DON BOASO INSTITUTE OF TECHNOLOGY, MUMBAI
DEPARTMENT OF ELECTRONICS AND TELECOMMUNICATION ENGG
Question bank for sensor technology
IA2 AY 2022-233 ODD SEM

2M Questions

1. Advantages of MEMS

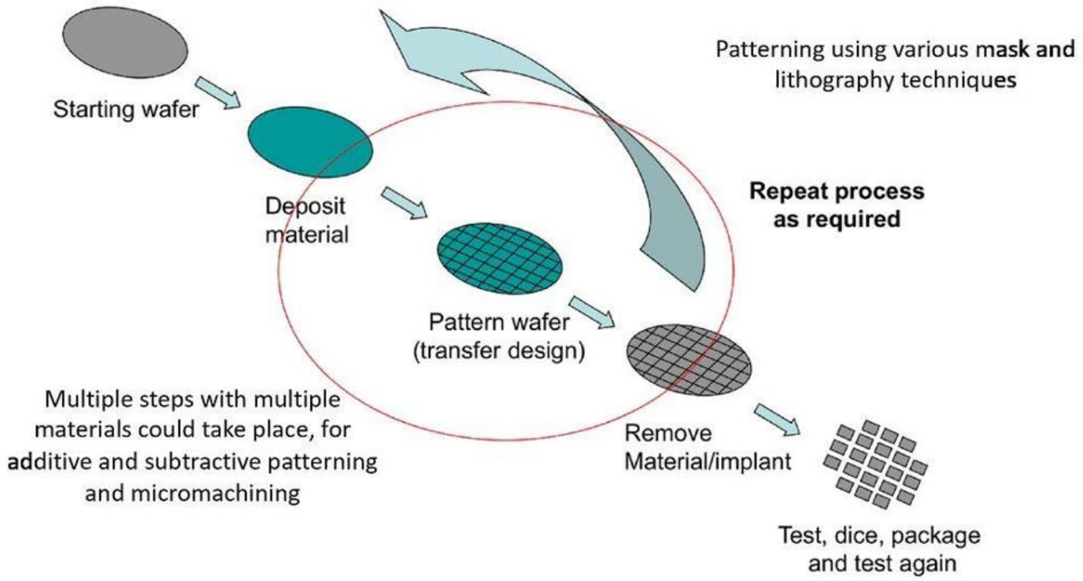
Advantages of MEMS

- Extremely scalable in manufacturing, resulting in very low unit costs when mass-produced
- MEMS sensors possess extremely high sensitivity
- MEMS switches and actuators can attain very high frequencies
- MEMS devices require very low power consumption
- MEMS can be readily integrated with microelectronics to achieve embedded mechatronic systems
- Scaling effects at microscopic levels can be leveraged to achieve designs and dynamic mechanisms otherwise not possible at macro-scales

2. Explain general design methodology for MEMS technology

General Design Methodology or How are MEMS made?

MEMS are classically micromachined from silicon. Various types of silicon wafers exist, and silicon can be doped to varying levels of conductivity. Additional functional materials can be added to provide various capabilities, such as electrode layers or piezoelectric layers. MEMS design and fabrication involves a series of steps and cycles, which can be summarised into:



•Design, modelling and simulation (using analytical, numerical, CAD and FEA methods)

•Layout and wafer tape-out (using Layout Editor)

•Starting wafer substrate (such as silicon, glass, quartz, stainless steel, plastics)

•Microfabrication process (cycling through the following steps until desired design is achieved)

- •Additive (material deposition: chemical vapour, sputtering, evaporation, oxidisation)
- •Additive (material deposition: chemical vapour, sputtering, evaporation, oxidisation)
- •Pattern (masks, photolithography, contact lithography, projection lithography)
- •Subtractive (material etching: wet chemical, dry ion or plasma, DRIE)

•Die dicing (laser, diamond saw, plasma etch)

•Wire bonding (to connect to interface circuitry)

•Packaging and encapsulation (hermetic seal, plastic/ceramic/metal seal, wafer-level packaging)

General Design Methodology

Starting with a list of specifications for the MEM device or system, the design process begins with the identification of the general operating principles and overall structural elements, then proceeds onto analysis and simulation, and finally onto outlining of the individual steps in the fabrication process. This is often an iterative process involving continuous adjustments to the shape, structure, and fabrication steps. The layout of the lithographic masks is the final step before fabrication and is completed using specialized CAD tools to define the two-dimensional patterns.

Early design considerations include the identification of the general sensing or actuation mechanisms based on performance requirements. For instance, the output force requirement of a mechanical microactuator may favor thermal or piezoelectric methods and preclude electrostatic actuation. Similarly, the choice of piezoresistive sensing is significantly different from capacitive or piezoelectric sensing. The inter disciplinary nature of the field brings together considerations from a broad range of specialties, including mechanics, optics, fluid dynamics, materials science, electronics, chemistry, and even biological sciences. On occasion, determining a particular approach may rely on economic considerations or ease of manufacture rather than performance. For example, the vast majority of pressure sensors use cost-effective piezoresistive sense elements instead of the better performing, but more expensive, resonant-type sense structures.

The design process is not an exact analytical science but rather involves developing engineering models, many for the purpose of obtaining basic physical insights. Computer-based simulation tools using finite-element modeling are convenient for analyzing complex systems.

In planning a fabrication process, the choice is to use a standard foundry service with a completely predefined process flow, to use a service that allows the selection of previously developed individual process steps, or to design a custom process specific to the device or system. If the production unit volume is not sufficiently large, it may be challenging to identify reputable manufacturing facilities willing to develop and implement custom processes.

