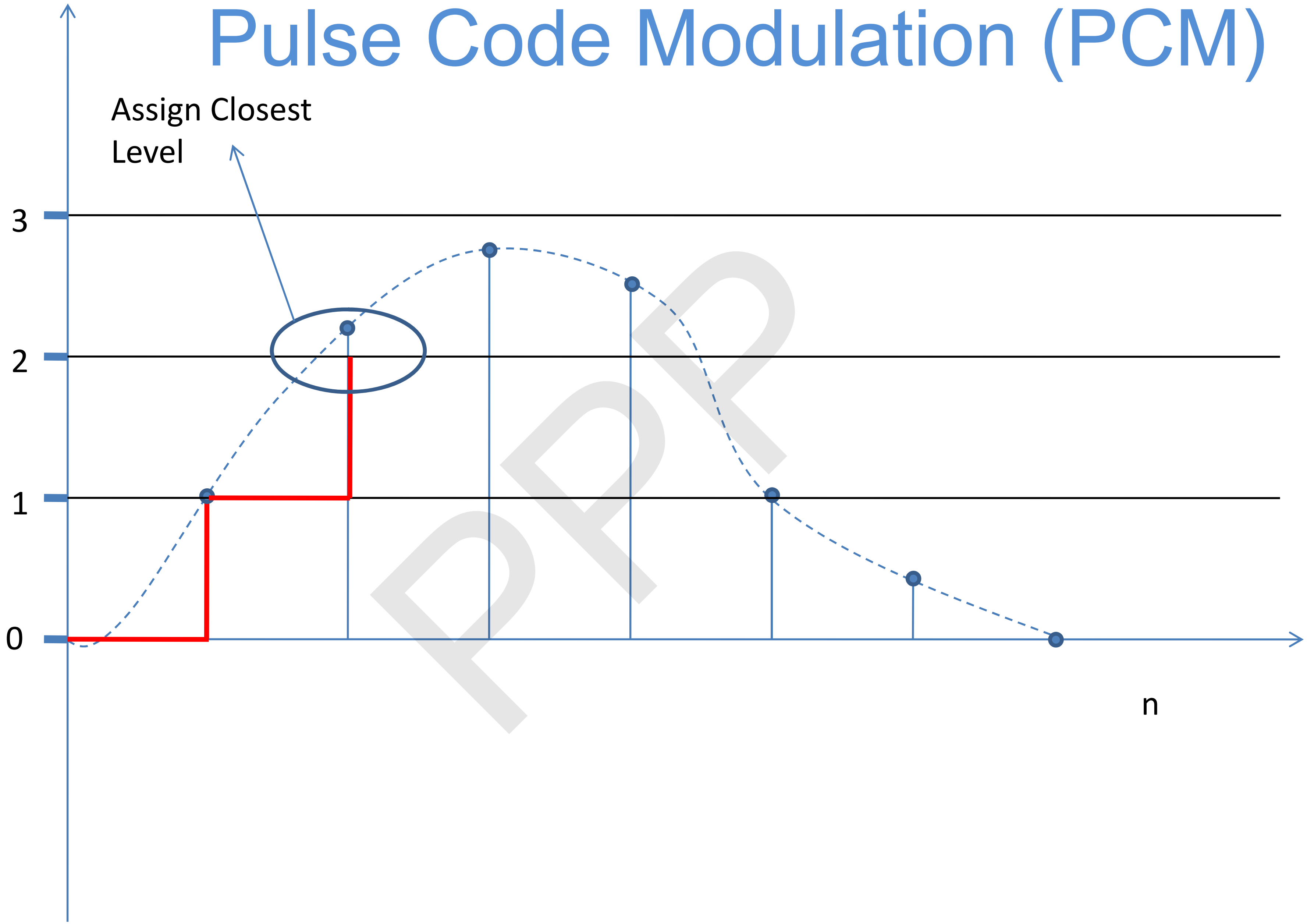

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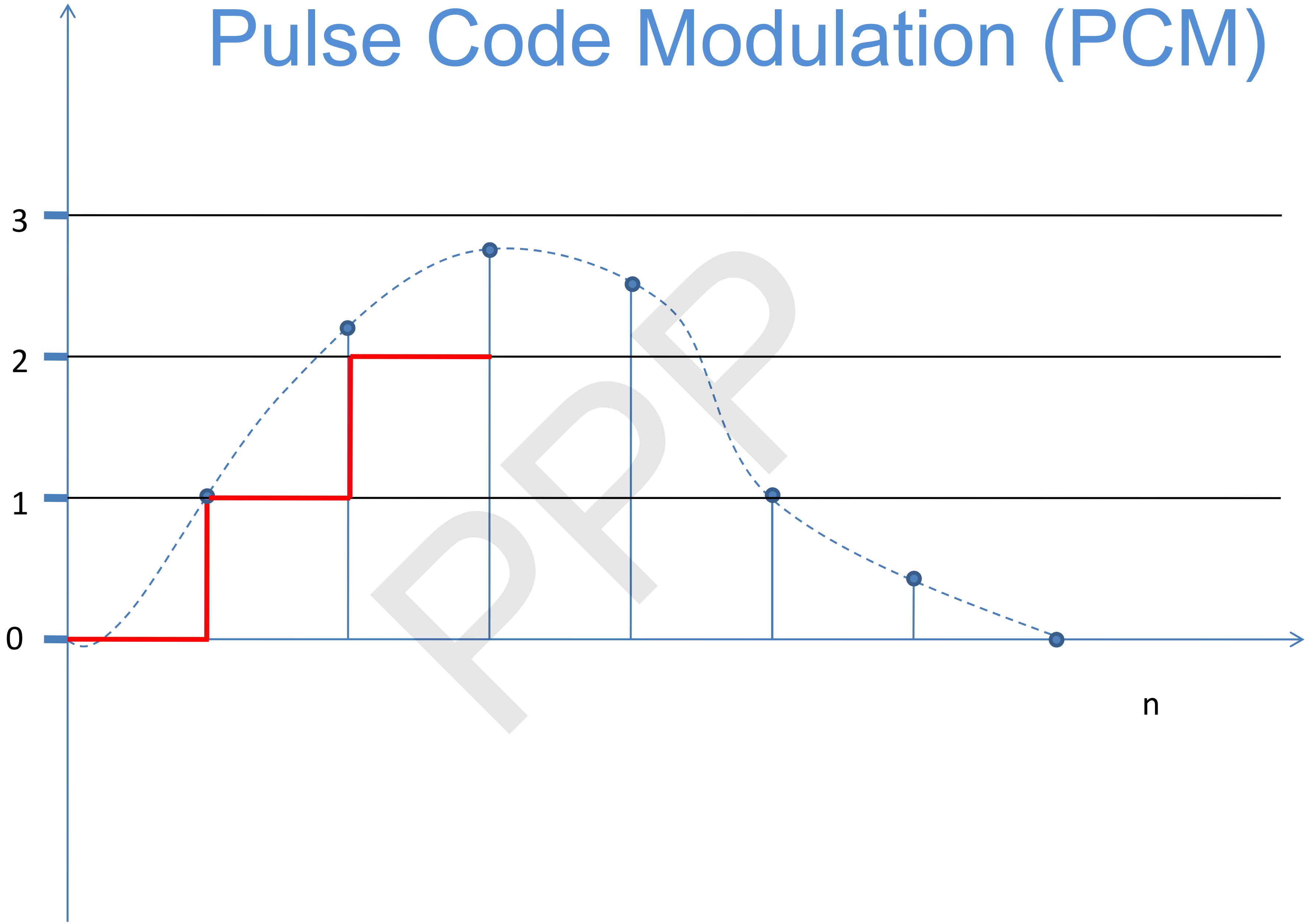
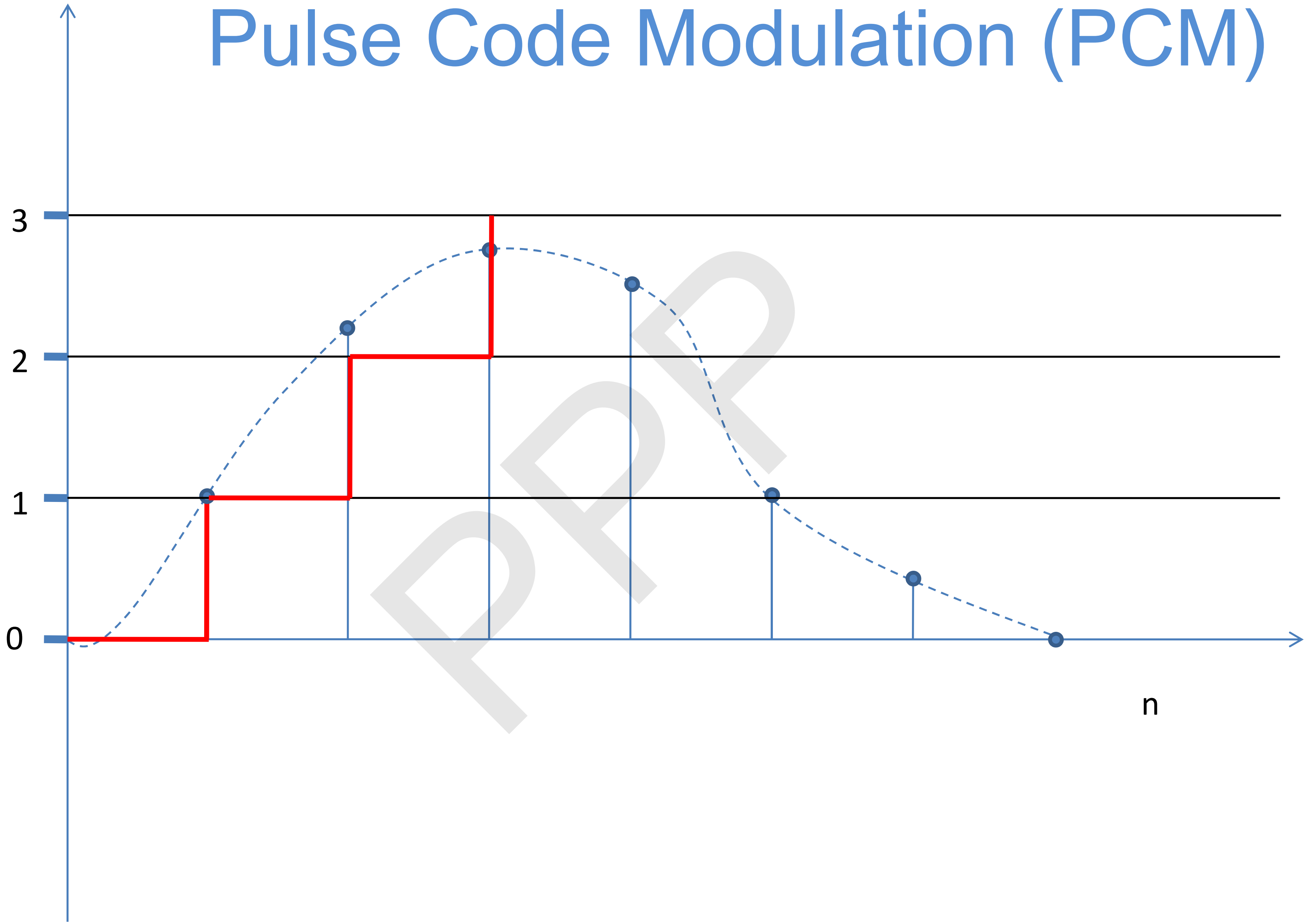
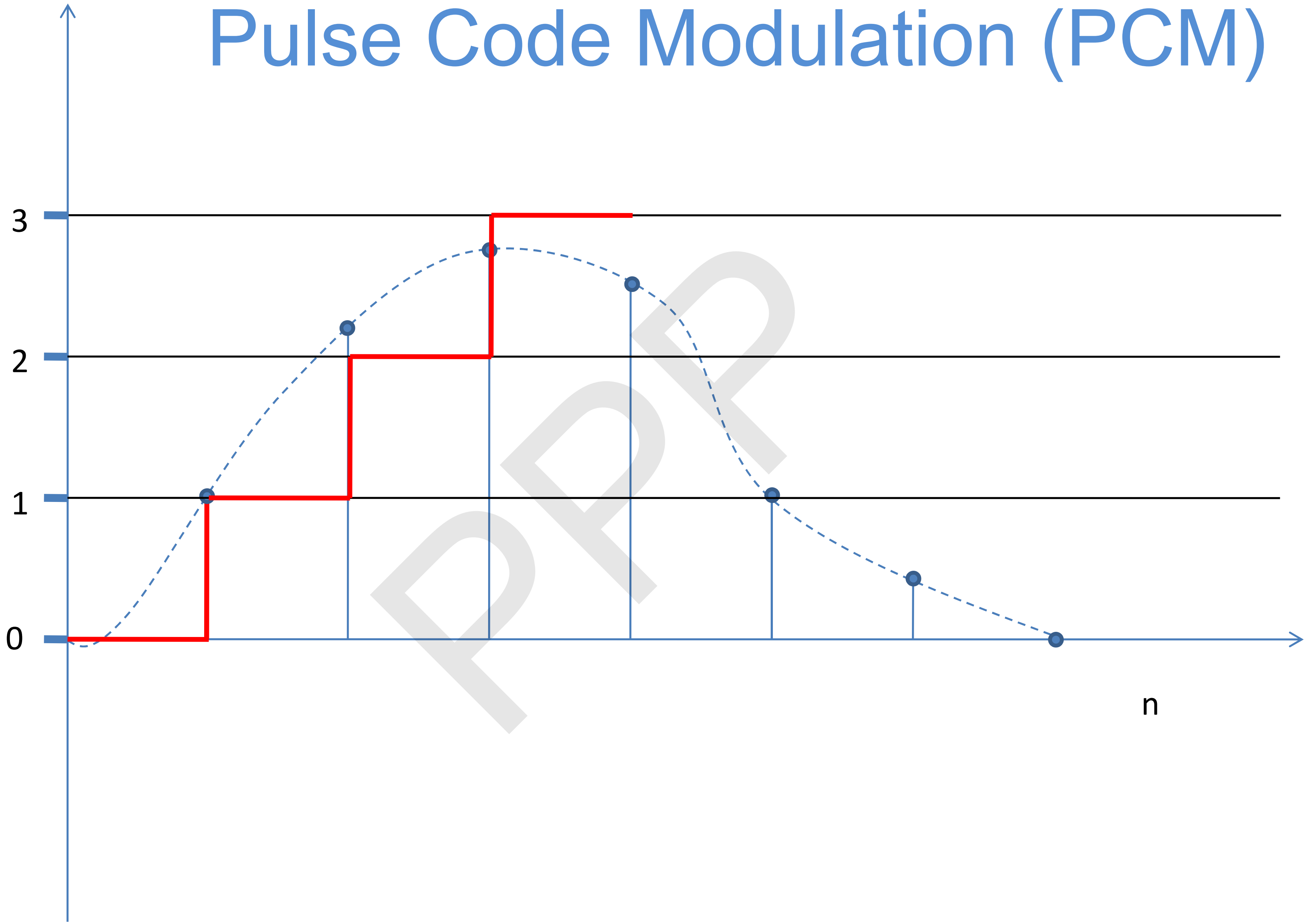


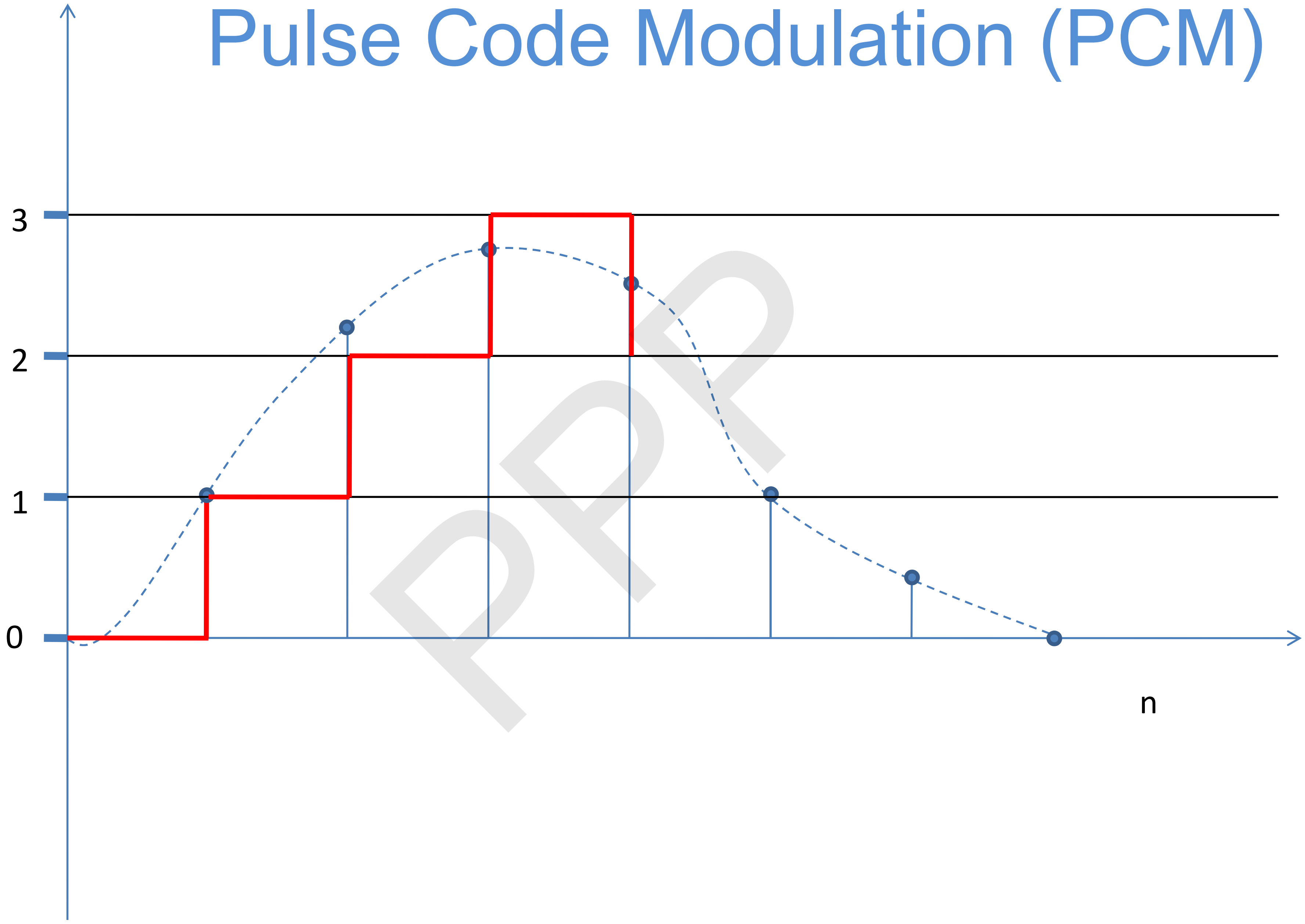
Pulse Code Modulation (PCM)



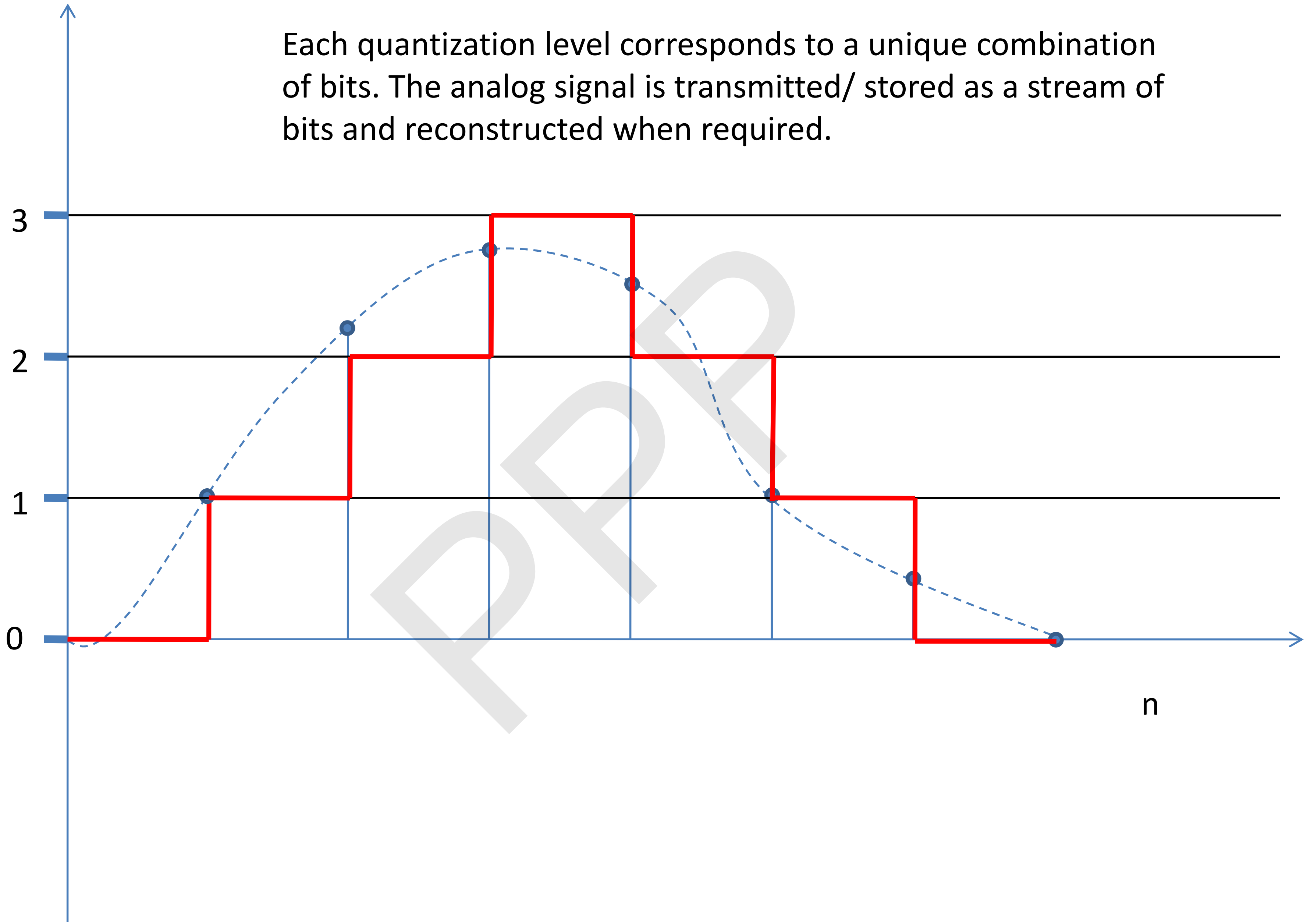
Pulse Code Modulation (PCM)



Pulse Code Modulation (PCM)



Each quantization level corresponds to a unique combination of bits. The analog signal is transmitted/ stored as a stream of bits and reconstructed when required.



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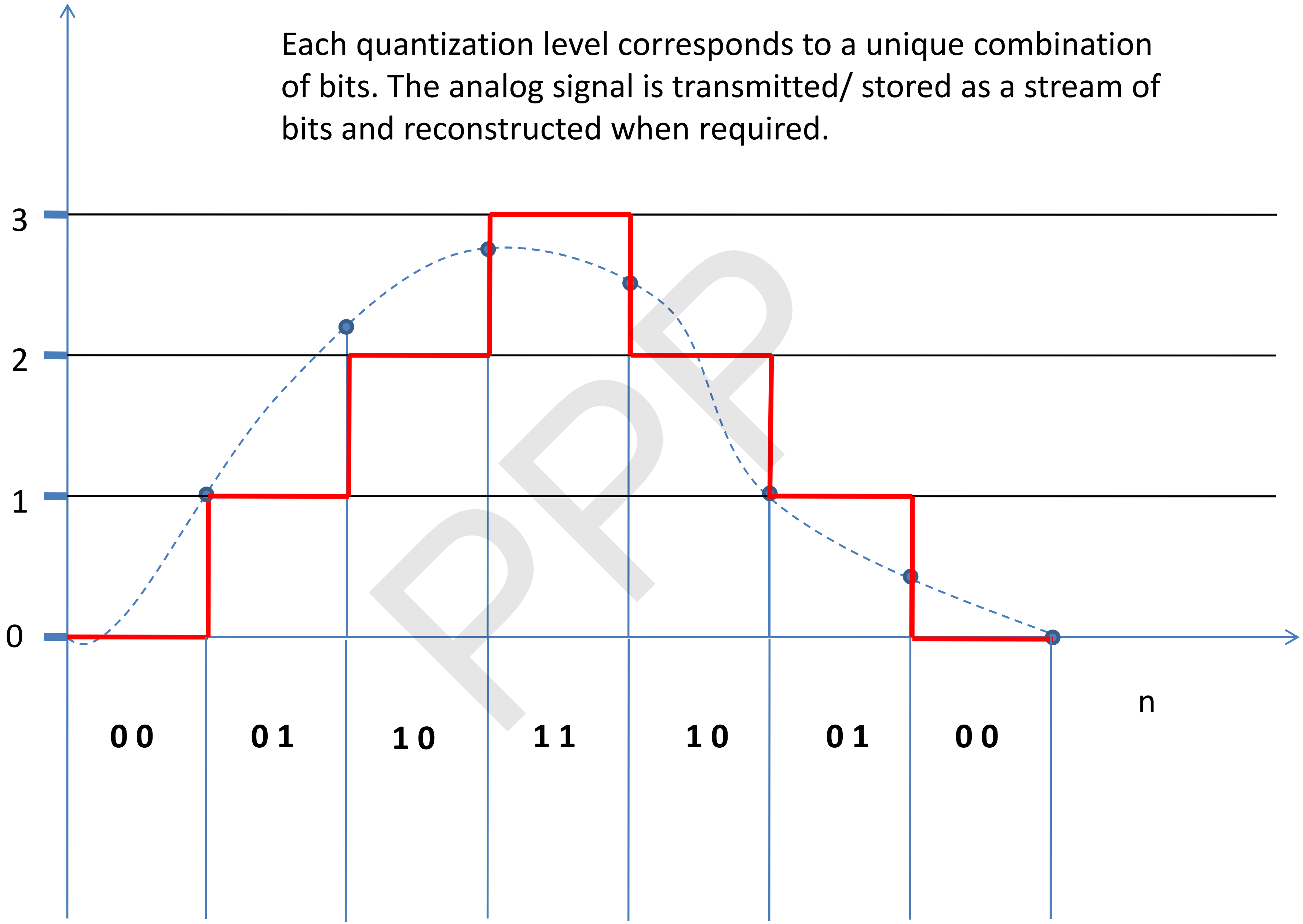
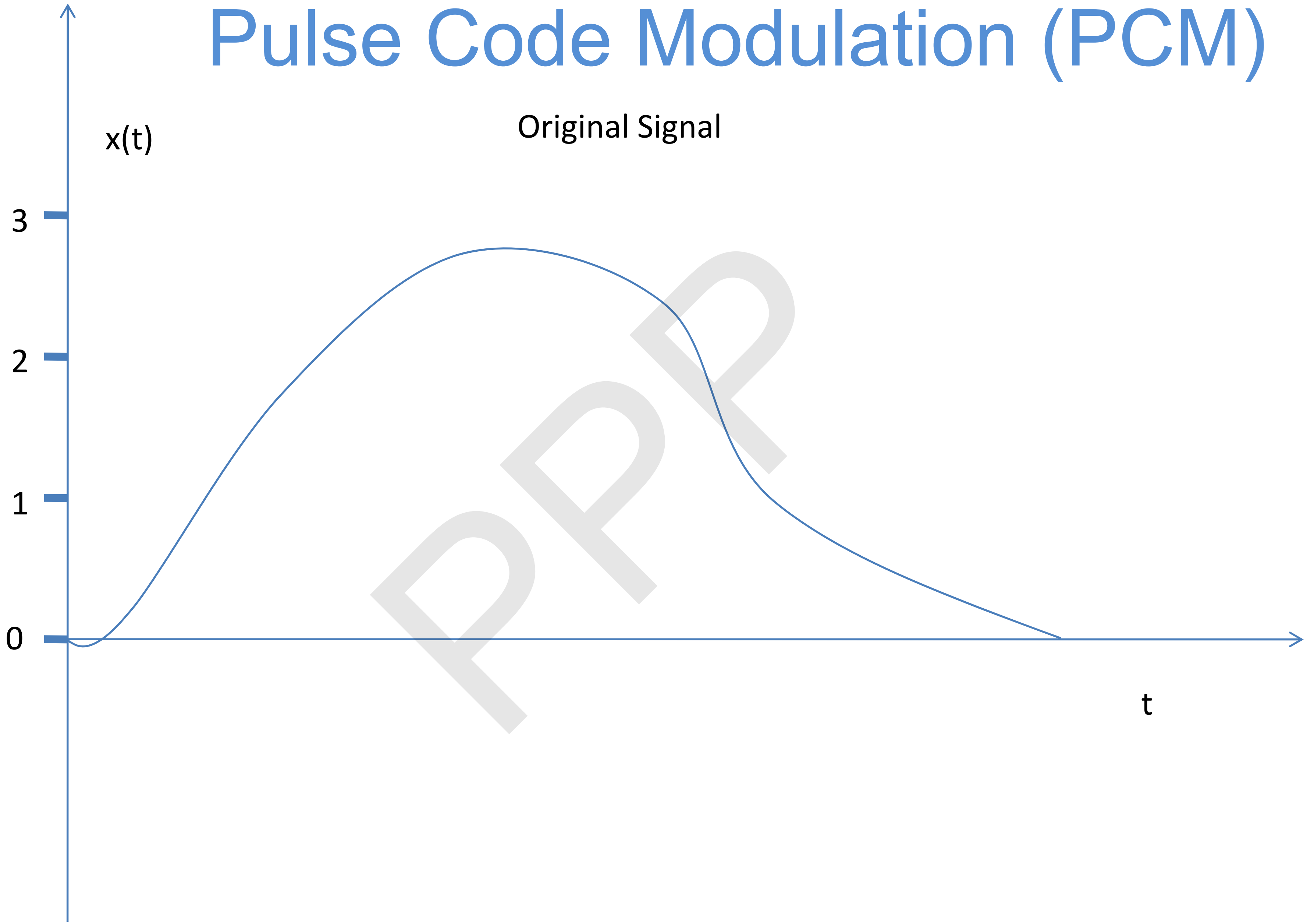


