Data Communication
[ENCT 253]

Chapter 1
Introduction

Data communication: It is the process of exchange of data/information between two or more devices or transmitter and receiver or source and destination through a transmission medium such as cables, optical fibers, or wireless channels. It involves the transmission, reception, and processing of digital or analog signals to convey information from one point to another.

Data communication system: A data communication system is a collection of hardware, software, and protocols designed to facilitate the exchange of data between two or more devices or systems.

The effectiveness of data communication system depends on its four fundamental characteristics:

Delivery: The system must deliver data to the correct destination .Data must be received by the intended receiver only.

Accuracy: The System must deliver the data accurately. The data that have been altered in transmission and uncorrected at the receiver are useless.

Timeliness: The system must deliver data in time. The data which are delivered late are useless. This is more sensitive in case of real time transmission.

Jitter: Jitter is any deviation in, or displacement of the signal pulses in a high-frequency digital signal. The deviation can be in terms of amplitude, phase timing or the width of the signal pulse.

Data communication system may be analog or digital.

Analog data communication system: An analog data communication system is a system that transmits and receives data in the form of analog signals. Analog systems transmit data as continuous waveforms that vary in amplitude, frequency, or phase. Telephones, radios are the example of analog communication system.

Digital data communication system: A digital data communication system is a system that transmits and receives data in the form of digital signals, where data is represented as discrete binary values (0s and 1s). Digital communication systems encode information into digital signals, allowing for more efficient and reliable transmission, processing, and storage of data compared to analog systems. Computer networking, chat and conferencing, social media, etc. are the example of digital communication system.

Block Diagram of Analog Data Communication System

The block diagram of Analog communication system is a pictorial view of communication system in which different functional elements are represented in the form of block as shown in figure below.

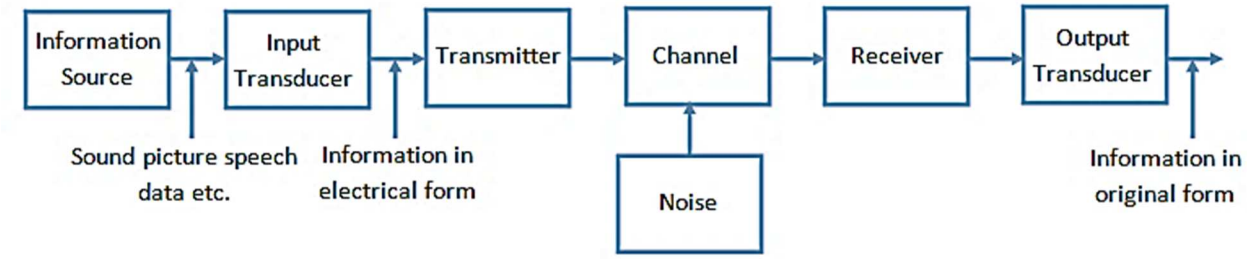

Figure: Block diagram of Communication system

Information source

- A communication system serves to communicate a message or information. This information originates in the information source.
- The function of information source is to produce required message which has to be transmitted.
- There can be various messages in the form of words, group of words, code, symbols, sound, images, videos, etc.

Input Transducer

- The transducer is a device which converts one form of energy into another form.
- The message produced by information source is not electrical in nature.
- An input transducer is used to convert it into a time varying electrical signal.
- For example- in the case of radio broadcasting, a microphone converts the information or message which is in the form of sound waves into corresponding electrical signal.

Transmitter

- The function of transmitter is to process the electrical signal from different aspects.
- Modulation is the main function of the transmitter
- For example-in the radio broadcasting, the electrical signal is obtained from sound signal is processed to restrict its range of audio frequencies (upto 5KHz in AM radio broadcast) and is often amplified.

Channel

- The function of channel is to provide a physical connection between transmitter and receiver.
- The channel is also called a medium through which message travels from the transmitter to receiver.
- There are two types of channels.
  I. Point to point channel- examples are wire lines, microwave links, optical fiber etc.
  II. Broadcast channel- example- satellites in geostationary orbit.

Noise

- The noise is an unwanted signal, which tends to interfere with the required signal.
- Noise signal is always random in nature.
- Noise may interfere with signal at any point in communication system.
- Noise has its greatest effect on the signal in the channel.

Receiver

- The main function of receiver is to reproduce the message signal in electrical form from distorted received signal.
- This reproduction of the original signal is accomplished by a process known as the demodulation or detection.
- Demodulation is the reverse process of modulation carried out in the transmitter.

Destination

- Destination is the final stage, which is used to convert an electrical signal into its original form.
- For example- in radio broadcasting, the destination is a loud speaker which works as a transducer. i.e. converts the electrical signal in the form of original sound signal.

Advantages of analog communication system

The advantages of analog communication system are as follows:

- Analog signal uses less bandwidth as compared to the digital signal. It is due to the use of amplifier in the analog communication system, which improves the signal and reduces the distortion.
- It provides a more accurate method of representation due to its continuous nature.
- Audio signals are preferred for audio and video transmissions. It is because these signals can be easily modulated and demodulated using Amplitude Modulation and Demodulation.
- Analog signals are easy to process as compared to the digital signals.
- It offers a infinite amount of signal resolution.
- Analog signals have high density because it is continuous and requires a medium to transmit.

Disadvantages of analog communication system

The disadvantages of analog communication system are as follows:

- Analog signals are more susceptible to noise and distortion during transmission. Noise can degrade the quality of the signal.
- Over a long distance, analog signal can degrade which reduces the quality of communication.
- Analog signals are not as easily manipulated or processed as digital signals.
- It has lack of error detection and correction.