3. Application of acceleration sensor

1. Vehicle Safety
2. Game control
3. Automatically Flipped the Image
4. Tilt Correction of Electronic Compass
5. Compensation for Dead Angle of GPS Navigation System
6. Pedometer Function

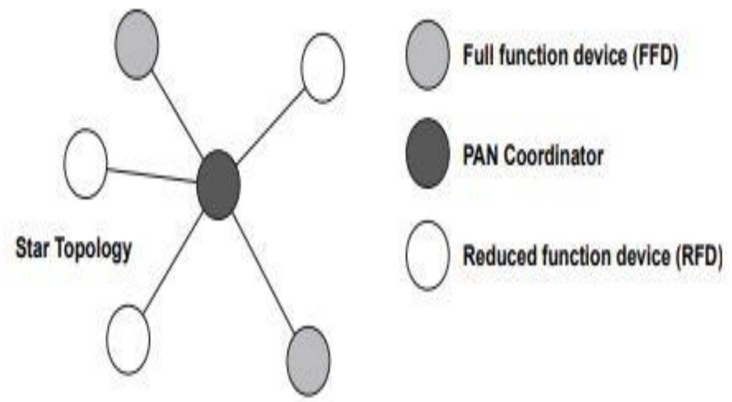
7. Image stabilization
8. Flash SMS

4. Explain MEMS actuation

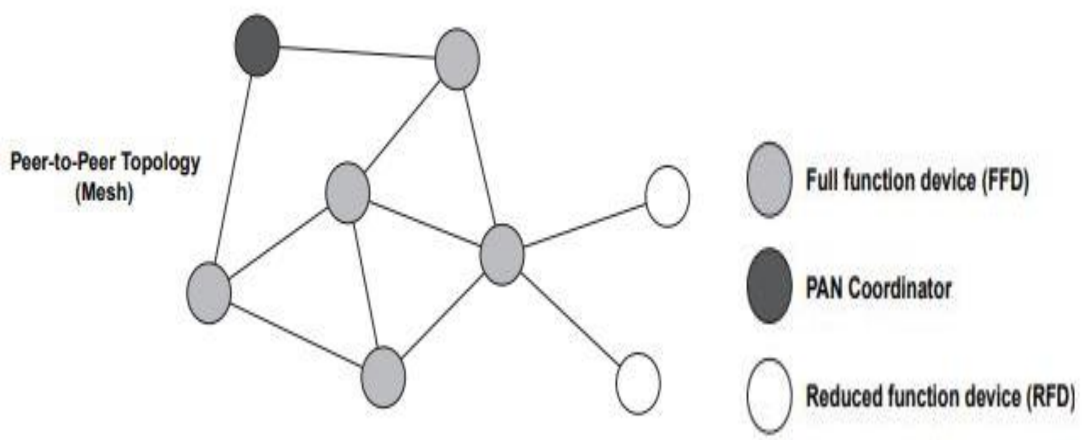
5. Explain Zigbee topologies

Zigbee supports three types of topologies: star topology, peer-to-peer topology and cluster-tree.

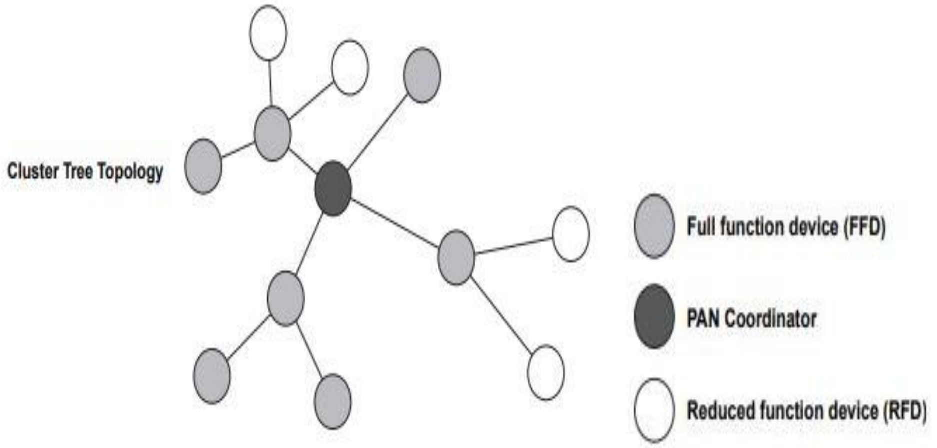
In the star topology, communication is established between devices and a single central controller, called the PAN coordinator.
After an FFD is activated for first time, it may establish its own network and become PAN coordinator.
Each star network **chooses a PAN identifier,** which is not currently used by any other network within the radio sphere of influence. This allows each star network to operate independently.
The **PAN coordinator may be powered by mains** while the ***devices will most likely be battery powered.***
Applications that benefit from this topology are **home automation, personal computer (PC) peripherals, toys and games**



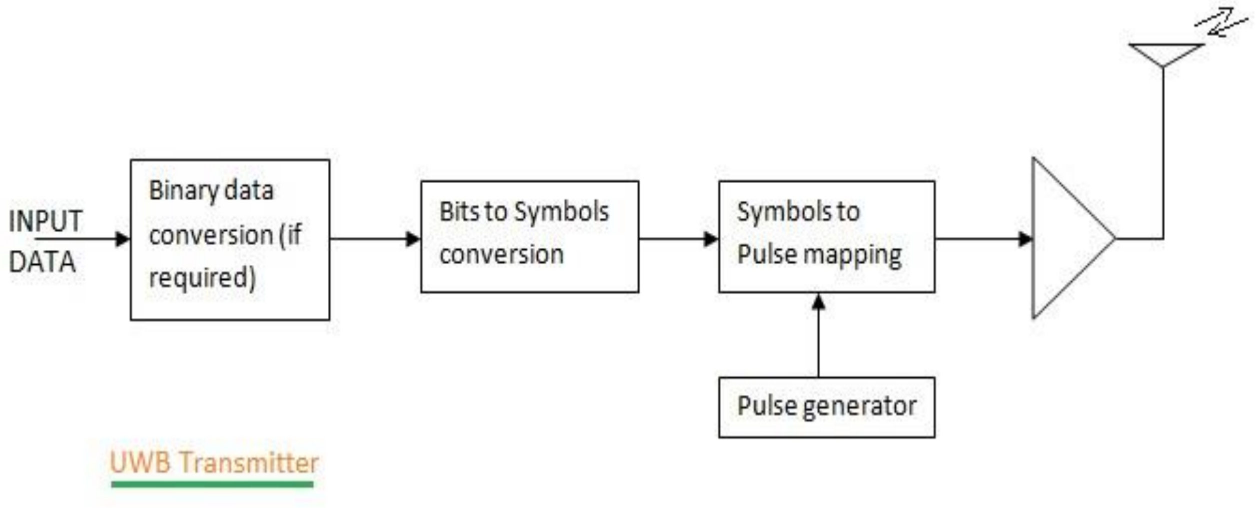
In peer-to-peer topology too, there is one PAN coordinator.
Any device can communicate with any other device as long as they are in range of one another.
Thus a peer-to-peer network can be ad hoc (unfixed), self-organizing, and self-healing.
Peer-to-peer topology allows multiple hops to route messages from any device to any other device in the network. It can provide reliability by multipath routing.
Applications such as industrial control and monitoring, wireless