Pulse Code Modulation (PCM)



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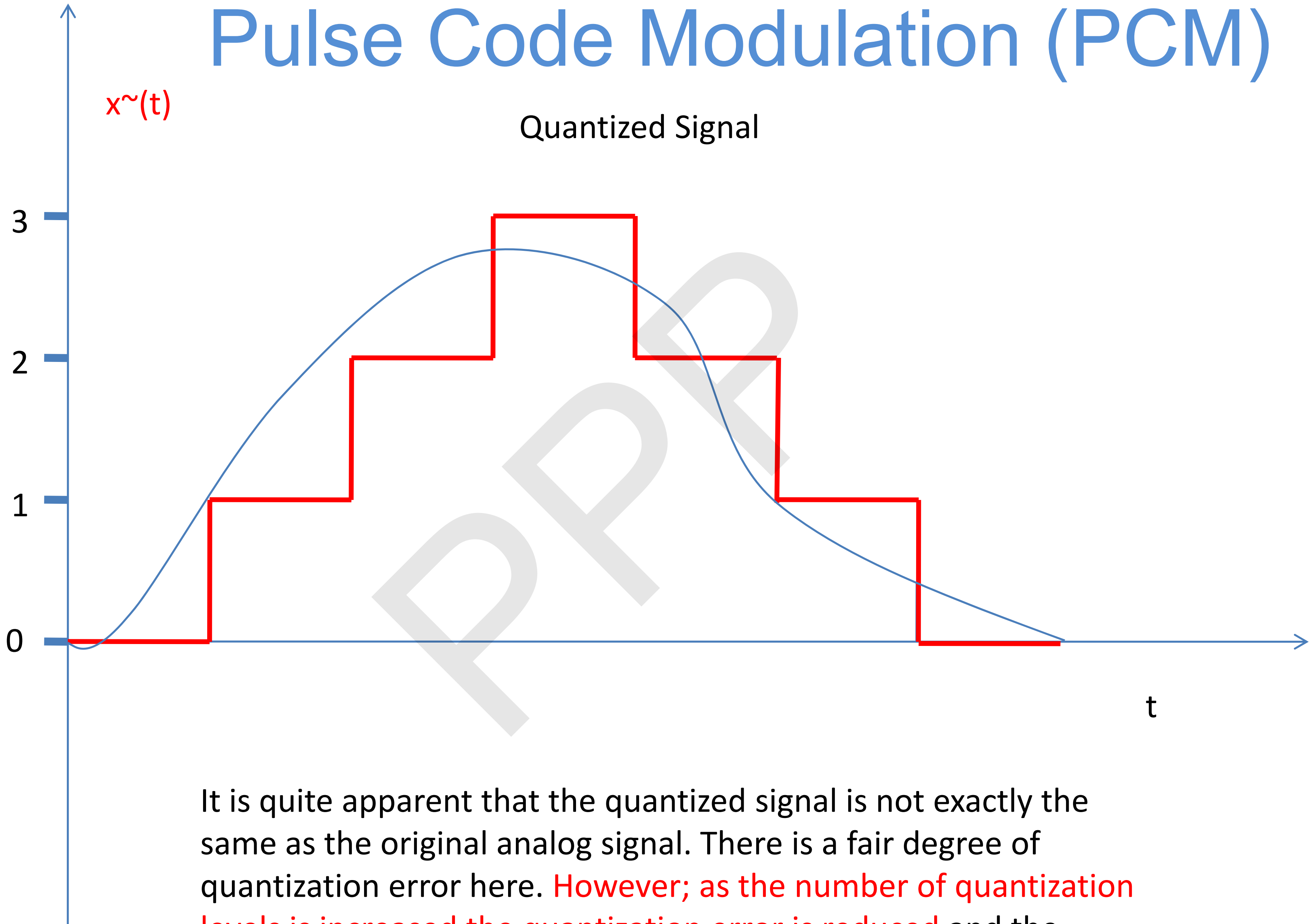
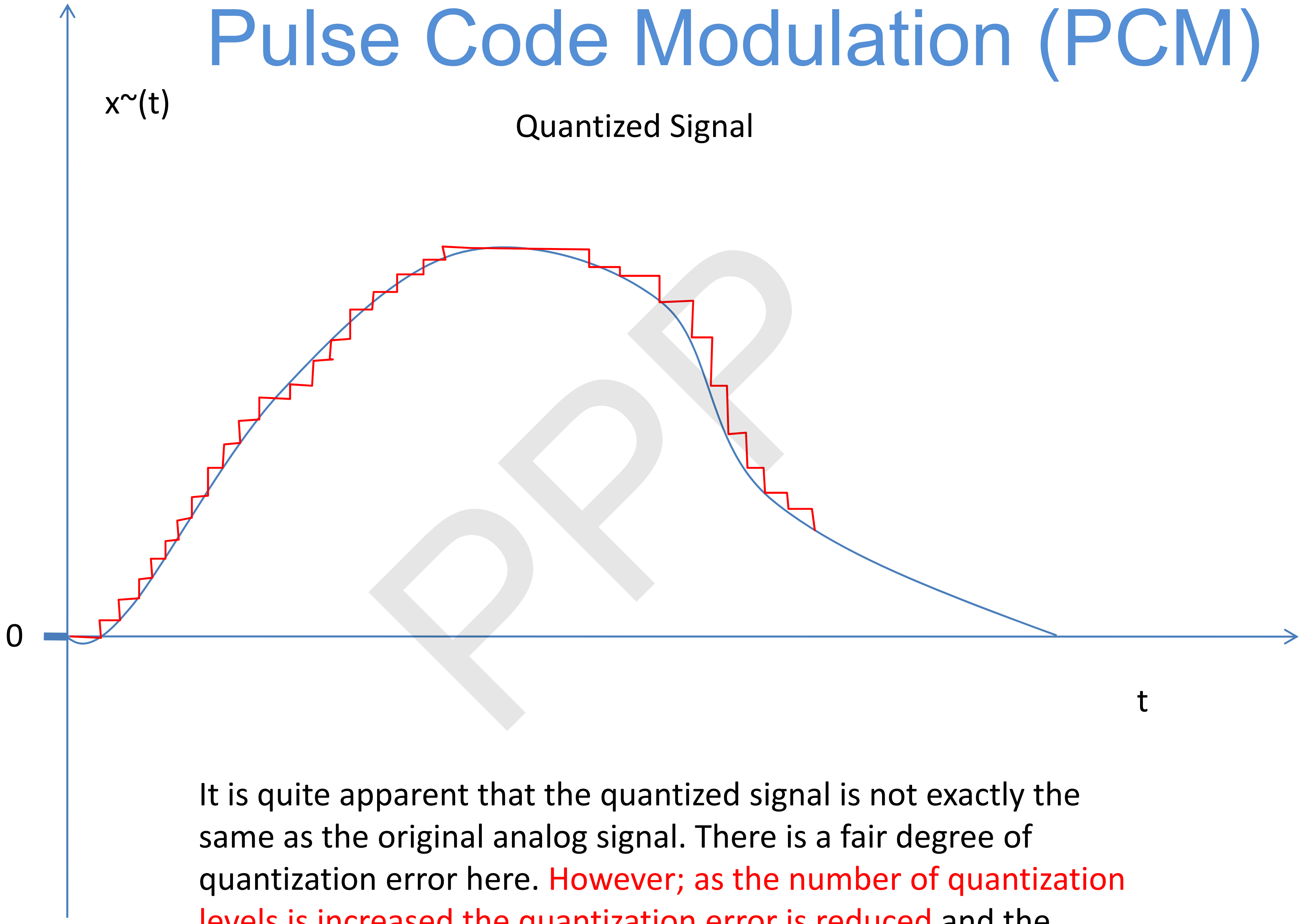


It is quite apparent that the quantized signal is not exactly the same as the original analog signal. There is a fair degree of quantization error here. However; as the number of quantization levels is increased the quantization error is reduced and the quantized signal gets closer and closer to the original signal

Pulse Code Modulation (PCM)



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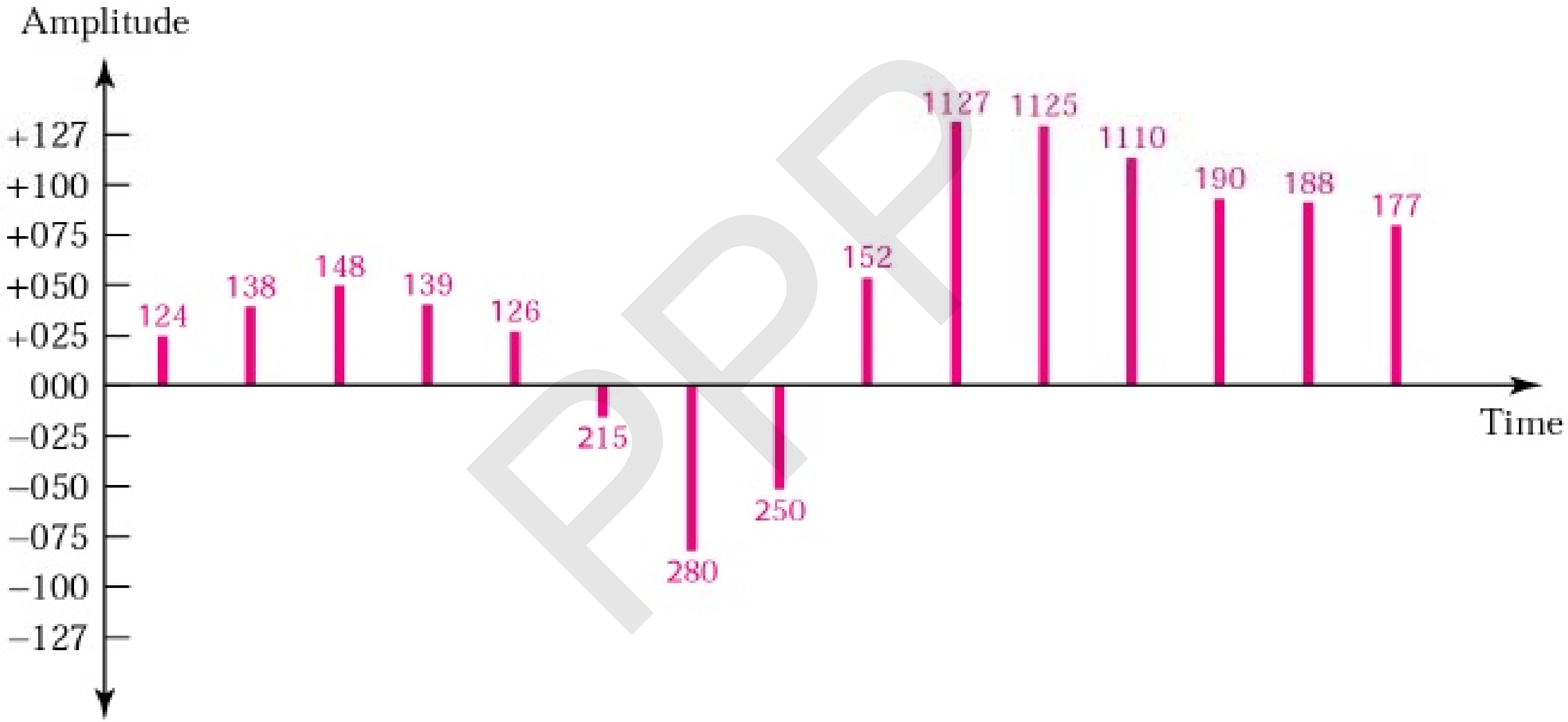
Quantized PAM Signal

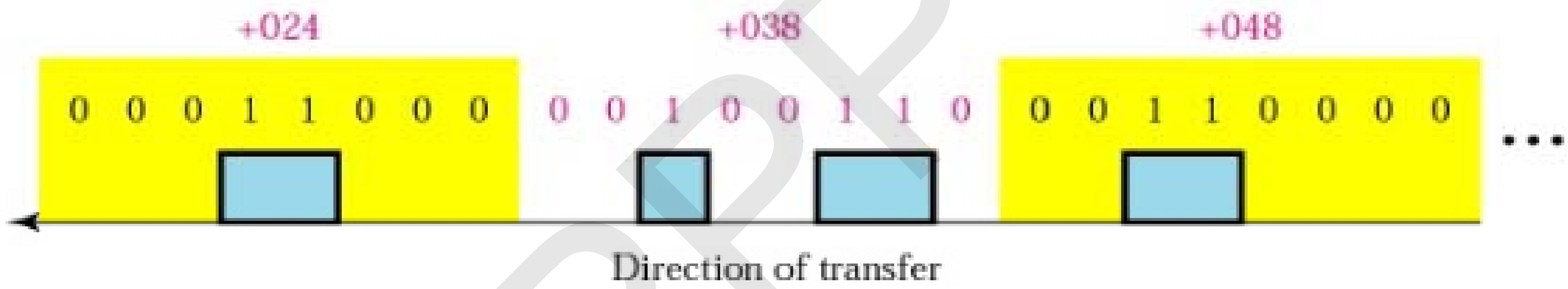


Quantizing using sign and magnitude

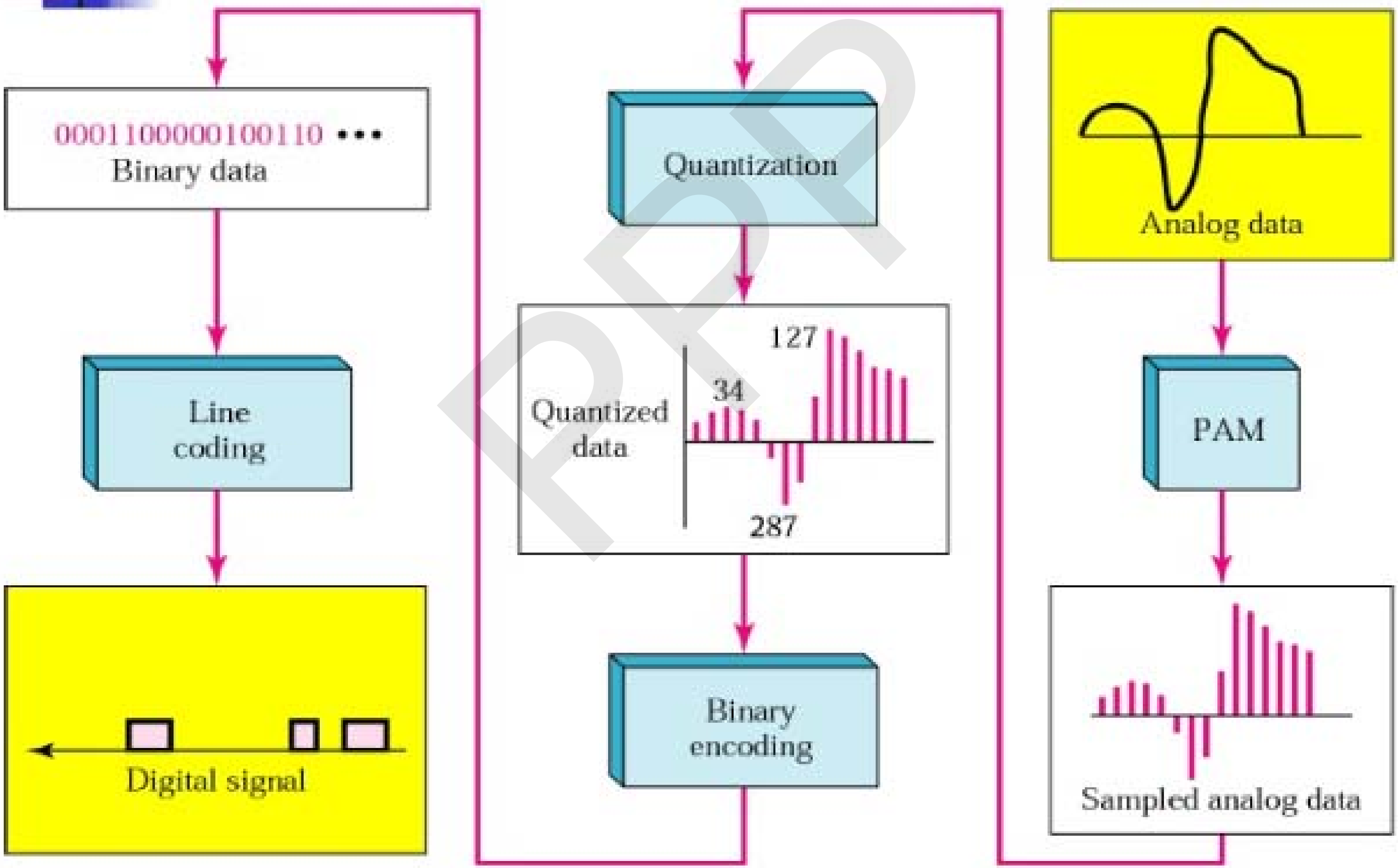
+024	00011000	–015	10001111	+125	01111101
+038	00100110	–080	11010000	+110	01101110
+048	00110000	–050	10110010	+090	01011010
+039	00100111	+052	00110110	+088	01011000
+026	00011010	+127	01111111	+077	01001101

Sign bit
+ is 0 – is 1

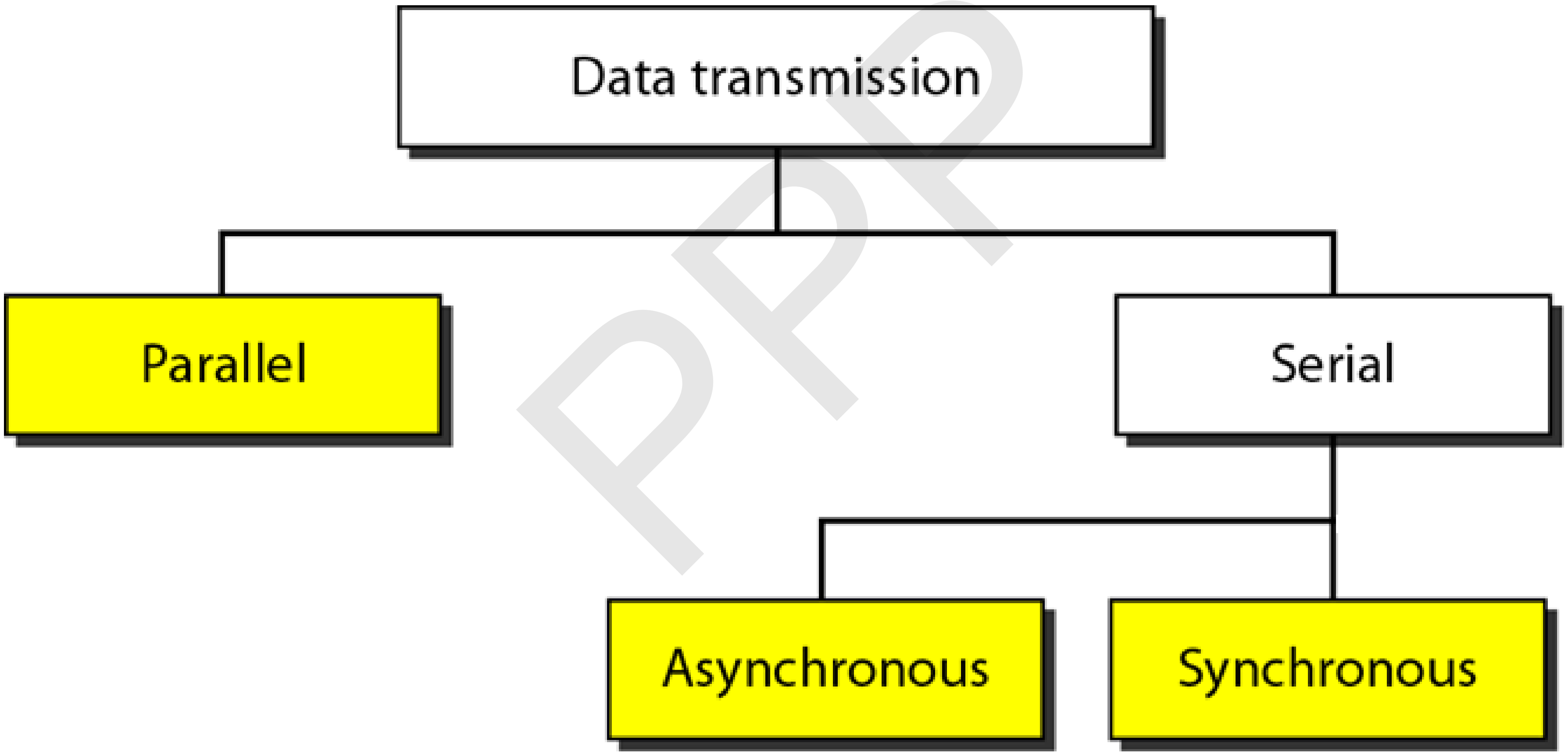
PCM


+024
+038
+048
0 0 0 1 1 0 0 0
0 0 1 0 0 1 1 0
0 0 1 1 0 0 0 0
• • •
Direction of transfer

