QB - Difference between bluetooth & BLE

QB - Describe different types of Topologies used in sensor Network.

QB - List differences between bluetooth & BLE.

2.1 INTRODUCTION TO SENSORS AND TRANSDUCERS

Introduction

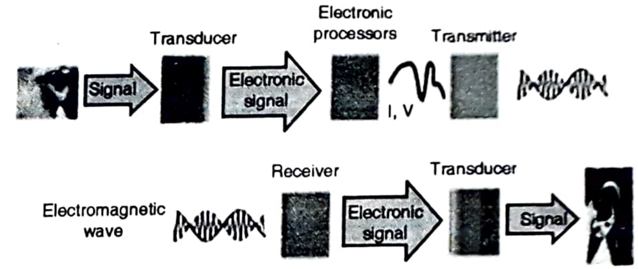

Fig. 2.1.1 : Introduction to Sensors and Transducers

Measurement is an important subsystem in any major system, whether it may be a mechanical system or an electronic system. A measurement system consists of sensors, actuators, transducers and signal processing devices. The use of these elements and devices is not limited to measuring systems.

These are also used in the systems which perform specific tasks, to communicate with the real world. The communication can be anything like reading the status of a signal from a switch or to trigger a particular output to light up an LED.

2.2 SENSOR AND TRANSDUCER DEFINITIONS

GQ. Define Sensor and Transducer. **(4 Marks)**

- The words sensors and transducers are widely used in association with measurement systems. The sensor is an element that produces signals relating to the quantity that is being measured. According to Instrument Society of America, "a sensor is a device that provides usable output in response to a specified quantity which is measured." The word sensor is derived from the original meaning 'to perceive'.
- In simple terms, a sensor is a device that detects changes and events in a physical stimulus and provides a corresponding output signal that can be measured and/or recorded. Here, the output signal can be any measurable signal and is generally an electrical quantity.
- Sensors are devices that perform input function in a system as they 'sense' the changes in a quantity. The best example of a sensor is mercury thermometer. Here the quantity that is being measured is heat or temperature.

- The measured temperature is converted to a readable value on the calibrated glass tube, based on the expansion and contraction of liquid mercury.
- Actuators are devices that work opposite to sensors. A sensor converts a physical event into an electrical signal, whereas an actuator converts electrical signal into a physical event. When sensors are used at input of a system, actuators are used to perform output function in a system as they control an external device.
- Transducers are the devices that convert energy in one form into another form. Generally the energy is in the form of a signal. Transducer is a term collectively used for both sensors and actuators.

☞ Criteria to Choose a Sensor

GQ. Explain different criteria to choose Sensor. **(4 Marks)**

The following are certain features that are considered when choosing a sensor.

1. **Type of Sensing :** The parameter that is being sensed like temperature or pressure.
2. **Operating Principle :** The principle of operation of the sensor.
3. **Power Consumption :** The power consumed by the sensor will play an important role in defining the total power of the system.
4. **Accuracy :** The accuracy of the sensor is a key factor in selecting a sensor.
5. **Environmental Conditions :** The conditions in which the sensor is being used will be a factor in choosing the quality of a sensor.
6. **Cost :** Depending on the cost of application, a low cost sensor or high cost sensor can be used.
7. **Resolution and Range :** The smallest value that can be sensed and the limit of measurement are important.
8. **Calibration and Repeatability :** Change of values with time and ability to repeat measurements under similar conditions.

☞ Basic Requirements of a Sensor or Transducer

GQ. Explain basic requirement of a Sensor or Transducer.

The basic requirements of a sensor are :

1. **Range :** It indicates the limits of the input in which it can vary. In case of temperature measurement, a thermocouple can have a range of 25 – 250°C.

2. **Accuracy :** It is the degree of exactness between actual measurement and true value Accuracy is expressed as percentage of full range output.
3. **Sensitivity :** Sensitivity is a relationship between input physical signal and output electrical signal. It is the ratio of change in output of the sensor to unit change in input value that causes change in output.
4. **Stability :** It is the ability of the sensor to produce the same output for constant input over a period of time.
5. **Repeatability :** It is the ability of the sensor to produce same output for different applications with same input value.
6. **Response Time :** It is the speed of change in output on a stepwise change in input.
7. **Linearity :** It is specified in terms of percentage of nonlinearity. Nonlinearity is an indication of deviation of curve of actual measurement from the curve of ideal measurement.
8. **Ruggedness :** It is a measure of the durability when the sensor is used under extreme operating conditions.
9. **Hysteresis :** The hysteresis is defined as the maximum difference in output at any measurable value within the sensor's specified range when approaching the point first with increasing and then with decreasing the input parameter. Hysteresis is a characteristic that a transducer has in being unable to repeat its functionality faithfully when used in the opposite direction of operation.

☞ Classification of Sensors

GQ. Explain different types of sensor. **(4 Marks)**

The scheme of classifying sensors can range from very simple to very complex. The stimulus that is being sensed is an important factor in this classification.

Some of the stimuli are :

1. **Acoustic :** Wave, spectrum and wave velocity.
2. **Electric :** Current, charge, potential, electric field, permittivity and conductivity.
3. **Magnetic :** Magnetic field, magnetic flux and permeability.
4. **Thermal :** Temperature, specific heat and thermal conductivity.
5. **Mechanical :** Position, acceleration, force, pressure, stress, strain, mass, density, momentum, torque, shape, orientation, roughness, stiffness, compliance, crystallinity and structural.

...een actual measurement and true value
...e output.
...ween input physical signal and output
...put of the sensor to unit change in input
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...ge of nonlinearity. Nonlinearity is an
...asurement from the curve of ideal
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...ximum difference in output at any
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(4 Marks)

...ery simple to very complex. The
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6. **Optical :** Wave, wave velocity, refractive index, reflectivity, absorption and emissivity.

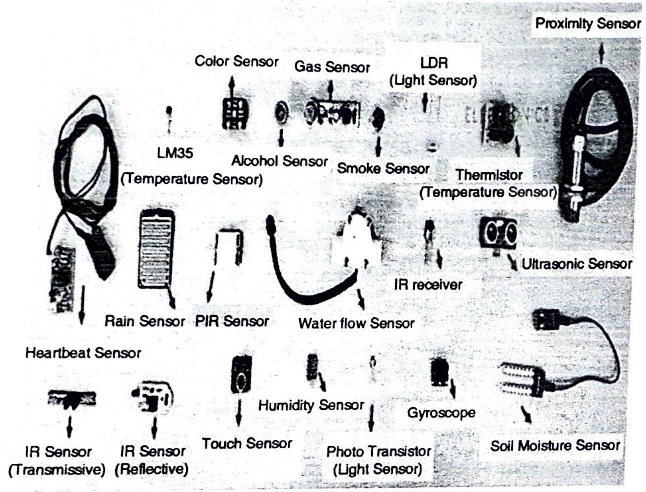


Fig. 2.2.1 : Different Types of Sensors

The sensors' conversion phenomenon is also an important factor in classification of sensors. Some of the conversion phenomena are magneto electric, thermoelectric and photoelectric.

Based on the applications of sensors, their classification can be made as follows.

I. Displacement, Position and Proximity Sensors

- Resistive Element or Potentiometer
- Capacitive Elements
- Strain Gauged Element
- Inductive Proximity Sensors
- Eddy Current Proximity Sensors
- Differential Transformers
- Optical Encoders
- Hall Effect Sensors

- Pneumatic Sensors
- Proximity Switches
- Rotary Encoders

II. Temperature Sensors

- Thermistors
- Thermocouple
- Bimetallic Strips
- Resistance Temperature Detectors
- Thermostat

III. Light Sensors

- Photo Diode
- Phototransistor
- Light Dependent Resistor

IV. Velocity and Motion

- Pyroelectric Sensors
- Tachogenerator
- Incremental encoder

V. Fluid Pressure

- Diaphragm Pressure Gauge
- Tactile Sensor
- Piezoelectric Sensors
- Capsules, Bellows, Pressure Tubes

VI. Liquid Flow and Level

- Turbine Meter
- Orifice Plate and Venturi Tube

VII. IR Sensor

- Infrared Transmitter and Receiver Pair

VIII. Force

- Strain Gauge
- Load Cell

IX. Touch Sensors

- Resistive Touch Sensor
- Capacitive Touch Sensors

X. UV Sensors

- Ultraviolet Light Detector
- Photo Stability Sensors
- UV Photo Tubes
- Germicidal UV Detectors

All the sensors can be classified into two types based on the power or signal requirement. They are Active sensors and passive sensors.

In order to operate active sensors, require power signal from an external source. This signal is called an excitation signal, and based on this excitation signal the sensor produces output. Strain gauge is an example of active sensor. It is a pressure sensitive resistive bridge network and doesn't produce the output electrical signal on its own. The amount of force applied can be measured by relating it to the resistance of the network. The resistance can be measured by passing current through it. Current acts as the excitation signal.

In contrast, passive sensors directly produce the output electrical signal in response to the input stimulus. All the power required by a passive sensor is obtained from the measurand. A thermocouple is a passive sensor.

Commonly used Sensors and Transducers

Some of the most commonly used sensors and transducers for different stimuli (the quantity to be measured) are :

- For sensing light, the input devices or sensors are photo diode, photo transistor, light dependent resistor and solar cells. The output devices or actuators are LEDs, displays, lamps and fiber optics.
- For sensing temperature, the sensors are thermistor, thermocouple, resistance temperature detectors and thermostat. The actuators are heaters.

- For sensing position, the input devices are potentiometer, proximity sensor, and differential transformer. The output devices are motor and panel meter.
- For sensing pressure, the sensors are strain gauge and load cell. The actuators are lifts and jacks and electromagnetic vibrations.
- For sensing sound, the input devices are microphones and output devices are loudspeakers and buzzers.
- For sensing speed, the sensors used are tachogenerator and Doppler Effect sensors. The actuators are motors and brakes.