Block Diagram of Digital Data Communication System

The block diagram of digital data communication system is given below

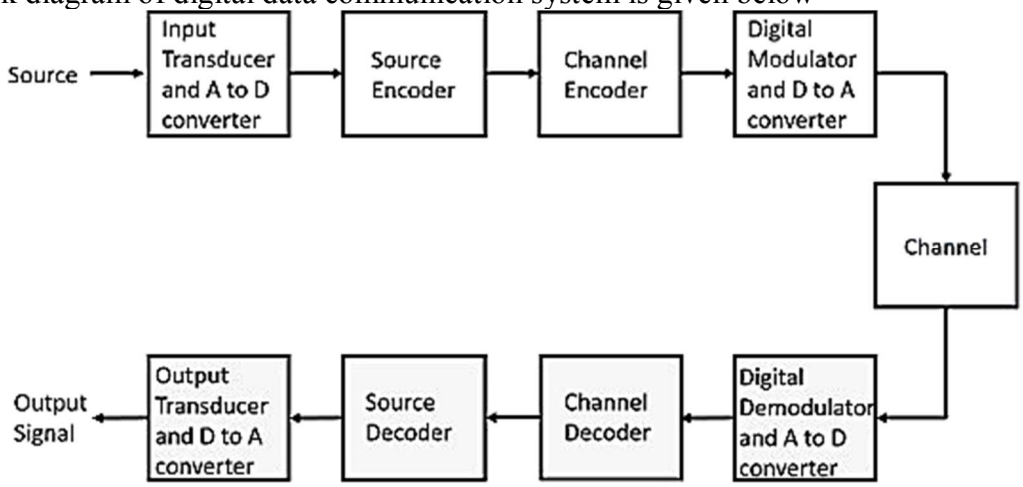

Figure: Block diagram of digital data communication system

The blocks of the digital communication system are described individually

Source: The source can be an analog signal. Example: A Sound signal

Input Transduce: This is a transducer which takes a physical input and converts it to an electrical signal (Example: microphone). This block also consists of an **analog to digital** converter where a digital signal is needed for further processes. A digital signal is generally represented by a binary sequence.

Source Encoder: The source encoder is used to compress the data into minimum number of bits. This helps in effective utilization of the bandwidth. It removes the redundant bits or unnecessary excess bits that are zeros from the input data.

Channel Encoder: The channel encoder, does the coding for error correction. During the transmission of the signal, due to the noise in the channel, the signal may get altered and hence to avoid this, the channel encoder adds some redundant bits to the transmitted data. These are the error correcting bits.

The channel encoder plays an important role in the communication system.

Digital Modulator: The signal to be transmitted is modulated here by a carrier. The signal is also converted to analog from the digital sequence, in order to make it travel through the channel or medium.

Channel: The channel or a medium, allows the analog signal to transmit from the transmitter end to the receiver end. It is the part of model at which maximum noise is added to the signal.

Digital Demodulator: This is the first step at the receiver end. The received signal is demodulated as well as converted again from analog to digital. The signal gets reconstructed here.

Channel Decoder: The channel decoder, after detecting the sequence, does some error corrections. The distortions which might occur during the transmission are corrected by adding some redundant bits. This addition of bits helps in the complete recovery of the original signal.

Source Decoder: The resultant signal is once again digitized by sampling and quantizing so that the pure digital output is obtained without the loss of information. The source decoder recreates the source output.

Output Transducer: This is the last block which converts the signal into the original physical form, which was at the input of the transmitter. It converts the electrical signal into physical output (Example: loud speaker).

Output Signal: This is the output which is produced after the whole process. Example − the sound signal received.

Advantages of Digital Communication system

- Digital communication systems are cheaper to implement.
- The impact of noise interference, distortion is less.
- The correction and detection of errors are easy in digital communication, as there is a use of channel coding.
- The probability of cross-talk is very less in digital communication.\
- The implementation of hardware is more flexible in digital communication.

Disadvantages of Digital Communication system

- There is high power consumption in digital communication system.
- There is a sampling error.
- It requires more transmission bandwidth.
- Synchronization is required.
- It has complex circuit.
- Numbers of ADC and DAC have to be used.

Differences between Analog and Digital Communication

Category	Analog Communication	Digital Communication
Definition	It uses analog signals for transmitting data from transmitter to the receiver.	It uses digital signals for transmitting data from transmitter to the receiver.
Signal	The analog signal is a continuous time varying signal.	Digital signal uses two bits for transmission of level 0 (LOW) and 1 (HIGH).
Noise Immunity	Poor	Good
Error Probability	High	Low
Coding	No	Yes (The digital communication system uses an encoder and decoder for coding at the transmitting and receiving end.)
Flexible	Less flexible	More flexible
Cost	Low cost	High cost
Power consumption	Low	High
Data transmission	Less accurate	More accurate
Examples	Audio signals, speech signals, video signals, etc.	Clock signals
Applications	Radar, Telephony, etc.	Digital watches, Compact Disks, computers, etc.

Data: Data is a collection of raw, unorganized facts and details like text, observations, figures, symbols, and descriptions of things etc. In other words, data does not carry any specific purpose and has no significance by itself. It is measured in terms of bits and bytes in context of computer storage and processing. Data may be analog or digital, qualitative, or quantitative, structured, or unstructured etc.

Analog data: Analog data refers to information that is continuous and take continuous values. It has an infinite number of values.

Digital data: Digital data refers to information that has discrete states and takes only discrete values. It has finite number of values.

Qualitative data: It is non-numerical data. It describes the quality of something or someone. It is descriptive information. For example, the skin colour, eye colour, hair texture, etc. gives us the qualitative information about a person.

Quantitative data: It is a numerical data which provides numerical information. Example: the height and weight of a person.

Structured Data: The data which is organized into specific format, making it easy to search, analyze and process is known as structured data. Structured data is found in relational databases that includes information like numbers, data, and categories.