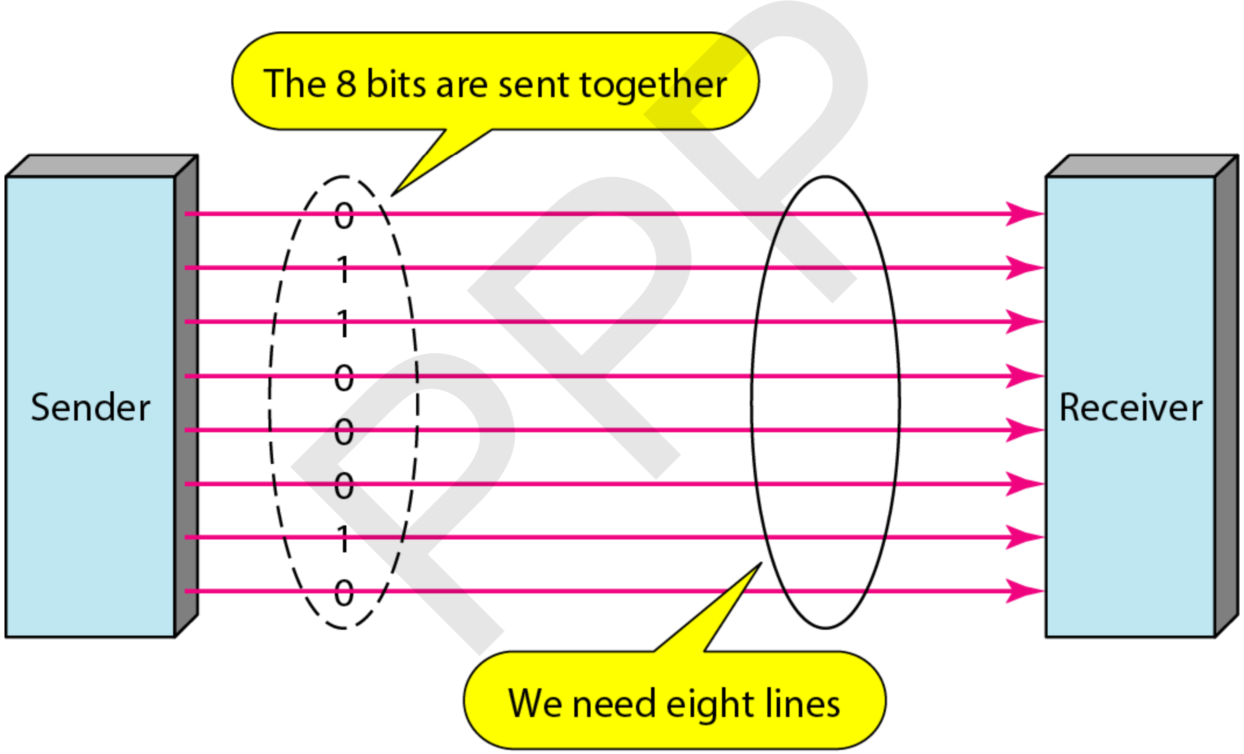
From analog signal to PCM digital code



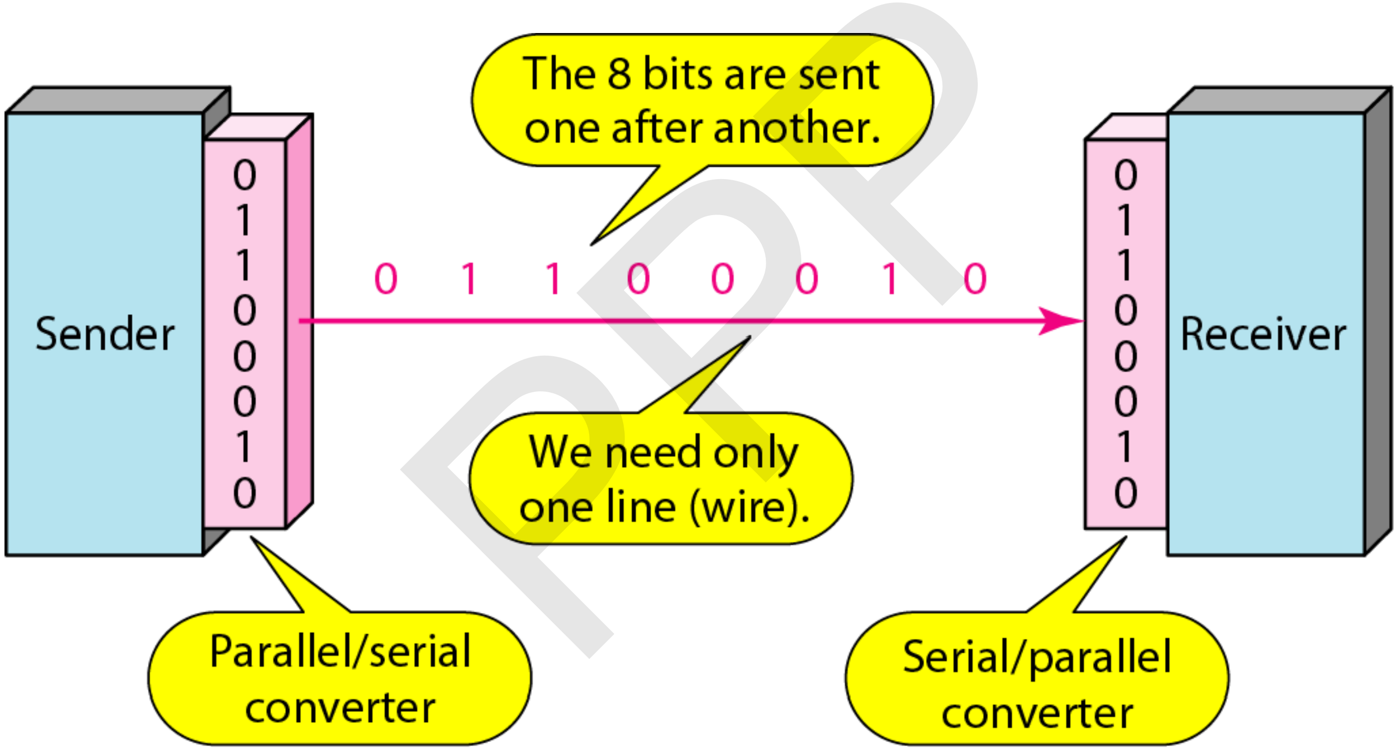
Data transmission and modes



Parallel transmission

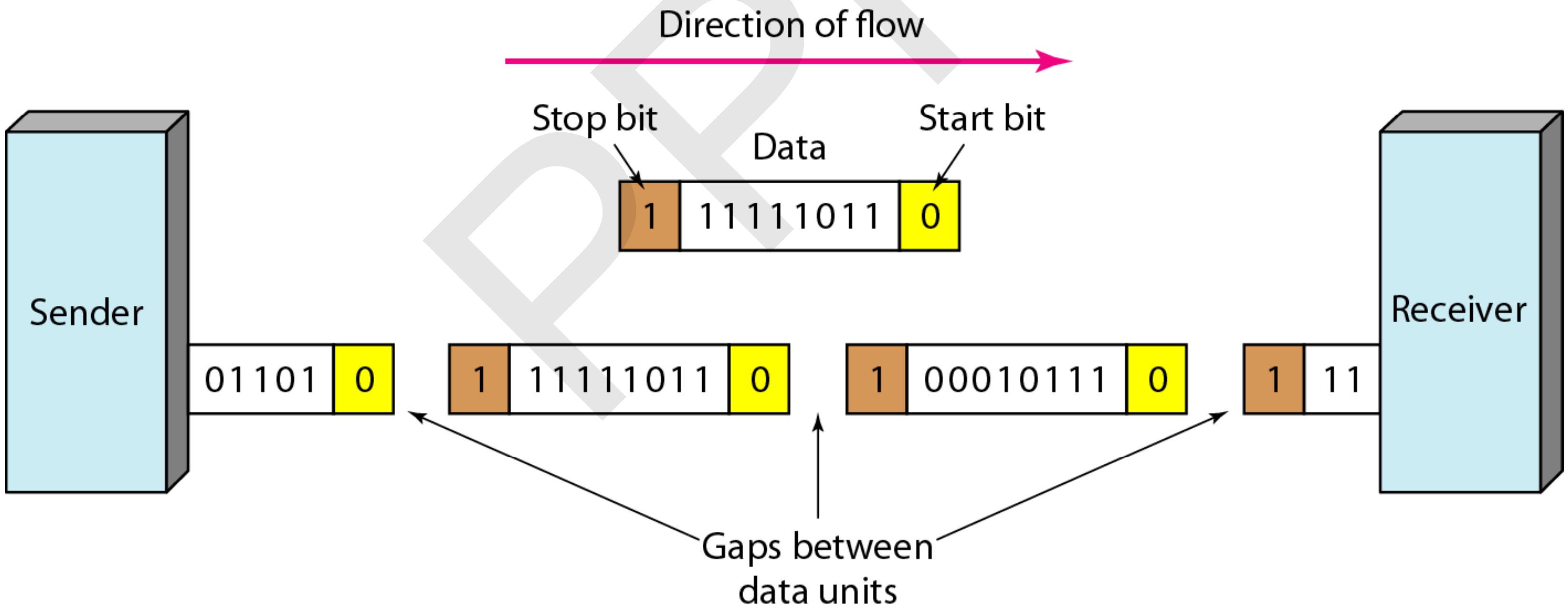


Serial transmission



Asynchronous transmission

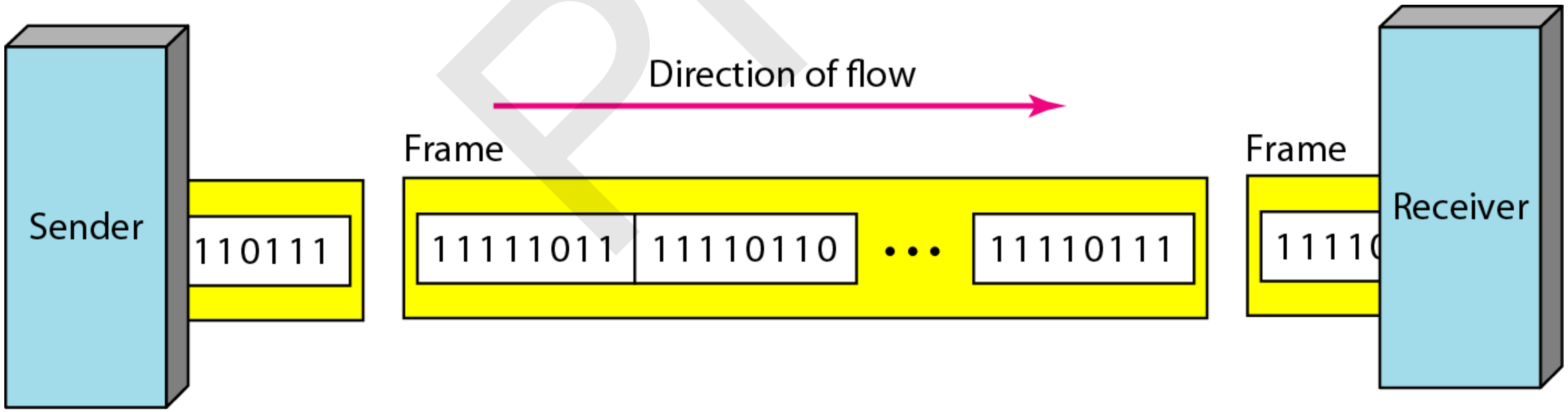
We send 1 start bit (0) at the beginning and 1 or more stop bits (1s) at the end of each byte.
There may be a gap between each byte.



It is "asynchronous at the byte level," bits are still synchronized; their durations are the same.

Synchronous transmission

We send bits one after another without start or stop bits or gaps.
It is the responsibility of the receiver to group the bits.

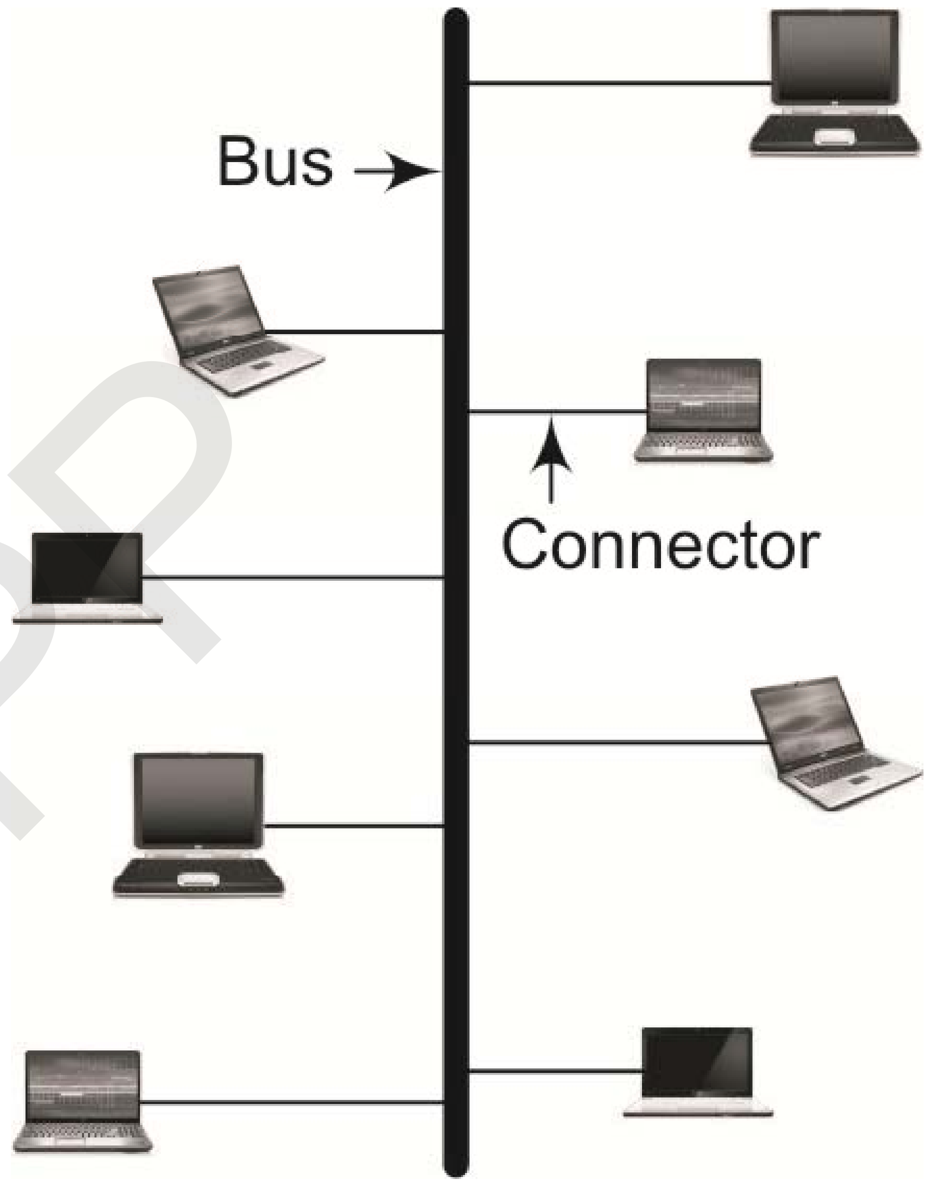


Asynchronous vs. Synchronous Transmission

Asynchronous Transmission	**Synchronous Transmission**
Start and Stop bits reduce efficiency	More efficient use of bandwidth
A character can be transmitted at random times	Characters buffered into blocks for transmission
Variable idle time between characters	No idle time between characters
Constant bit rate within a character. No limit on block length	Constant bit rate over a block. Blocks limited to a maximum size
Low speed communications (19.2 Kbits/s)	Higher speed communication (>=10 Mbits/s)
Synchronisation errors result in loss of only a single character	Synchronisation errors result in loss of a complete block

Ethernet First version

Topology: Bus
Cable: Co-axial
Speed: 2.94Mbps, 10 Mbps
Connector: Vampire Tape/T-connector
Transmission Type: Broadcasting
Transceiver: Carrier Sense
Frame Size: Min. 64 Bytes
Network Length: 2500 meter

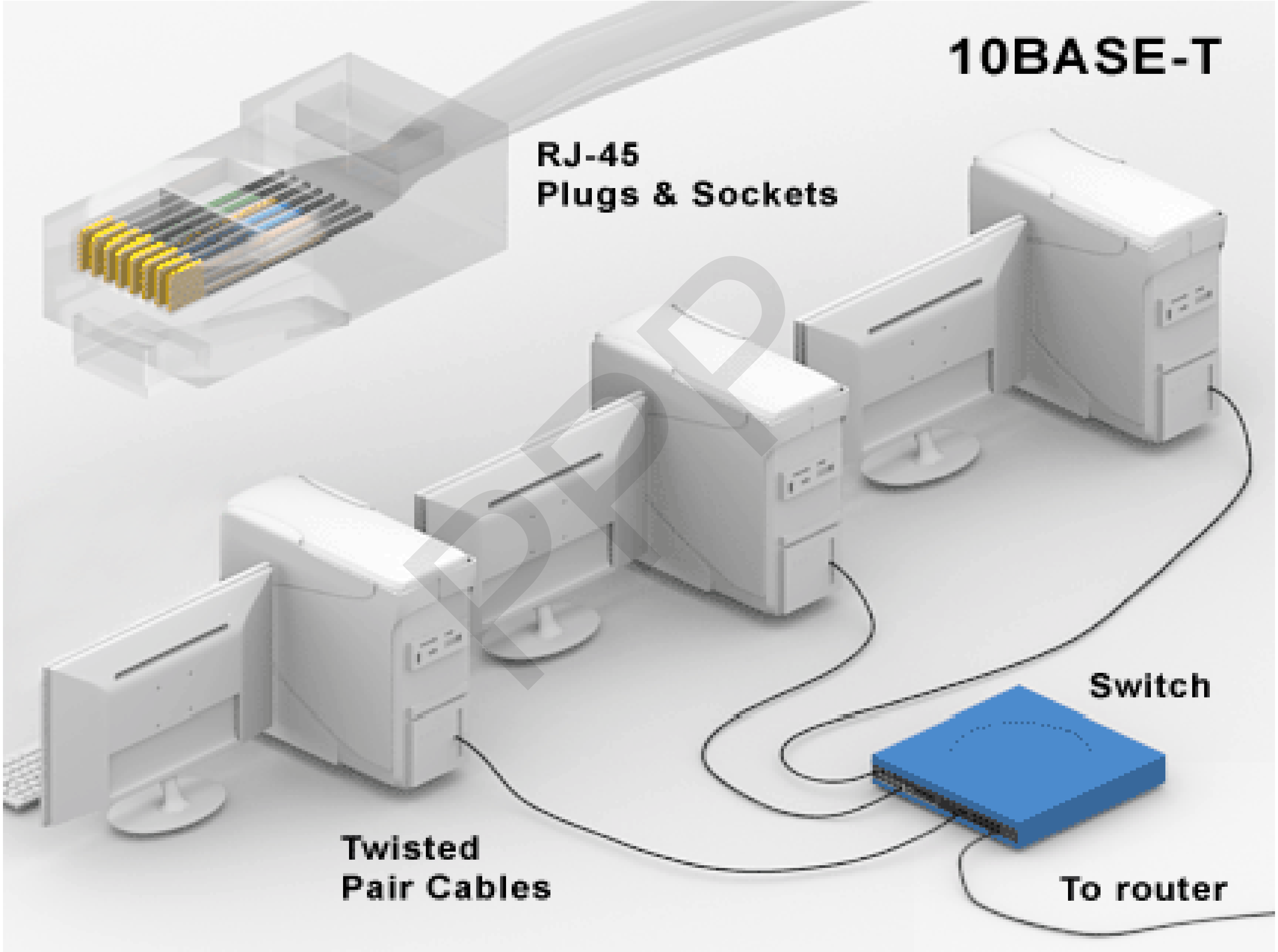


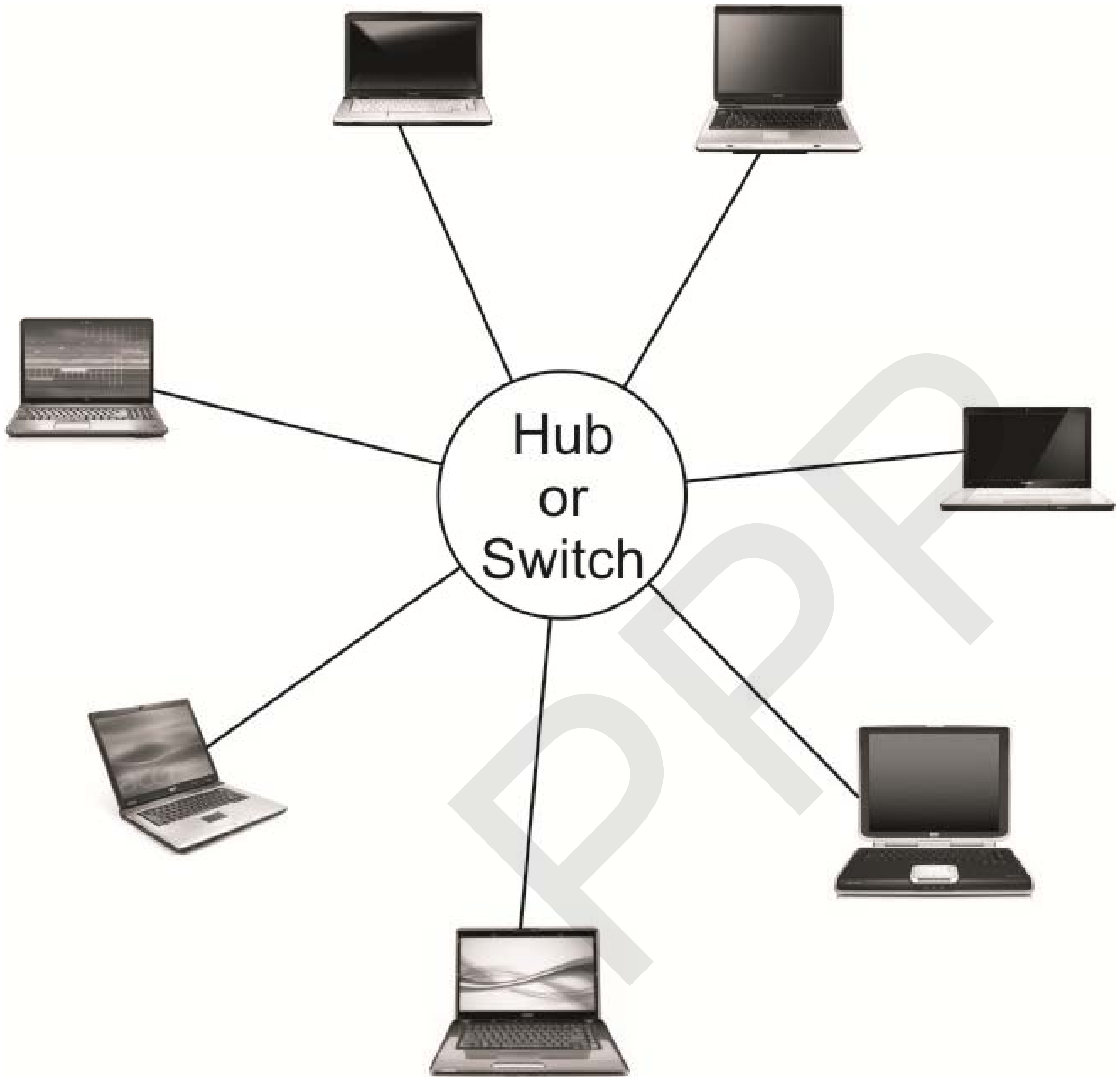
DEC (Digital Equipment Corporation, Compaq , HP) 2.94 Mbps
DIX (Digital , Intel & Xerox) 10 Mbps Classic Ethernet

- Two standards, DIX and 802.3 (IEEE)
- Initially Bus and Hubs were used
- Later switches took over

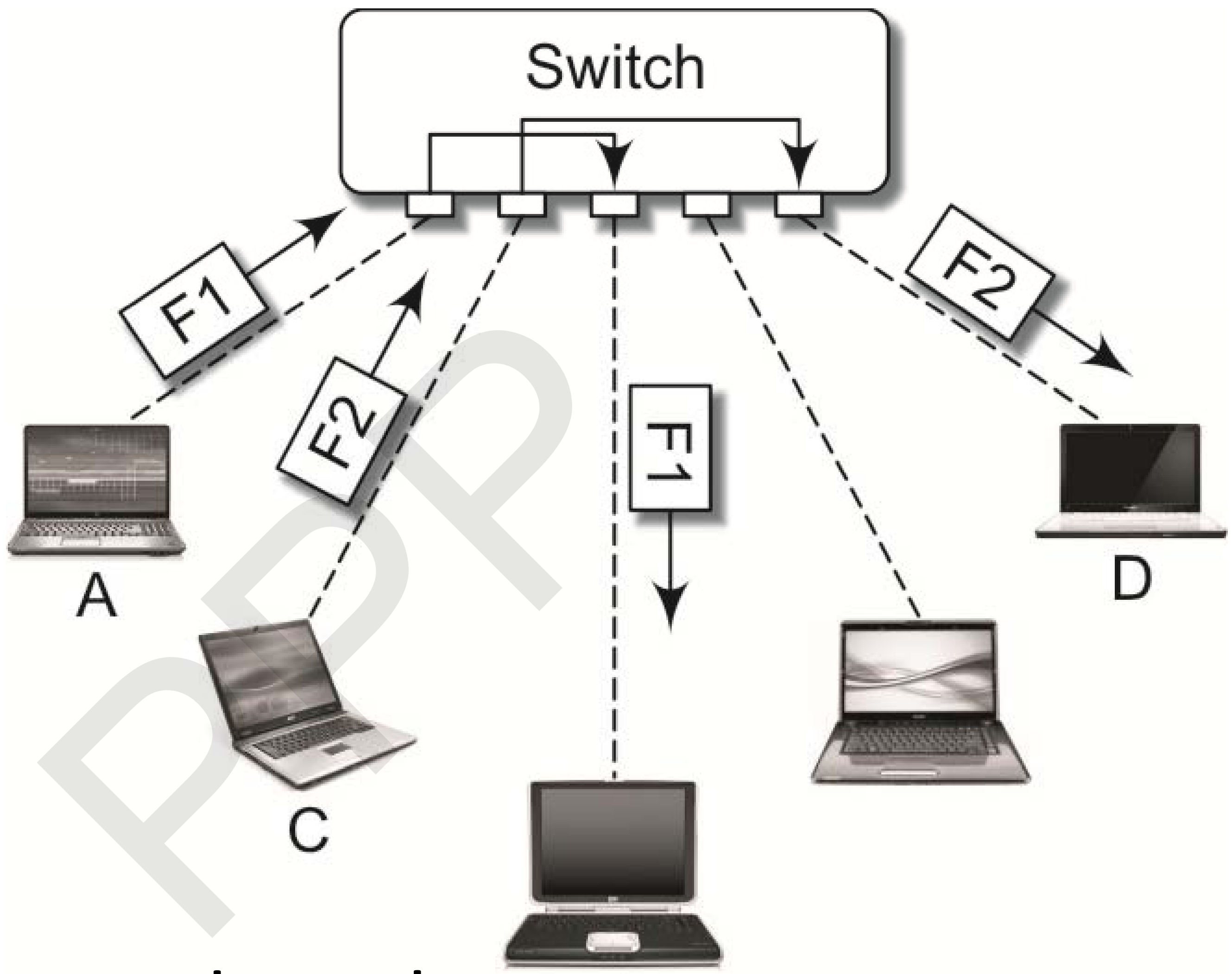
- Problems to use co-axial cable in bus topology
  - A machine cannot be added or removed without affecting others.
  - Reduce the overall capacity for a single user.
  - Maintenance is difficult. (Difficult to detect faulty node)
- Advantages of Cat-3 UTP cables
  - A machine can be added or replaced or removed without affecting others.
  - A node can have 10 Mbps bandwidth because of switch.
  - Maintenance is easy. (Easy to detect a faulty node).

Name	Type	Length (Max)	Advantage
10Base5	Thick coax	500 m	Good interconnection option.
10Base2	Thin coax	200 m	Flexible and easy to maneuver. It can bend easily than the thicker cable.
10BaseT	UTP (cat-3)	100 m	Best for Star topology.
10BaseF	Fiber optics	2 km	Best option for interconnection. Best noise immunity.

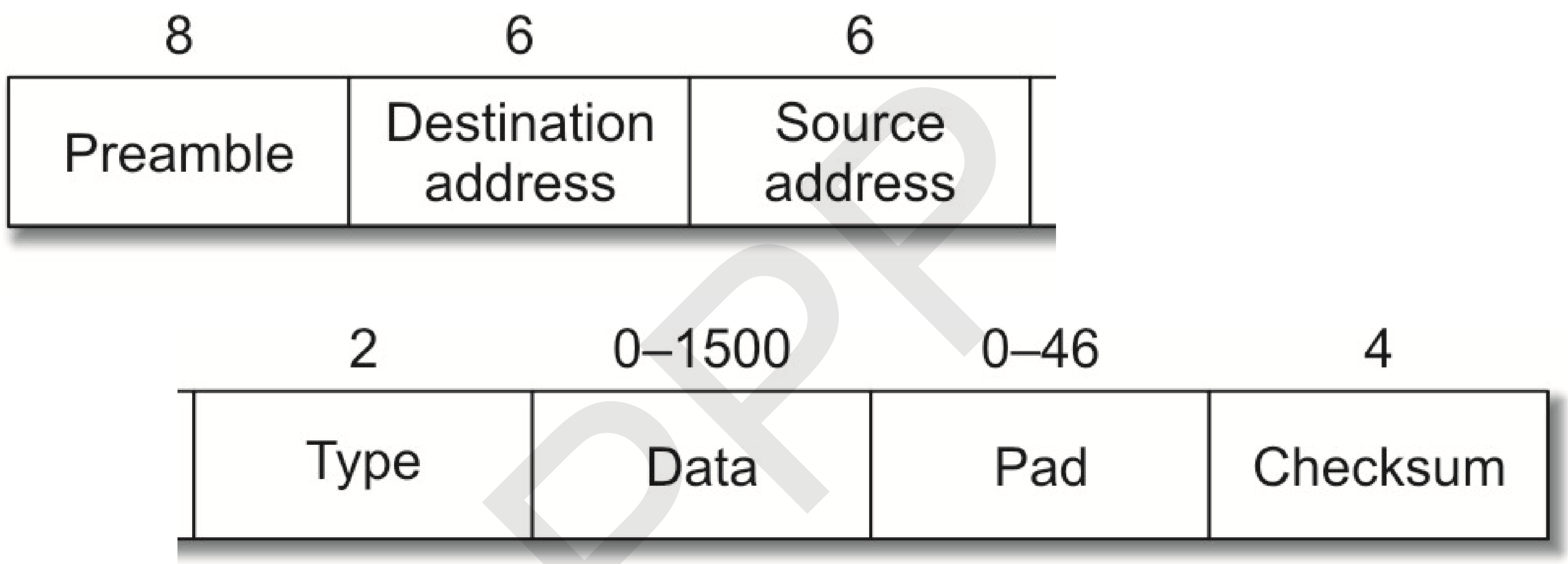

10BASE-T
RJ-45
Plugs & Sockets
Switch
Twisted
Pair Cables
To router

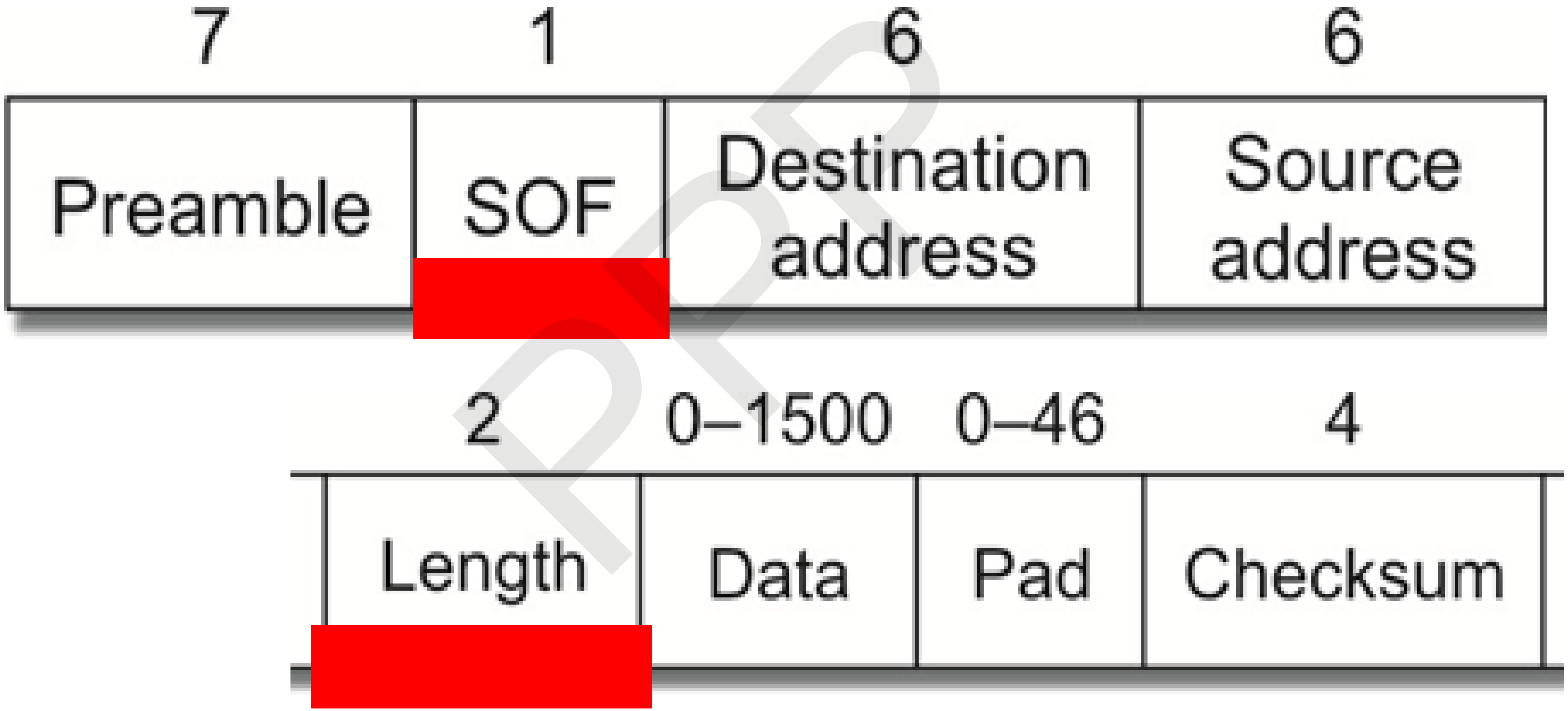


Star Topology



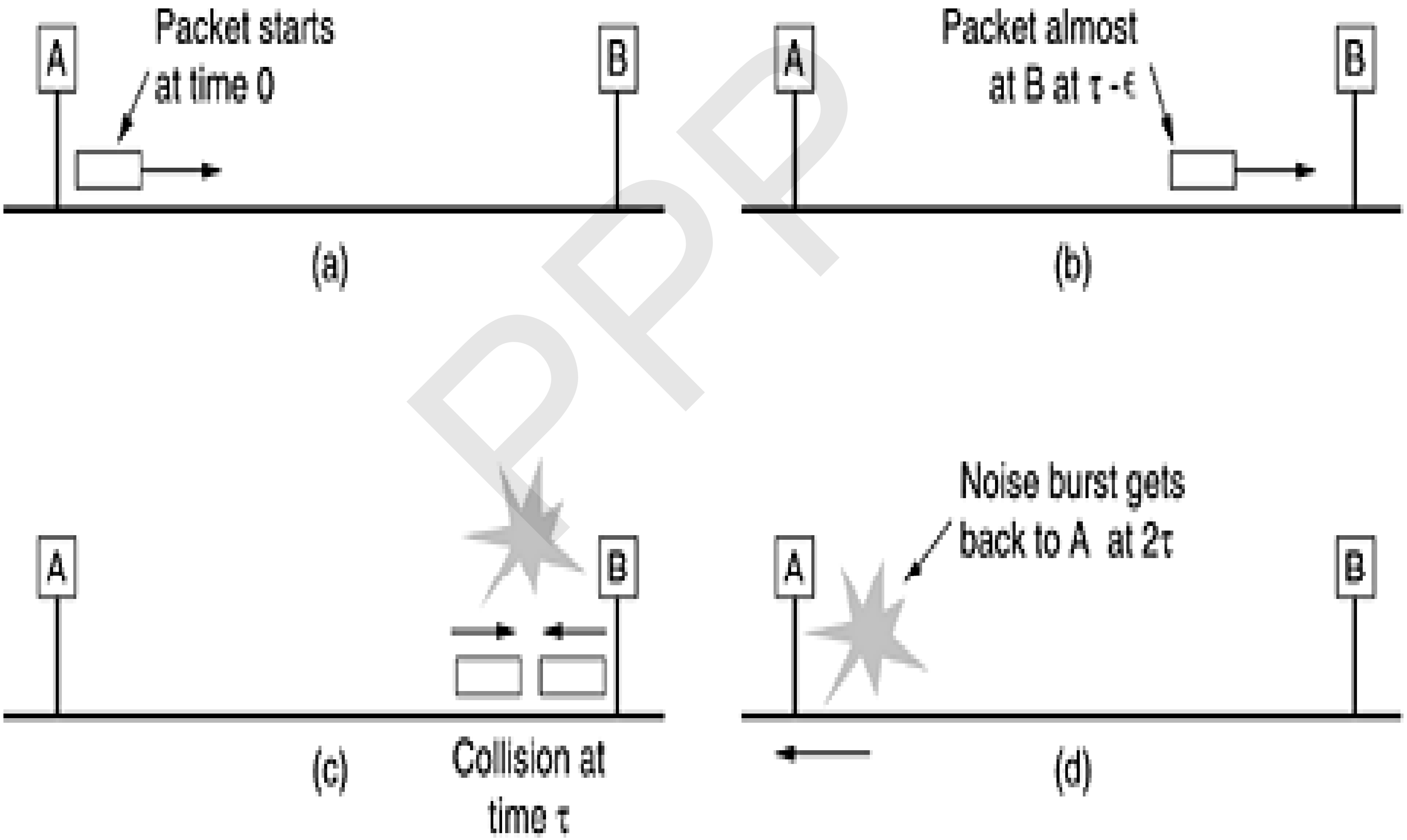
Switch improved the performance by reducing collision domain


8
6
6
Preamble
Destination address
Source address
2
0–1500
0–46
4
Type
Data
Pad
Checksum


7
1
6
6
Preamble
SOF
Destination address
Source address
2
0–1500
0–46
4
Length
Data
Pad
Checksum

7	1	6	6
10101010 repeated seven times	10101010 in DIX and 10101011 in 802.3	A group address begins with 1. An individual address begins with 0 A broadcast address contains all 1s	Source Addres is the sender's unicast addres

2	0-1500	0-46	4
Type in DIX and Length in Ethernet 802.3	Data contains IPv4 or IPv6 or ICMP or IGMP packet in case of Internet	Pad to add bytes when the frame is shorter than 64 bytes	Checksum in CRC


A
B
Packet starts
at time 0
(a)
A
B
Packet almost
at B at $\tau - \epsilon$
(b)
A
B
(c)
Collision at
time τ
A
B
Noise burst gets
back to A at 2τ
(d)

Why is the minimum size of the frame 64 bytes?