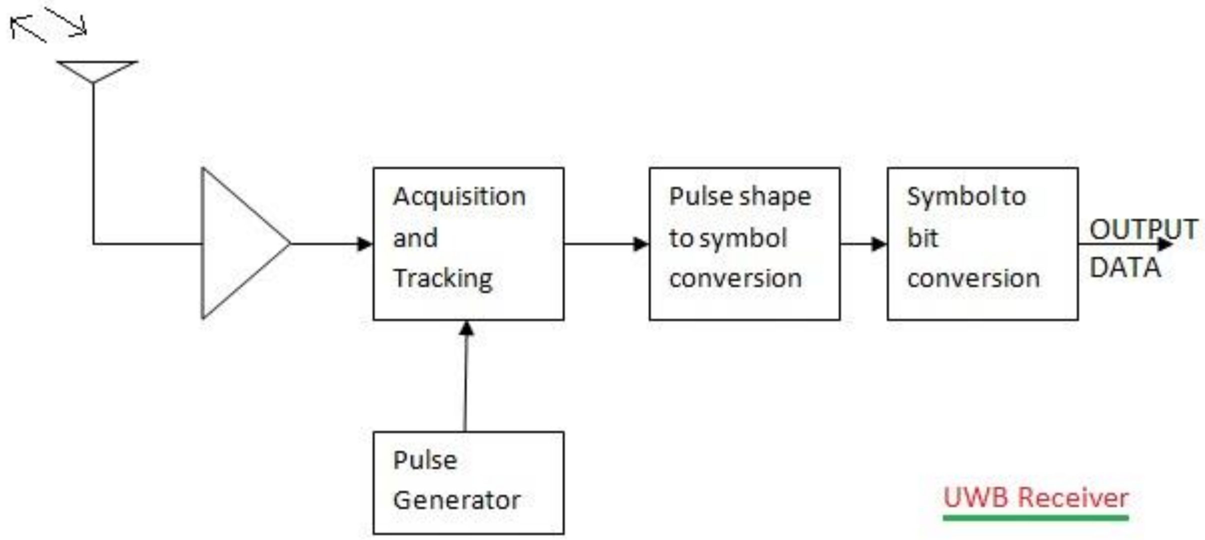
The cluster-tree topology is a **special case of a peer-to-peer network in which most devices are FFDs**.
Any of the FFDs can act as a coordinator and provide synchronization services to other devices and coordinators. **However, only one of these coordinators is PAN coordinator.**
The PAN coordinator forms the first cluster by establishing itself as cluster head (CLH) with a cluster identifier of zero (CID), choosing an unused PAN identifier.
The CLH broadcasts beacon frames to neighboring devices.
A candidate device receiving a beacon frame may request to join the network at cluster head.
If the PAN coordinator permits the device to join, it will add this new device to its neighbor list.



6. Draw block diagram of UWB transmitter and receiver



UWB transmitter consists of binary data source, conversion of bits to symbols, symbols to pulses using pulse generator and RF part



UWB receiver consists of front end part and symbols to bits conversion. Front end part does acquisition, tracking and conversion of pulses to symbols. After bits conversion data conversion is taken place based on application need.

7. Write the application of RFID

- It utilized in tracking shipping containers, trucks and railroad, cars.
- It uses in Asset tracking.
- It utilized in credit-card shaped for access application.
- It uses in Personnel tracking.
- Controlling access to restricted areas.
- It uses ID badging.
- Supply chain management.
- Counterfeit prevention (e.g., in the pharmaceutical industry).

8. Draw Bluetooth architecture

5 Marks question

1. **Explain MEMS pressure sensor**

Microelectromechanical systems (MEMS) devices combine small mechanical and electronic components on a silicon chip.

The fabrication techniques used for creating transistors, interconnect and other components on an integrated circuit (IC) can also be used to construct mechanical components such as springs, deformable membranes, vibrating structures, valves, gears and levers.

This technology can be used to make a variety of sensors including several types of pressure sensor. It enables the combination of accurate sensors, powerful processing and wireless communication (for example, Wi-Fi or Bluetooth) on a single IC.