2.3 ACTUATORS - DEFINITION, PRINCIPLES, CLASSIFICATIONS, TYPES, CHARACTERISTICS AND SPECIFICATIONS

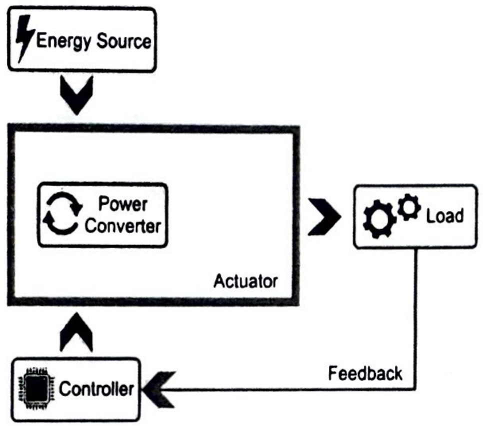
(5 marks)

GQ. Explain in details Actuators. **(4 Marks)**

- An actuator is a machine, or rather a part of a machine used to convert externally available energy into motion based on the control signals.
- Much like how hands and legs enable humans to move around and perform actions, actuators let machines perform various mechanical movements. The topic for discussion for this article is actuators. We will explain what is an actuator, how actuators work, and what are the different types of actuators used in industrial and domestic applications.
- From the perspective of systems engineering, functions of any engineering product can be classified into three distinct categories; the collection of input, processing and producing an output.
- For electromechanical systems, the input is detected and measured by a device called a sensor. The task of a sensor is to sample the signals available to it and convert them into a form understandable by the system. The system then processes the information and decides how to respond.
- But how exactly does a system respond? The answer is, with the help of an Actuator.
- Typically, an actuator consists of :

  (1) **Energy source :** Energy sources provide actuators with the ability to do work. Actuators draw electrical or mechanical energy from external sources for carrying out their operation. The energy available to the actuator can be regulated or unregulated depending on the system that it is a part of.

(2) **Power converter :** If the energy source attached to the actuators is unregulated, it requires some additional apparatus to regulate it and convert it into a form suitable for the actuation action. Hydraulic valves or solid-state power electronic converters are examples of converters used in industrial actuators.



(1B1)Fig. 2.3.1 : Power Converter

Functional block diagram of an actuator

(1) **Controller :** In addition to enabling the operation of the power converter, a control unit is responsible for generating actuating signals. In some systems, it provides the user with an interface to provide inputs or check the system's status.

(2) **Load :** The mechanical system attached to the actuator that uses the motion of the actuator is called the load. Characteristics like Force/Torque and Speed are carefully tuned before interfacing an actuator with the load.

☞ Classification of actuators based on the motion

GQ. Explain Different types of Actuators. **(4 Marks)**

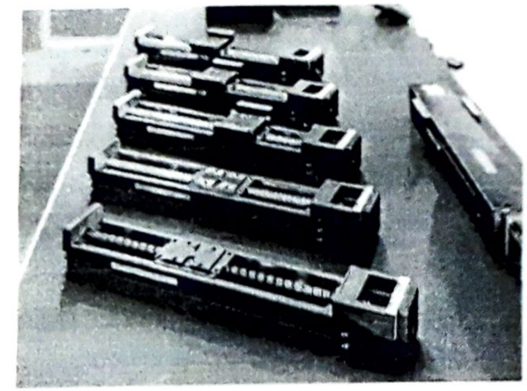
The most apparent and basic classification of actuators is based on the type of motion that it produces.

1. Rotary Actuator

The actuators that can provide a circular motion at their output can be classified under the category of rotary actuators. When it comes to rotational motion, it is hard to think of any other device than the motors, which we shall discuss in the next section of this article.

2. Linear Actuators

The actuators that can provide motion in a straight line at their output can be classified under the category of linear actuators. Hydraulic or Pneumatic actuators are the most common linear actuators used in the industry. We will also discuss these devices in detail.



(1B2)Fig. 2.3.2 : Linear Actuators

With the help of suitable equipment, it is possible to use a rotary actuator to produce linear motion and a linear actuator to produce rotary motion

☞ Classification of actuators based on the energy source

The energy source can be another means of classification for the actuators.

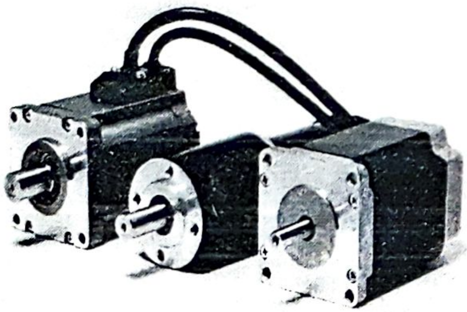
1. Electromagnetic Actuators

Electromagnetic actuators make use of electricity and magnetism to perform actuation. These actuators are among the most commonly used actuators in the industries.

2. AC and DC Servo Motor actuators

- Electrical motors are among the most versatile actuators suitable for a plethora of different application scenarios.
- Servo drives can be powered by an AC or DC power supply and consist of a motor, feedback unit, control unit, and sometimes a gearbox. The working of a servo motor greatly differs from that of ordinary AC or DC motors. To operate a servo motor, a control signal is required in addition to the power.
- Initially, when a voltage is applied to the terminals of a servo motor, it begins to rotate. The position of the shaft is continuously monitored by a rotary encoder, and the voltage-current levels are kept in check by the voltmeter-ammeter combination.

The controller then computes the motor's actual speed, compares it with the target speed, and adjusts the voltage and current levels to reduce the error between the target speed and actual speed.



(1B3) Fig. 2.3.3 : AC and DC Servo Motor

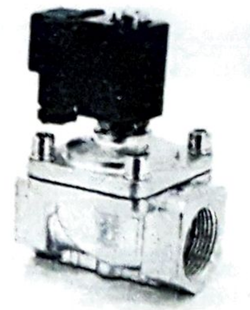
3. Stepper Motor Actuators

- Stepper motors are used for applications where the angular position of the shaft needs to be accurately controlled. The control scheme of the stepper motor is simple, accurate and doesn't require any feedback. This is the reason why they are often more affordable.
- The stator of the stepper motor contains multiple teeth, each acting as a pole for the rotor. When a particular pole or a set of poles are energised, the rotor reorients itself to allow maximum MMF to pass through it. When the next step of the poles is energised, the rotor shifts its position. This allows the rotor to complete a revolution in several distinct steps, and that's how the motor gets its name.

4. Solenoid Actuators

- A solenoid actuator consists of a conducting coil wound on a ferromagnetic core with a flat head on one side and a spring connected on the other. The whole apparatus is placed in a hollow cylindrical body.
- Whenever current flows through the wire, the coil acts as an electromagnet, attracting the ferromagnetic core in one direction and compressing the spring during the process.
- Solenoid Valves are used in controlling flow of liquids in industrial processes

- Once the power supply is removed, the spring pushes the core back to the original position. The strength of the actuator depends upon the number of turns in the coil. The setup looks and acts a lot like a piston.



(1B4)Fig. 2.3.4 : Solenoid Actuators

5. Fluid Power Actuators

- The actuators that make use of liquids or gasses are called fluid power actuators. On a very superficial level, we can think of a fluid power actuator as a moving disk inside a hollow cylinder filled with fluid forming a piston.
- he movement of the disk appears as the motion of the actuator. Advanced fluid actuators with dual-acting cylinders make use of fluid for both extension and retracement strokes.

6. Hydraulic Actuators

- These actuators make use of liquids as a driving force to produce mechanical work. Hydraulic Actuators are probably the most widely used linear actuators in real-life applications. These devices are used when stable, but high actuating thrust/forces are required in a small region.

(1B5)Fig. 2.3.5 : Hydraulic Actuators

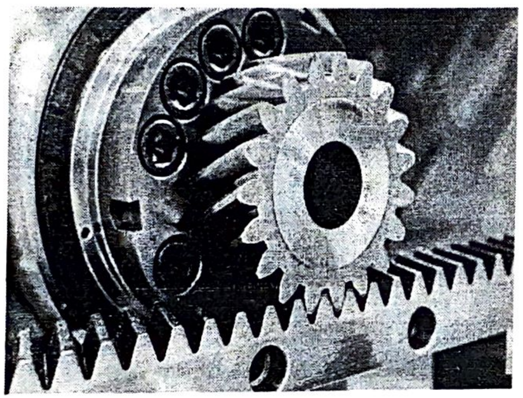
- Hydraulic and pneumatic actuators use the power of fluids to apply a force

7. Pneumatic Actuators

The design and construction of pneumatic actuators are very similar to that of hydraulic actuators. The difference is that instead of using a liquid, energy from compressed gases or vacuum is used to facilitate the actuation process.

8. Mechanical Actuators

- These actuators are used to interconvert rotary and linear motion in machines. Some examples of mechanical actuators are rack and pinion arrangements, crankshafts, gears, pulleys, and chains.



(1B6)**Fig. 2.3.6 : Mechanical Actuators**

- Rack and pinion arrangement for converting rotational motion into linear motion and vice versa

9. Thermal Actuators

Thermal actuators make use of materials that expand or contract by the application of heat. These actuators can be used to sense temperatures and shut off a supply to the system they are a part of. Thermal actuators combine the functions of a temperature switch and an actuator in a single package.

10. Special Actuators

Apart from the commonly used actuators, some actuators are still under research and find their application in limited fields.

11. Piezoelectric Actuators

- Piezoelectric materials exhibit a contraction/expansion whenever a voltage is applied to them. By applying a controlled signal, this property of piezoelectric materials can be used to build actuators for small but highly precise and rapid positioning mechanisms.
- Piezoelectric plates are used in mist makers to atomise water into small droplets and create mist.

(1B7)**Fig. 2.3.7 : Piezoelectric Actuators**

12. Shape Memory Alloy Actuators

- Shape Memory Alloys (SMAs) undergo a change in their molecular arrangement when they are heated or cooled. When a force is applied to alloys like Nitinol (Nickel-Titanium), they experience a deformation that can be reversed with heating.
- Heating can be done directly by application of thermal energy or with the help of electric power. This property of SMAs can be used to build actuators.

13. Supercoiled Polymer Actuators

- It gets challenging to downsize conventional actuators like electric motors beyond a certain limit, making them unsuitable for miniature machines. This is where Supercoiled Polymer Actuators (SPAs) come in. Supercoiling is a property of DNA strands that makes it possible for them to relieve stress by twisting around themselves.
- SPAs are inspired by a similar design that lets them reversibly change their shape and size when stimulated. These structures respond quickly and can last for millions of cycles.