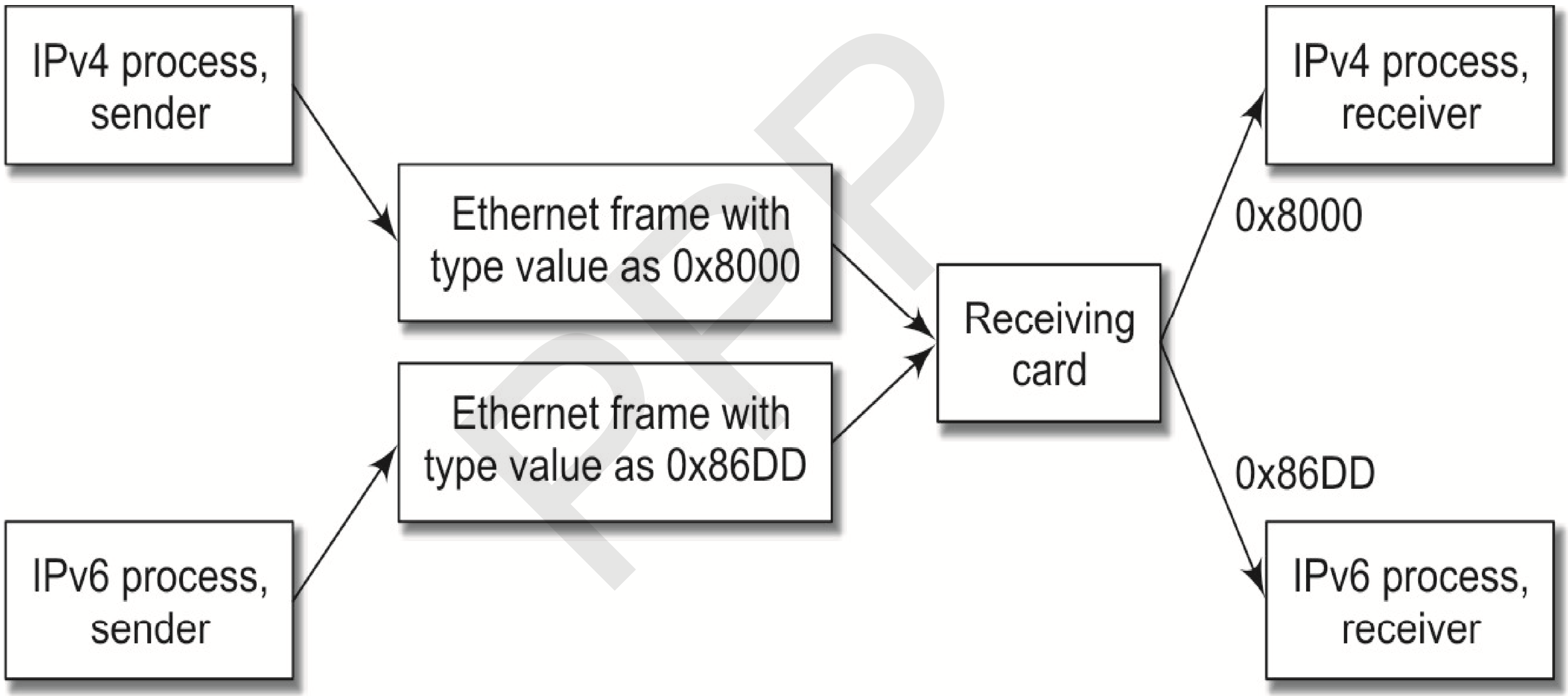
10 Mbps LAN , 2500 m , 4 repeaters

Round-trip Time 2τ = 50 μsec or slot time = 50 μsec

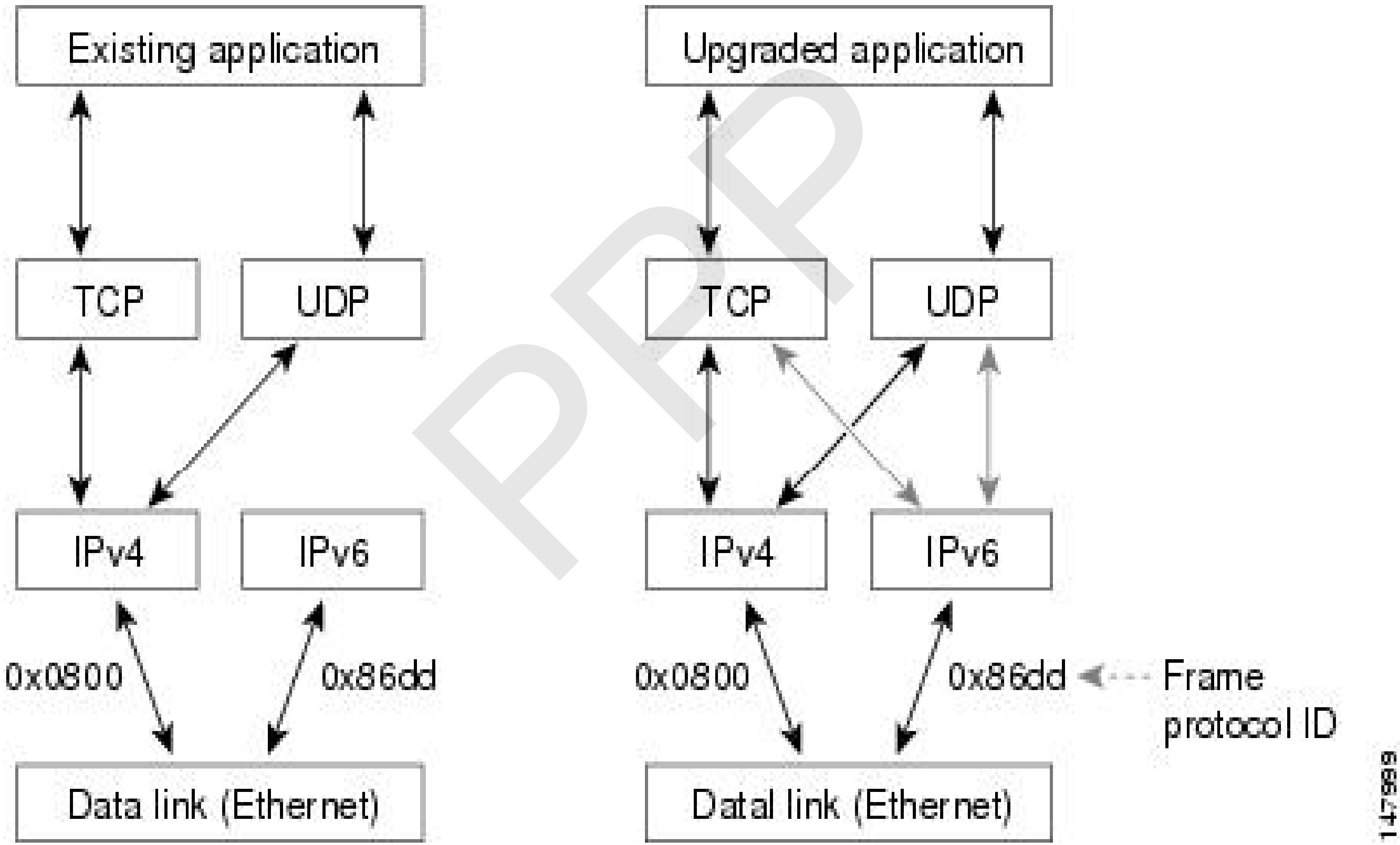
Sec	**No. of bits transferred**
1	$\mathbf{10 * 10^6}$
$\mathbf{50 * 10^{-6}}$	**?**

500 bits = Approx(512 bits) = 64 bytes

Multiplexing at Ethernet



Multiplexing at Network Layer & Transport Layer



CSMA/CD

- Carrier Sense
- Multiple Access
- Collision Detection
- Interframe gap
  - Gap between two frames
  - (time to transmit 96 bits)
  - (96 msec in case of 10Mbps.)

Limitations of CSMA/CD

- Maximum distance limitation 2500m with 4 Repeaters
- Minimum frame size limitation 64 bytes = approx.(500 bits)
- Max. Speed is 10Mbps

500 bits / 10 Mbps = 50 μsec

So To increase speed form 10 to 100 Mbps either the frame size goes up or max. cable length goes down.

If we kept min. size of frame constant and decrease the round-trip time by 10 (**5 μsec),** the distance becomes 250 m. **500 bits / 100 Mbps = 5 μsec**

Same way for **0.5 μsec** Collision domain must decrease 10 times , from 250 m to 25 m, we can achieve 1 Gbps. **500 bits / 1000 Mbps = 0.5 μsec**

So to transmit a frame at 1Gbps , the maximum distance = 25 m.

The 802.3z committee consider a radius of 25 m to be unacceptable and added two features to increase the radius.

Speed : 1Gbps , distance = 25 m & Frame Size = 64 bytes

Distance 25 m is not acceptable so alternate solution as follow.

<u>Carrier Extension</u>

Tells the h/w to add its own padding after the normal frame to extend the **frame to 512 bytes** & **distance to 250 m** to achieve 1 Gbps speed.

<u>Problem :</u> If user data is only 46 bytes then also transmit 512 byte

So line utilization = 9 %

This padding is added by the sending h/w and removed by the receiving h/w, the s/w is unaware of it.

<u>Frame Bursting</u>

Allows a sender to transmit a concatenated sequence of multiple frames in a single transmission.

This features extend the **radius of the network to 200 m** , which is enough for most offices.

MAC (Medium Access Control) Sublayer

It is sub layer of data link layer.

Channel Allocation Problem

How to allocate a single broad cast channel among competing users.

ALOHA

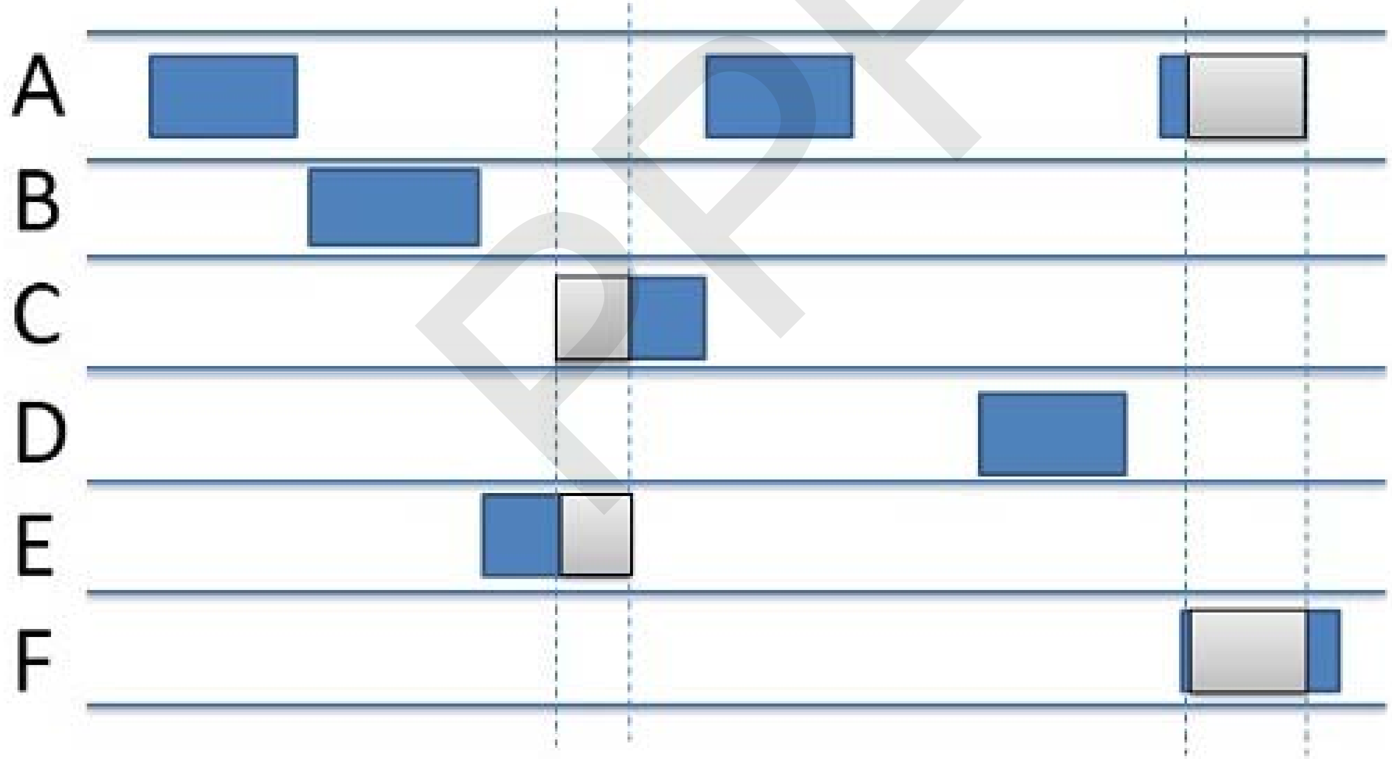
- Uncoordinated users are competing for the use of a single shared channel.

•**Slot time** is at least twice the **time** for an electronic signal to travel the maximum distance between two nodes.

•Two Version of Aloha
  - •Pure Aloha
  - •Slotted Aloha

Pure Aloha

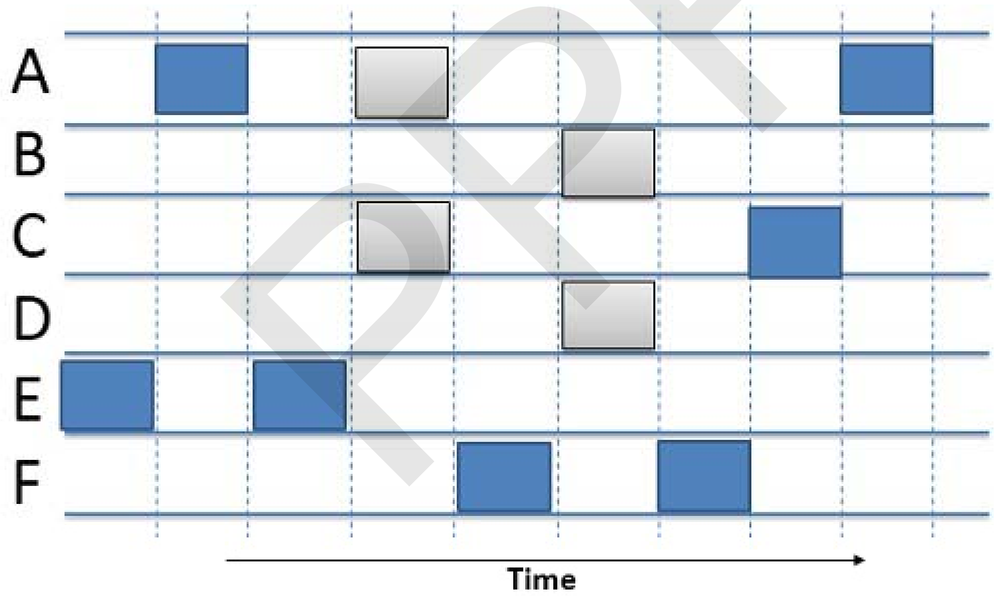
- User transmit frame whenever they have data to be sent
- More probability of collision.



Pure ALOHA

Slotted Aloha

- User transmit only at the starting of time slot.
- Less probability of collision.

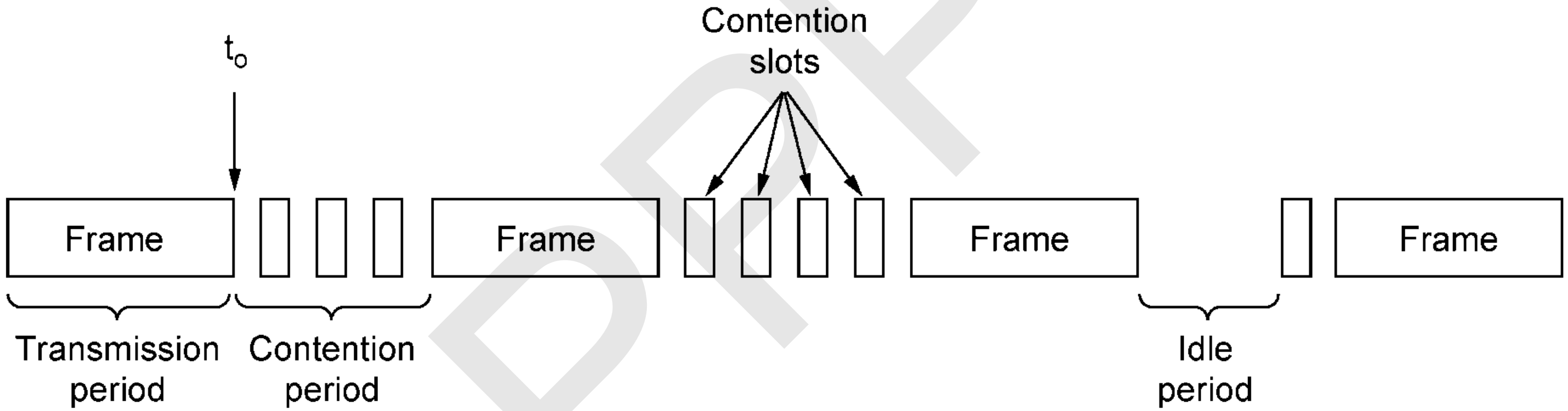


Slotted ALOHA

CSMA Protocol

- Versions of CSMA protocol
  - 1 – Persistent CSMA
  - Non-persistent CSMA
  - P-persistent CSMA

CSMA/CD Conceptual Model



CSMA/CD can be in contention, transmission, or idle state.

Binary Exponential Back-off

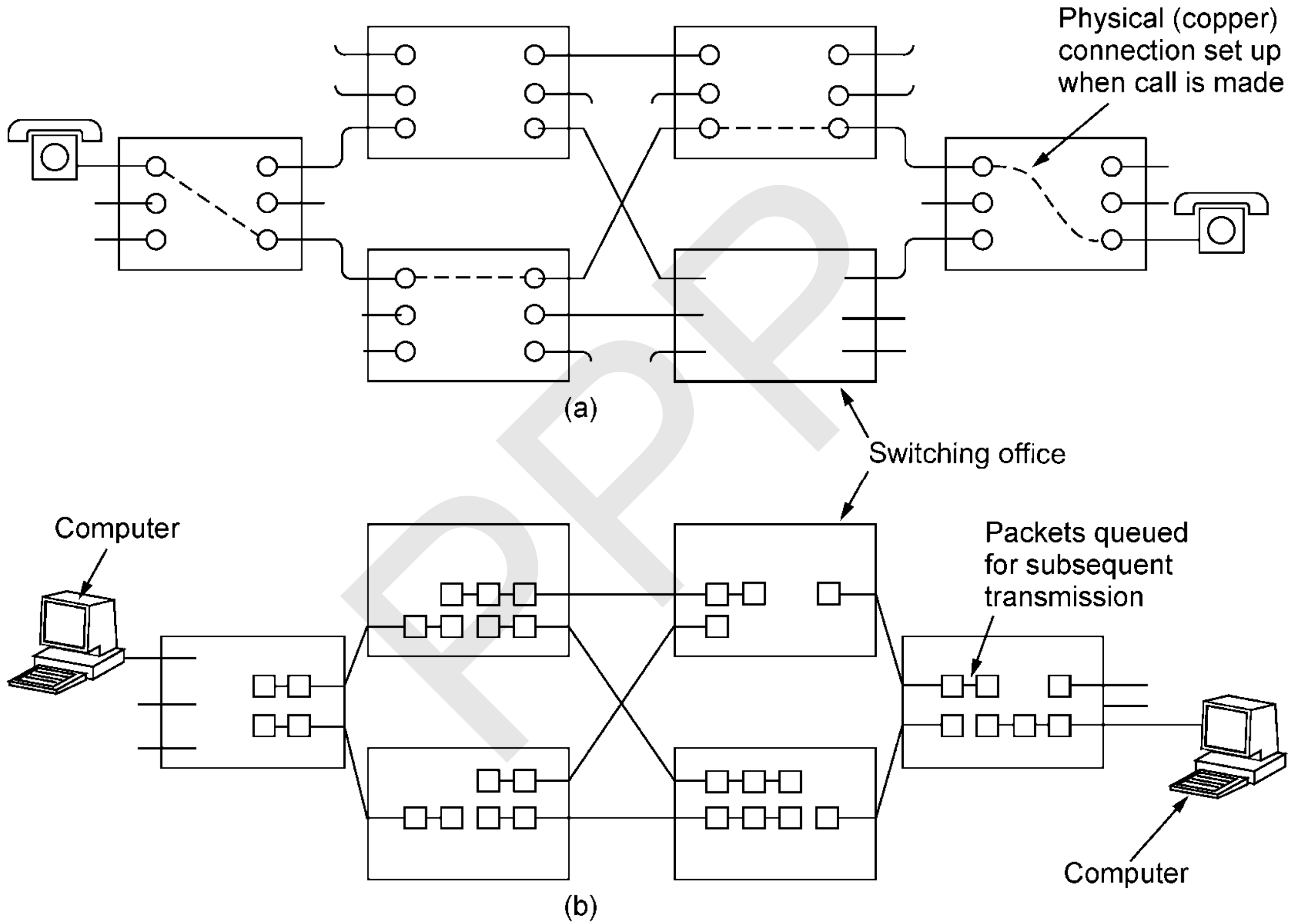
- Sender sends immediately with idle channel
- Continues to listen while transmitting
- In case of a collision, the sender waits for a random period (maximum of two time slots)
- In case they collide again, the interval is just doubled every time it experiences a collision,
- When doubling is repeated to the slot size to 0–1023 it will not increase further.

Que. The number of time slots to be skipped before retrying in binary exponential backoff algorithm, after 8th collision is randomly chosen between o and _______________.

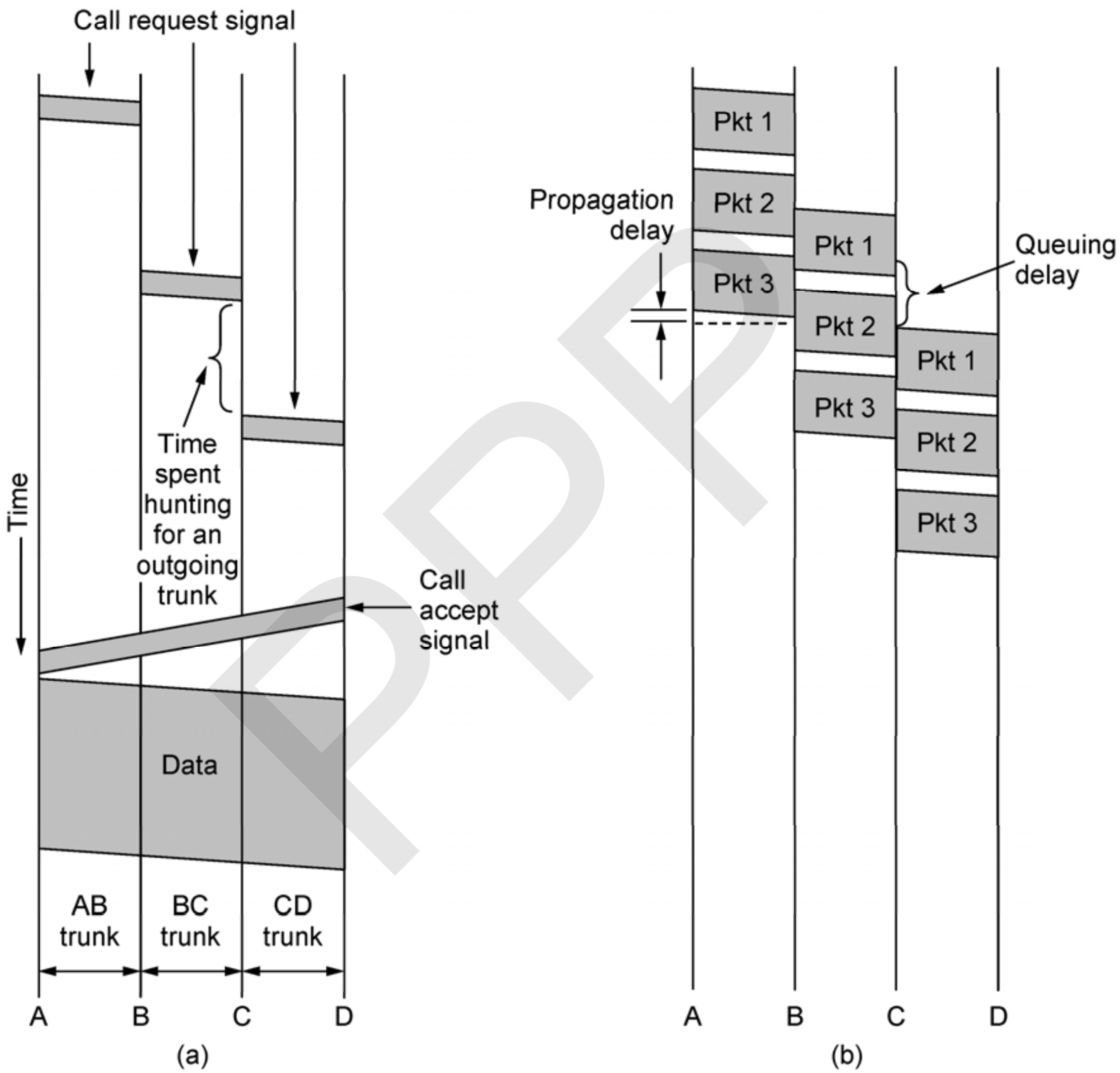
Ans. 255

Que. If there are 15 nodes in a mesh network, how many links are required?