Unstructured Data: The data which is not organized into specific format is known as unstructured data. It may include some text documents, images, videos, and other data that is not easily organized or analyzed without additional processing.

Information: It is processed, organized, and structured data. It provides context for data and enables decision making.

Data Representation

Data representation is the process of converting raw data into a format that can be understood, processed, and manipulated by a computer system. It involves encoding information in a structured manner so that it can be stored, transmitted, and interpreted effectively.
The data can be represented into different forms such as

- Text
- Numbers
- Images
- Audio
- Video

Text: Text is represented as bit pattern or sequence of bits (such as 0001111). Various types of bits are assigned to represent text symbols. A code where each number represents a character can be used to convert text into binary.
Text File Formats: .doc, .docx, .pdf, .rtf, .txt, etc.

Numbers: Numbers include combination of digits from 0 to 9. Numbers are directly converted into binary patterns by dividing by 2 without any encoding. The numbers we want to transfer generally will be in the decimal number system. We need to convert the numbers from decimal to a binary number system to get a bit stream.
Number File Formats: Integer, Fixed point, Date, Boolean, Decimal, etc.

Images: Images are also represented as bit patterns. An image is composed of matrix of pixels with different values of pixels each where each pixel is represented as dots. Size of the picture is dependent on its resolution. Consider a simple black and white image. If 1 is black (or on) and 0 is white (or off), then a simple black and white picture can be created using binary.
Image File Formats: Image can be in the format of JPEG, PNG, TIFF, GIF, etc.

Audio: Audio signal is a representation of sound or music. Audio differs from all i.e. from text, number, and images. Audio is a series of binary numbers for digital signals. It is continuous but not discrete.
Audio File Formats: MP3, M4A audio file type, FLAC, WAV, WMA, AAC, etc.

Video: Videos consist of a sequence of images (frames) displayed rapidly to create the illusion of motion. Video formats, such as MPEG, compress and store these frames along with audio data to produce a coherent multimedia presentation. Video refers to the recording, broadcasting, copying or playback. Video can either be produced or it is continuous.
Video File Formats: MP4, MOV, AVI, FLV, etc.

Data Flows: It refers the movement of data between devices or processes in computer network. It shows how the data is transferred from source to destination. Data flow is essential for communication, ensuring that information reaches its target accurately and efficiently.
Typically, data flow categorized as simplex, half-duplex, or full-duplex.

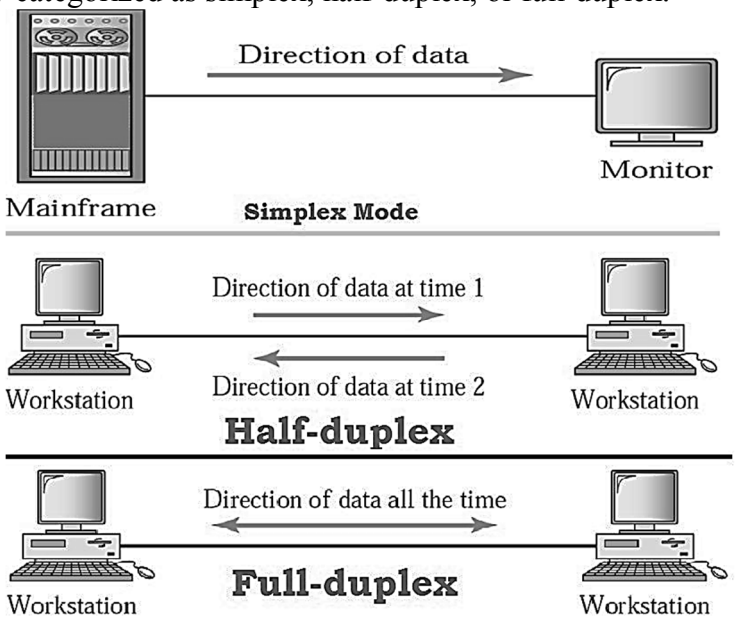

Figure: Data flow or Mode of Communication

Simplex Mode of Communication: Data can only flow in one direction. Think of a keyboard or monitor, where you input data (keyboard) or receive data (monitor), but not both at the same time.

Half-Duplex Mode of Communication: Half-duplex communication allows both parties to transmit and receive data, but not simultaneously. A walkie-talkie is a good example, where one person can speak (transmit) while the other listens (receive), but not both at the same time.

Full-Duplex Mode of Communication: Full-duplex communication allows both parties to transmit and receive data simultaneously. This is common in telephone conversations, where both people can speak and listen at the same time.

Evolution of data communication

The evolution of data communication has been a fascinating journey, shaped by technological advancements and the increasing need for efficient information exchange. It all started with early forms of communication like smoke signals and drum beats, but here's a quick dive into some key milestones:

1. **Telegraph (1830s)**: Samuel Morse's invention revolutionized long-distance communication with Morse code, transmitting messages over wires using electrical signals.
2. **Telephone (1870s)**: Alexander Graham Bell's invention allowed voice communication over long distances, replacing telegraphs for personal and business conversations.
3. **Radio and Television (1900s)**: These mediums enabled broadcast communication, reaching mass audiences globally, transforming how information and entertainment were disseminated.
4. **Computers and Internet (1960s-1990s)**: The development of computers led to the creation of networks like ARPANET, evolving into the internet, allowing computers worldwide to communicate and share data.
5. **Digital Revolution (2000s)**: The proliferation of digital devices, high-speed internet, and mobile technology accelerated data communication, enabling instant messaging, video calls, and cloud computing.
6. **IoT and Big Data (2010s-present)**: The Internet of Things (IoT) expanded data communication to everyday objects, generating massive amounts of data used for analytics, automation, and AI.
7. **5G and Future Innovations**: The rollout of 5G promises even faster and more reliable communication, supporting advanced technologies like autonomous vehicles, virtual reality, and real-time data processing.