14. Hydrogel actuators

- Hydrogel actuators demonstrate a change in their shape with changes in the temperature, light, pH and concentration of certain substances. The fact that hydrogels can be effective only in aqueous medium limits their applications to some specific specialised fields.

(1B8)Fig. 2.3.8 : Hydrogel actuators

- Bending behaviour of Polydimethylsiloxane Hydrogel actuator in aqueous solution. Source : The Faboratory at Yale University
- Research shows that some hydrogel actuators can be optically and sonically camouflaged as their properties are similar to that of water.

☞ Applications of Actuators

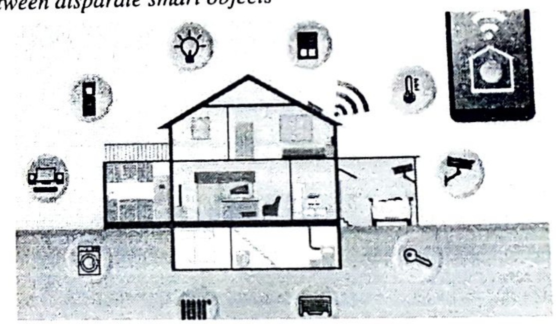
- An actuator that can generate sufficient force has suitable load-speed characteristics, works in the operating range with high efficiency, and comes with a robust design is considered ideal for a given application.
- Industrial automation and robotics are the two fields where it is just impossible to imagine getting anything done without actuators. These parts enable production machines to move from one place to another and grab objects. Actuators are also widely used in heavy construction equipment and agricultural machinery to enable several different sets of movements. Another beautiful application of actuators can be in solar panels. As the sun rises and sets during the day, the solar panels equipped with actuators keep changing their angle to harness maximum solar energy.
- Coming to household applications, actuators can be found in almost every smart home appliance, from furniture to robotic vacuum cleaners that require any sort of manoeuvre. A lot of toys too contain some small actuators built-in them. The applications are endless.

⏭ 2.4 SMART OBJECT

GQ. Write a short note on Smart Object. **(2 Marks)**

- "A **smart object** is an object that enhances the interaction with other smart objects as well as with people also.

- The world of IoT is the network of interconnected heterogeneous objects (such as smart devices, smart objects, sensors, actuators, RFID, embedded computers, etc.) uniquely addressable and based on standard communication protocols.
- In a day to day life, people have a lot of object with internet or wireless or wired connection. Such as :
  - Smartphone
  - Tablets
  - TV computer
- These objects can be interconnected among them and facilitate our daily life (smart home, smart cities) no matter the situation, localization, accessibility to a sensor, size, scenario or the risk of danger.
- Smart objects are the building blocks of the Internet of Things (IoT). In the past, I've built an Infrared Temperature Scanner using a Raspberry Pi and some accessories. A standalone device like this can be extremely useful.
- However, "*the real power of smart objects in IoT comes from being networked together rather than being isolated as standalone objects. This ability to communicate over a network has a multiplicative effect and allows for very sophisticated correlation and interaction between disparate smart objects*"



(1B9)Fig. 2.4.1 : Smart Objects

By **definition**, a smart object must contain the following features :

1. **Processing Unit :** A small computer, typically featuring an AMD chipset, which receives input from sensors and produces output for actuators and/or for communication with other devices (which can include other smart objects, controllers, gateways, routers, back haul network)

2. **Sensor(s) and/or actuator(s) :** Sensors collect or measure data, which is then processed by the processing unit (see above) to produce a digital representation of that data which can then be acted upon, either by actuation or communication. Actuators do things and are usually classified by the type of motion they produce, their power output, whether they're binary or continuous, their area of application or their type of energy (mechanical, electrical, hydraulic, electromagnetic, etc.)

3. **Communication device(s) :** This unit is responsible for connecting the smart object with other smart objects and/or the network. In IoT Edge devices, communication is usually wireless.

4. **Power source :** because IoT devices are often scattered in the field, it's often impractical to power them externally. This, most smart objects are battery-powered (long-lasting) or utilize solar or other power which can be claimed from the surrounding environment.

☞ Trends in Smart Objects

(1) Size is decreasing
(2) Power consumption is decreasing
(3) Processing power is increasing
(4) Communication capabilities are improving
(5) Communication is being increasingly standardized

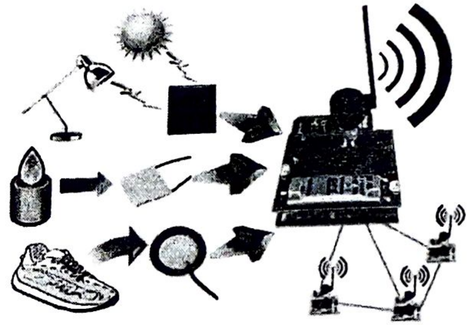
The future of IoT is tremendous and experts predict we'll see trillions of sensors in the field within a few years.

⏭ 2.5 WHAT IS A WIRELESS SENSOR NETWORK?

GQ. Explain WSN. **(4 Marks)**

- A Wireless Sensor Network is one kind of wireless network that includes a large number of circulating, self-directed, minute, low powered devices named sensor nodes called motes.
- These networks certainly cover a huge number of spatially distributed, little, battery-operated, embedded devices that are networked to caringly collect, process, and transfer data to the operators, and it has controlled the capabilities of computing & processing. Nodes are tiny computers, which work jointly to form networks.
- The sensor node is a multi-functional, energy-efficient wireless device. The applications of motes in industrial are widespread. A collection of sensor nodes collects the data from the surroundings to achieve specific application objectives.

- The communication between motes can be done with each other using transceivers. In a wireless sensor network, the number of motes can be in the order of hundreds/ even thousands. In contrast with sensor networks, Ad Hoc networks will have fewer nodes without any structure.



(1B10) Fig. 2.5.1 : Wireless Sensor Network

Wireless Sensor Network Architecture

- The most common wireless sensor network architecture follows the OSI architecture Model. The architecture of the WSN includes five layers and three cross layers.
- Mostly in sensor network, we require five layers, namely application, transport, network, data link and physical layer. The three cross planes are namely power management, mobility management, and task management.
- These layers of the WSN are used to accomplish the n/w and make the sensors work together in order to raise the complete efficiency of the network. Please follow the below link for Types of wireless sensor networks and WSN topologies

☞ Types of WSN Architectures

- The architecture used in WSN is sensor network architecture. This kind of architecture is applicable in different places such as hospitals, schools, roads, buildings as well as it is used in different applications such as security management, disaster management & crisis management, etc.
- There are two types of architectures used in wireless sensor networks which include the following :

- There are 2 types of wireless sensor architectures :

1. Layered Network Architecture
2. Clustered Network Architecture

1. Layered Network Architecture

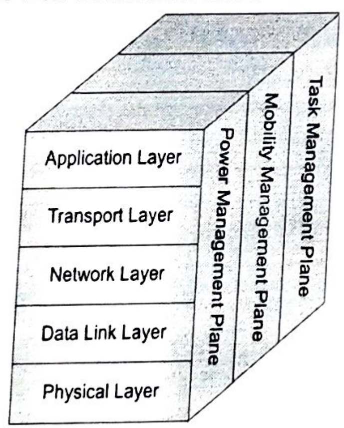
- This kind of network uses hundreds of sensor nodes as well as a base station. Here the arrangement of network nodes can be done into concentric layers. It comprises five layers as well as 3 cross layers which include the following.
- The five layers in the architecture are :

(a) Application Layer (b) Transport Layer
(c) Network Layer (d) Data Link Layer
(e) Physical Layer

- The three cross layers include the following :

(1) Power Management Plane
(2) Mobility Management Plane
(3) Task Management Plane

- These three cross layers are mainly used for controlling the network as well as to make the sensors function as one in order to enhance the overall network efficiency. The above mentioned five layers of WSN are discussed below.



(1B11)**Fig. 2.5.2 : Wireless Sensor Network Architecture**

(a) Application Layer

- The application layer is liable for traffic management and offers software for numerous applications that convert the data in a clear form to find positive information.
- Sensor networks arranged in numerous applications in different fields such as agricultural, military, environment, medical, etc.

(b) Transport Layer

- The function of the transport layer is to deliver congestion avoidance and reliability where a lot of protocols intended to offer this function are either practical on the upstream.
- These protocols use dissimilar mechanisms for loss recognition and loss recovery. The transport layer is exactly needed when a system is planned to contact other networks.
- Providing a reliable loss recovery is more energy-efficient and that is one of the main reasons why TCP is not fit for WSN.
- In general, Transport layers can be separated into Packet driven, Event-driven. There are some popular protocols in the transport layer namely STCP (Sensor Transmission Control Protocol), PORT (Price-Oriented Reliable Transport Protocol and PSFQ (pump slow fetch quick).

(c) Network Layer

- The main function of the network layer is routing, it has a lot of tasks based on the application, but actually, the main tasks are in the power conserving, partial memory, buffers, and sensor don't have a universal ID and have to be self-organized.
- The simple idea of the routing protocol is to explain a reliable lane and redundant lanes, according to a convincing scale called a metric, which varies from protocol to protocol.
- There are a lot of existing protocols for this network layer, they can be separated into; flat routing and hierarchal routing or can be separated into time-driven, query-driven & event-driven.

(d) Data Link Layer

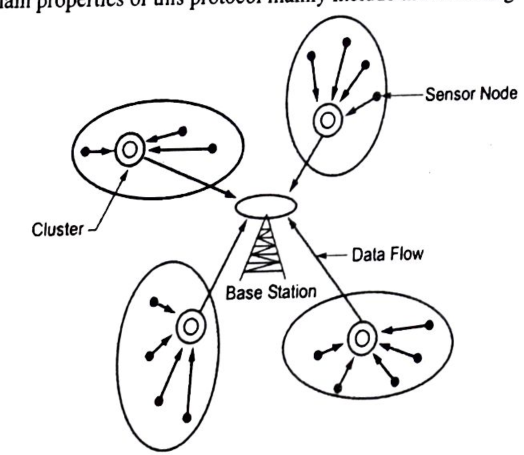
The data link layer is liable for multiplexing data frame detection, data streams, MAC, & error control, confirm the reliability of point–point (or) point– multipoint.