Ans. 105 (Hint : N nodes than links = [(N * (N – 1)) / 2]



(a)Circuit switching. (b)Packet switching.

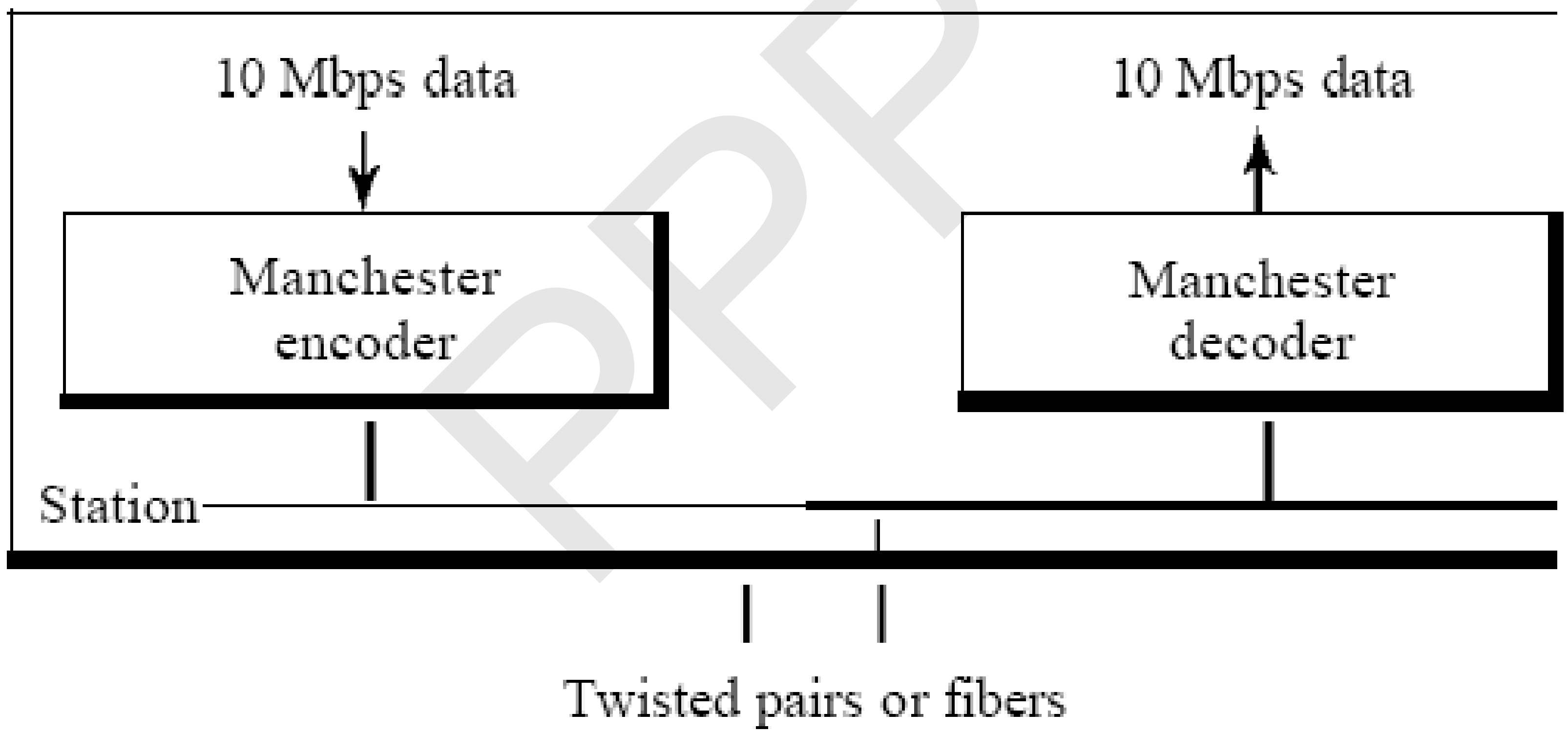


Timing of events in (a)circuit switching, (b)packet switching.

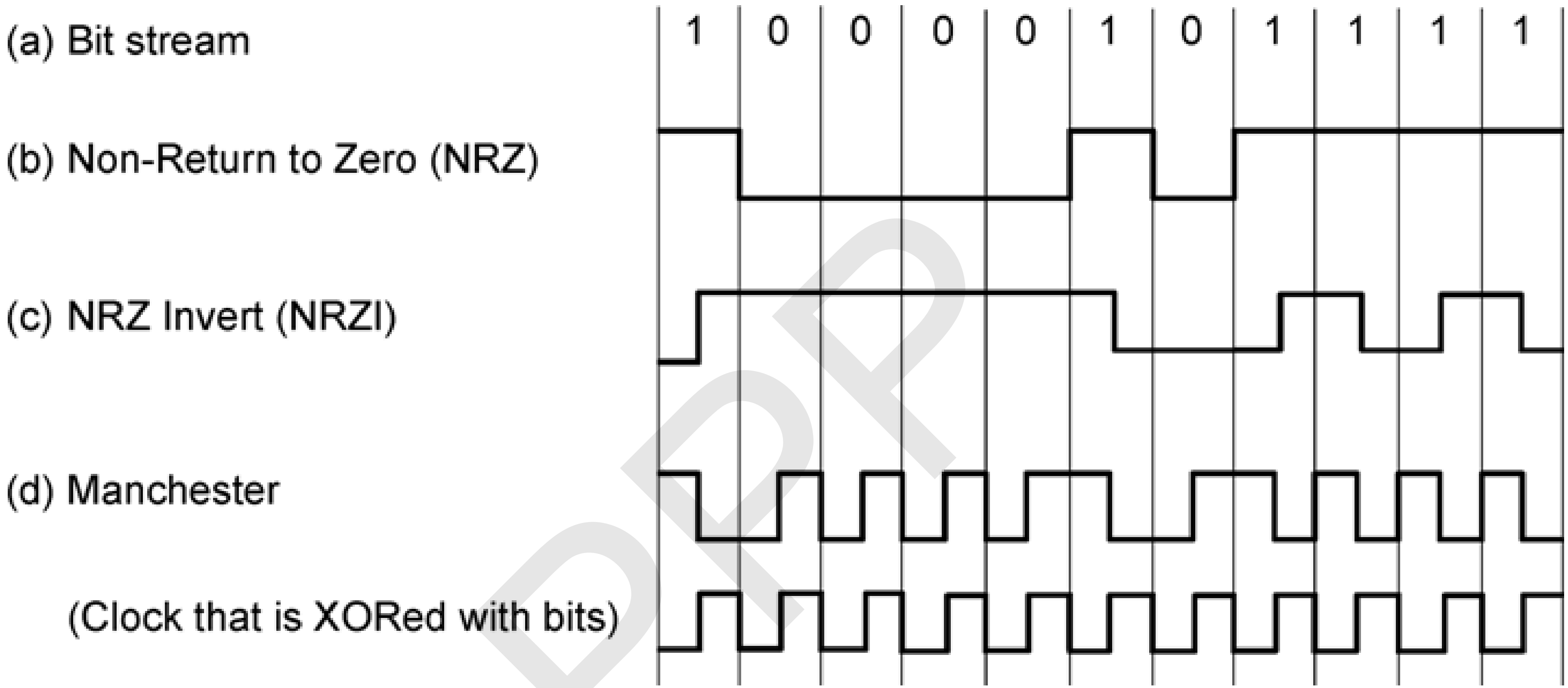
A comparison of circuit-switched and packet-switched networks.

Item	Circuit switched	Packet switched
Call setup	Required	Not needed
Dedicated physical path	Yes	No
Each packet follows the same route	Yes	No
Packets arrive in order	Yes	No
Is a switch crash fatal	Yes	No
Bandwidth available	Fixed	Dynamic
Time of possible congestion	At setup time	On every packet
Potentially wasted bandwidth	Yes	No
Store-and-forward transmission	No	Yes
Charging	Per minute	Per packet

Encoding in a Standard Ethernet implementation



Manchester Encoding



In **Manchester encoding**, the duration of the bit is divided into two halves. The voltage remains at one level during the first half and moves to the other level in the second half. The transition at the middle of the bit provides synchronization.

A digital-to-digital polar encoding method in which a transition occurs at the middle of each bit interval to provide synchronization.

Bandwidth utilization is the wise use of available bandwidth to achieve specific goals.

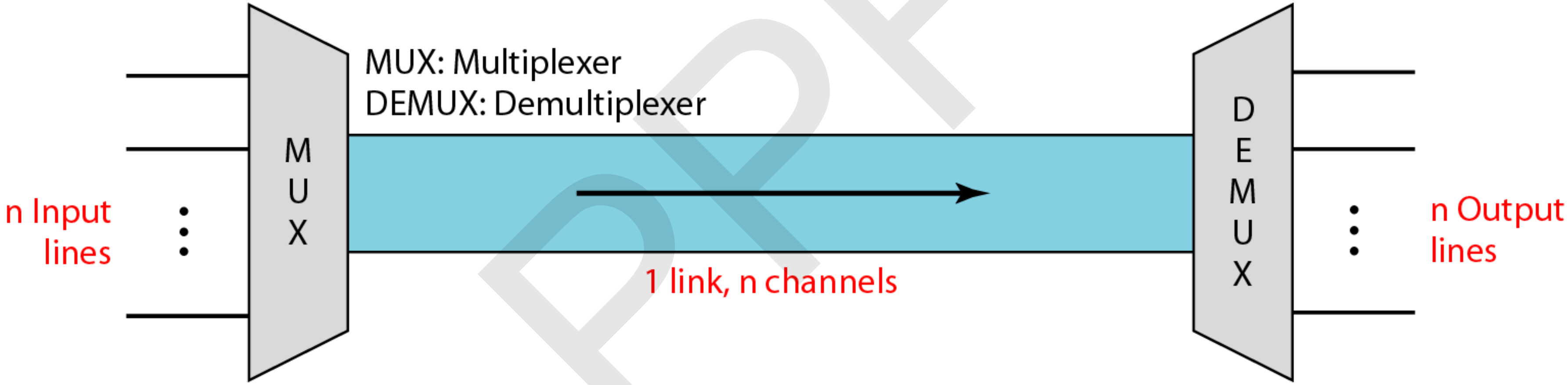
Efficiency can be achieved by multiplexing; i.e., sharing of the bandwidth between multiple users.

Multiplexing

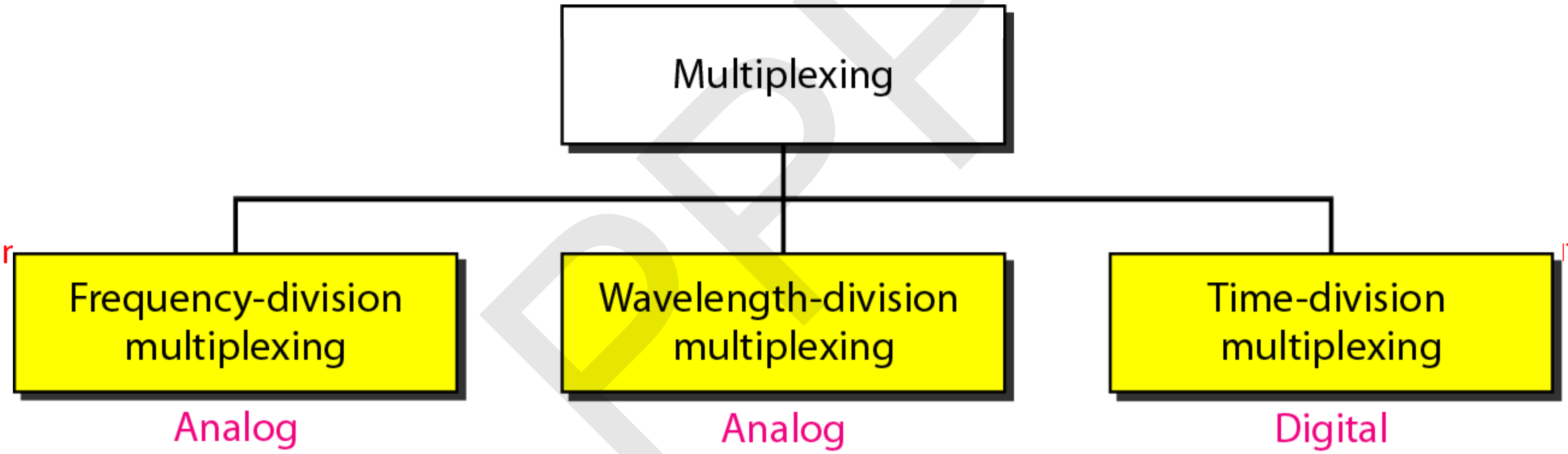
Whenever the bandwidth of a medium linking two devices is greater than the bandwidth needs of the devices, the link can be shared. Multiplexing is the set of techniques that allows the (simultaneous) transmission of multiple signals across a single data link. As data and telecommunications use increases, so does traffic.

- Frequency-Division Multiplexing
- Wavelength-Division Multiplexing
- Time-Division Multiplexing

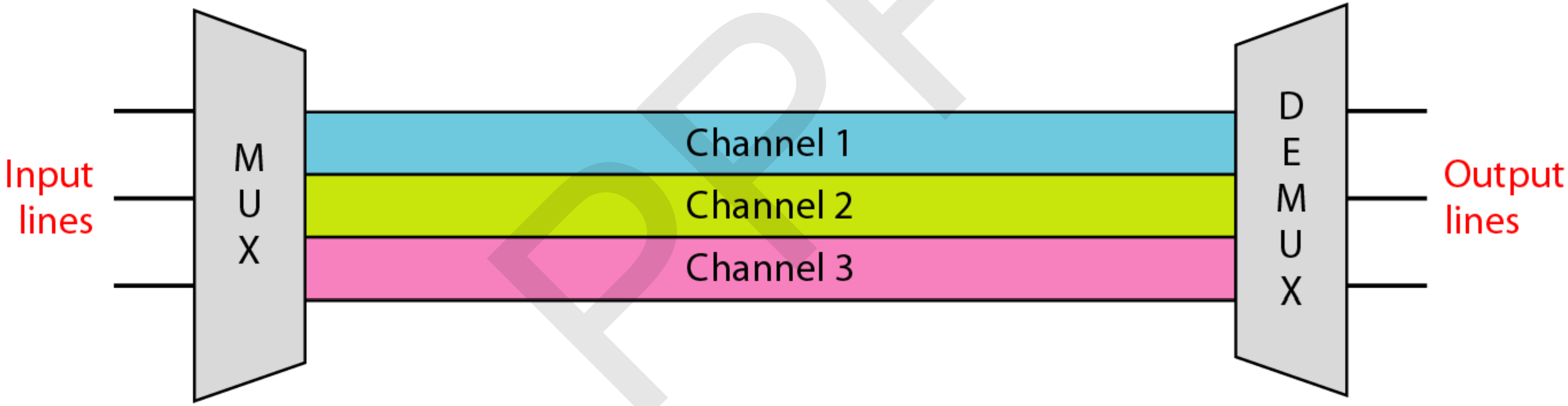
Dividing a link into channels



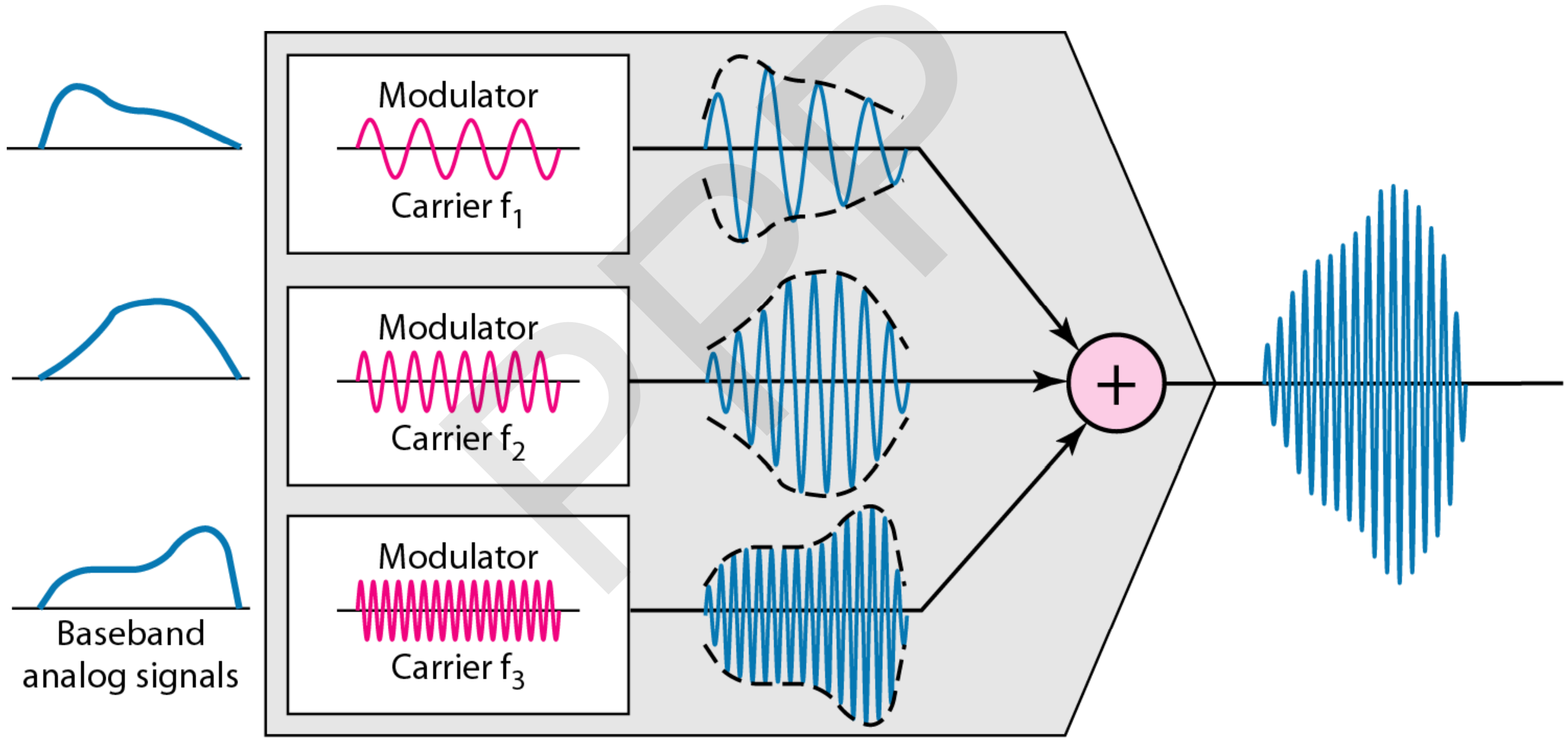
Categories of multiplexing



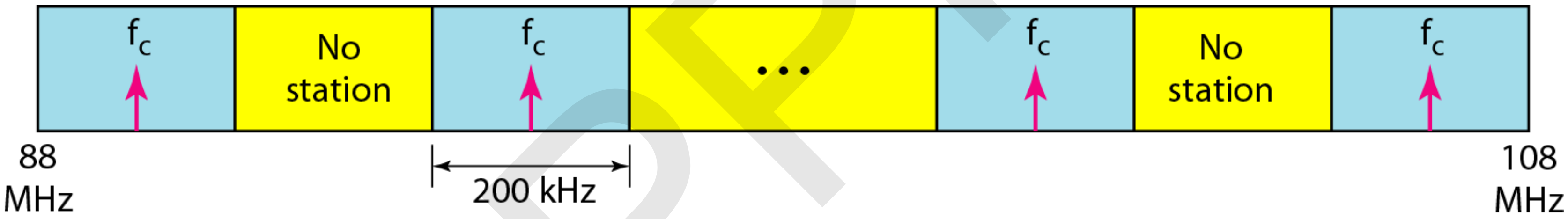
Frequency-division multiplexing (FDM)



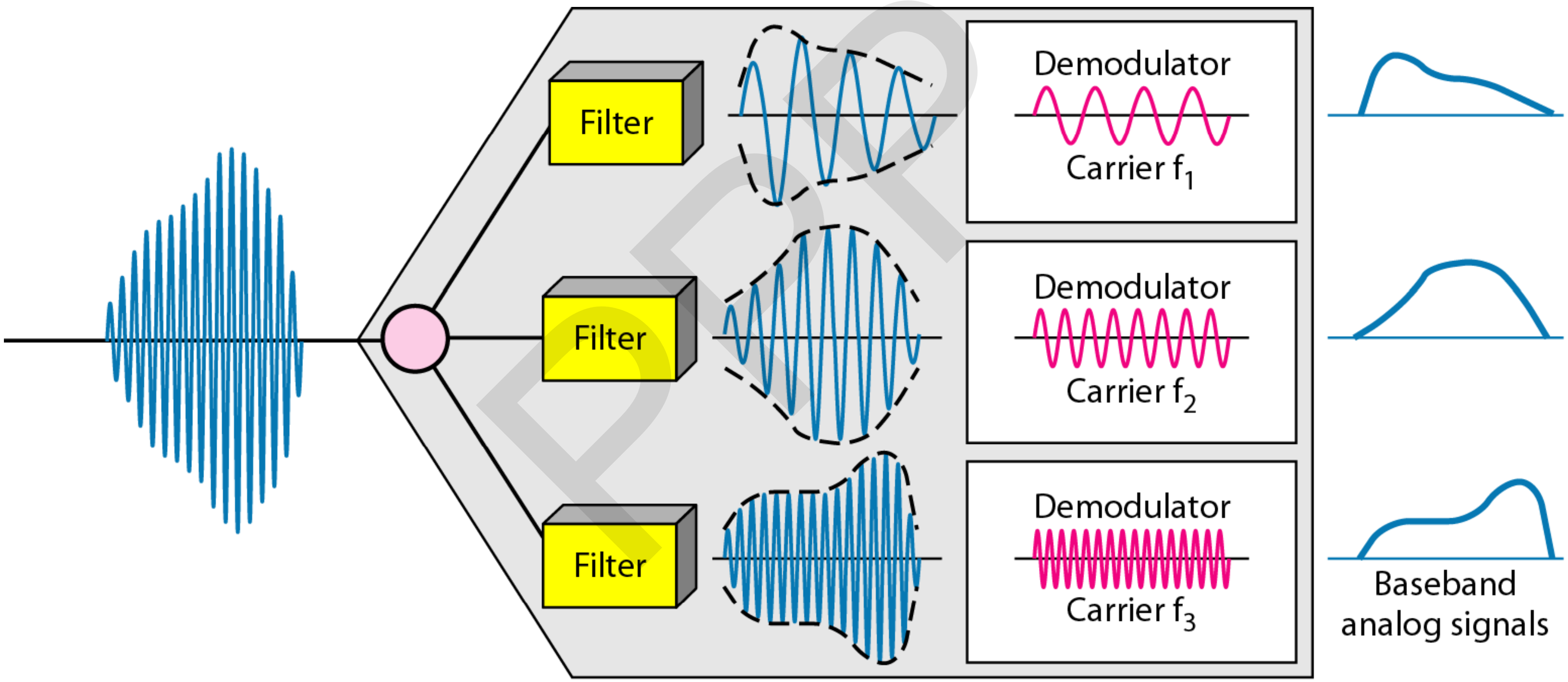
FDM process


Modulator
Carrier f_1
Modulator
Carrier f_2
Modulator
Carrier f_3
Baseband analog signals
+

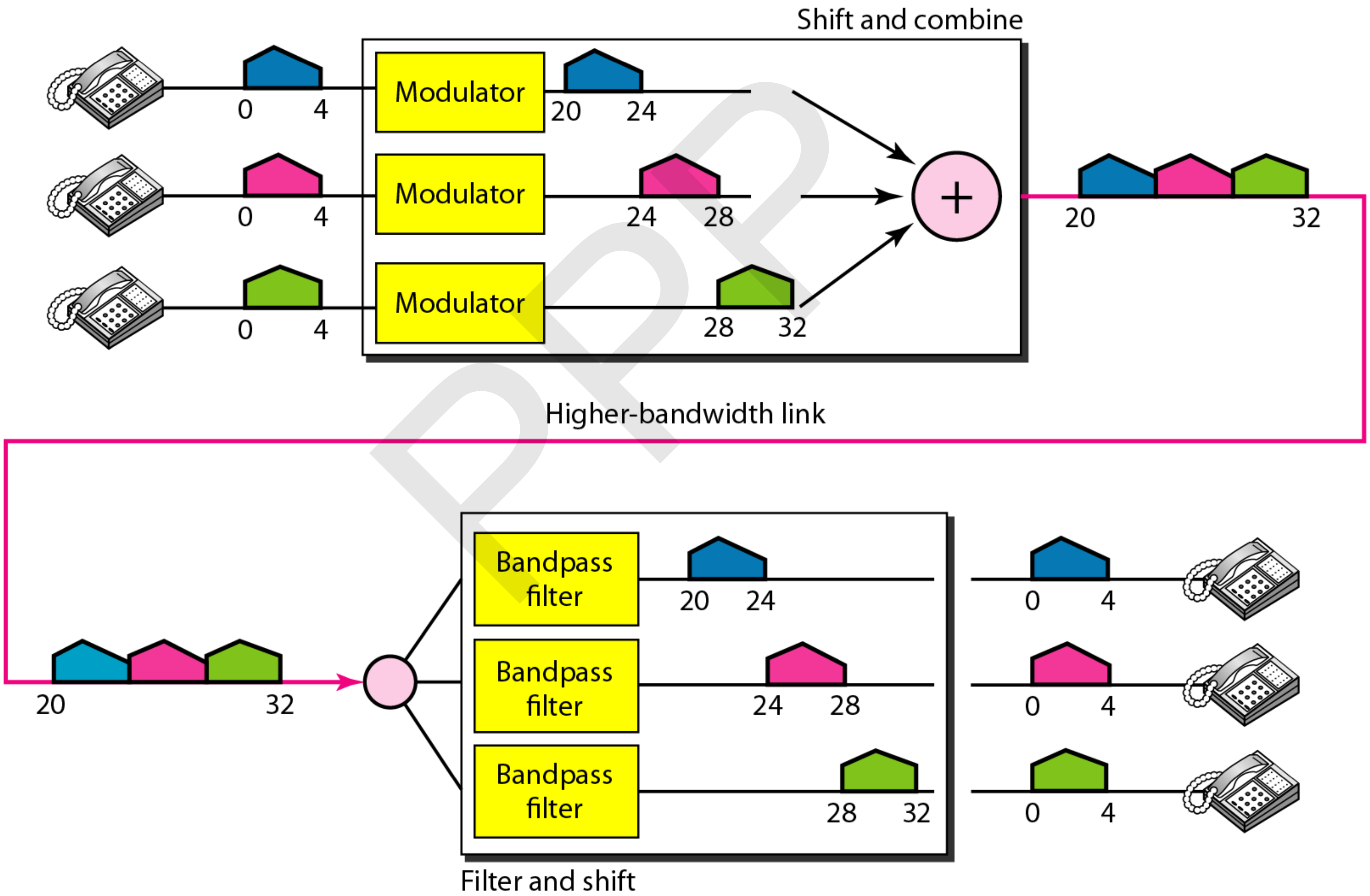
FM



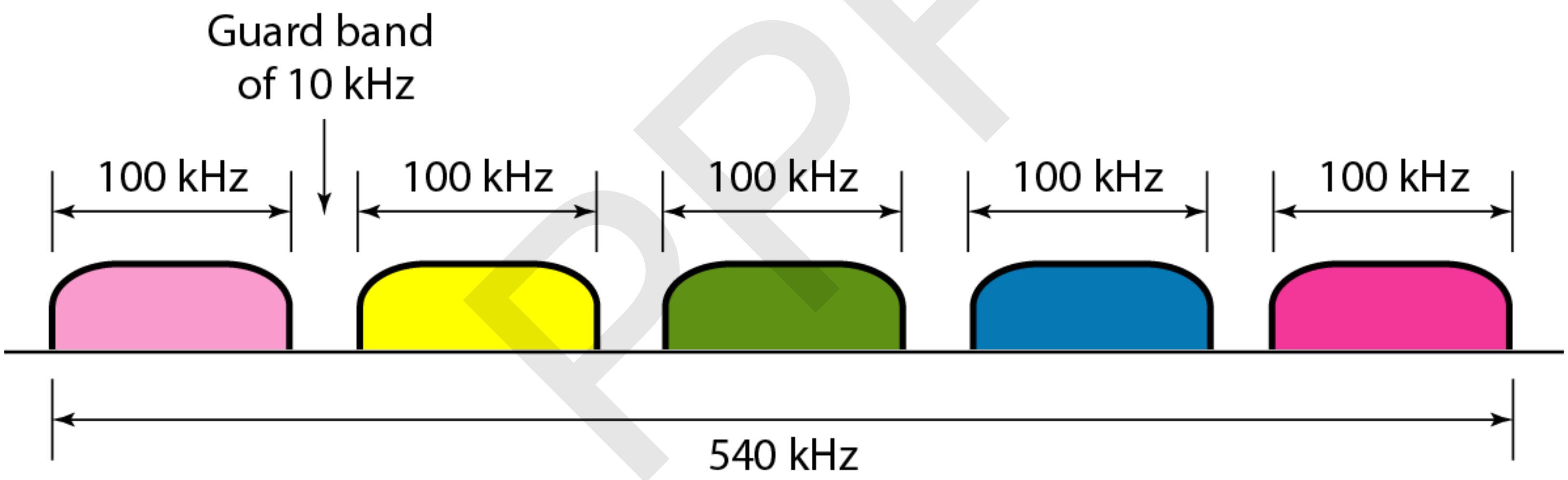
FDM demultiplexing example



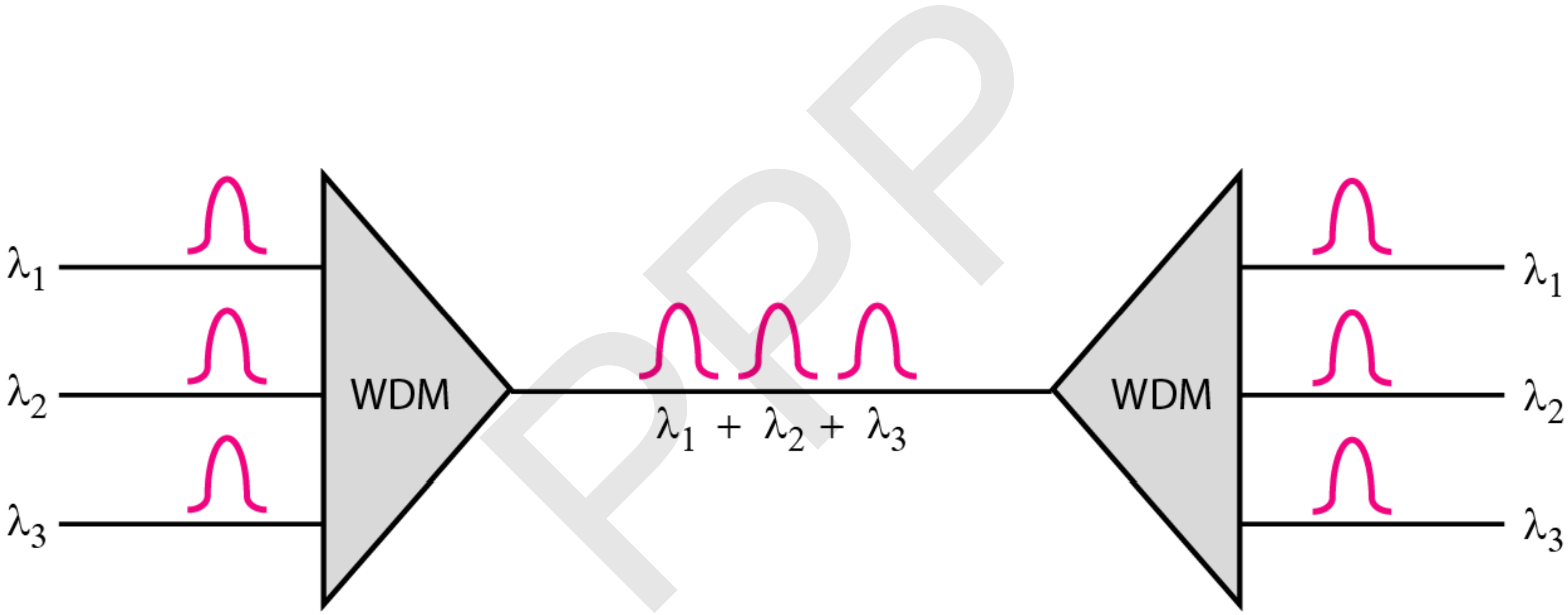
Assume that a voice channel occupies a bandwidth of 4 kHz. We need to combine three voice channels into a link with a bandwidth of 12 kHz, from 20 to 32 kHz. Show the configuration, using the frequency domain. Assume there are no guard bands.