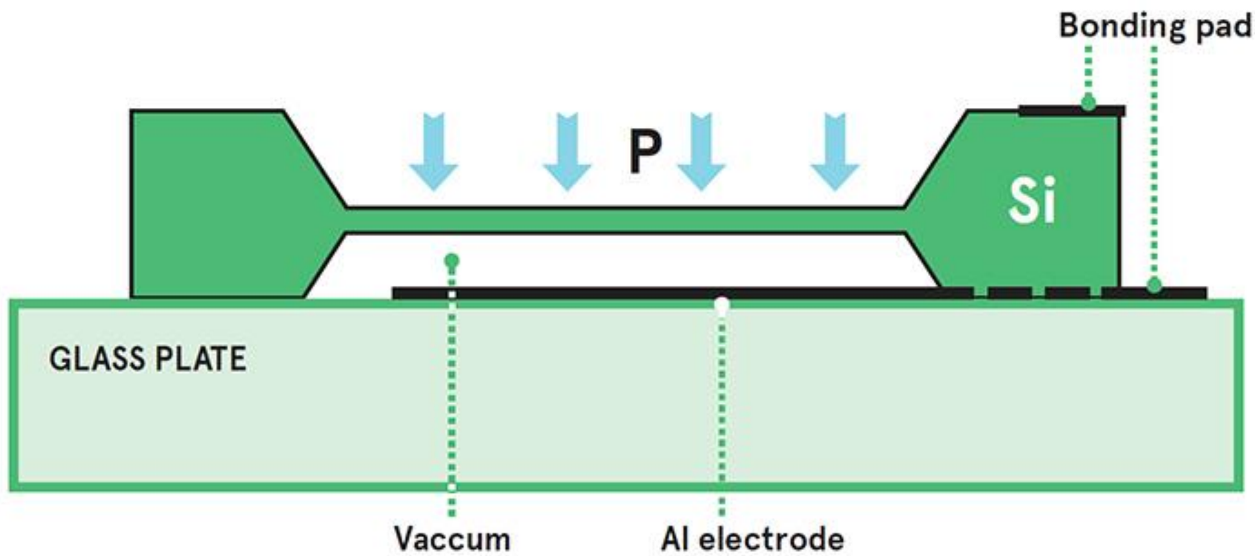
Large numbers of devices can be made at the same time so they benefit from the same scaling advantages and cost efficiencies as traditional Ics.

Function

Several types of pressure sensor can be built using MEMS techniques. Here we will discuss two of the most common: piezoresistive and capacitive. In both of these, a flexible layer is created which acts as a diaphragm that deflects under pressure but different methods are used to measure the displacement.

MEMS capacitive pressure sensors

To create a capacitive sensor, conducting layers are deposited on the diaphragm and the bottom of a cavity to create a capacitor. The capacitance is typically a few picofarads.



A cross section of a MEMs capacitive pressure sensor

Deformation of the diaphragm changes the spacing between the conductors and hence changes the capacitance (see right). The change can be measured by including the sensor in a tuned circuit, which changes its frequency with changing pressure.

The sensor can be used with electronic components on the chip to create an oscillator, which generates the output signal. Because of the difficulty of fabricating large inductances on silicon, this will usually be based on an RC circuit.

This approach is well suited for wireless readout because it generates a high frequency signal that can be detected with a suitable external antenna.

Alternatively, the capacitance can be measured more directly by measuring the time taken to charge the capacitor from a current source. This can be compared with a reference capacitor to account for manufacturing tolerance and to reduce thermal effects.

In both cases, the proximity of the electronics and the sensor element minimises errors caused by stray capacitance and noise.

MEMS piezoresistive strain gauge sensors

Piezoresistive strain gauge sensors were the first successful MEMS pressure sensors and are widely used in applications such as automotive, medical and household appliances.

Conductive sensing elements are fabricated directly on to the diaphragm. Changes in the resistance of these conductors provide a measure of the applied pressure. The change in resistance is proportional to the strain, which is the relative change in length of the conductor.

The resistors are connected in a Wheatstone bridge network, which allows very accurate measurement of changes in resistance. The piezoresistive elements can be arranged so that they experience opposite strain (half are stretched and the other half are compressed) to maximise the output signal for a given pressure.

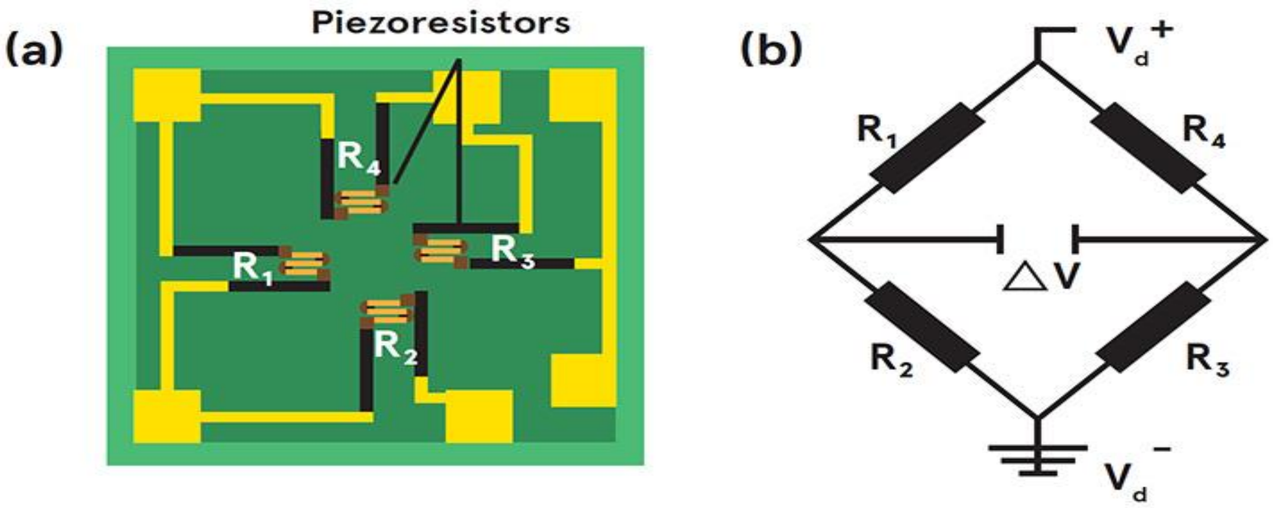


Figure: Two ways in which piezoresistive elements might be arranged

An excitation voltage Vex is applied and the output voltage is proportional to the change in resistance:

$$V_o = \frac{\Delta R}{R} V_{ex}$$

Other MEMS pressure sensors

There are other ways of making MEMS pressure sensors that can be used.

For example, a mechanical structure can be created with a resonant frequency that is a function of applied pressure (like tuning a piano string). A signal is applied to cause the structure to vibrate and the change in resonant frequency is measured. Such devices can be very accurate but are difficult to manufacture and are sensitive to other environmental factors, such as temperature, that also change the resonant frequency.

A surface acoustic wave (SAW) sensor works by sending vibrations through a thin film of piezoelectric material. The waves are picked up by another transducer and converted back to an electrical signal. The changes in the amplitude or phase of the acoustic signal caused by deformation of the surface can be measured to give an indication of pressure.