(e) Physical Layer

- The physical layer provides an edge for transferring a stream of bits above the physical medium.
- This layer is responsible for the selection of frequency, generation of a carrier frequency, signal detection, Modulation and data encryption. IEEE 802.15.4 is suggested as typical for low rate particular areas and wireless sensor networks with low cost, power consumption, density, the range of communication to improve the battery life.
- CSMA/CA is used to support star & peer to peer topology. There are several versions of IEEE 802.15.4.V.
- The main benefits of using this kind of architecture in WSN is that every node involves simply in less-distance, low- power transmissions to the neighboring nodes due to which power utilization is low as compared with other kinds of sensor network architecture. This kind of network is scalable as well as includes a high fault tolerance.

2. Clustered Network Architecture

- In this kind of architecture, separately sensor nodes add into groups known as clusters which depend on the "Leach Protocol" because it uses clusters.
- The term 'Leach Protocol' stands for "Low Energy Adaptive Clustering Hierarchy". The main properties of this protocol mainly include the following.



(1B12)Fig. 2.5.3 : Clustered Network

☞ Clustered Network Architecture

- This is a two-tier hierarchy clustering architecture.
- This distributed algorithm is used to arrange the sensor nodes into groups, known as clusters.
  - o In every cluster which is formed separately, the head nodes of the cluster will create the TDMA (Time-division multiple access) plans.
  - o It uses the Data Fusion concept so that it will make the network energy efficient.
- This kind of network architecture is extremely used due to the data fusion property. In every cluster, every node can interact through the head of the cluster to get the data.
- All the clusters will share their collected data toward the base station. The formation of a cluster, as well as its head selection in each cluster, is an independent as well as autonomous distributed method.

☞ Design Issues of Wireless Sensor Network Architecture

GQ. Explain Design Issues of WSN. **(4 Marks)**

The design issues of wireless sensor network architecture mainly include the following.

1. Energy Consumption	2. Localization
3. Coverage	4. Clocks
5. Computation	6. Cost of Production
7. Design of Hardware	8. Quality of Service

1. Energy Consumption

- In WSN, power consumption is one of the main issues. As an energy source, the battery is used by equipping with sensor nodes.
- The sensor network is arranged within dangerous situations so it turns complicated for changing otherwise recharging batteries. The energy consumption mainly depends on the sensor nodes' operations like communication, sensing & data processing.
- Throughout communication, the energy consumption is very high. So, energy consumption can be avoided at every layer by using efficient routing protocols.

2. Localization

- For the operation of the network, the basic, as well as critical problem, is sensor localization. So sensor nodes are arranged in an ad-hoc manner so they don't know about their location.
- The difficulty of determining the sensor's physical location once they have been arranged is known as localization. This difficulty can be resolved through GPS, beacon nodes, localization based on proximity.

3. Coverage

- The sensor nodes in the wireless sensor network utilize a coverage algorithm for detecting data as well as transmit them to sink through the routing algorithm. To cover the whole network, the sensor nodes should be chosen.
- There efficient methods like least and highest exposure path algorithms as well as coverage design protocol are recommended.

4. Clocks

- In WSN, clock synchronization is a serious service. The main function of this synchronization is to offer an ordinary timescale for the nodes of local clocks within sensor networks.
- These clocks must be synchronized within some applications like monitoring as well as tracking.

5. Computation

- The computation can be defined as the sum of data that continues through each node. The main issue within computation is that it must reduce the utilization of resources.
- If the life span of the base station is more dangerous, then data processing will be completed at each node before data transmitting toward the base station. At every node, if we have some resources then the whole computation should be done at the sink.

6. Production Cost

- In WSN, the large number of sensor nodes is arranged. So if the single node price is very high then the overall network price will also be high.
- Ultimately, the price of each sensor node has to be kept less. So the price of every sensor node within the wireless sensor network is a demanding problem.

7. Hardware Design

- When designing any sensor network's hardware like power control, micro-controller and communication unit must be energy-efficient.
- Its design can be done in such a way that it uses low-energy.

8. Quality of Service

- The quality of service or QoS is nothing but, the data must be distributed in time. Because some of the real-time sensor-based applications mainly depend on time. So if the data is not distributed on time toward the receiver then the data will turn useless.
- In WSNs, there are different types of QoS issues like network topology that may modify frequently as well as the accessible state of information used for routing can be imprecise.

☞ Structure of a Wireless Sensor Network

The structure of WSN mainly comprises various topologies used for radio communications networks like a star, mesh, and hybrid star.

These topologies are discussed below in brief.

Star Network

- The communication topology like a star network is used wherever only the base station can transmit or receive a message toward remote nodes. There is a number of nodes are available which are not allowed to transmit messages to each other. The benefits of this network mainly comprise simplicity, capable of keeping the power utilization of remote nodes to a minimum.
- It also lets communications with less latency among the base station as well as a remote node. The main drawback of this network is that the base station should be in the range of radio for all the separate nodes. It is not robust like other networks because it depends on a single node to handle the network.

Mesh Network

- This kind of network permits to the transmission of the data from one node to another within the network that is in the range of radio transmission.
- If a node needs to transmit a message to another node and that is out of radio communications range, then it can utilize a node like an intermediate to send the message toward the preferred node.

- The main benefit of a mesh network is scalability as well as redundancy. When an individual node stops working, a remote node can converse to any other type of node within the range, then forwards the message toward the preferred location.
- Additionally, the network range is not automatically restricted through the range among single nodes; it can extend simply by adding a number of nodes to the system.
- The main drawback of this kind of network is power utilization for the network nodes that execute the communications like multi-hop are usually higher than other nodes that don't have this capacity of limiting the life of battery frequently.
- Moreover, when the number of communication hops increases toward a destination, then the time taken to send the message will also increase, particularly if the low power process of the nodes is a necessity.

Hybrid Star – Mesh Network

- A hybrid among the two networks like star and mesh provides a strong and flexible communications network while maintaining the power consumption of wireless sensor nodes to a minimum.
- In this kind of network topology, the sensor nodes with less power are not allowed to transmit the messages. This permits to maintenance least power utilization.
- But, other network nodes are allowed with the capability of multi-hop by allowing them to transmit messages from one node to another on the network.
- Usually, the nodes with the multi-hop capacity have high power and are frequently plugged into the mains line.
- This is the implemented topology through the upcoming standard mesh networking called ZigBee.

☞ Structure of a Wireless Sensor Node

- The components used to make a wireless sensor node are different units like sensing, processing, transceiver and power. It also includes additional components that depend on an application like a power generator, a location finding system and a mobilizer.
- Generally, sensing units include two subunits namely ADCs as well as sensors. Here sensors generate analog signals which can be changed to digital signals with the help of ADC, after that it transmits to the processing unit.
- Generally, this unit can be associated through a tiny storage unit to handle the actions to make the sensor node work with the other nodes to achieve the allocated sensing tasks.

- The sensor node can be connected to the network with the help of a transceiver unit. In the sensor node, one of the essential components is a sensor node. The power-units are supported through power scavenge units like solar cells whereas the other subunits depend on the application.
- A wireless sensing nodes functional block diagram is shown above. These modules give a versatile platform to deal with the requirements of wide applications. For instance, based on the sensors to be arranged, the replacement of signal conditioning block can be done.
- This permits to use of different sensors along with the wireless sensing node. Likewise, the radio link can be exchanged for a specified application.

☞ Characteristics of Wireless Sensor Network

The characteristics of WSN include the following :

(1) The consumption of Power limits for nodes with batteries

(2) Capacity to handle node failures

(3) Some mobility of nodes and Heterogeneity of nodes

(4) Scalability to a large scale of distribution

(5) Capability to ensure strict environmental conditions

(6) Simple to use

(7) Cross-layer design

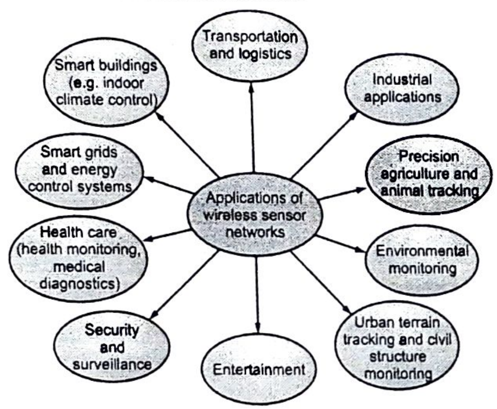
☞ Advantages of Wireless Sensor Networks

The advantages of WSN include the following

1. Network arrangements can be carried out without immovable infrastructure.
2. Apt for the non-reachable places like mountains, over the sea, rural areas, and deep forests.
3. Flexible if there is a casual situation when an additional workstation is required.
4. Execution pricing is inexpensive.
5. It avoids plenty of wiring.
6. It might provide accommodations for the new devices at any time.
7. It can be opened by using centralized monitoring.

Wireless Sensor Network Applications

- Wireless sensor networks may comprise numerous different types of sensors like low sampling rate, seismic, magnetic, thermal, visual, infrared, radar, and acoustic, which are clever to monitor a wide range of ambient situations.
- Sensor nodes are used for constant sensing, event ID, event detection & local control of actuators.
- The applications of wireless sensor networks mainly include health, military, environmental, home and other commercial areas.



(1B13)Fig. 2.5.4 : Application of WSN

WSN Application

GQ. Explain different Application of WSN. **(4 Marks)**

(1) Military Applications	(2) Health Applications
(3) Environmental Applications	(4) Home Applications
(5) Commercial Applications	(6) Area monitoring
(7) Health care monitoring	(8) Environmental/Earth sensing
(9) Air pollution monitoring	(10) Forest fire detection
(11) Landslide detection	(12) Water quality monitoring
(13) Industrial monitoring	

What are the different types of wireless sensor networks?

- The development of network technologies has prompted sensor folks to consider alternatives that reduce costs and complexity and improve reliability.
- Early sensor networks used simple twisted shielded–pair (TSP) implementations for each sensor. Later, the industry adopted multidrop buses (e.g., Ethernet).
- Now we're starting to see true web-based networks (e.g., the World Wide Web) implemented on the factory floor.
- As wireless sensors become real commodities on the market, new options or new arguments for old options are causing professionals to consider network strategies once ruled out.
- Let's look at the three classic network topologies (point-to-point, multidrop, and web), assess their strengths and weaknesses, and look at how the rules have changed now that wireless systems are coming online.
- In addition, to build functional sensor networks, you'll probable have to integrate hardware and software from multiple vendors (see the sidebar "Network Questions,").
- So along with everything else, you have to come to terms with standards and protocols those that exist, those that are emerging, and those needed to ensure interoperability on the factory floor.