A Communication Model

The fundamental purpose of a communications system is the exchange of data between two parties. Generally, communication model has the following key elements i.e. Source system, transmission system and Destination system.

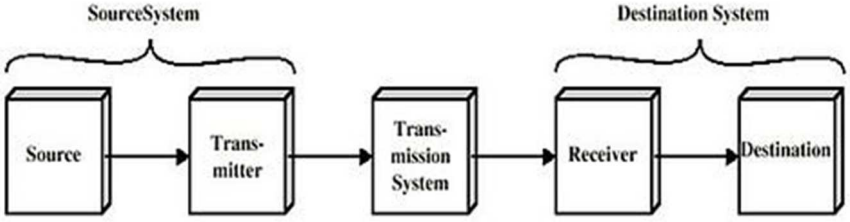

Figure: General block diagram of Communication Model

Source: This device generates the data to be transmitted, examples are telephones and personal computers.

Transmitter: The data generated by a source system are not transmitted directly in the form in which they were generated. Rather, a transmitter transforms and encodes the information in such a way as to produce electromagnetic signals that can be transmitted across some sort of transmission system.

For example, a modem takes a digital bit stream from an attached device such as a personal computer and transforms that bit stream into an analog signal that can be handled by the telephone network.

Transmission System: This can be a single transmission line or a complex network connecting source and destination.

Receiver: The receiver accepts the signal from the transmission system and converts it into a form that can be handled by the destination device.
For example, a modem will accept an analog signal coming from a network or transmission line and convert it into a digital bit stream.

Destination: Takes the incoming data from the receiver.

Communications Tasks
The key tasks that must be performed in a data communications system are:

- **Transmission system utilization:** need to make efficient use of transmission facilities typically share among a number of communicating devices.
- A device must **interface** with the transmission system.
- Once an interface is established, **signal generation** is required for communication.
- There must be **synchronization** between transmitter and receiver, to determine when a signal begins to arrive and when it ends.
- There is a variety of requirements for communication between two parties that might be collected under the term **exchange management**.
- **Error detection and correction** are required in circumstances where errors cannot be tolerated
- **Flow control** is required to assure that the source does not overwhelm the destination by sending data faster than they can be processed and absorbed
- **Addressing and routing**, so a source system can indicate the identity of the intended destination, and can choose a specific route through this network
- **Recovery** allows an interrupted transaction to resume activity at the point of interruption or to condition prior to the beginning of the exchange
- **Message formatting** has to do with an agreement between two parties as to the form of the data to be exchanged or transmitted
- Frequently need to provide some measure of **security** in a data communications system
- **Network management** capabilities are needed to configure the system, monitor its status, react to failures and overloads, and plan intelligently for future growth

Data Communications Model

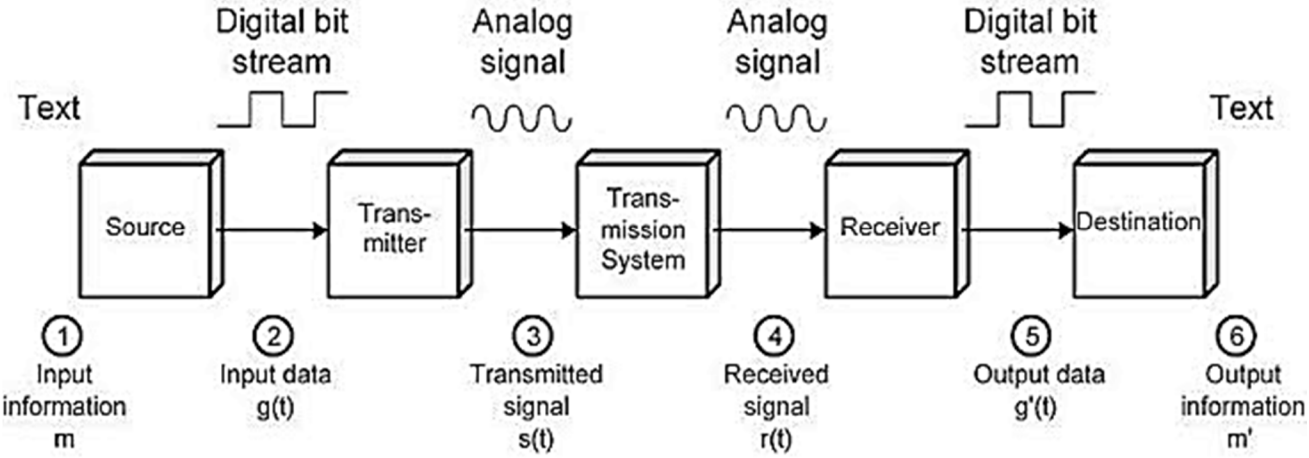

Figure: Simplified data communications model

A new perspective on the communications model shown above is explained below.
We trace the details of above figure using electronic mail as an example. Assume a PC user wants to send an email message m to another user.

The process is modeled as follows:

- User keys in message (m) comprising bits (g) buffered in source PC memory.
- Input data is transferred to I/O device (transmitter) as sequence of bits g(t) using voltage shifts.
- Transmitter converts these into a signal s(t) suitable for transmission media being used.
- whilst transiting media signal may be impaired so received signal r(t) may differ from s(t)
- Receiver decodes signal recovering g'(t) as estimate of original g(t).
- Which is buffered in destination PC memory as bits (g') being the received message (m').

Networks

A network is a group of interconnected nodes or computing devices that exchange data and resources with each other. A network connection between these devices can be established using cable or wireless media.