Applications

Pressure sensors have long been used in medicine, in non-invasive applications such as controlling the air pressure in respiratory equipment and measuring blood pressure. More recently, the miniaturisation provided by MEMS devices has enabled use in more invasive applications such as catheter tip sensors, as well as for implantable devices monitoring properties such as blood pressure and heart rate.

For medical applications there is a challenge in making the standard package (which is made from rigid material with sharp edges) compatible with the biological environment. This can be achieved by enclosing the device in biocompatible plastic or wire.

> The small size, low power consumption and long-term stability of MEMS devices also makes them well suited to markets such as aerospace where long life and reliability are important. They are used in a variety of applications including cabin pressure monitoring, engine control, and instruments such as altimeters and barometers.

2.Explain working of MEMS accelerometer

Working

One of the most commonly used MEMS accelerometer is the capacitive type. The capacitive MEMS accelerometer is famous for its high sensitivity and its accuracy at high temperatures. The device does not change values depending on the base materials used and depends only on the capacitive value that occurs due to the change in distance between the plates.

If two plates are kept parallel to each other and are separated by a distance'd', and if 'E' is the permitivity of the separating material, then capacitance produced can be written as

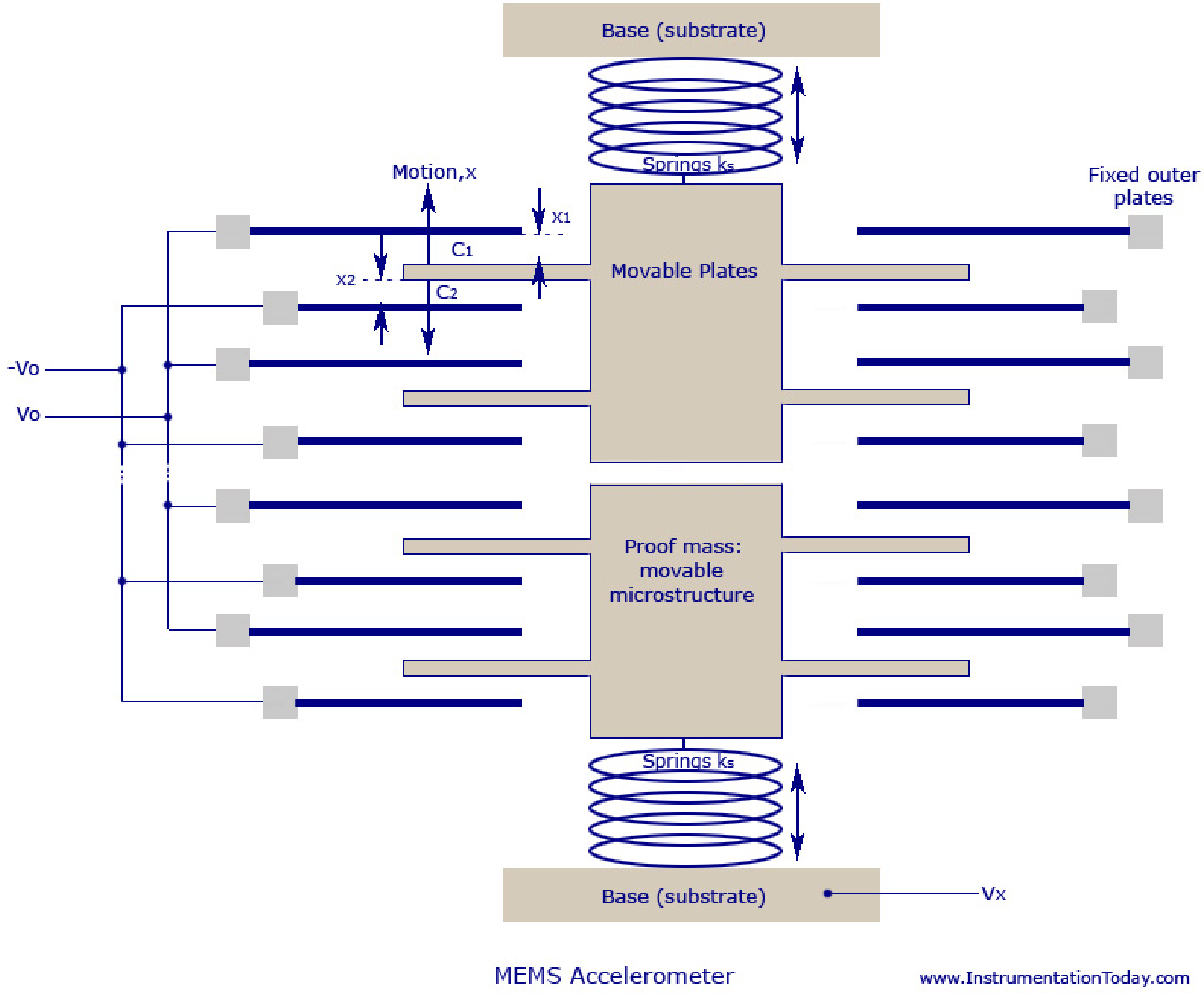
C0 = E0.E A/d = EA/d

EA = E0EA

A – Area of the electrodes

A change in the values of E, A or d will help in finding the change in capacitance and thus helps in the working of the MEMS transducer. Accelerometer values mainly depend on the change of values of d or A.

A typical MEMS accelerometer is shown in the figure below. It can also be called a simple one-axis accelerometer. If more sets of capacitors are kept in 90 degrees to each other you can design 2 or 3-axis accelerometer. A simple MEMS transducer mainly consists of a movable microstructure or a proof mass that is connected to a mechanical suspension system and thus on to a reference frame.



MEMS Accelerometer

The movable plates and the fixed outer plates act as the capacitor plates. When acceleration is applied, the proof mass moves accordingly. This produces a capacitance between the movable and the fixed outer plates.

When acceleration is applied, the distance between the two plates displace as X1 and X2, and they turn out to be a function of the capacitance produced.