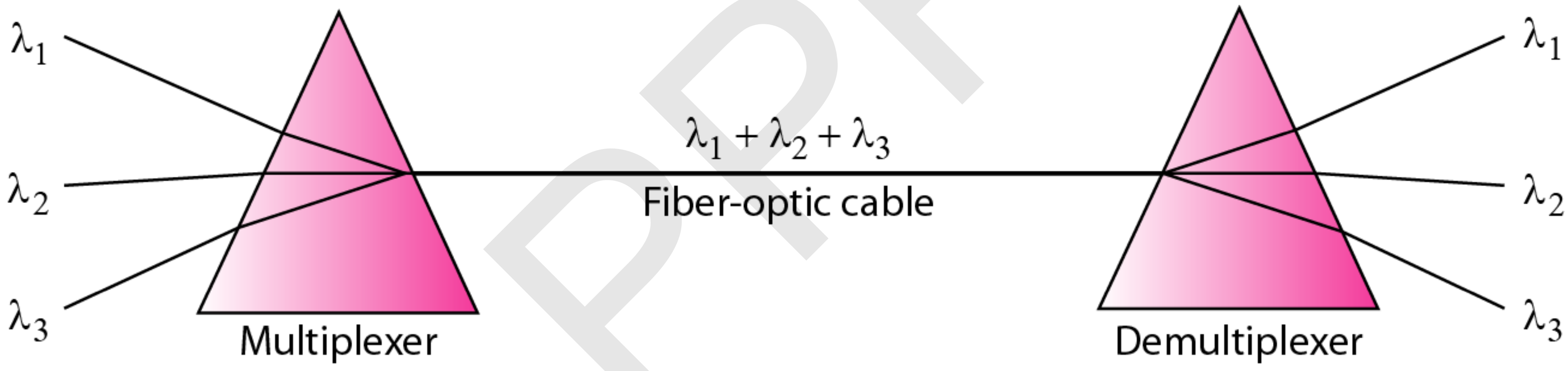
Five channels, each with a 100-kHz bandwidth, are to be multiplexed together. What is the minimum bandwidth of the link if there is a need for a guard band of 10 kHz between the channels to prevent interference?



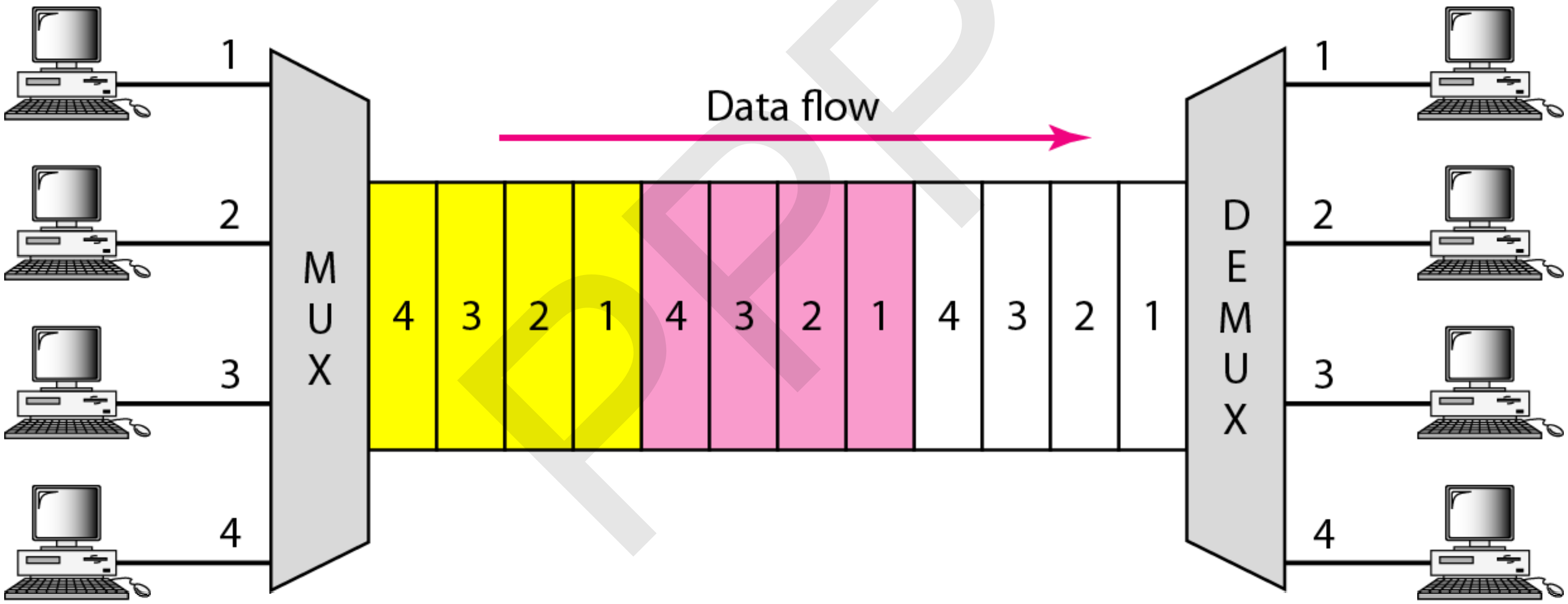
Wavelength-division multiplexing (WDM)



Prisms in wavelength-division multiplexing and demultiplexing



Time Division Multiplexing (*TDM*)



IPv4

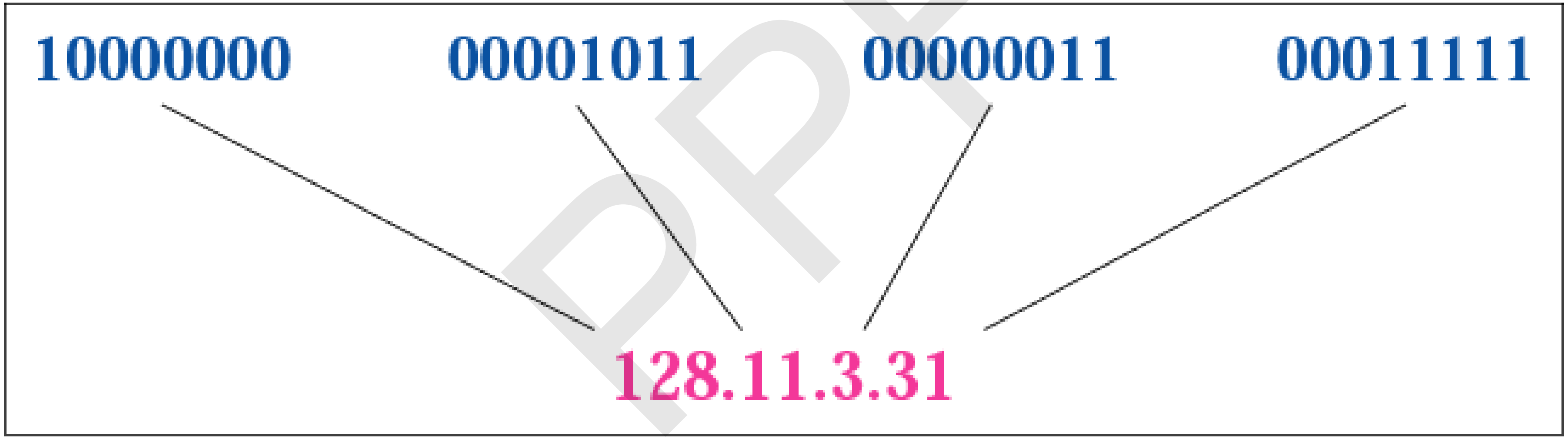
The address space of IPv4 is

2^{32}

or

4,294,967,296.

IPv4 Dotted-decimal notation



IPv4 Hexa-decimal notation

0111 0101 1001 0101 0001 1101 1110 1010

75 95 1D EA

0x75951DEA

Example 1

Change the following IP address from binary notation to dotted-decimal notation.

10000001 00001011 00001011 11101111

Solution

129.11.11.239

Example 2

Change the following IP address from dotted-decimal notation to binary notation.

111.56.45.78

Solution

01101111 00111000 00101101 01001110

Example 3 (continued)

Find the error, if any, in the following IP address:

75.45.301.14

Solution

In dotted-decimal notation, each number is less than or equal to 255; 301 is outside this range.

Example 4

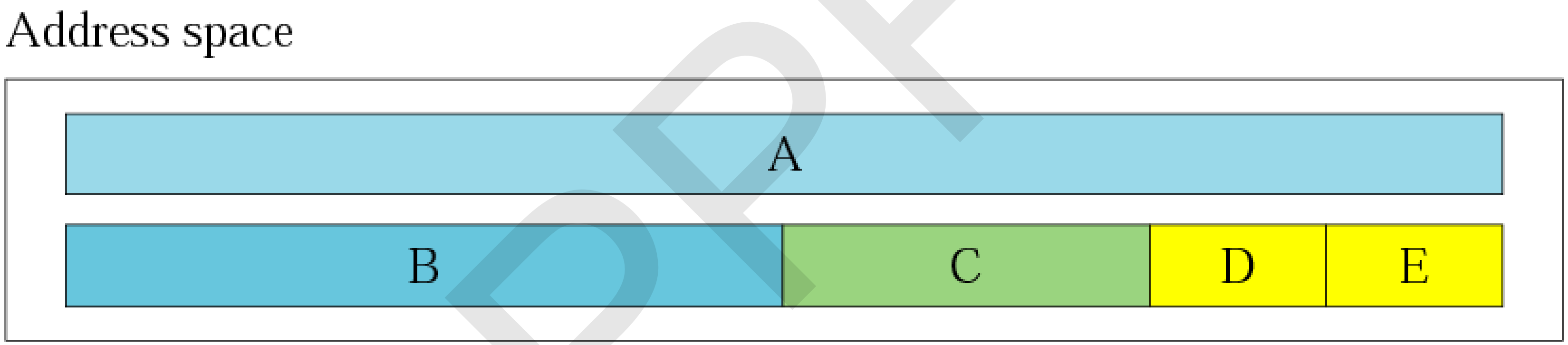
Change the following IP addresses from binary notation to hexadecimal notation.

10000001 00001011 00001011 11101111

Solution

$810B0BEF_{16}$

Occupation of the address space

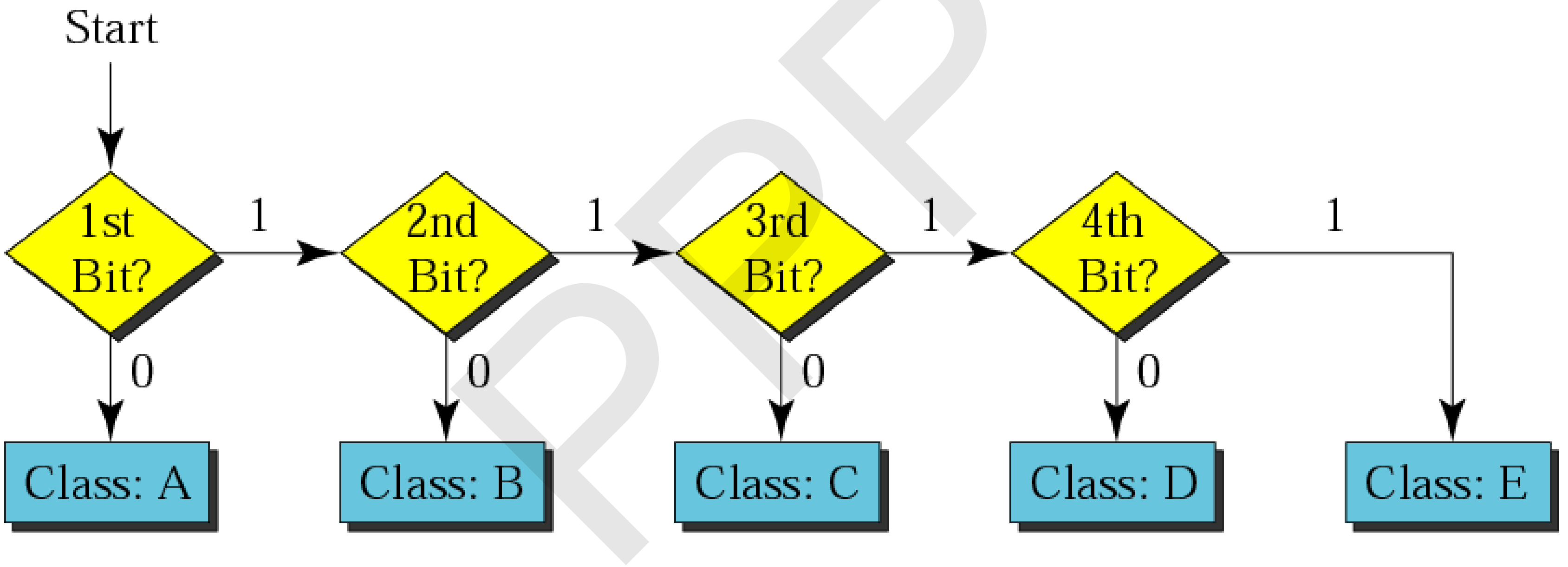


Finding the class in Binary and Decimal Notation

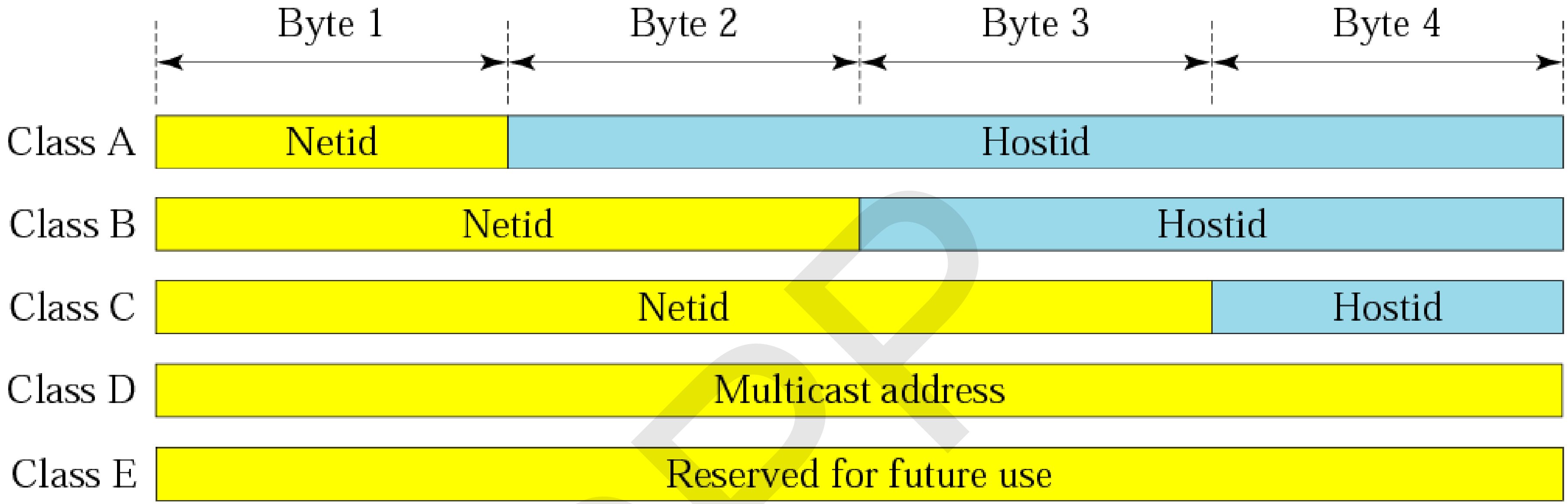
	First byte	Second byte	Third byte	Fourth byte
Class A	**0**			
Class B	**10**			
Class C	**110**			
Class D	**1110**			
Class E	**1111**			

	First byte	Second byte	Third byte	Fourth byte
Class A	**0 to 127**			
Class B	**128 to 191**			
Class C	**192 to 223**			
Class D	**224 to 239**			
Class E	**240 to 255**			

Finding the address class in Binary Notation



Netid and hostid



Class	No. Of Addresses	Percentage (%)	No. of N/ws	No. of Hosts Per Network
A	2^{31}	50	**128**	2^{24} = **1,67,77,216**
B	2^{30}	25	64 * 256 = **16,384**	2^{16} = **65,536**
C	2^{29}	12.5	32*256*256 = **20,97,152**	2^{8} = **256**
D	2^{28}	6.5	-----	-----
E	2^{28}	6.5	-----	-----

Example 5

How can we prove that we have 2,147,483,648 addresses in class A?

Solution

In class A, only 1 bit defines the class. The remaining 31 bits are available for the address. With 31 bits, we can have 2^{31} or 2,147,483,648 addresses.

Example 6

Find the class of the address:

00000001 00001011 00001011 11101111

Solution

The first bit is 0. This is a class A address.

Example 7

Find the class of the address:

11000001 10000011 00011011 11111111

Solution

The first 2 bits are 1; the third bit is 0. This is a class C address.

Example 7

Find the class of the address:

227.12.14.87

Solution

The first byte is 227 (between 224 and 239) the class is D.

Example 7 (Continued)

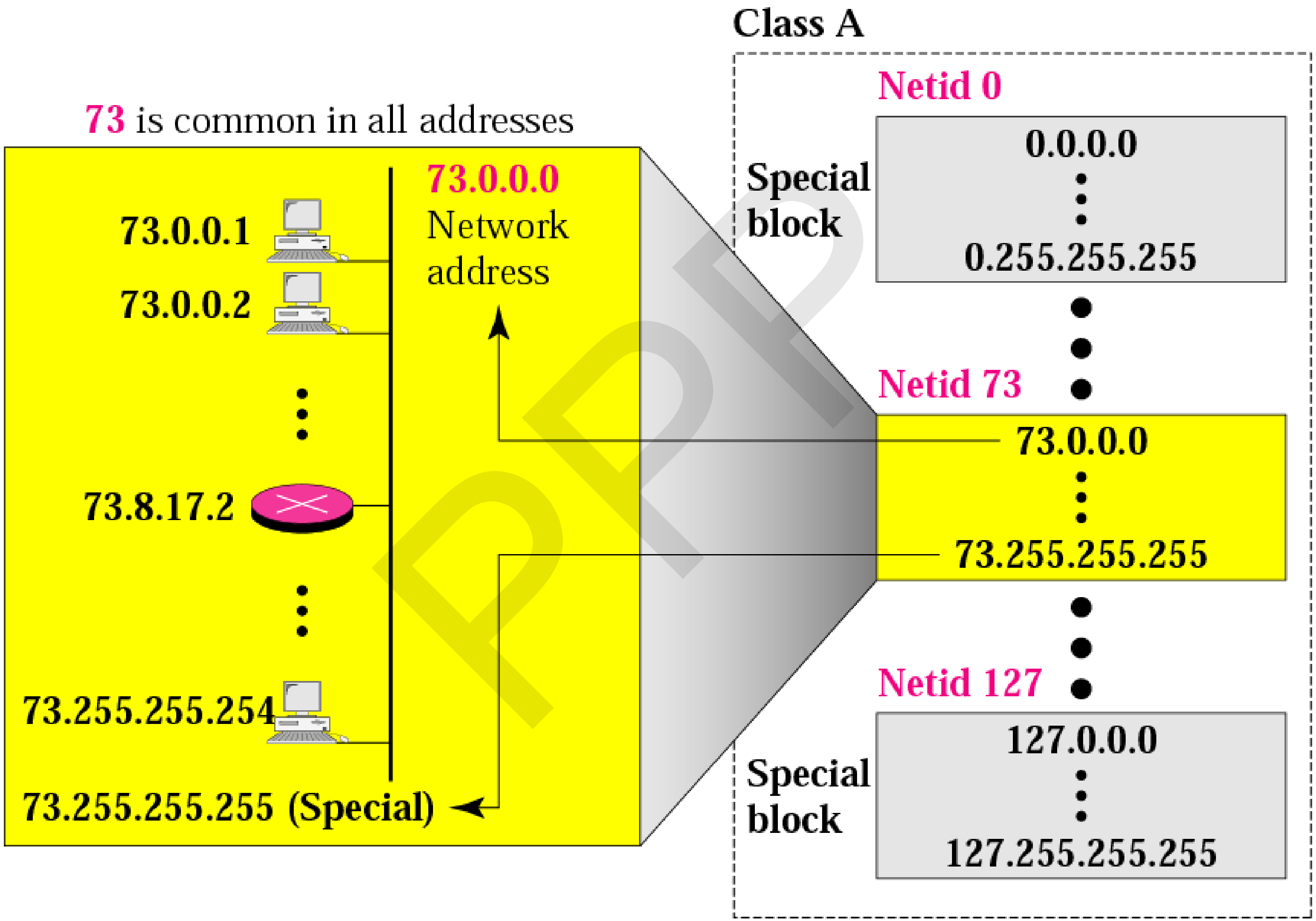
Find the class of the address:

193.14.56.22

Solution

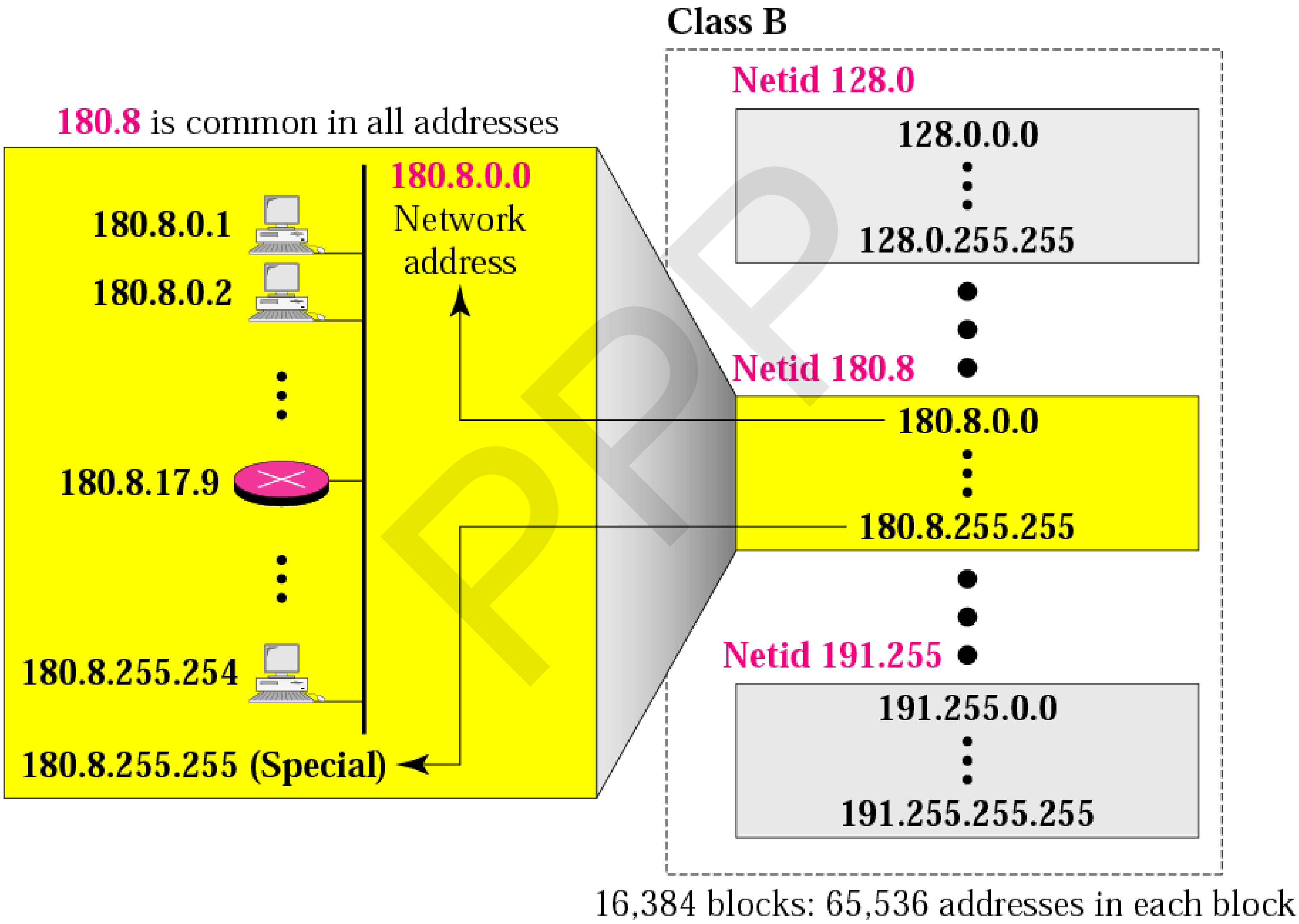
The first byte is 193 (between 192 and 223) the class is C.