Networks are categorized on the basis of their size. The three basic categories of computer networks are:

- Local Area Network (LAN)
- Metropolitan Area Network (MAN)
- Wide Area Network (WAN)

Local Area Network (LAN)

A Local Area Network (LAN) is a network that connects computers and other devices within a small geographical area, such as a home, school, office, or building. It provides a means for information exchange among those devices.

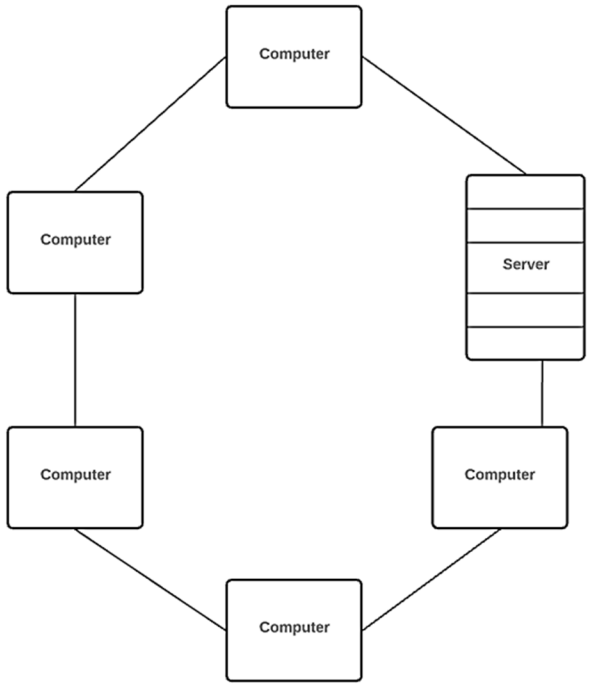

Figure: Local Area Network (LAN)

- Network in which LAN protocols are used or devices are used in LAN
- Communication Infrastructure:
  - Twisted pair cables (Computer below 100)
  - Co-axial Cables (>100)

- Optical Fibers (>1000)

- LAN offers a much higher speed (around 100 mbps) and data transfer rate comparatively to WAN.
- LANs come in a number of different configurations. The most common are
  - switched LANs, e.g. Ethernet LAN, ATM & Fiber Channel LANs
  - wireless LANs
- LAN Transmission Method
  - **Broadband LAN:** FDM, Analog signal, wideband 440 MHz, Data rate slow, expensive
  - **Baseband LAN:** multimedia complications, TDM, digital signal, Bandwidth 50 MHz, Data rate high, use repeaters at each 1500m length, cheap
- The initial setup cost of installing Local Area Networks is high because there is special software required to make a server.
- LANs are restricted in size and cover only a limited area.

Metropolitan Area Networks (MAN)

A Metropolitan Area Network (MAN) is a type of network that connects computers and devices within a city or large campus, covering a larger area than a LAN but smaller than a WAN.

- A MAN is larger than a LAN but smaller than a WAN.
- MAN offers high-speed connectivity in which the speed ranges from 10-100 Mbps.
- large coverage area from 5Km to 50 Km.
- The security level in MAN is high and strict as compared to WAN.
- It may be private or public network
- Communication Infrastructure:
  - CATV (Community Antenna Television Cable)
  - Cables (Twisted, Coaxial)
  - Optical Fibers
  - Radio Links

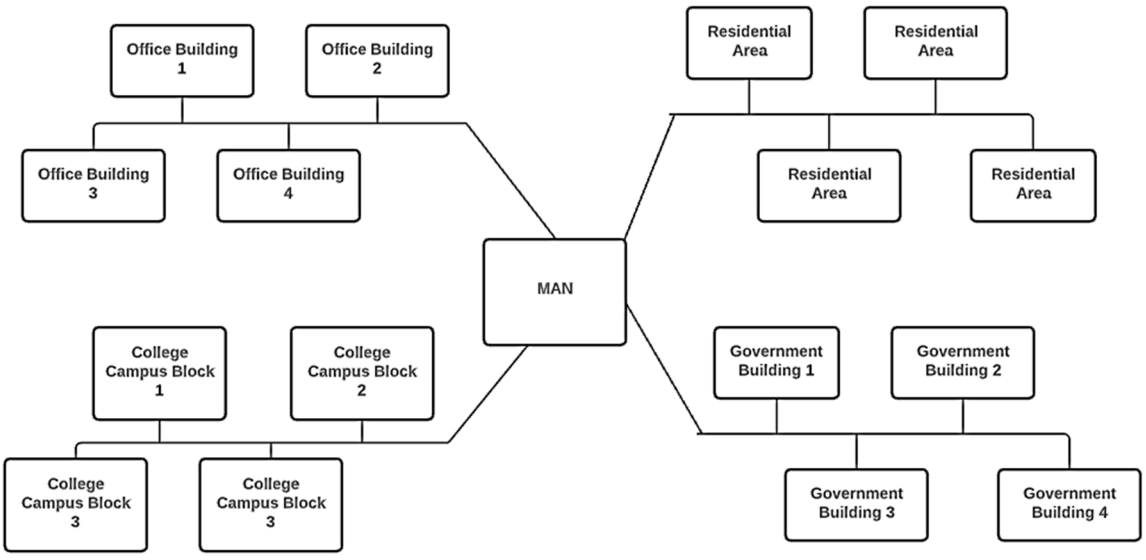

Figure: Metropolitan Area Network (MAN)

Wide Area Networks (WAN)

A Wide Area Network (WAN) is a network that spans a large geographical area, such as a country or even the entire world. It connects multiple LANs and MANs, often using public networks like telephone lines, satellites, or undersea cables.