From the image above it is clear that all sensors have multiple capacitor sets. All upper capacitors are wired parallel to produce an overall capacitance C1 and the lower ones produce an overall capacitance of C2.

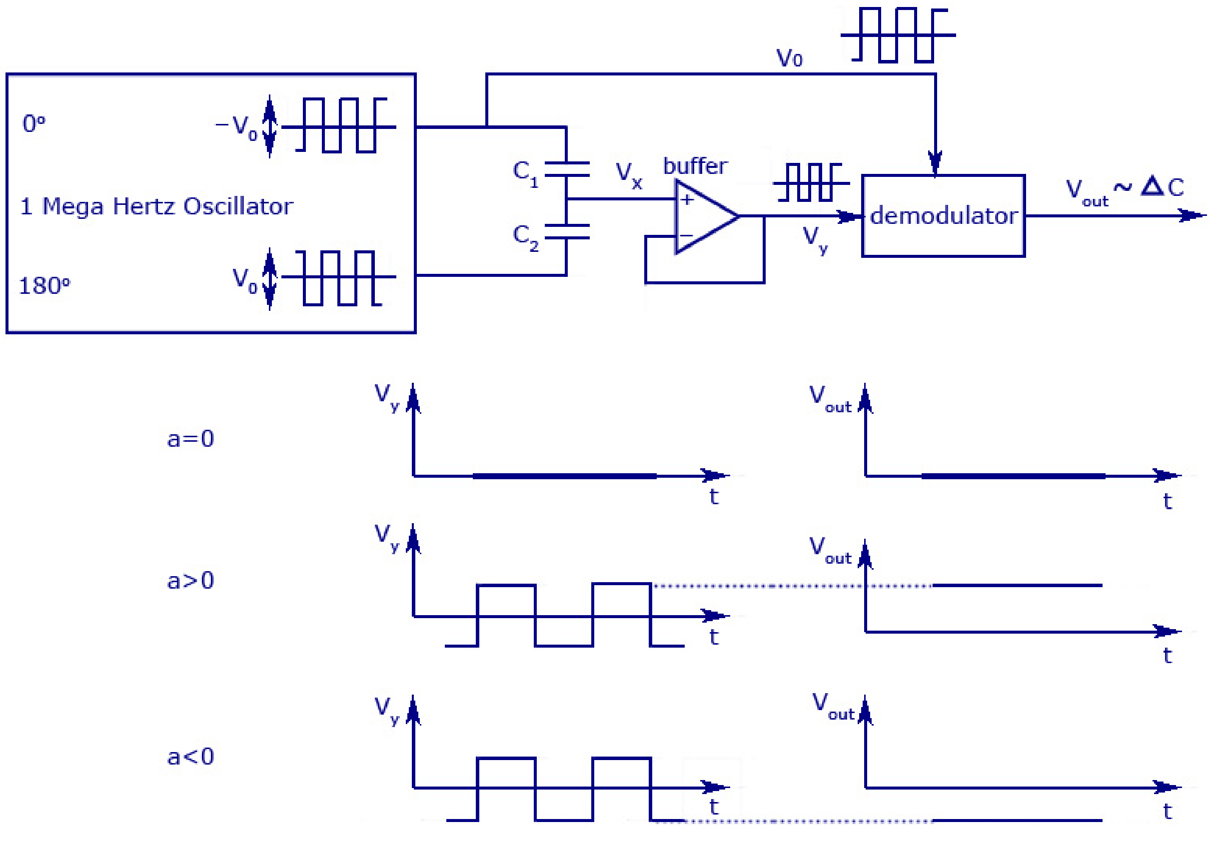
If Vx is the output voltage of the proof mass, and V0 is the output voltage produced between the plates, then

$(V_x + V_0)\, C_1 + (V_x - V_0)\, C_2 = 0$

We can also write

$V_x = V_0\,[(C_2-C_1)/(C_2+C_1)] = (x/d)\,V_0$

The figure below shows the circuit that is used to calculate the acceleration, through change in distance between capacitor plates. The output obtained for different values of acceleration is also shown graphically.



Acceleration Calculation - Capacitor Type MEMS Accelerometer

3. **Explain MEMS Micro machined microphones**

A **MEMS microphone** is an electro-acoustic transducer housing a sensor (MEMS) and an application-specific integrated circuit (ASIC) in a single package.

The sensor converts variable incoming sound pressure to capacitance variations that the ASIC transforms into analog or digital output. The acoustic wave enters the microphone through a sound inlet in the top or bottom of the package, hence the **top or bottom** port nomenclature.

MEMS microphones target all audio applications where key requirements are small size, high sound quality, reliability, and affordability.

MEMS microphone applications

MEMS microphones find application in many fields, including **personal electronics**, **industrial**, **automotive**, **peripherals, and computers**.

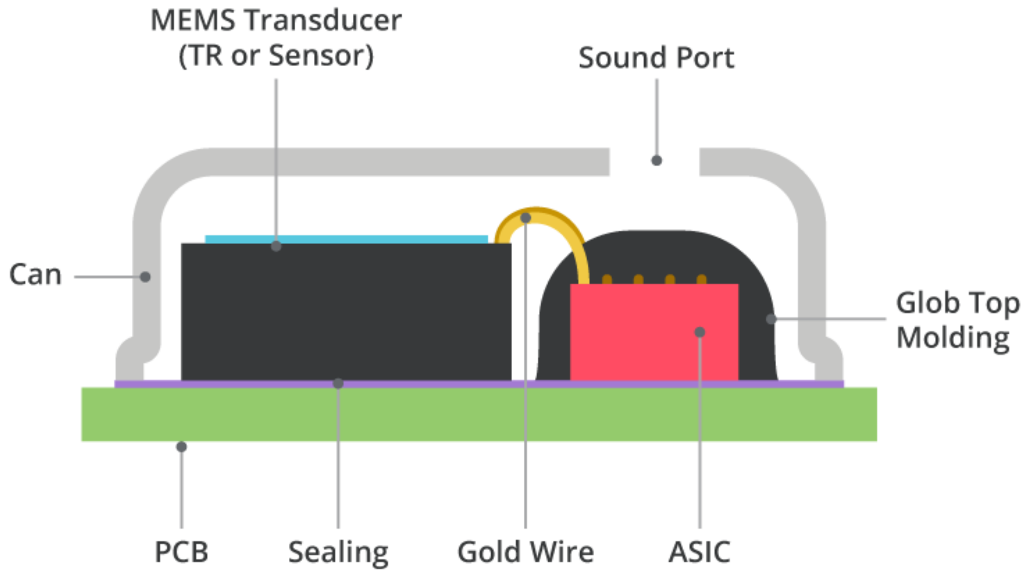
Best-in-class acoustic overload point (AOP) and signal-to-noise ratio (SNR) makes MEMS microphones suitable for applications that require a very high dynamic range.