Blocks in class A

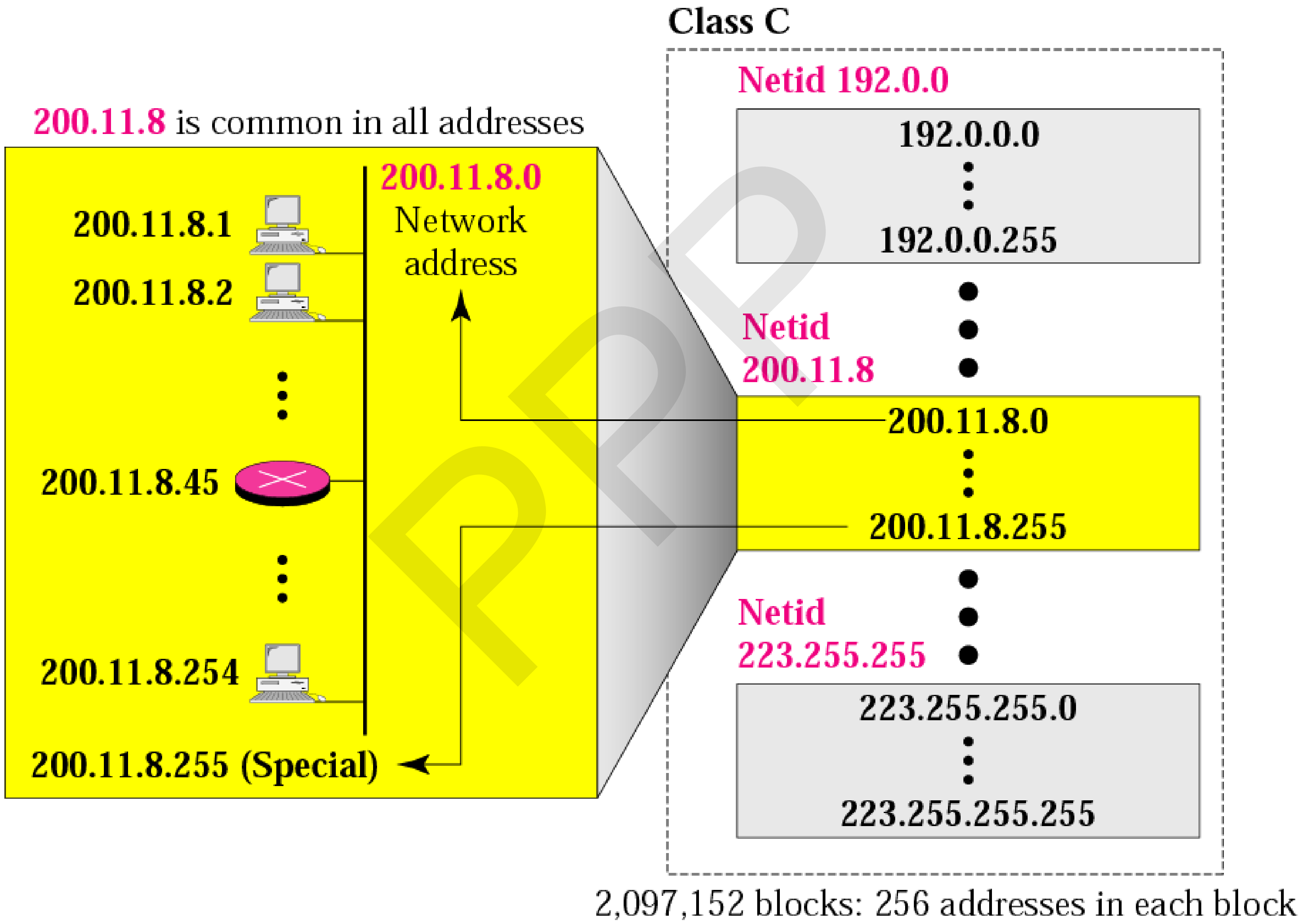


128 blocks: 16,777,216 addresses in each block

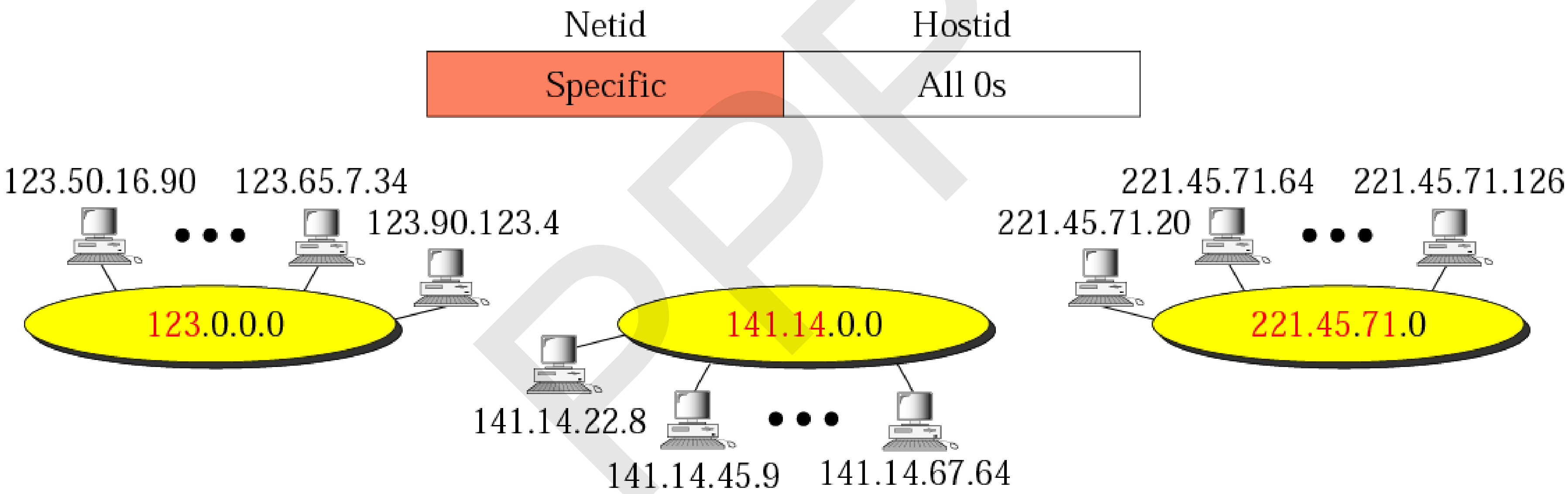
Blocks in class B



Blocks in class C



Network addresses



(a) Class A (b) Class B (c) Class C

Example 9

Given the network address 17.0.0.0, find the class, the block, and the range of the addresses.

Solution

The class is A because the first byte is between 0 and 127.
The block has a netid of 17.
The addresses range from 17.0.0.0 to 17.255.255.255.

Example 10

Given the network address 132.21.0.0, find the class, the block, and the range of the addresses.

Solution

The class is B because the first byte is between 128 and 191.
The block has a netid of 132.21.
The addresses range from 132.21.0.0 to 132.21.255.255.

Example 11

Given the network address 220.34.76.0, find the class, the block, and the range of the addresses.

Solution

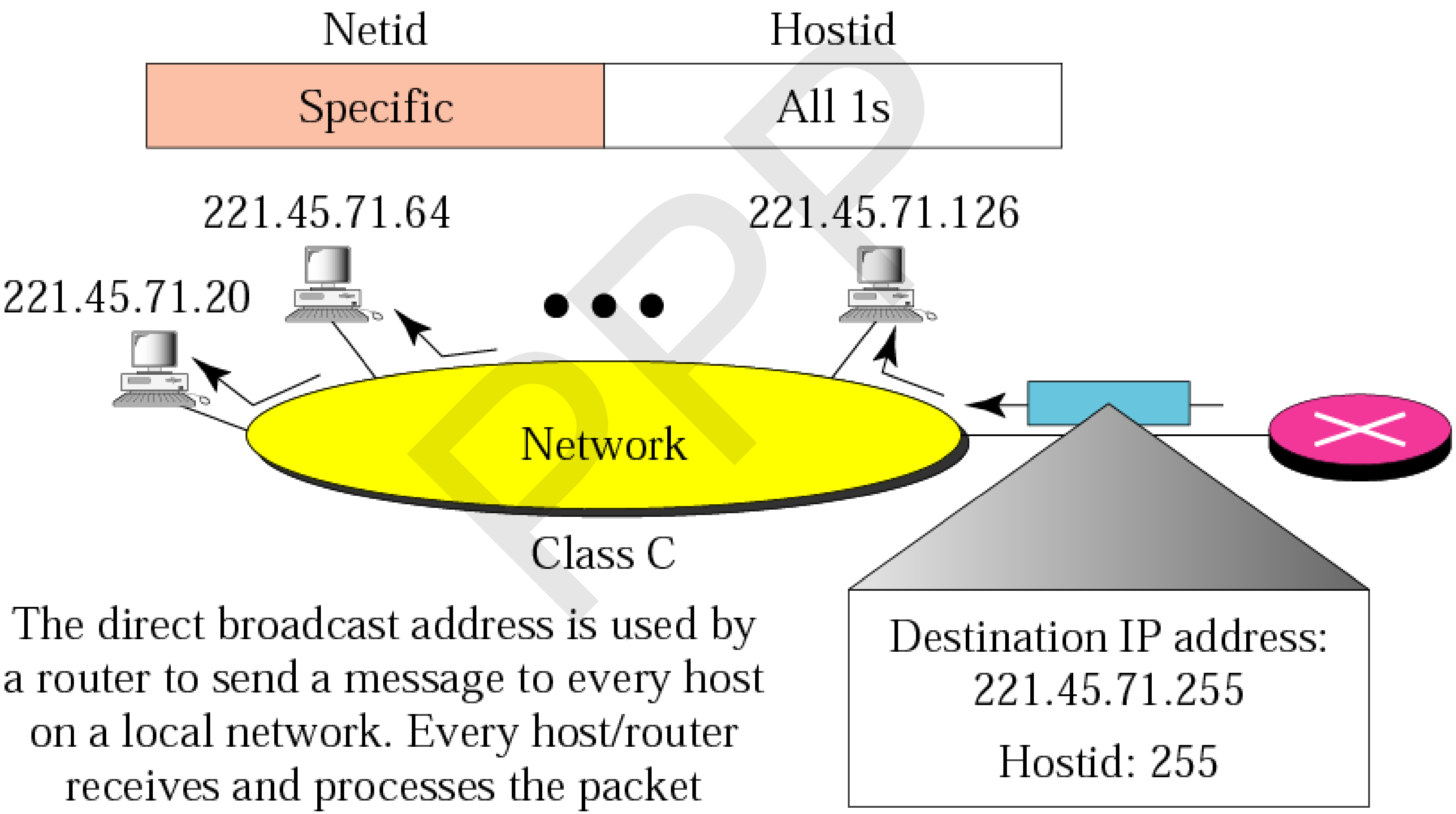
The class is C because the first byte is between 192 and 223.
The block has a netid of 220.34.76.
The addresses range from 220.34.76.0 to 220.34.76.255.

Special Addresses

- Some parts of the address space are used for special addresses

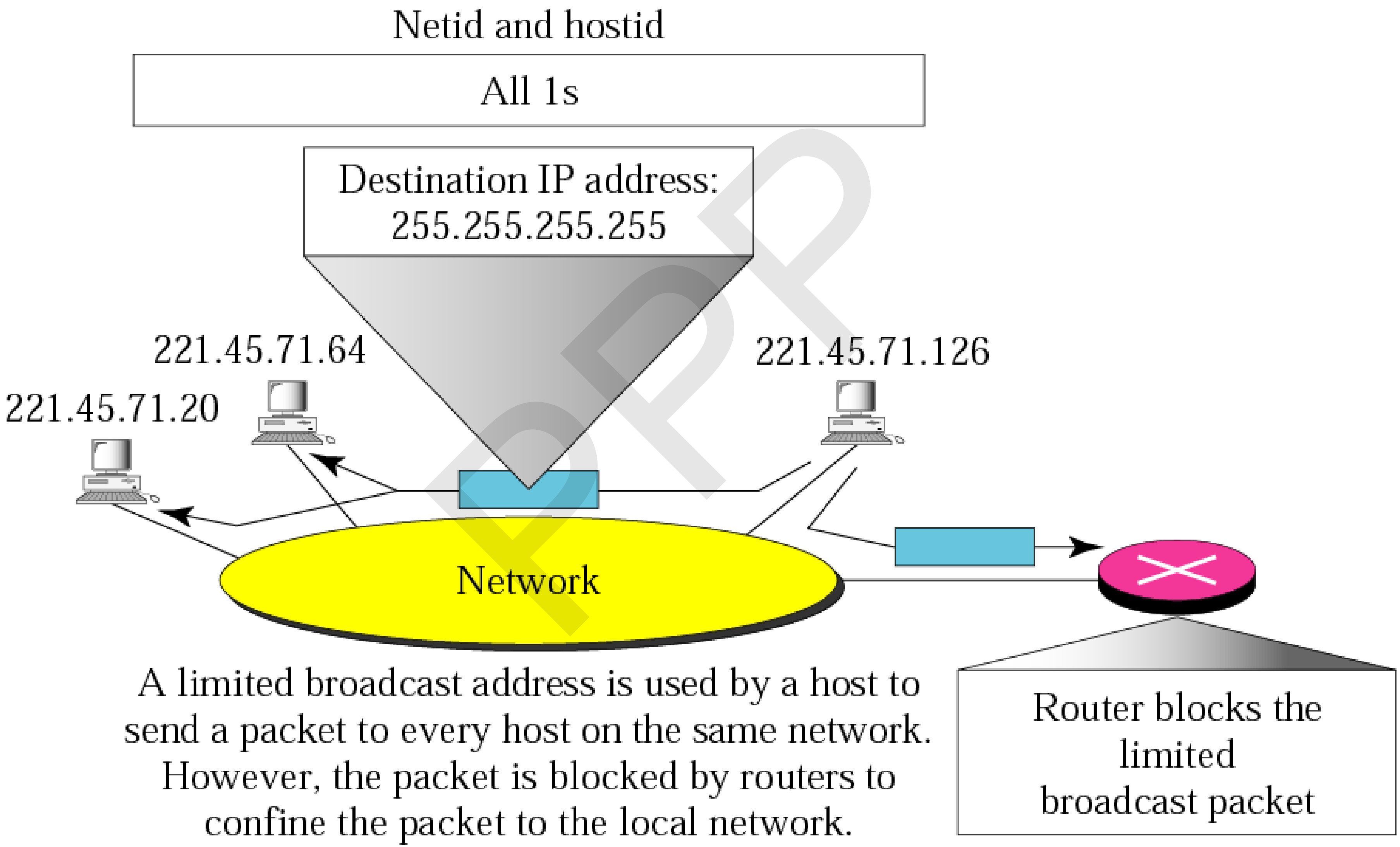
Special Address	*Netid*	*Hostid*	*Source or Destination*
Network address	Specific	All 0s	None
Direct broadcast address	Specific	All 1s	Destination
Limited broadcast address	All 1s	All 1s	Destination
This host on this network	All 0s	All 0s	Source
Specific host on this network	All 0s	Specific	Destination
Loopback address	127	Any	Destination

Example of direct broadcast address

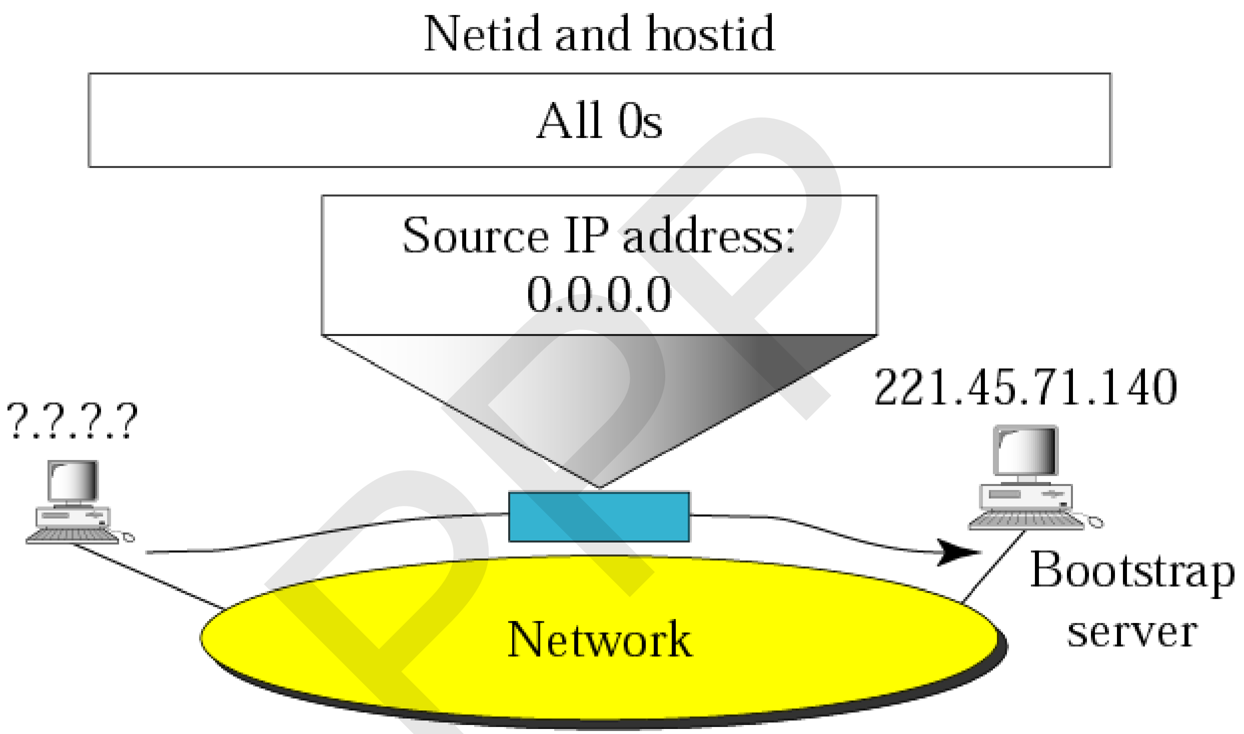


The direct broadcast address is used by a router to send a message to every host on a local network. Every host/router receives and processes the packet with a direct broadcast address.

Example of limited broadcast address

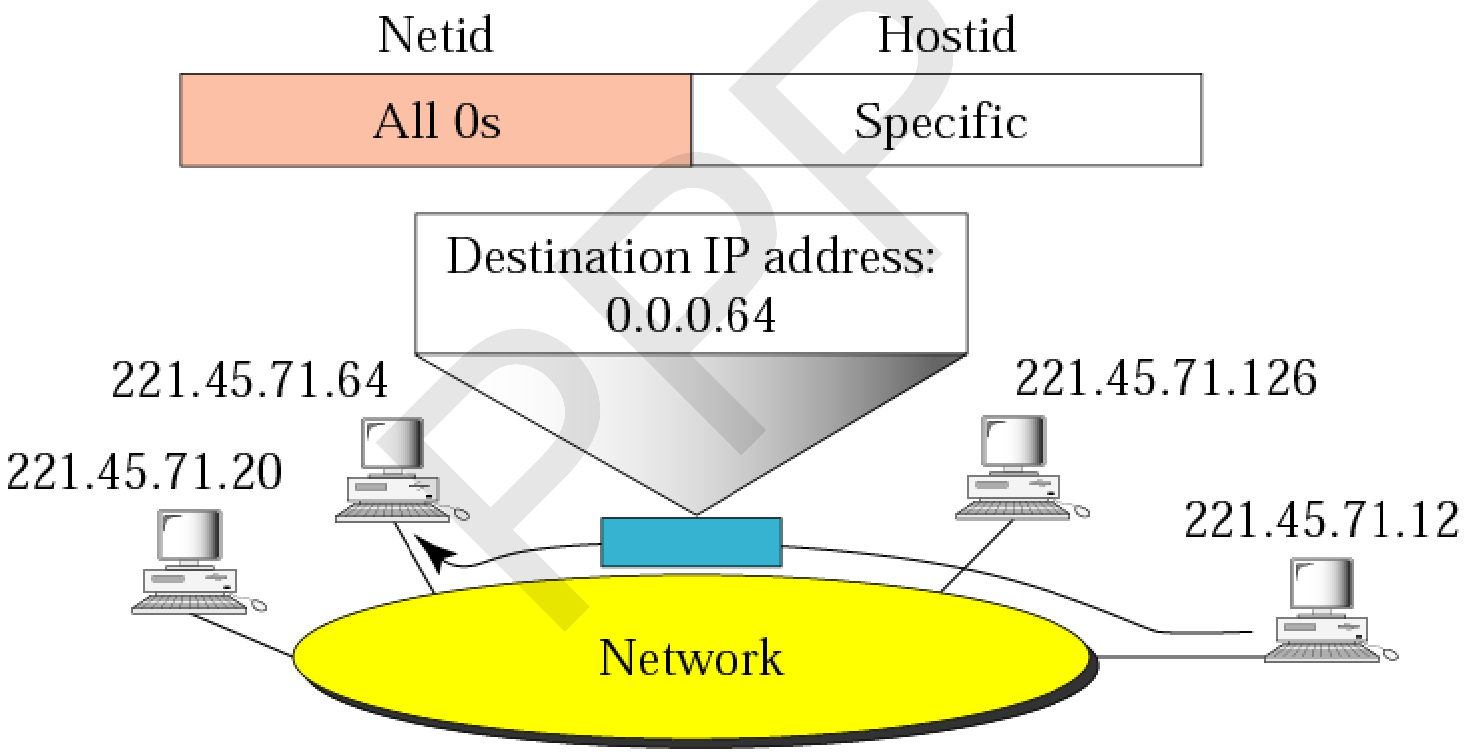


Example of *this* host on *this* address



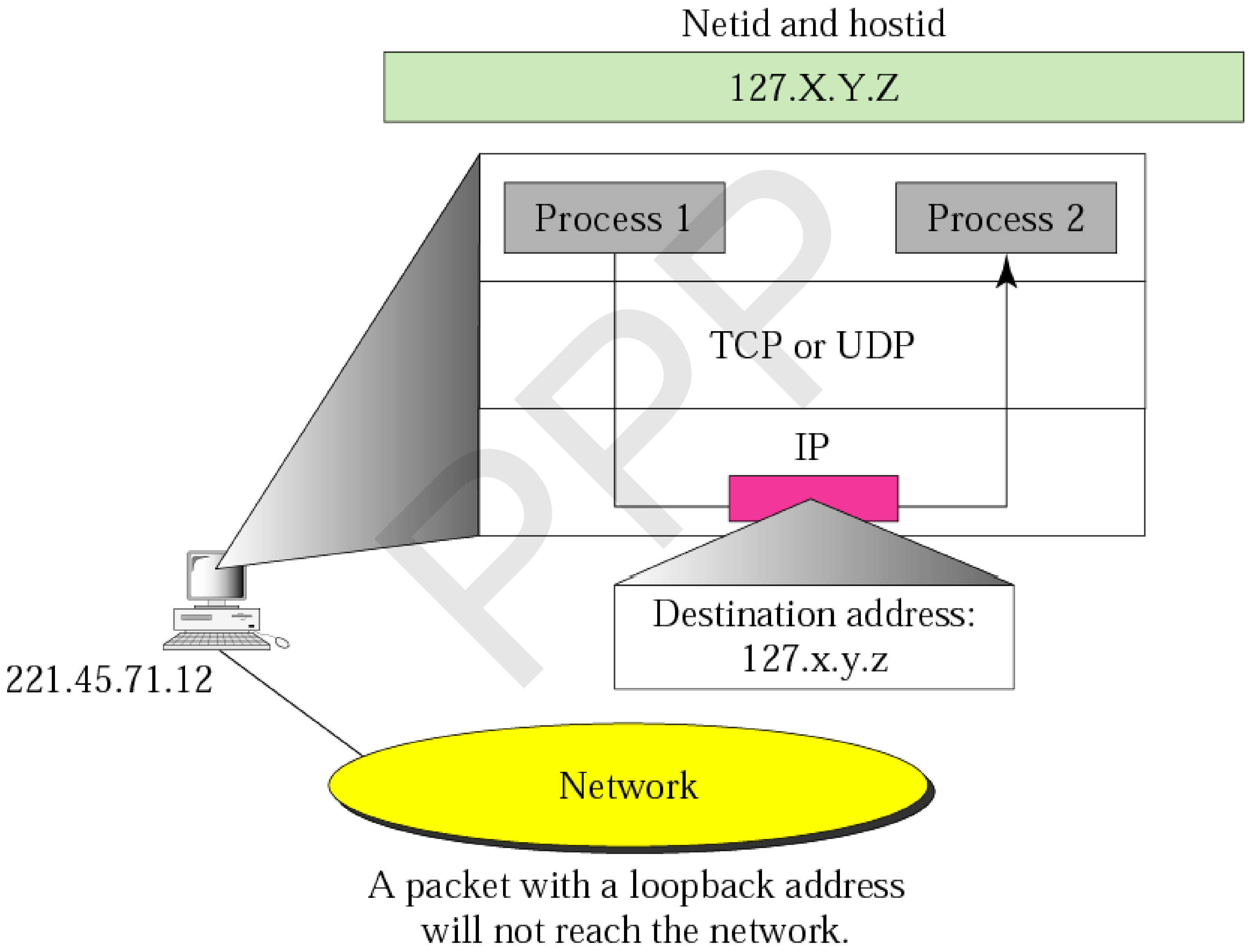
A host that does not know its IP address uses the IP address 0.0.0.0 as the source address and 255.255.255.255 as the destination address to send a message to a bootstrap server.

Example of specific host on *this* network



This address is used by a router or host
to send a message to a specific host on the same network.

Example of loopback address



Private IP Addresses

Class	Private Networks	Address Range
A	10.0.0.0	10.0.0.0 - 10.255.255.255
B	172.16.0.0 - 172.31.0.0	172.16.0.0 - 172.31.255.255
C	192.168.0.0	192.168.0.0 - 192.168.255.255

Network Address

- ***The network address is the beginning address of each block.***

- ***It can be found by applying the default mask to any of the addresses in the block (including itself).***

- ***It retains the netid of the block and sets the hostid to zero.***

Mask

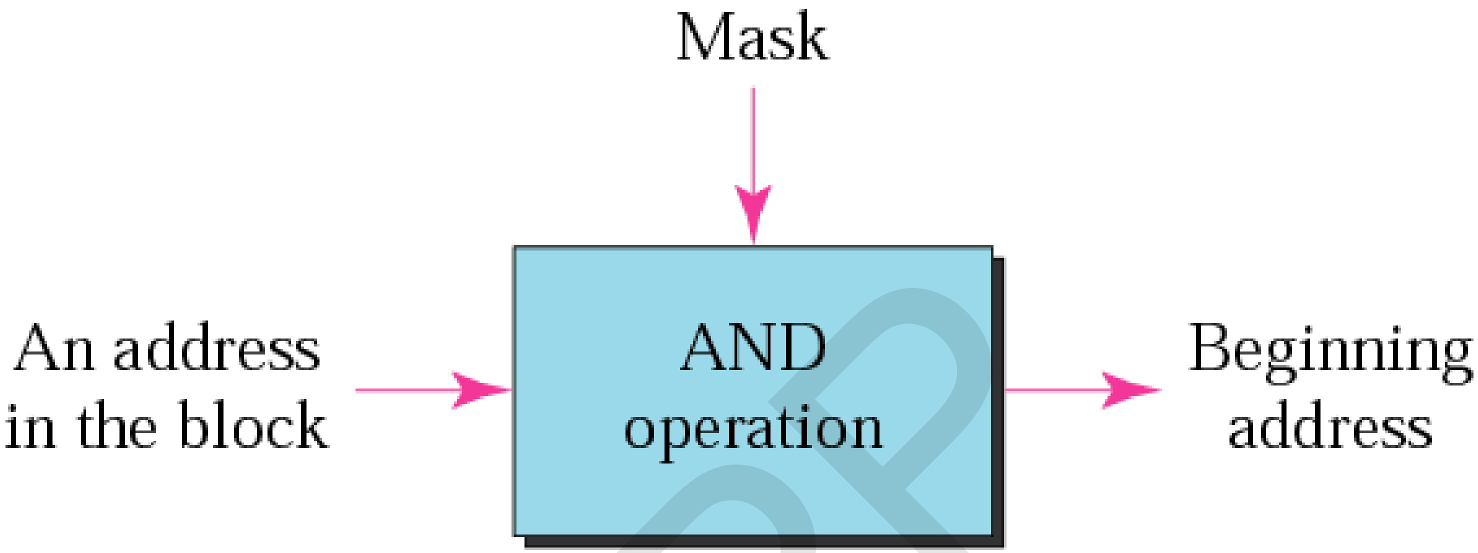
A mask is a 32-bit binary number that gives the first address in the block (the network address) when bitwise ANDed with an address in the block.

Default Standard Subnet Masks

- There are default standard subnet masks for Class A, B and C addresses:

Default Subnet Masks	
Address Class	***Subnet Mask***
Class A	255.0.0.0
Class B	255.255.0.0
Class C	255.255.255.0

Masking concept



- Boolean Algebra is a process that applies binary logic to yield binary results.
- Working with subnet masks, you need only 4 basic principles of Boolean Algebra:
  - 1 and 1 = 1
  - 1 and 0 = 0
  - 0 and 1 = 0
  - 0 and 0 = 0

Example 12

Given the address 23.56.7.91 and the default class A mask, find the beginning address (network address).

Solution

The default mask is 255.0.0.0, which means that only the first byte is preserved and the other 3 bytes are set to 0s.
The network address is 23.0.0.0.

Example 13

Given the address 132.6.17.85 and the default class B mask, find the beginning address (network address).

Solution

The default mask is 255.255.0.0, which mear
that the first 2 bytes are preserved
and the other 2 bytes are set to 0s.
The network address is 132.6.0.0.