- Span a large geographical area (Inter City, Inter Country, Inter Continental)
- require the crossing of public right-of-ways
- WAN consists of a number of interconnected switching nodes.
- The data transfer rate is slow in comparison to LAN and MAN
- Traffic congestion in Wide Area Network is very high.
- Communication Infrastructure:
  - **Terrestrial Data Networks:** Cables, Fiber Optics, Radio links etc.
  - **Satellite Based Data Networks:** Geostationary Satellites
- WANs have been implemented using following technologies:
  - circuit switching
  - packet switching
  - frame relay
  - Asynchronous Transfer Mode (ATM)

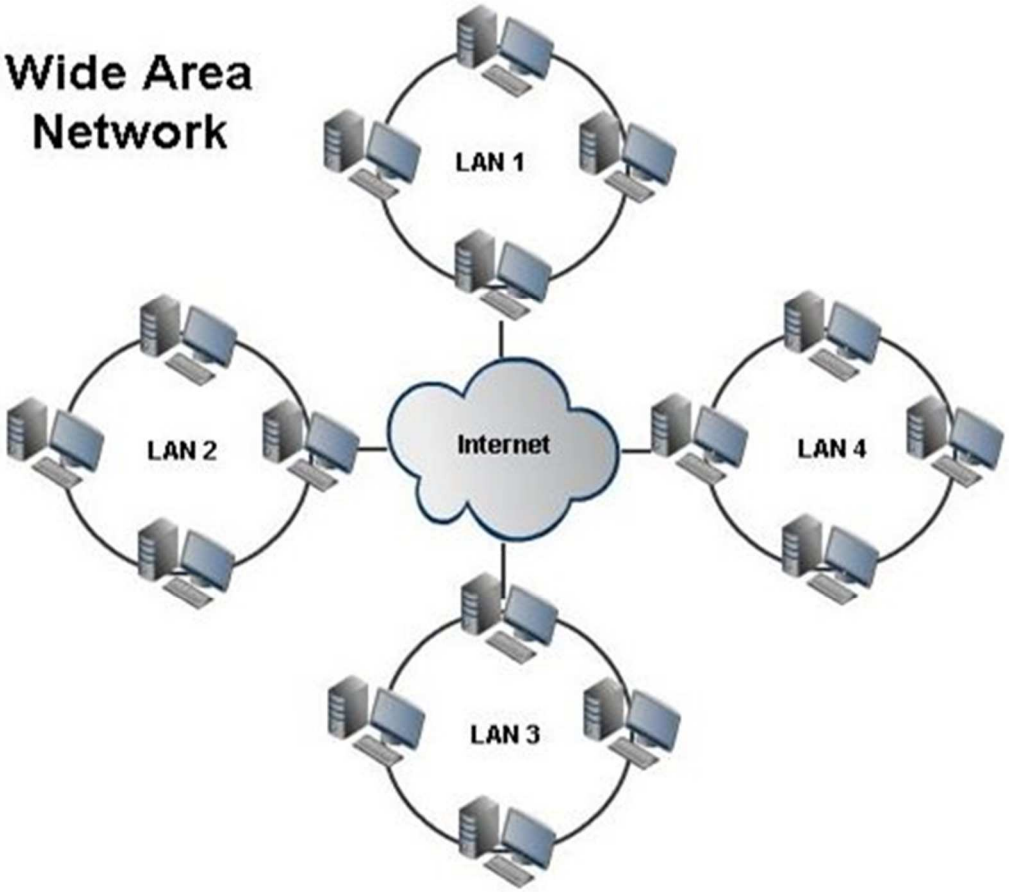

Figure: Wide Area Network

(**Note: PSTN:** Public Switched Telephone Network- any switching system that provides switching transmission facilities to many customers and **PDN:** Public Data Network- any switching system that provides switching transmission facilities as well as storing facilities)

Simplified Network Architecture

Network architecture refers to the design and layout of a computer network. It defines how devices are connected and how data is transmitted between them.

Components of network architecture

The main components of network architecture include the following:

- **Network topology:** The physical or logical layout of the network, which determines how devices are connected and how data is transmitted.
- **The client:** Requests and receives services or resources from a server.
- **Routers:** Find the best paths for smooth communication and connect networks and devices.
- **Switches:** Connect devices like printers and servers. They receive the data and deliver it to the target device.
- **Protocols:** Define the rules that explain how to exchange data and communicate across the network.
- **Transmission media**: Data is transmitted through twisted-pair cables, coaxial cables, fiber optic cables, or wireless media (radio waves).

Network Architecture Types
Computer networks can be classified based on architecture into two primary types:
- Peer-to-Peer Architecture
- Client/Server Architecture

Peer-to-Peer (P2P) Network
A peer-to-peer network is an easy-to-set-up network where each peer or node acts as client and server. Every peer can share resources and data with other peers directly. Also, users can control who can access their data and resources. This type of network is ideal for small-scale applications usually up to at least 10 computers like:
- File sharing
- Messaging
- Gaming

Client-Server Architecture
In client-server architecture, there's a difference between both clients and servers. A server receives client requests, processes them, and delivers them to the target point. It performs the following tasks:
- Stores data.
- Ensures security.
- Manages resources

Client-service architecture supports efficient file sharing, database management, email, and web hosting.

Hybrid Network Architecture
Hybrid network architecture combines the elements of both peer-to-peer and client-server network architecture. In this network, the devices can act as both clients and servers. These days, sensors are installed in almost all physical objects. The network of these objects is defined as IoT, which is based on hybrid network architecture.

Cloud-Based Architecture
Cloud computing architecture designs a platform where users can access resources and services on demand. It has two main parts:
- **The front end** is the client-side interface where users interact with cloud services.
- **The back end** includes the cloud provider's resources, such as data storage, services, and applications.

The OSI Model

Open System Interconnection (OSI) is a reference model developed in 1984 by the International Organization for Standardization that specifies how information from one computer's software application passes through physical media to another computer's software application.