Point-to-Point Networks

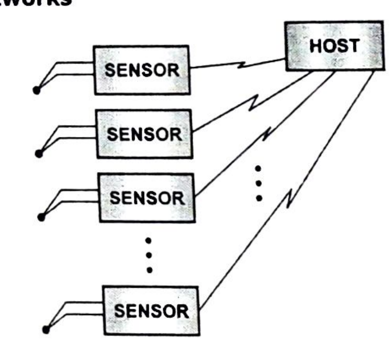


Fig. 2.5.5 : point-to-point network topologies

- Theoretically, these systems are the most reliable because there is only one single point of failure in the topology .

- You can improve the system by adding redundant hosts, but wiring two hosts can be a problem. The 4–20 mA standard allows multiple readout circuits if the standard loads are used at each readout.
- Problems can arise if readout devices load the circuit beyond its capability, but most designers are familiar with the limitations and are sufficiently careful.
- each sensor node puts its information onto a common medium. This requires careful attention to protocols in hardware and software. The single-wire connection represents a potential single-point failure. But some vendors supply redundant connections to mitigate this potential problem
- Some networks provide frequency-modulated (FM) signals on the wires to carry multiple sensor readings on separate FM channels. Some standards (e.g., the HART bus) support multiplexing of digital signals on the existing analog wiring in older plants.
- These architectures blur the distinction between point-to-point and multidrop networks.
- Early wireless networks were simple radio-frequency (RF) implementations of this topology. These networks used RF modems to convert the RS-232 signal to a radio signal and back again.
- Fluke (Everett, Washington) developed a digital voltmeter that could be configured to accept a voltage signal and transmit the signal over a dedicated radio frequency channel.
- The reliability of these implementations was sometimes suspect because most were designed with simple FM coding. Interference and multipath propagation effects caused significant degradation in factory environments, so many networks proved to be unreliable unless designers were particularly careful.
- The Federal Communications Commission licensed companies and devices to operate at the allocated frequencies.
- Complete wireless Local Area Networks (LANs) were implemented using this technique. These were successful in the office environment but didn't fare as well in factories.
- Many designers implemented remote data acquisition systems with this topology by using a data concentrator in the field to feed the data to a radio transmitter for transmission to the hosts, where the signals were demultiplexed into the original sensor signals.

Multidrop Networks

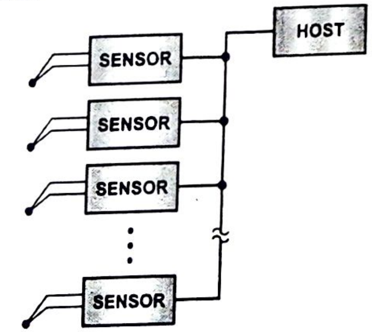
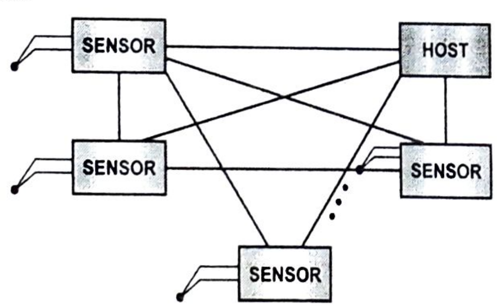


Fig. 2.5.6 : Multidrop Network

- In a web topology, all nodes are potentially connected to all other nodes. Connectivity among a large collection of sensors gets complex because all nodes must have a connection to all other nodes. Some connections can be eliminated by using repeaters and routers to make virtual connections. The World Wide Web is a good example of this topology
- Multidrop buses began to appear in the late 70s and early 80s. One of these, Modbus from Modicon (Schneider Auto mation, North Andover, Massa chusetts), led the way into the industrial sphere, followed by several proprietary and open buses (e.g., the Manufacturing Auto mation Protocol, QBus, and VME Bus).
- The emergence of intelligent sensors and microcomputers capable of operating in industrial environments irrevocably changed the sensor network landscape.
- Multidrop networks (buses) reduced the number of wires required to connect field devices to the host, but they also introduced another single point of failure the cable.
- Several suppliers of industrial-grade products offered redundant cabling designs, but these came with an increase in complexity .
- Once the industry began the migration to multidrop buses, problems associated with digitization began to emerge.
- With the previous point-to-point systems, digitization occurred in the host, where a single clock could be used to time stamp when the analog signals from multiple sensors were acquired.

- With the distributed intelligence required to implement a multidrop network, synchronization of clocks became a critical issue in some applications. This remains an important design parameter for any distributed digital system.
- An architecture consisting of a decoder for each channel and a direct-sequence spread-spectrum receiver can perform simultaneous sampling because the same baseband signal goes to each decoder. But the decoders represent a significant cost, power, and size limitation.
- The introduction of Ethernet in the mid-80s was a landmark in standardization, if not technological innovation. A group of large companies agreed that the future of computer networking required an open interconnect standard that would allow multiple-vendor systems to work together with minimal difficulty.
- Researchers looked closely at the carrier sense multiple access with collision detection (CSMA/CD) protocol when they investigated the behavior of networks under stress. But they considered most industrial applications too time critical for such a nondeterministic protocol. Now, fifteen years later, most factories have converted their shop floor networks to Ethernet because it is the best compromise between cost and performance. Many companies now offer solutions that use Ethernet to implement suitable robust industrial networks.
- Wireless systems use the same types of protocols to implement multidrop topologies, simulating hard-wired connections with RF links. The IEEE-802.11 standard was the first wireless standard that promised to bring the interoperability of Ethernet connectivity to wireless networks. Many of these, however, are not compatible at the over-the-air level.

☞ Web Networks



(1B16)Fig. 2.5.7 : Web Network

- Simultaneous sampling is more difficult with this receiver architecture. The selected channel codes can be stored and stepped through so that each channel's data gets to the data system bus.
- The promise of the web topology (i.e., when all nodes are connected all the time) had to wait until vendors developed a way to interconnect nodes without the required wiring connections.
- A network of any appreciable size becomes infeasible if all wires must be connected specifically for the network.Early star topologies were successful as long as the star wasn't too large.
- The World Wide Web illustrates what is possible, though, if you can use wiring that is already in place. The telephone network provides the available connectivity in most parts of the country, although at less than suitable speeds in many locations.
- The advantages of web connectivity for sensor networks become clear as the level of intelligence in each sensor increases.
- Cooperating sensors can form a temporary configuration that provides sufficient capacity to replace the host. Self-hosting networks then become self-configuring and finally, years from now, perhaps even self-aware.
- But several problems remain and are the topic of significant research, such as size and power consumption reduction, throughput and performance during transmissions, and algorithms for allocating priorities and authority.
- In a wireless web network, individual nodes have the potential of being constantly connected (physically) with many other nodes in the network. How the network is configured at any instant becomes a matter of how the software configures it. In a code division multiple access (CDMA) network, the radios can receive all channels at once.
- The architecture suggested in Fig.2.4.8 requires a separate decoder for each channel. This requires hardware to be dedicated to channels that may not be currently important but could be required later. Fig. 2.4.9 eliminates the need for dedicated hardware but introduces the problem of simultaneous sampling.
- The decoder-per-channel implementation samples the data stream looking for a particular channel code embedded in the chip stream.

- The single decoder will decode a new data stream for each channel unless the data stream is stored and decoded over and over with different candidate codes for each channel. Both implementations represent a compromise and should be implemented carefully, depending on the application.
- Network routing is a serious concern in web architectures. Because all nodes can't reach all other nodes in a single hop, a repeating mechanism is required.
- The assigned input and output channels dictate to each node which signals are meant for its own use and which should be passed on to the next node. The routing is one of the things that makes web architectures more complicated to implement than the others.
- In sensor or mobile phone networks, nodes can come and go frequently. How the network responds to the reconfiguration has a severe impact on performance and reliability.
- Mobile ad hoc networking is a hot topic in the research community because reconfiguring on the fly makes all networks better. Without this technology, sensor networks will be severely limited in harsh environments, where connections can change quickly as the RF environment changes.

So What?

- Network topologies usually work best when they map closely to the topology of the application. If the application looks hierarchical, then a hierarchical (point-to-point or multidrop) topology might be most suitable. But if the application looks like a collection of peers interacting and cooperating, then a web architecture might work best.
- The potential for web connectivity in the sensor world seems most tempting. The dynamic nature provides the opportunity for cooperating sensors to form smart clusters that can work together to solve a problem, then reorganize to solve the next one. As the hardware and software technologies mature, you'll see more and more web implementations showing up on factory floors. Watch for them.

NOTES

2.6 ENABLING IOT TECHNOLOGIES

GQ. Explain different Enabling IOT Technologies. **(6 Marks)**

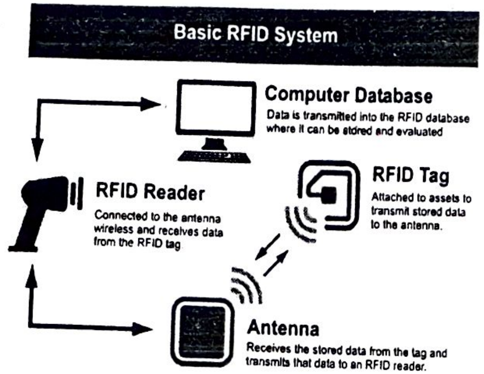
Radio Frequency Identification Technology, Micro Electro-Mechanical Systems (MEMS), NFC (Near Field Communication), Bluetooth Low Energy (BLE), LTE-A (LTE Advanced), IEEE 802.15.4–Standardization and Alliances, ZigBee.