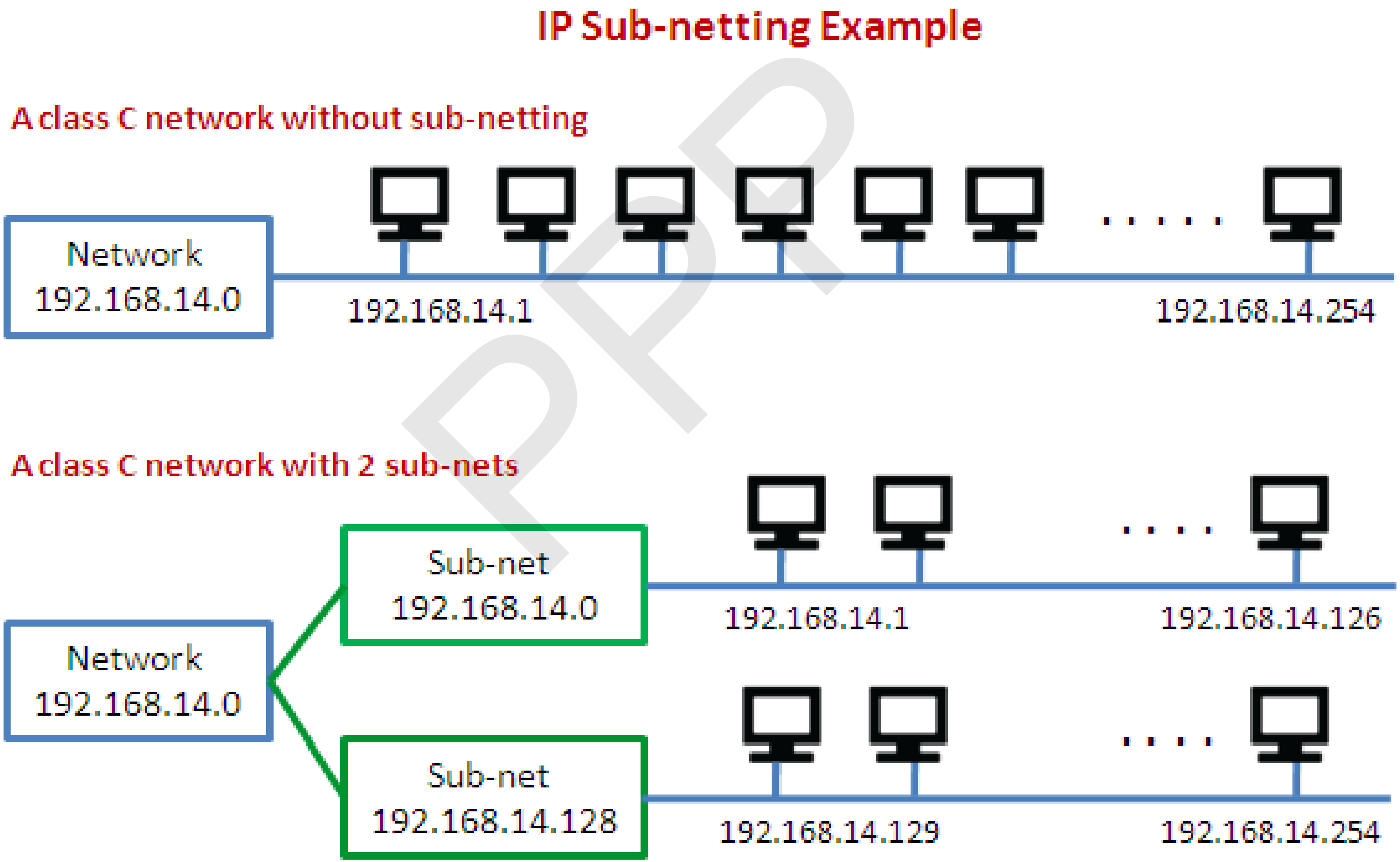
Example 14

Given the address 201.180.56.5 and the class C default mask, find the beginning address (network address).

Solution

The default mask is 255.255.255.0, which means that the first 3 bytes are preserved and the last byte is set to 0. The network address is 201.180.56.0.

<u>Subnetting:</u>Dividing a network into two or more networks is called **subnetting**. Computers that belong to a subnet are addressed with a common, identical, most-significant bit-group in their IP address.



<u>**Steps for Create a Subnetwork**</u>

- Decide the no. of subnets. It should be in power of 2. i.e. 2^n
- Find the default subnet mask
- To find the new subnet mask add extra 1's (n) with the default subnet mask.

- E.g. For above example,
  - Class C network 192.168.1.0 divide into 2 sub networks.
  - It means that value of n = 1.
  - Default subnet mask for class C is 255.255.255.0
  - New subnet mask : **11111111.11111111.11111111.10000000**
  - New subnet mask (In Decimal) = 255.255.255.128

Example

For Class C, Default Mask : 255.255.255.0

For above subnetting example, Subnet Mask : 255.255.255.128

<u>How To find the nework address of any IP address belongs to above example</u>.

If IP address in the range of 192.168.14.1 ……………… 192.168.14.126
than apply the bit by bit anding with subnet mask, the answer should be 192.168.14.0. It means that network address **192.168.14.0**

If I take any IP address in the range of 192.168.14.129 ………………. 192.168.14.254
than apply the bit by bit anding with subnet mask, the answer should be 192.168.14.128. It means that network address **192.168.14.128**

Example

Class C network 192.168.1.0 divide into 4 sub networks.

- It means that value of n = 2.
- Default subnet mask for class C is 255.255.255.0
- New subnet mask : **11111111.11111111.11111111.11000000**
- New subnet mask (In Decimal) = 255.255.255.192
- The total number of 0s in the subnet mask is = 6 (32 – 26).
- So, In each sub network the number of addresses are $2^6 = 64$

```
Address:   192.168.1.0          11000000.10101000.00000001 .00000000
Netmask:   255.255.255.0 = 24   11111111.11111111.11111111 .00000000
Wildcard:  0.0.0.255            00000000.00000000.00000000 .11111111
=>
Network:   192.168.1.0/24       11000000.10101000.00000001 .00000000 (Class C)
Broadcast: 192.168.1.255        11000000.10101000.00000001 .11111111
HostMin:   192.168.1.1          11000000.10101000.00000001 .00000001
HostMax:   192.168.1.254        11000000.10101000.00000001 .11111110
Hosts/Net: 254                  (Private Internet)


Subnets

Netmask:   255.255.255.192 = 26 11111111.11111111.11111111.11 000000
Wildcard:  0.0.0.63             00000000.00000000.00000000.00 111111

Network:   192.168.1.0/26       11000000.10101000.00000001.00 000000 (Class C)
Broadcast: 192.168.1.63         11000000.10101000.00000001.00 111111
HostMin:   192.168.1.1          11000000.10101000.00000001.00 000001
HostMax:   192.168.1.62         11000000.10101000.00000001.00 111110
Hosts/Net: 62                   (Private Internet)


Network:   192.168.1.64/26      11000000.10101000.00000001.01 000000 (Class C)
Broadcast: 192.168.1.127        11000000.10101000.00000001.01 111111
HostMin:   192.168.1.65         11000000.10101000.00000001.01 000001
HostMax:   192.168.1.126        11000000.10101000.00000001.01 111110
Hosts/Net: 62                   (Private Internet)


Network:   192.168.1.128/26     11000000.10101000.00000001.10 000000 (Class C)
Broadcast: 192.168.1.191        11000000.10101000.00000001.10 111111
HostMin:   192.168.1.129        11000000.10101000.00000001.10 000001
HostMax:   192.168.1.190        11000000.10101000.00000001.10 111110
Hosts/Net: 62                   (Private Internet)


Network:   192.168.1.192/26     11000000.10101000.00000001.11 000000 (Class C)
Broadcast: 192.168.1.255        11000000.10101000.00000001.11 111111
HostMin:   192.168.1.193        11000000.10101000.00000001.11 000001
HostMax:   192.168.1.254        11000000.10101000.00000001.11 111110
Hosts/Net: 62                   (Private Internet)


Subnets:   4
Hosts:     248
```

Example

A company is granted the site address 201.70.64.0 (class C). The company needs eight subnets. Design the subnets.

No. of subnet = 8 = (2^3). Value of n for 2^n is 3.

So Need of 3 more 1s in the default subnet mask.

The number of 1s in the default mask is 24 (class C).

The total number of 1s in the subnet mask is = 27 (24 + 3).

$$\underline{11111111\ 11111111\ 11111111}\ \underline{111}00000$$

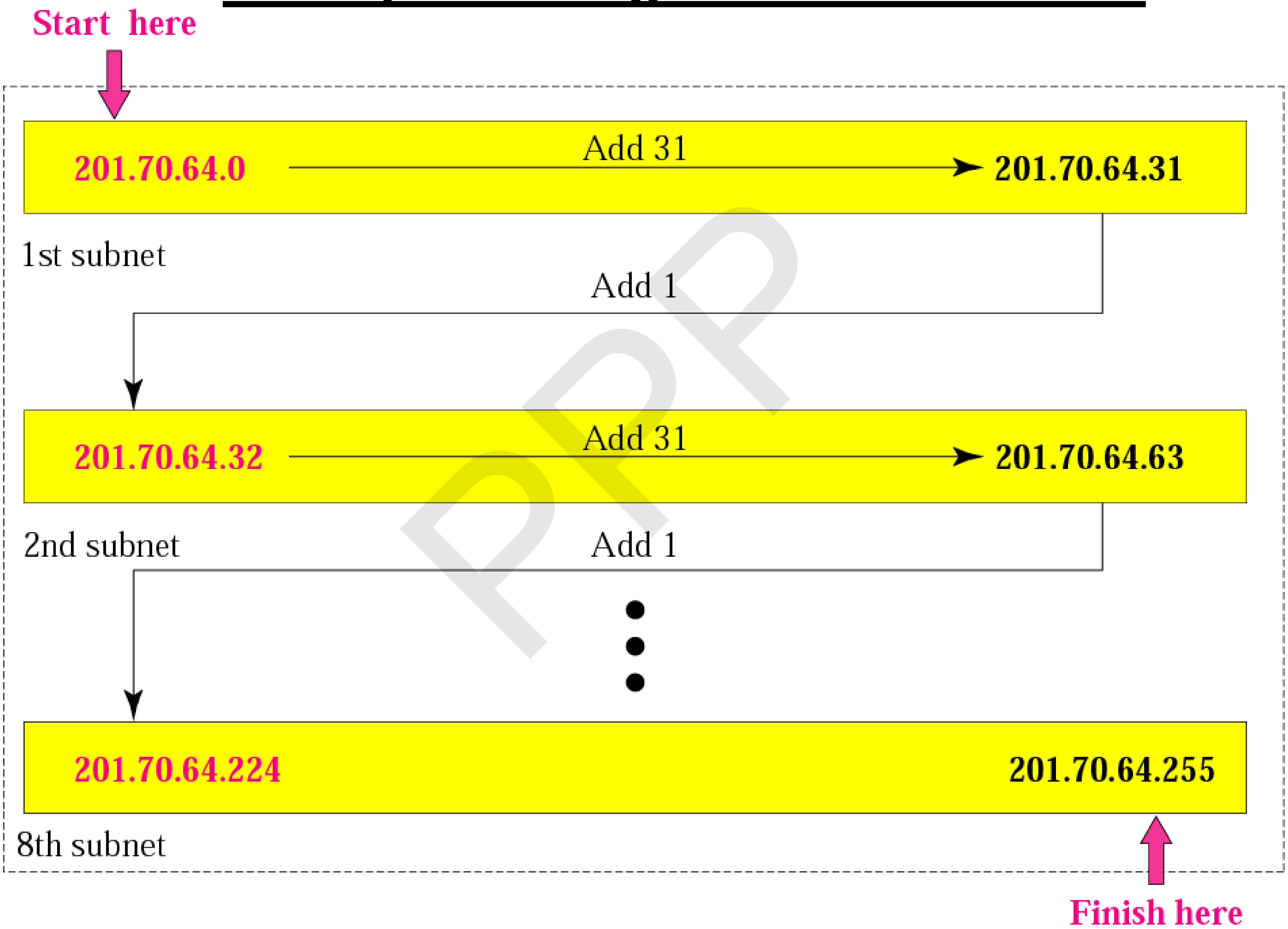
or

255.255.255.224

The total number of 0s in the subnet mask is = 5 (32 – 27).

So, In each sub network the number of addresses are $2^5 = 32$

Example : Range of subnetworks



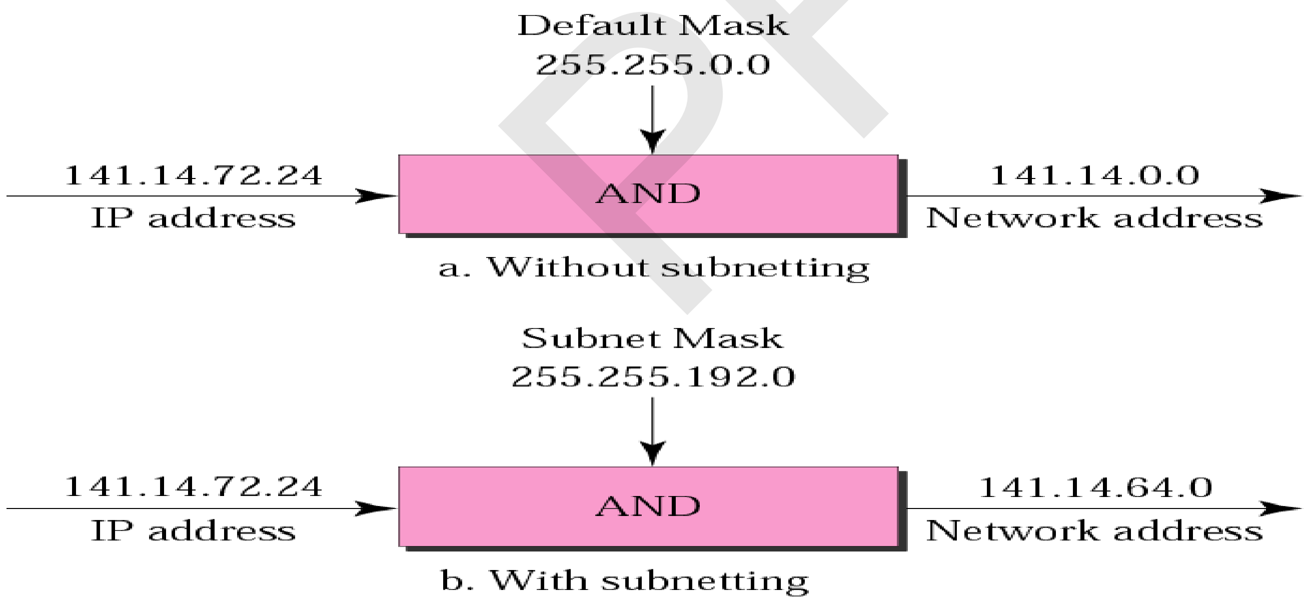
Network with and without subnetting

Que. How to find the network address of a packet with IP address 141.14.72.24 ?

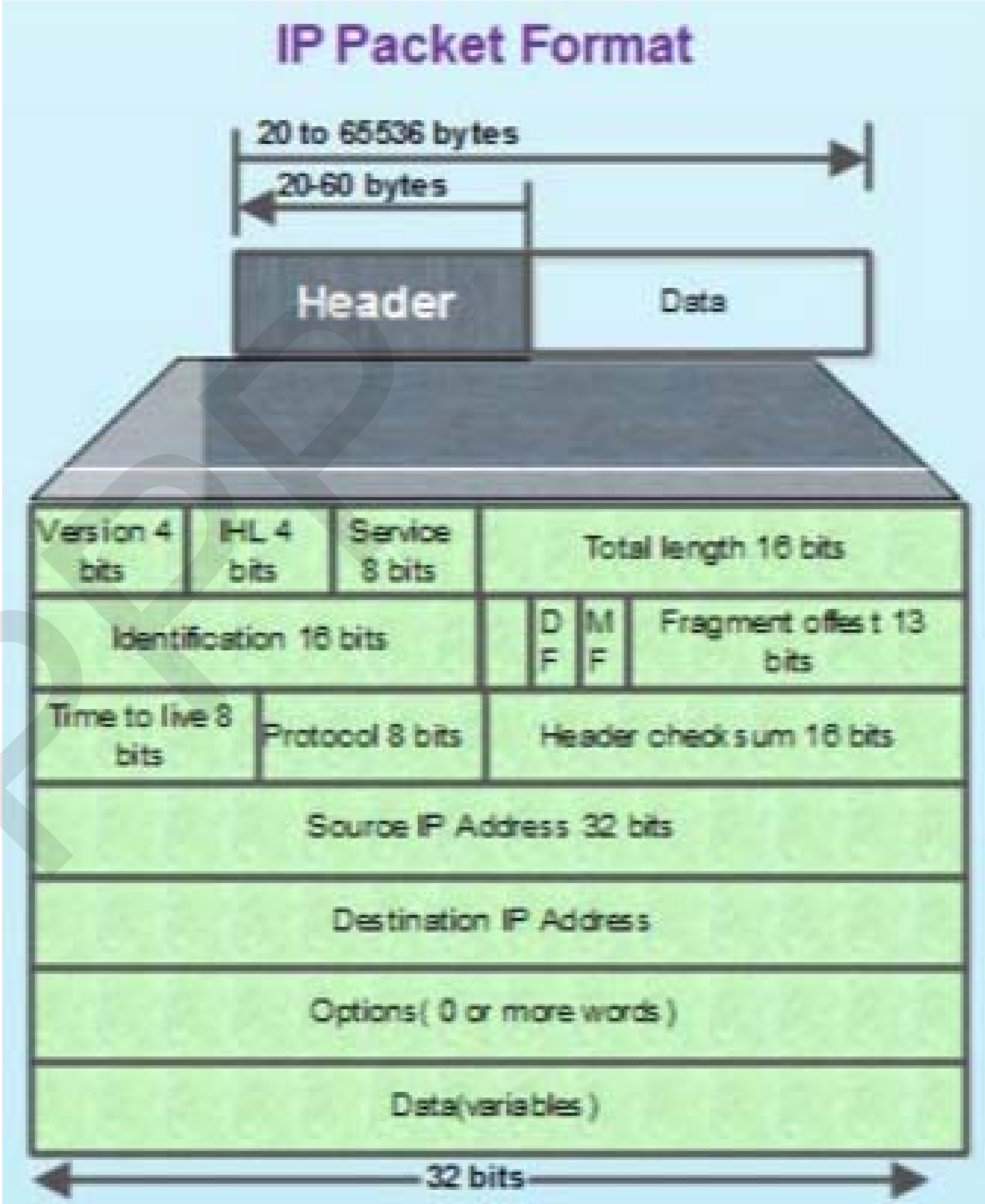
Ans. It belongs to class B and class B having two bytes for netowork, so network address is 141.14.72.24.

Que. If 141.14.0.0 network divide into 4 sub network than, how to find the sub network address of a packet with IP address 141.14.72.24 ?

Ans. It belongs to class B and subnet mask is 255.255.192.0. So apply the bit by bit anding of 141.14.72.24 & 255.255.192.0 gives the network address 141.14.64.0.



IP Packet Format



- **Version:** The first header field in an IP packet is the four-bit version field. For IPv4, this is always equal to 4.
- **Internet Header Length (IHL) :** This field has 4 bits, which is the number of 32-bit words. Since an IPv4 header may contain a variable number of options, this field specifies the size of the header (this also coincides with the offset to the data).
- The minimum value for this field is 5,which indicates a length of 5 × 32 bits = 160 bits = 20 bytes.
- As a 4-bit field, the maximum value is 15 words (15 × 32 bits, or 480 bits = 60 bytes).

Type of Service

TOS Bits	*Description*
0000	Normal (default)
0001	Minimize cost
0010	Maximize reliability
0100	Maximize throughput
1000	Minimize delay

- **Total Length:** This 16-bit field defines the entire datagram size, including header and data, in bytes.
- The minimum is 20 bytes (20-byte header + 0 bytes data) and the maximum is 65,535 bytes — the maximum value of a 16-bit word.
- In the case of a fragment (MF bit set), this field denotes the size of the fragment, and not the size of the entire packet.
- **Identification:** This field is an identification field and is primarily used for uniquely identifying the group of fragments of a single IP datagram.

- **Flags:** A three-bit field follows and is used to control or identify fragments. They are :
- bit 0: Reserved; must be zero.
- bit 1: Don't Fragment (DF)
- bit 2: More Fragments (MF)
- If the DF flag is set (Value is 1), and fragmentation is required to route the packet, then the packet is dropped. This can be used when sending packets to a host that does not have sufficient resources to handle fragmentation.
- For unfragmented packets, the MF flag is cleared (Value 0). For fragmented packets, all fragments except the last have the MF flag set (Value 1).

Fragment Offset:

The fragment offset field is measured in units of eight byte blocks.

- It is 13 bits long and specifies the offset of a particular fragment relative to the beginning of the original unfragmented IP datagram.
- The first fragment has an offset of zero.
- Maximum value of offset is $(2^{13} - 1) \times 8 = 65{,}528$ bytes.

Time To Live (TTL):

- An eight-bit time to live field helps prevent datagrams from looping on an internet. This field limits a datagram's lifetime.
- It is specified in seconds, but time intervals less than 1 sec. In practice, the field has become a hop count — when the datagram arrives at a router, the router decrements the TTL field by one.
- When the TTL field hits zero, the router discards the packet and typically sends an ICMP time Exceeded message to the sender.

- **Protocol:** This field defines the protocol used in the data portion of the IP datagram.

Value	*Protocol*
1	ICMP
2	IGMP
6	TCP
17	UDP
89	OSPF

Checksum:

- The 16-bit checksum field is used for error-checking of the header.
- When a packet arrives at a router, the router calculates the checksum of the header and compares it to the checksum field. If the values do not match, the router discards the packet.
- The checksum field is the 16-bit one’s complement of the one's complement sum of all 16-bit words in the header.

Calculation of Checksum

4	5	0	28
1		0	0
4	17	0	
10.12.14.5			
12.6.7.9			

4, 5, and 0 → 0100010100000000
28 → 0000000000011100
1 → 0000000000000001
0 and 0 → 0000000000000000
4 and 17 → 0000010000010001
0 → 0000000000000000
10.12 → 0000101000001100
14.5 → 0000111000000101
12.6 → 0000110000000110
7.9 → 0000011100001001

Sum → 0111010001001110
Checksum → 1000101110110001

Source address:

This field is the IPv4 address of the sender of the packet.

Destination address:

This field is the IPv4 ddress of the receiver of the packet

IP Options

- Used for network testing and debugging
  - The Record Route Option
  - Strict Source Route Option
  - Loose Source Route Option
  - The Timestamp Option

The Record Route Option

- Source creates an empty list of IP addresses in the header & Set Record route option
- Each router that handles the datagram appends its IP address to the list
- Destination machine can extract and process the route information

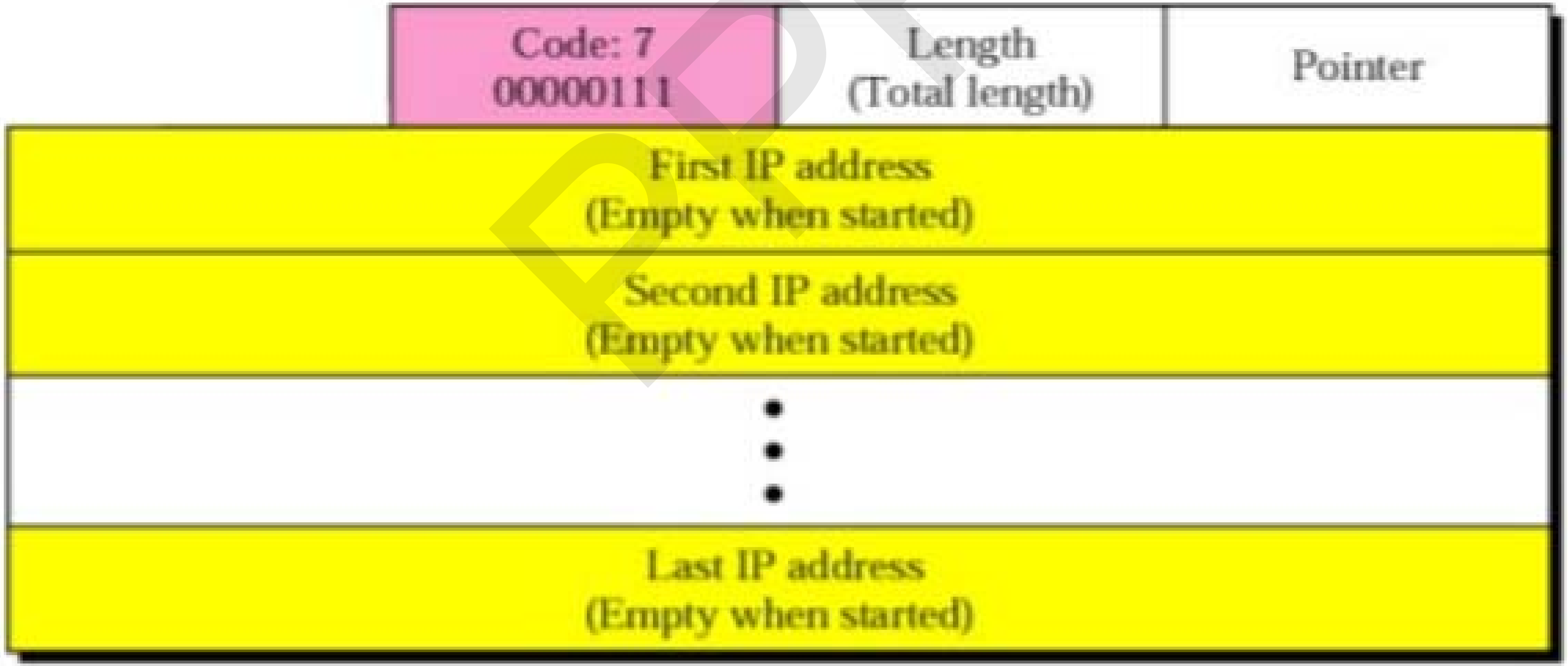
Source Route Option

- Sender dictates a path through the internet over which the datagram **must** travel.
- Sender lists IP addresses (in order) of the route the datagram should take.
- Sender sets the source route option
- **Strict source routing** - The path between two successive addresses in the list must consist of a single physical network
- **Loose source routing**
  - The datagram must follow the sequence of IP addresses in the list
  - Allows multiple network hops between successive addresses on the list

The Timestamp Option

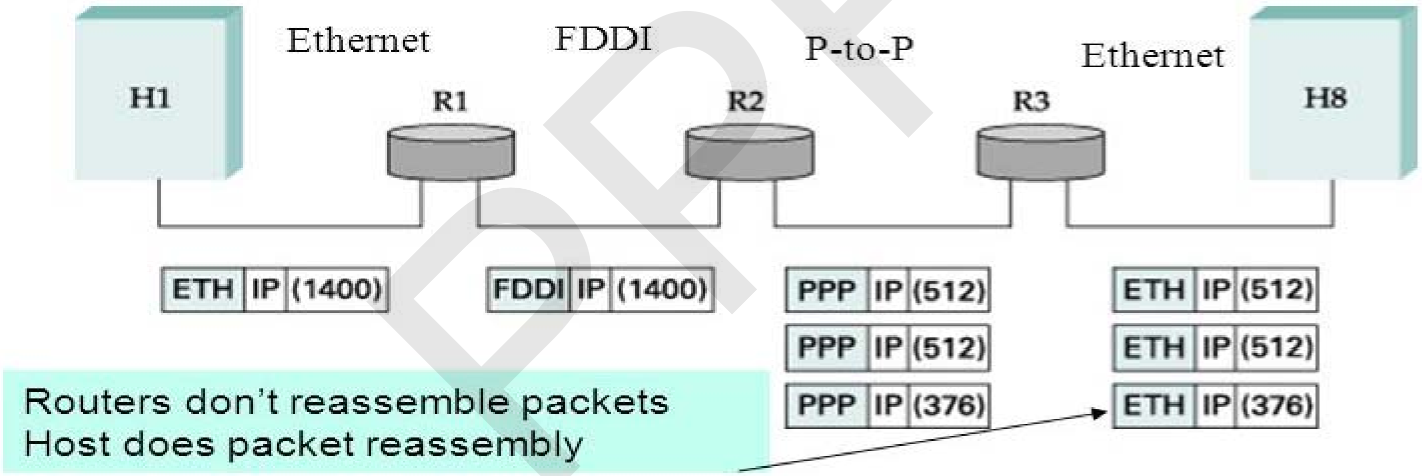
- Sender creates an empty list in the header
- Sender enables the timestamp option
- Each router that handles the datagram appends to the list its:
  - IP address
  - Local timestamp (in Universal Time)

The Record Route Option



Fragmentation: Example Network

- Ethernet R1 and FDDI R2 – No fragmentation needed
  - Why is that?
- PPP R3 – Fragmentation is needed



MTU (Maximum Transfer Unit) : Maximum size of packet in network

Ethernet : 1500
FDDI : 1500
PPP : 512

IP Packet Header Contains : 20 Bytes
MTU of Ethernet : 1500 (Including the header of 20 bytes)
Data Field contains 1480 (1500 – 20) bytes.
Total Length of packet : 4000 bytes.
To pass it through Ethernet it needs to divide packet into three (3980/ 1480) fragments.