The model defines a set of rules and requirements for data communication and interoperability between different devices, products, and software in a network infrastructure. The OSI model is split into seven fundamental layers (bottom to top): Physical, Data Link, Network, Transport, Session, Presentation, and Application. The data flows from layer 7 to layer 1 at the sender side, while from layer 1 to layer 7 at the recipient's side.

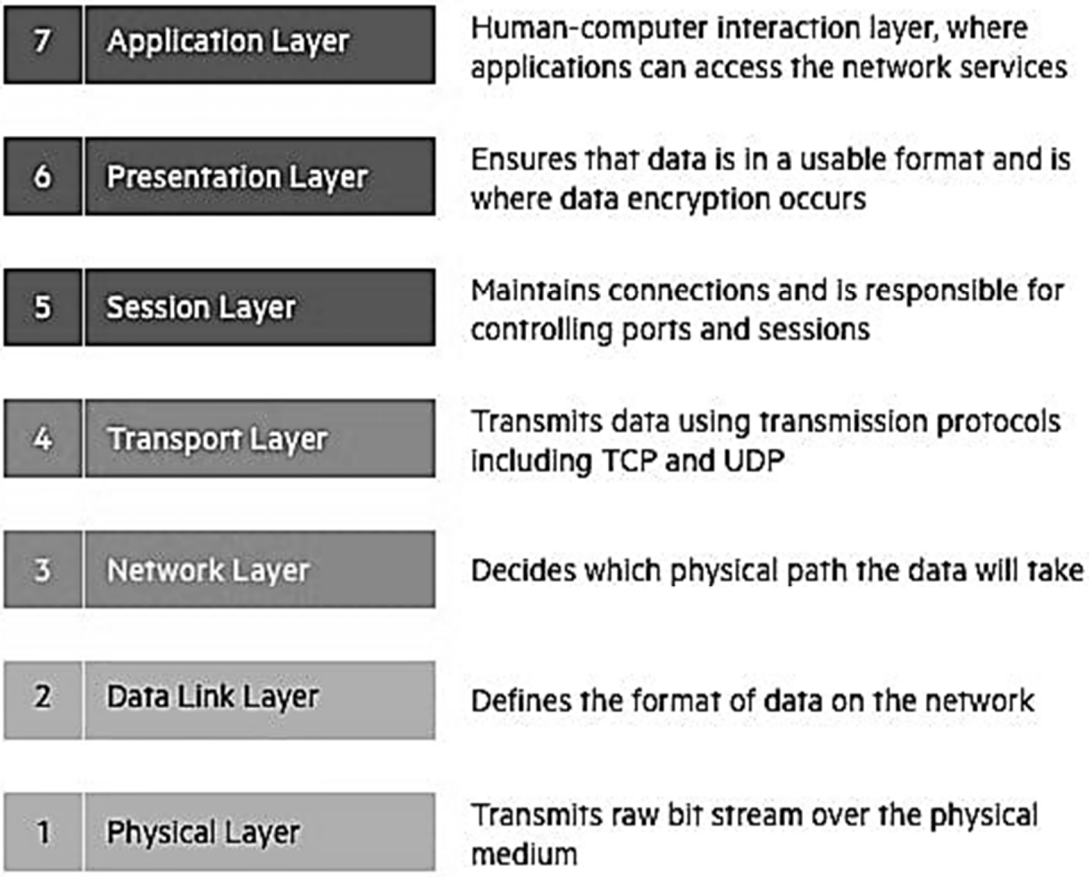

Figure: ISO model

7 Layers of the OSI Model:

- **Physical Layer:** Handles raw data transmission between devices via cables or wireless signals.
- **Data Link Layer:** Ensures error-free data transfer between nodes using frames and MAC addresses.
- **Network Layer:** Routes data packets to their destination using IP addresses and routing protocols.
- **Transport Layer:** Manages data flow, error checking, and delivery through TCP/UDP.
- **Session Layer:** Establishes, manages, and terminates communication sessions between devices.
- **Presentation Layer:** Translates, encrypts, and compresses data for application use.
- **Application Layer:** Provides a user interface and supports services like email and file transfer.

OSI Model Layers

Each layer in the OSI model performs a defined function essential to maintain smooth data flow in a network.

7. Application Layer

The application layer is the topmost layer in the OSI model. The layer establishes communication between the application on the network and the end user using it by defining the protocols for successful user interaction. An excellent example of this layer is that of web browsers.

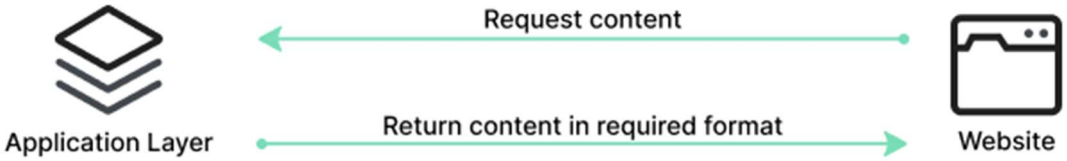

Figure: Application Layer

Application layer protocols allow the software to direct data flow and present it to the user. Some of the known protocols include Hypertext Transfer Protocol (HTTP), Simple Mail Transfer Protocol (SMTP), and File Transfer Protocol (FTP).

Key functions:

- The application layer provides user interfaces (UI) that are key to user interaction
- Supports a variety of applications such as e-mail and remote file transfer

6. Presentation Layer

The presentation layer is often referred to as syntax or translation layer as it translates the application data into a network format. This layer also encrypts and decrypts data before transmitting it over the network. This layer is known to compress data received from Application Layer to reduce the overall size of the data transferred.

Figure: Presentation Layer

Key functions:

- Performs data translation based on the application's data semantics
- Encrypts and decrypts sensitive data transferred over communication channels
- Performs data compression to reduce the number of bits in exchanged data

5. Session Layer

The session layer establishes a communication session between communicating entities. The session is maintained at a sufficient time interval to ensure efficient data transmission and avoid wasting computing resources.