2.6.1 What is RFID (Radio Frequency Identification) Technology?

GQ. Explain RFID. **(4 Marks)**

- Radio Frequency Identification or RFID is a specific type of radio technology that uses radio waves to identify tags attached to an object and thus identify the object.
- The tag contains a transceiver chip which is triggered by the electromagnetic wave from the RFID reader and transmits an identification number back to the reader. The identification number is then used for the inventory of the objects with tags.
- Tags can be passive or active. Passive tags are only powered by the incident electromagnetic wave from the reader and thus have a shorter operating range. Active tags are powered by a battery and can have greater range up to hundreds of meters. With the use of wireless technology, RFID tags do not need a direct line-of-sight to the RFID reader, which brings some significant advantages compared to the barcode scanners widely used in the industry today.
- The RFID tag can be embedded or hidden in the object, and several tags can be identified at the same time by a single reader. A barcode scanner has to 'see' a barcode to gather data.
- RFID is used in many applications and industries, including pharma, retail, agriculture and medical care, as well as tracking vehicles, pets, and livestock. For example, an object with an embedded RFID tag that is moving through a production line or a warehouse equipped with RFID readers, can be scanned at different production stations and thus its progress can be automatically tracked.
- The technology has continued to improve over the years, and the cost of implementing and using an RFID system has continued to decrease, making RFID a cost-effective and efficient alternative to conventional optical scanning.
- Standard specifications have been developed for RFID technology, addressing security and privacy concerns. Such standards use on-chip cryptography methods for untraceability and tag and reader authentication using digital signature data.

RFID Technology : How Does it Work?



(1B19)Fig. 2.6.1 : RFID

Source

GQ. What are the Main Components of RFID Technology?

(1) Tags

- RFID tags are what stores and transmits the data that needs to be deciphered. The tags can be attached to assets to send data to the antenna.
- The microchip embedded in the tag is what stores the tag's ID and programmable data related to the asset. This stored data is then transferred to the reader through antennas.

(2) Antennas

- Antennas are necessary elements in an RFID system because they transmit the RFID tag's data to the reader.
- Without some type of RFID antenna, whether integrated or standalone, the RFID reader cannot correctly send and receive signals to RFID tags.

(3) Readers

- RFID readers are connected to the antenna and receive data from the RFID tag. The reader is what receives and converts the radio waves into digital data on a computer database.
- There are two types of readers. There are Fixed Readers and Mobile Readers. Fixed readers are typically mounted to walls or other objects and stay in one location to read data stored in a tag. Mobile readers can be installed or carried anywhere it is needed.

(4) Computer Database

- The RFID system requires a computer database to process data stored in tags.
- This software can program tags, manage devices and data, remote monitoring and hardware configuration.

RFID Tags : Categories, Frequencies, and Applications

RFID transmits data to a reader through different frequencies of electromagnetic fields.

RFID tags are categorised according to the frequency at which they are designed to operate. There are three major frequency ranges that RFID tags operate.

1. Low-Frequency (LF) Tags
2. High-Frequency (HF) Tags
3. Ultra-High Frequency (UHF) Tags - passive and active

1. Low-Frequency Tags (LF)

- The primary frequency range of 125kHz – 134kHz
- Can read a span of a few inches
- Lowest data transfer rate among all the RFID frequencies
- Store a small amount of data
- LF Applications – Animal Tracking, Access Control, Car Key-Fob, Asset Tracking. and Healthcare

2. High-Frequency Tags (HF)

Most widely used around the world

- The primary frequency range of 13.56MHz
- Read range: 30 cm
- The capability of reading multiple tags simultaneously
- Can store up to 4k of data
- Easily read while attached to objects containing water, tissues, metal, wood, and liquids.
- HF Applications – Library Books, Personal ID Cards, Airline Baggage, and Credit Cards

3. Ultra-High Frequency Tags (UHF)

- There are two types of tags that use different frequencies under UHF RFID.
- UHF Passive Tags - use energy from the RFID reader
  - The primary frequency range: 860MHz – 960MHz
  - Read Range: 25 meters
  - High data transmission rate
  - Wide variety of tag sizes
- UHF Passive Tag Applications – Supply Chain Tracking, Manufacturing, Pharmaceuticals and Electronic Tolling
- UHF Active Tags - battery operated
  - The primary frequency range: 433MHz
  - Read Range: 30 - 100+ meters
  - Large memory capacity
  - High data transfer rate
- UHF Active Tag Applications – Vehicle Tracking, Auto Manufacturing, and Construction

☞ Pros and Cons of RFID

- RFID can be used to reduce production costs and optimise operations.

However, If you are considering RFID technology to streamline production, track, and analyze data collection and more, there are pros and cons to weigh.

Pros of RFID in Manufacturing	Cons of RFID in Manufacturing
Does not require line of sight to be scanned or identified	Initial system costs are higher than with conventional optical scanning
Readers can read hundreds of tags within seconds	Partner companies may not use the same technology causing a disconnect
Tags can be rewritten, and reused	vulnerability to software attacks (viruses and security breaches)
Tag data is encrypted and can also be locked for extra security	If a tag does become damaged, a redundant system is required
Tags are durable and can withstand impact	Privacy concerns
Tags can have additional information printed on them such as instructions. barcodes, or company names	
RFID systems can be susceptible to certain materials and environmental factors	
Systems can be integrated with other internal systems or processes	
Tags can hold more data than other types of tags or labels	

- The most significant benefit of using RFID technology over other methods in manufacturing is that it does not need a line of sight to be scanned or identified. This gives more flexibility to the production and supply chain process.

2.6.2 Micro-electromechanical Systems (MEMS)

GQ. What is MEMS?

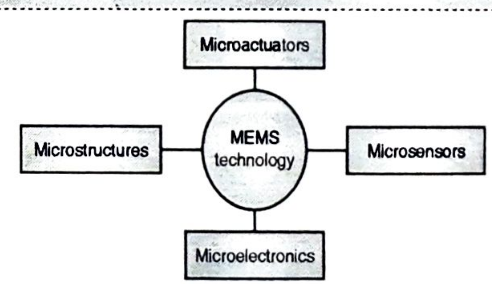


Fig.2.6.2 : Schematic illustration of MEMS components

- Micro-electromechanical systems (MEMS) is a process technology used to create tiny integrated devices or systems that combine mechanical and electrical components.
- They are fabricated using integrated circuit (IC) batch processing techniques and can range in size from a few micrometers to millimetres. These devices (or systems) have the ability to sense, control and actuate on the micro scale, and generate effects on the macro scale.

- An Introduction to MEMS Prime Faraday Technology Watch - January 20022MEMS, an acronym that originated in the United States, is also referred to as Microsystems Technology (MST) in Europe and Micromachines in Japan.
- Regardless of terminology, the uniting factor of a MEMS device is in the way it is made. While the device electronics are fabricated using 'computer chip' IC technology, the micromechanical components are fabricated by sophisticated manipulations of silicon and other substrates using micromachining processes.
- Processes such as bulk and surface micromachining, as well as High-Aspect-Ratio Micromachining (HARM) selectively remove parts of the silicon or add additional structural layers to form the mechanical and electromechanical components.
- While integrated circuits are designed to exploit the electrical properties of silicon, MEMS takes advantage of either silicon's mechanical properties or both its electrical and mechanical properties.
- In the most general form, MEMS consist of mechanical microstructures, microsensors, microactuators and microelectronics, all integrated onto the same silicon chip. This is shown schematically in Fig. 2.6.2.
- Microsensors detect changes in the system's environment by measuring mechanical, thermal, magnetic, chemical or electromagnetic information or phenomena. Microelectronics process this information and signal the microactuators to react and create some form of changes to the environment. MEMS devices are very small; their components are usually microscopic.
- Levers, gears, pistons, as well as motors and even steam engines have all been fabricated by MEMS .

2.6.3 Definitions and Classifications.

- This section defines some of the key terminology and classifications associated with MEMS. It is intended to help the reader and newcomers to the field of micromachining become familiar with some of the more common terms. A more detailed glossary of terms has been included in Appendix A.
- Fig. 2.6.3 illustrates the classifications of microsystems technology (MST). Although MEMS is also referred to as MST, strictly speaking, MEMS is a process technology used to create these tiny mechanical devices or systems, and as a result, it is a subset of MST.

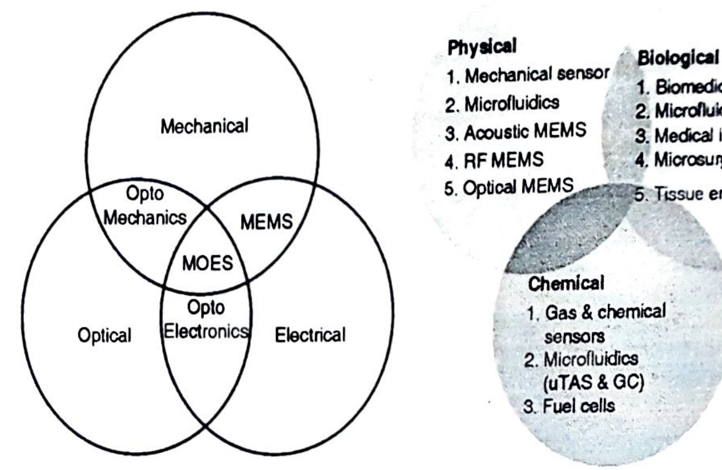


Fig. 2.6.3 : Classifications of microsystems technology .

- An Introduction to MEMS Prime Faraday Technology Watch – January 20024Micro-optoelectromechanical systems (MOEMS) is also a subset of MST and together with MEMS forms the specialized technology fields using miniaturized combinations of optics, electronics and mechanics. Both their microsystems incorporate the use of microelectronics batch processing techniques for their design and fabrication.
- There are considerable overlaps between fields in terms of their integrating technology and their applications and hence it is extremely difficult to categorise MEMS devices in terms of sensing domain and/or their subset of MST.
- The real difference between MEMS and MST is that MEMS tends to use semiconductor processes to create a mechanical part. In contrast, the deposition of a material on silicon for example, does not constitute MEMS but is an application of MST.

2.6.4 Near Field Communication (NFC)

GQ. Short note on NFC. **(2 Marks)**

NFC stands for Near Field Communication. It enables short range communication between compatible devices. At least one transmitting device and another receiving device is needed to transmit the signal. Many devices can use the NFC standard and are considered either passive or active.