Very tight sensitivity matching allows optimization of **beamforming**, **sound source localization,** and **noise canceling** algorithms for multimicrophone arrays. These are key elements in voice activated applications like **smart home** and **smart speakers.**

The flat frequency response and high performance enable automotive applications like **hands-free call and e-Call**, **noise canceling**, and **in-car communications.**

Low power consumption products extend the autonomy of **battery-operated applications**.

MEMS microphones are constructed with a MEMS (Micro-Electro-Mechanical System) component placed on a printed circuit board (PCB) and protected with a mechanical cover. A small hole is fabricated in the case to allow sound into the microphone and is either designated as top-ported if the hole is in the top cover or bottom-ported if the hole is in the PCB. The MEMS component is often designed with a mechanical diaphragm and mounting structure created on a semiconductor die.



The MEMS diaphragm forms a capacitor and sound pressure waves cause movement of the diaphragm. MEMS microphones typically contain a second semiconductor die which functions as an audio preamplifier, converting the changing capacitance of the MEMS to an electrical signal. The output of the audio preamplifier is provided to the user if an analog output signal is desired. If a digital output signal is desired, then an analog-to-digital converter (ADC) is included on the same die as the audio preamplifier. A common format used for the digital encoding in MEMS microphones is pulse density modulation (PDM), which allows for communication with only a clock and a single data line. Decoding of the digital signal at the receiver is simplified due to the single bit encoding of the data. Digital I^2S outputs are a third option that include an internal decimation filter, which allows for processing to be completed in the microphone itself. This means the microphone can connect directly to a digital signal processor (DSP) or microcontroller, eliminating the need for an ADC or codec in many applications.

4. Explain Bluetooth architecture

Bluetooth Architecture:

The architecture of Bluetooth defines two types of networks:

1. Piconet

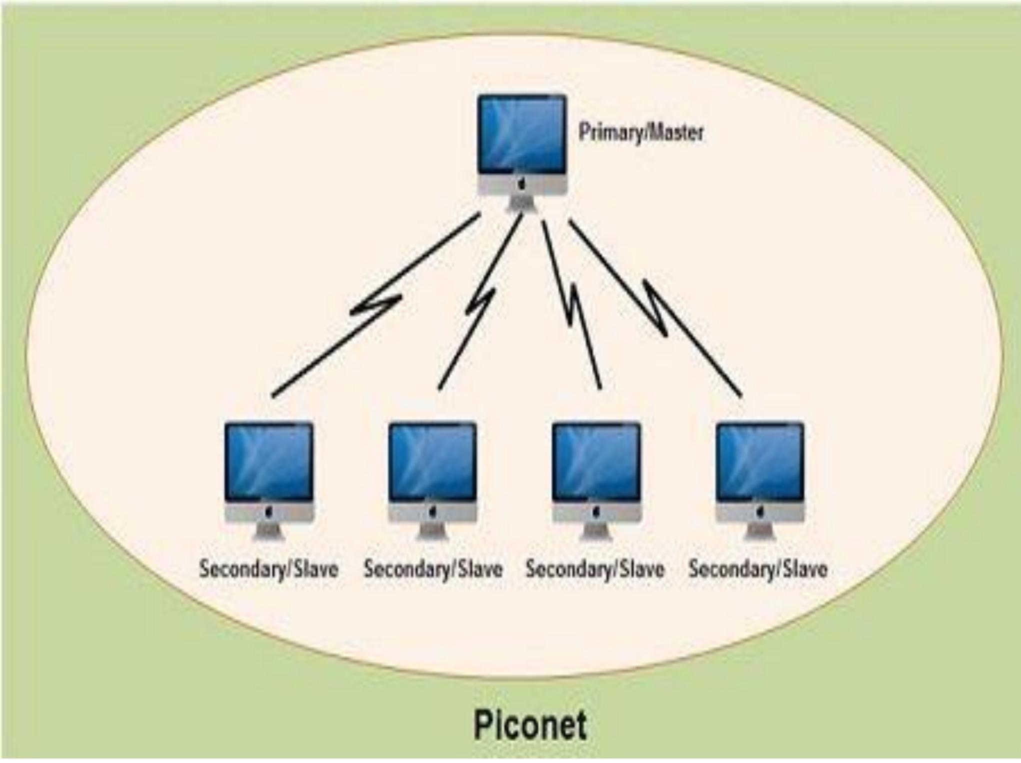
2. Scatternet

Piconet:

Piconet is a type of Bluetooth network that contains one primary node **called master node** and seven active secondary nodes **called slave nodes.** Thus, we can say that there are total of 8 ***active nodes which are present at a distance of 10 meters.***

The communication between the primary and secondary node can be one-to-one or one-to-many. Possible communication is only between the master and slave; Slave-slave communication is not possible.

It also have 255 parked node**s**, these are secondary nodes and cannot take participation in communication unless it gets converted to the active state.