Figure: Session Layer

This OSI layer is also responsible for data synchronization to maintain smooth data flow. This implies that in situations where large volumes of data are sent at once, Session Layer can break down the data into smaller chunks by adding checkpoints.

Key functions:

- Opens maintains, and closes communication sessions
- Enables data synchronization by adding checkpoints to data streams

4. Transport Layer

The transport layer allows safe message transfer between the sender and the receiver. It divides the data received from the session layer into smaller segments. It also reassembles the data at the receiver side to allow the session layer to read it.

Figure: Transport Layer

Transport layer performs two critical functions: flow control and error control.

Flow control: It implies regulating data transfer speeds. It ensures that the communicating device with a good network connection does not send data at higher rates, which is difficult for devices with slower connections to handle.

Error control: It refers to the error-checking functionality to ensure the completeness of data. In incomplete data cases, this layer requests the system to resend the incomplete data.

Transport layer protocols include transmission control protocol (TCP) and user datagram protocol (UDP).

Transmission Control Protocol (TCP): It is connection oriented and ensures reliable data transfer with error checking and flow control, making it suitable for applications like email and web browsing

User Datagram Protocol (UDP): It is connectionless, offering faster, though less reliable, transmission, suitable for application like online gaming and video streaming.

Key functions:

- Ensures completeness of each message exchanged between source and destination
- Maintains proper data transmission through flow control and error control
- Performs data segmentation and reassembling of data

3. Network Layer

The network layer enables the communication between multiple networks. It receives data segments from the layer above, further broken down into smaller packets at the sender side. On the receiver side, this layer reassembles the data together.

Figure: Network layer

The network layer also handles routing functionality, wherein the data transmission is accomplished by choosing the best possible route or path that connects different networks and ensures efficient data transfer. This network layer uses internet protocol (IP) for data delivery.

Key functions:

- Handles routing to recognize suitable routes from sender to receiver
- Performs logical addressing that assigns unique names to each device operating over the network

2. Data Link Layer

The data link layer transmits data between two nodes that are directly connected or are operating over the same network architecture. Typically, this layer takes data packets from network layer and breaks them down into frames before sending them to the destination.

Figure: Data Link Layer

Data link layer is divided into two sub-layers: media access control (MAC) and logical link control (LLC). The MAC layer encapsulates data frames transmitted through the network connecting media such as wires or cables. In situations where such data transmission fails, LLC helps manage packet retransmission.

The well-known data link layer protocol includes the Address Resolution Protocol (ARP) that translates IP addresses to MAC addresses to establish communication between systems whose addresses vary in bit length (32 bits vs. 48 bits).

Key functions:

- Detects damaged or lost frames and retransmits them
- Performs framing where data received from layer 3 is further subdivided into smaller units called frames
- Updates headers of created frames by adding the MAC address of the sending device and receiving device

1. Physical Layer:

The physical layer manages physical hardware and network components such as cables, switches, or routers that transmit data.

In the context of data, Physical layer transmits data in the form of ones and zeros. Technically, this layer picks up bits from the sender end, encodes them into a signal, sends the signal over the network, and decodes the signal at the receiver end. Thus, without Physical layer, communicating data bits across network devices through physical media is not possible.

Figure: Physical layer

Key functions:

- Synchronizes data bits
- Enables modulation (conversion of a signal from one form to another for data transmission)
- Defines data transmission rate (bits/sec)
- Outlines the arrangement of network devices across different network topologies such as bus, tree, star, or mesh topology
- Defines transmission modes such as simple or half-duplex mode

Advantages of the OSI Model

- OSI model is a generic tool supported by a wide range of device manufacturers. It serves as a tool to develop any network model.
- Each layer is separate from the other layers. Changes in one layer do not impact the other layers unless there are changes in the layer interface.
- The OSI model highlights the different tasks in each layer. It helps all the devices that work with the OSI model to support each other.
- It is flexible.
- The model can work with both connection-oriented and connectionless services.

Disadvantages of the OSI Model

- It is a theoretical model. It does not consider the availability of appropriate technology, which restricts its practical implementation.
- OSI model is complex in structure compared to a TCP/IP model.
- It is not as effective as the TCP/IP model.
- Some layers, including the session layer and presentation layer, have little functionality when deployed practically.

Data Communication and Networking for Today's Enterprise

Data Communication and Networking refers to the technologies, systems, and practices that organizations use to exchange data securely, reliably, and efficiently across internal and external networks. This is foundational to modern business operations, enabling communication, collaboration, and access to resources in real-time, regardless of location.

Modern Technologies in Enterprise Networking

Technology	Description
Cloud Computing	Data and applications hosted on the cloud (e.g., AWS, Azure) require efficient networking.
Wi-Fi 6 / 6E	New standards improving wireless speed and capacity.
Fiber Optics	High-speed backbone for enterprise data transmission.
5G Connectivity	Supports mobile enterprise solutions with faster wireless speeds.
IoT Integration	Networks support sensors and smart devices (e.g., in manufacturing, logistics).
Network Virtualization	Uses software to manage networks, increasing flexibility and reducing costs.

Today's trends in enterprises

Network Automation: Reduces human error speeds up configuration.
AI & Machine Learning in Networking: Predictive maintenance, traffic optimization.
Hybrid Cloud Networks: Seamless connectivity between on-premises and cloud services.
Edge Computing: Processing data closer to the source to reduce latency.

Importance of Data Communication and Networking for Today's Enterprises

- Enables remote work and global collaboration.
- Supports real-time applications (e.g., video conferencing, VoIP).
- Facilitates data-driven decision-making via fast data access.
- Protects sensitive business data.
- Reduces downtime and improves business continuity.