So NFC devices can be classified into 2 types:

1. Passive NFC devices

- These include tags, and other small transmitters which can send information to other NFC devices without the need for a power source of their own.
- These devices don't really process any information sent from other sources, and cannot connect to other passive components. These often take the form of interactive signs on walls or advertisements.

2. Active NFC devices .

- These devices are able to both the things i.e. send and receive data.
- They can communicate with each other as well as with passive devices. Smartphones the best example of active NFC device. Card readers in public transport and touch payment terminals are also good examples of the technology.

How does NFC work?

- Like other wireless signals Bluetooth and WiFi, NFC works on the principle of sending information over radio waves.
- Near Field Communication is another standard for wireless data transition which means devices must adhere to certain specifications in order to communicate with each other properly.
- The technology used in NFC is based on older technology which is the RFID (Radio-frequency identification) that used electromagnetic induction in order to transmit information.
- This creates one major difference between NFC and Bluetooth/WiFi. NFC can be used to induce electric currents within passive components rather than just send data.
- This means that their own power supply is not required by passive devices. Instead they can be powered by the electromagnetic field produced by an active NFC component when it comes into range.
- NFC technology unfortunately does not command enough inductance to charge our smartphones, but QI charging is based on the same principle.
- The transmission frequency is 13.56 megahertz for data across NFC. Data can be sent at either 106, 212, or 424 kilobits per second which is quick enough for a range of data transfers like contact details to swapping pictures and music.

- The NFC standard currently has three distinct modes of operation to determine what sort of information will be exchanged between devices.
  1. The most common used in smartphones is the peer-to-peer mode. Exchange of various piece of information is allowed between 2 devices. In this mode both devices switch between active when sending data and passive when receiving.
  2. The second mode i.e. read/write mode is a one-way data transmission. The active device, possibly your smartphone, links up with another device in order to read information from it. NFC advertisement tags use this mode.
  3. The third mode of operation is card emulation. The NFC device can function as a smart or contactless credit card and make payments or tap into public transport system

2.6.5 The Basics of Bluetooth Low Energy (BLE)

GQ. Write short note on BLE. **(2 Marks)**

- Bluetooth Low Energy (BLE) is a low power wireless technology used for connecting devices with each other. BLE operates in the 2.4 GHz ISM (Industrial, Scientific, and Medical) band, and is targeted towards applications that need to consume less power and may need to run on batteries for longer periods of time months, and even years.
- Bluetooth started as a short-distance cable replacement technology. For example, to replace wires in devices such as a mouse, keyboard, or a PC communicating with a Personal Digital Assistant (PDA) which were popular in the late 1990s and early 2000s.
- The first official version of Bluetooth was released by Ericsson in 1994, named after King Harald "Bluetooth" Gormsson of Denmark who helped unify warring factions in the 10th century CE.
- Bluetooth Low Energy (BLE), however, was introduced in the 4.0 version of the Bluetooth specification in 2010.
- The original Bluetooth defined in the previous versions is referred to as Bluetooth Classic. BLE was not an upgrade to the original Bluetooth: Bluetooth Classic, but rather it's a new technology that utilizes the Bluetooth brand but focuses on the Internet of Things (IoT) applications where small amounts of data are transferred at lower speeds.
- It's important to note that there's a big difference between Bluetooth Classic and Bluetooth Low Energy in terms of technical specification, implementation and the types of applications they're each suitable for.

- Some of the notable differences include :
  - **(1) Bluetooth Classic :** used for streaming applications such as audio streaming and file transfers.
  - **(2) BLE :** used for sensor data, control of devices, and low-bandwidth applications.
  - **(3) BLE :** low power, low duty data cycles.
  - **(4) Bluetooth Classic :** not optimized for low power, has a higher data rate.
  - **(5) BLE :** Operates over 40 RF (Radio Frequency) channels.
  - **(6) Bluetooth Classic :** Operates over 79 RF channels.
  - **(7) BLE :** connections are much quicker (discovery occurs on 3 channels).
  - **(8) Bluetooth Classic :** discovery on 32 channels, leading to slower connections.
- BLE has gone through some major revisions and changes in the short time since its official release in 2010, with the most recent major update being Bluetooth 5 in December 2016.
- Bluetooth 5.0 introduced many important upgrades to the Bluetooth specification, most of which were focused on BLE.
- Some of the most important enhancements include twice the speed, four times the range, and eight times the advertising data capacity.

Advantages and Disadvantages

Every technology has its own benefits and limitations, and BLE is no exception. It's important to know these pros and cons to be able to determine whether BLE is suitable for your specific application and use case or not.

Benefits of BLE

1. Lower power consumption even when compared to other low power technologies. BLE achieves the optimized and low power consumption by keeping the radio off as much as possible and sending small amounts of data at low transfer speeds.
2. No cost to access the official specification documents. With most other wireless protocols and technologies, you would have to be a member of the official group or consortium for that technology in order to access the specification.
3. Lower cost of modules and chipsets, even when compared to other similar technologies.

4. Most importantly, its existence in most smartphones in the market.

Limitations of BLE

(1) **Data Throughput :** the data throughput of BLE is limited by the physical radio layer (PHY) data rate, which is the rate at which the radio transmits data.

(2) This rate depends on the Bluetooth version used. For Bluetooth 4.2 and earlier, the rate is fixed at 1 Mbps. For Bluetooth 5 and later, however, the rate varies depending on the mode and PHY used. The rate can be 1 Mbps like earlier versions, or 2 Mbps when utilizing the high-speed feature.

Range

- Bluetooth Low Energy (and Bluetooth in general) was designed for short range applications and hence its range of operation is limited.
- There are a few factors that limit the range of BLE :
  - (1) BLE operates in the 2.4 GHz ISM spectrum which is greatly affected by obstacles that exist all around us such as metal objects, walls, and water (especially human bodies)
  - (2) Performance and design of the antenna of the BLE device.
  - (3) Physical enclosure of the device.
  - (4) Device orientation.
- Gateway Requirement for Internet Connectivity: In order to transfer data from a BLE-only device to the Internet, another BLE device that has an IP connection is needed to receive this data and then, in turn, relay it to another IP device (or to the Internet).

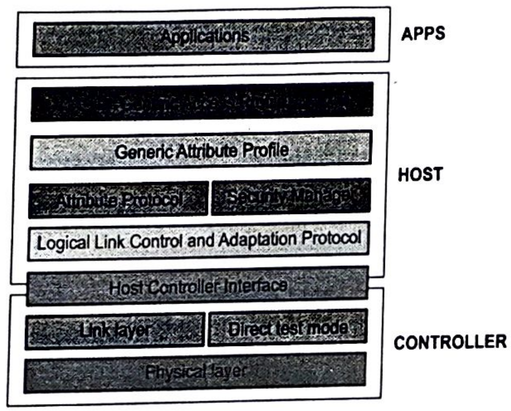
Bluetooth Low Energy Architecture

GQ. Explain BLE Architecture. **(4 Marks)**

Here's a diagram showing the different levels of the architecture of BLE :

NOTES

Bluthooth Low Energy Architecture

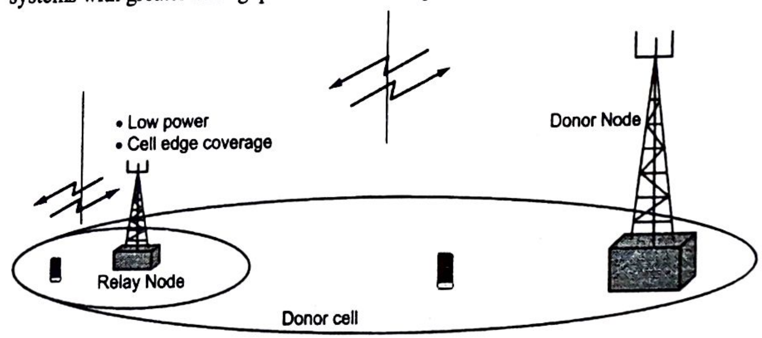


(1B20)**Fig. 2.6.5 : BLE Architecture**

- The good thing is that, as a developer looking to develop BLE applications, you won't have to worry much about the layers below the Security Manager and Attribute Protocol.
- But lets at least cover the definitions of these layers:
- The physical layer (PHY) refers to the physical radio used for communication and for modulating/ demodulating the data. It operates in the ISM band (2.4 GHz spectrum).
- The Link Layer is the layer that interfaces with the Physical Layer (Radio) and provides the higher levels an abstraction and a way to interact with the radio (through an intermediary level called the HCI layer which we'll discuss shortly).
- It is responsible for managing the state of the radio as well as the timing requirements for adhering to the Bluetooth Low Energy specification.
- Direct Test Mode : the purpose of this mode is to test the operation of the radio at the physical level (such as transmission power, receiver sensitivity, etc.).
- The Host Controller Interface (HCI) layer is a standard protocol defined by the Bluetooth specification that allows the Host layer to communicate with the Controller layer. These layers could exist on separate chips, or they could exist on the same chip.
- The Logical Link Control and Adaptation Protocol (L2CAP) layer acts as a protocol multiplexing layer. It takes multiple protocols from the upper layers and places them in standard BLE packets that are passed down to the lower layers beneath it.

2.6.6 LTE-A or LTE Advanced

- LTE-A or LTE Advanced is the upgraded version of LTE, which increases the stability, bandwidth, and speed of traditional LTE networks.
- According to 3GPP- "The main new functionalities introduced in LTE-Advanced are Carrier Aggregation (CA), enhanced use of multi-antenna techniques (MIMO) and support for Relay Nodes (RN)".
- Carrier Aggregation (CA) is a feature of LTE-Advanced that allows mobile operators to combine two or more LTE carriers into single data channel to increase the capacity of the network and the data rates by exploiting fragmented spectrum allocations. For more information about Carrier Aggregation, click here.
- Multi-Input Multi-Output (MIMO) technology is the use of multiple receive and transmit antennas to establish a communications link between two, or more, communications systems with greater throughput than would be possible with a single antenna system.



(1B22)**Fig. 2.6.6 : MIMO Spatial Multiplexing**

- Relay Nodes are low powered base stations that increases the coverage and capacity at cell edges. They also provide coverage in the areas where there is no fiber connection.

LTE-Advanced features

- Increased peak data rate: Downlink 3 Gbps, Uplink 1.5 Gbps
- Higher spectral efficiency: Uplink 16bps/Hz, Downlink 30 bps/Hz
- Increased number of simultaneously active subscribers
- Improved performance at cell edges, e.g. for Downlink 2x2 MIMO by at least 2.40 bps/Hz/cell

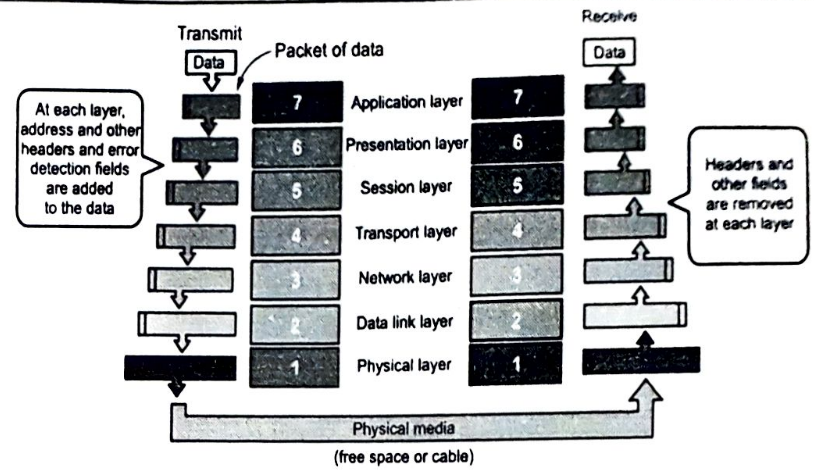
Comparison of LTE-A with other technologies

	WCDMA (UMTS)	HSPA+	LTE	LTE-A
Downlink speed	384 Kbps	1-28 Mbps	10 – 100 Mbps	1 Gbps
Uplink speed	128 Kbps	11 Mbps	5 – 50 Mbps	500 Mbps
Latency	150 ms	50ms (max)	~10 ms	less than 5 ms
3GPP Releases	Rel 99/4	Rel 7	Rel 8	Rel 10
Access Methodology	CDMA	CDMA	OFDMA / SC-FDMA	OFDMA / SC-FDMA

2.6.7 IEEE 802.15.4

GQ. Write a short note on IEEE 802.15.4. **(2 Marks)**

- The Institute of Electrical and Electronics Engineers (IEEE) supports many working groups to develop and maintain wireless and wired communications standards. For example, 802.3 is wired Ethernet and 802.11 is for wireless LANs (WLANs), also known as Wi-Fi. The 802.15 group of standards specifies a variety of wireless personal area networks (WPANs) for different applications. For instance, 802.15.1 is Bluetooth, 802.15.3 is a high-data-rate category for ultra-wideband (UWB) technologies, and 802.15.6 is for body area networks (BAN). There are several others.
- The 802.15.4 category is probably the largest standard for low-data-rate WPANs. It has many subcategories. The 802.15.4 category was developed for low-data-rate monitor and control applications and extended-life low-power-consumption uses. The basic standard with the most recent updates and enhancements is 802.15.4a/b, with 802.15.4c for China, 802.15.4d for Japan, 802.15.4e for industrial applications, 802.15.4f for active (battery powered) radio-frequency identification (RFID) uses, and 802.15.4g for smart utility networks (SUNs) for monitoring the Smart Grid. All of these special versions use the same base radio technology and protocol as defined in 802.15.4a/b.



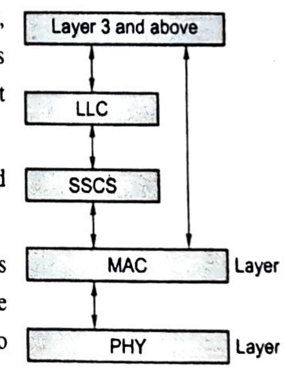
(1B23)Fig. 2.6.7 : IEEE 802.15.4 Architecture

- The 802.15.4 standard defines the physical layer (PHY) and media access control (MAC) layer of the Open Systems Interconnection (OSI) model of network operation *(Fig. 2.6.7)*. The PHY defines frequency, power, modulation, and other wireless conditions of the link.
- The MAC defines the format of the data handling. The remaining layers define other measures for handing the data and related protocol enhancements including the final application.

  1. Most networking systems, both wired and wireless, use the OSI communications model. Most systems also use at least the first four layers, but many do not use all seven layers.

     More specifically, Fig. 2.6.8 shows the layer 1 and layer 2 details of 802.15.4.

  2. The 802.15.4 standard uses only the first two layers plus the logical link control (LLC) and service specific convergence sub-layer (SSCS) additions to communicate with all upper layers as defined by additional standards.



(1B24)Fig.2.6.8

- The goal of the standard is to provide a base format to which other protocols and features could be added by way of the upper layers (layers 3 through 7). While three frequency assignments are available, the 2.4-GHz band is by far the most widely used *(see the table)*.

Most available chips and modules use this popular ISM band.

OPTIONS FOR FREQUENCY ASSIGNMENTS

Geographical	Europe	Americas	Worldwide
Frequency	868 to 868.6 MHz	902 to9.28	2.4 to 2.4835 GHz
Number at channels	1	10	16
Channel bandwidth	600 kHz	2 MHz	5 MHz
Symbol rate	20 ksymbols/s	40 k symbols/s	62.5 ksymbols/s
Data rate	20 kbits/s	40 kbits/s	250 kbits/s
Modulation	BPSK	BPSK	Q-QPSK

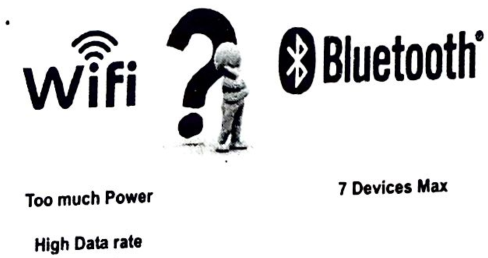
- The standard uses direct sequence spread spectrum (DSSS) modulation. It is highly tolerant of noise and interference and offers coding gain to improve link reliability.
- Standard binary phase-shift keying (BPSK) is used in the two low-speed versions, while offset-quadrature phase-shift keying (O-QPSK) is used for the higher-data-rate version. O-QPSK has a constant wave envelope meaning that more efficient non-linear power amplification techniques can be used to minimize power consumption.

2.6.8 ZigBee

GQ. Write a short note on ZigBee.

- ZigBee is a Personal Area Network task group with low rate task group 4. It is a technology of home networking. ZigBee is a technological standard created for controlling and sensor the network. As we know that ZigBee is the Personal Area network of task group 4 so it is based on IEEE 802.14.4 and is created by Zigbee Alliance.
- ZigBee is a standard that addresses the need of very low-cost implementation of Low power devices with Low data rate for short-range wireless communications.

Why another short-range communication standard?



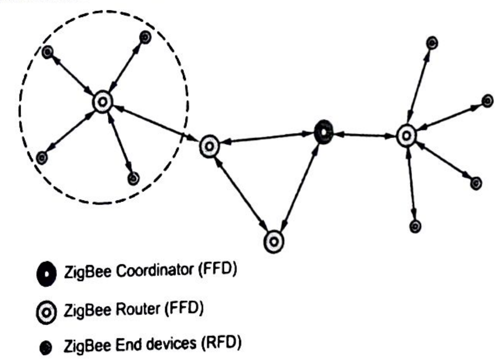
(1B25)Fig. 2.6.9 : Wifi and Bluetooth

Types of ZigBee Devices

(1) **Zigbee Coordinator Device :** It communicates with routers. This device is used for connecting the devices.

(2) **Zigbee Router :** It is used for passing the data between devices.

(3) **Zigbee End Device :** It is the device that is going to be controlled



(1B26)Fig. 2.6.10

General Characteristics of Zigbee Standard

- Low Power Consumption
- Low Data Rate (20- 250 kbps)
- Short-Range (75-100 meters)
- Network Join Time (~ 30 msec)
- Support Small and Large Networks (up to 65000 devices (Theory); 240 devices (Practically))
- Low Cost of Products and Cheap Implementation (Open Source Protocol)

☞ Operating Frequency Bands

(Only one channel will be selected for use in a network):

Channel 0 : 868 MHz (Europe)

Channel 1-10 : 915 MHz (US and Australia)

Channel 11-26 : 2.4 GHz (Across the World)

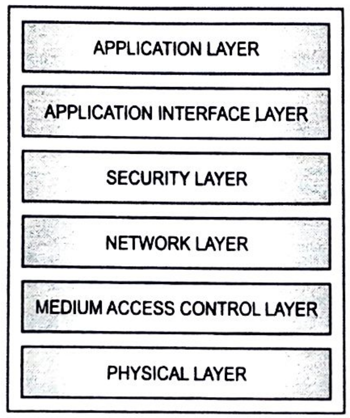
☞ Zigbee Network Topologies

- Star Topology (ZigBee Smart Energy)
- Mesh Topology (Self Healing Process)
- Tree Topology

☞ Architecture of Zigbee

Zigbee architecture is a combination of 6 layers.

- The Application layer is present at the user level.
- The Application Interface Layer, Security Layer, and Network Layer are the Zigbee Alliance and they are used to store data and they use the stack.
- Medium Access control and the Physical layer are the IEEE 802.15.4 and they are hardware which are silicon means they accept only 0 and 1.



(1B27)**Fig. 2.6.11 : Zigbee Architecture**

☞ Channel Access

1. **Contention Based Method** (Carrier-Sense Multiple Access With Collision Avoidance Mechanism)
2. **Contention Free Method** (Coordinator dedicates specific time slot to each device (Guaranteed Time Slot (GTS)))

☞ Zigbee Applications

1. Home Automation
2. Medical Data Collection
3. Industrial Control Systems

...Chapter Ends...

□□□

MODULE 3

CHAPTER 3

The Core IoT Functional Stack

Syllabus

Layer 1 - Things : Sensors and Actuators Layer, Layer 2 - Communications Network Layer, Access Network Sublayer, Gateways and Backhaul Sublayer, Network Transport Sublayer, IoT Network Management Sublayer, Layer 3 - Applications and Analytics Layer, Analytics Vs. Control Applications, Data Vs. Network Analytics, Data Analytics Vs. Business Benefits, Smart Services.