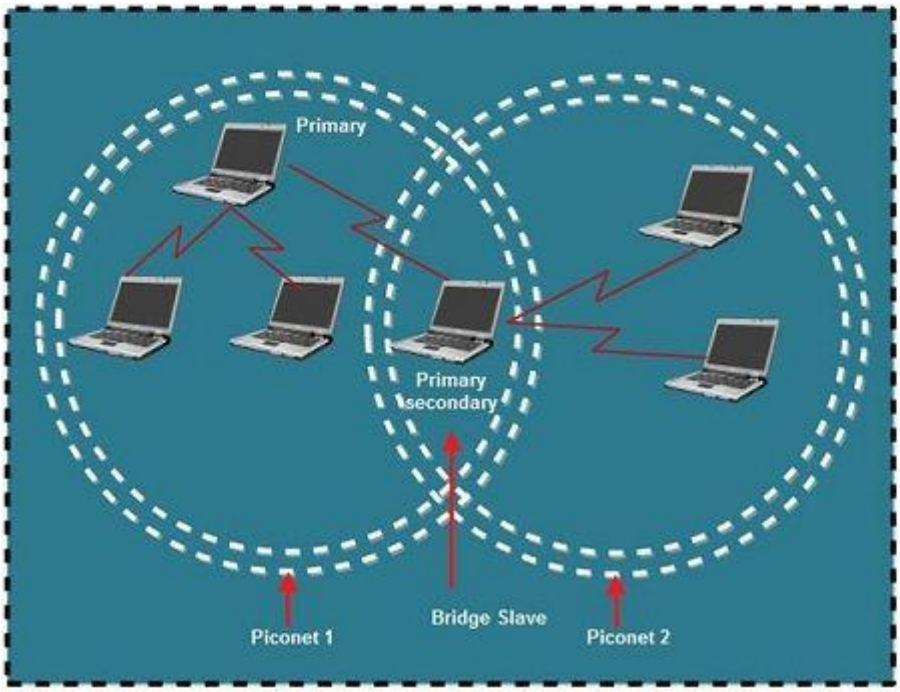


How many devices can be connected in a piconet?

- The bluetooth enabled devices can locate each other, but user action is essential in order to make connections with other devices and from networks. Upto eight devices can be connected in a Bluetooth network called, PICONET. One of them acts as a master and remaining act as slaves. Hence, a maximum of 7 slaves can be supported inside a piconet.

Scatternet:

It is formed by using **various piconets**. A slave that is present in one piconet can act as master or we can say primary in another piconet. This kind of node can receive message from master in one piconet and deliver the message to its slave into the other piconet where it is acting as a slave. This type of node is refer as bridge node.Thus a station can be a member of two piconets. A station cannot be master in two piconets.



Bluetooth devices have a built-in short range radio transmitter. The rate provided is 1Mbps and uses 2.4 GHz bandwidth.

5. Explain Near Field Communication

NFC(Near Field Communication)

NFC stands for Near field communication. NFC is a short range, low speed set of wireless communication protocols for exchange of data between two electronic devices. The range of NFC is about 4cm or less. They can be used for contact less payment using mobile handsets without the use of any credit or debit card. NFC can be used for sharing a small-sized file or even bootstrapping more capable wireless connections so that larger files such as photos, videos and other such files can be shared.

How does NFC works

This short-range, low- speed wireless technology works on the concepts of RFID(Radio Frequency Identification) technique based on the principles of electromagnetic induction for transmitting messages. It uses radio waves for sending and receiveing data. It uses two magnetic induction between two loop antennas which are placed at each othr's near field. The techniques uses an initiator and target. The initiator generates the Radio Frequency field which can supply power to the passive targets.

There are basically two types of NFC devices- passive and active.

Passive devices do not need any power source of their own. These types of passive devices have tags and some transmitters or antennas. They can send information to other NFC compatible devices through these antennas but they cannot connect to other passive NFC devices on their own.

Active devices can exchange data as well as establish a new connection with other active NFC devices. Examples of active NFC devices are public transport card readers and touch payment terminals. NFC uses transmission frequency of 13.56 Mhz. NFC operates in three different modes.

- **Peer to Peer mode-** It is widely used in smartphones and allows NFC-enabled smartphones and devices to exchange data between each other.
- **Read/Write mode-** It is a one-way transmission.In this mode NFC device can link with another NFC device to read or write from it.
- **Card emulation mode -** In this mode the NFC device can act as a means of cntact less payment mode without the use of any credit/debit card.

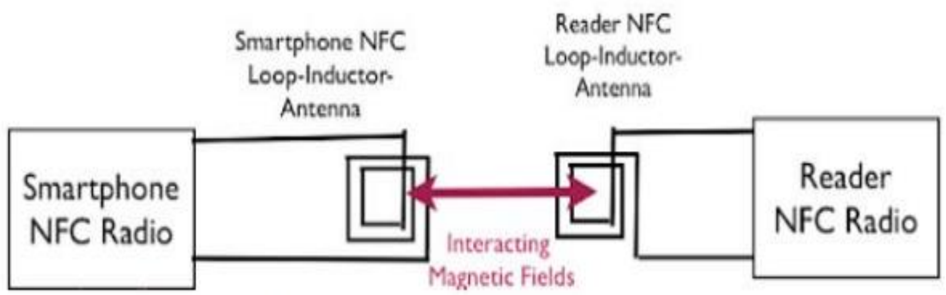


Figure. Working of Near Field Communication (NFC)

NFC application can be categorized as

- Touch and Go
- Touch and Confirm
- Touch and Connect

Touch and Go- it is used in application such as picking up Internet URL from a smart label on a poster. In this user only needs to bring his device closer to the access code on the poster.

Touch and Confirm- In this the device user has to confirm the interaction by accepting the transaction or entering a password.

Touch and Connect- It enables peer to peer transfer between two NFC- enabled devices such as exchanging of documents, a music video or an image.

Advantages of NFC

- It is highly convenient to the user as the data exchange can be conveniently done just by bringing the two NFC- enabled devices closer.
- Cost of electronic issuance is greatly reduced.
- Communication is highly secured due to the close proximity of the devices.
- There is no special software required for this type of data exchange.
- No manual setting or configuration is required
- No device search and pairing procedure is required.

Examples of device using NFC technology

- Galaxy Nexus
- Galaxy Nexus S 4G
- Samsung Galaxy Note
- Nexus S
- Nokia 6212 Classic
- Nokia 6131 NFC

NFC Vs RFID

Though both RFID and NFC are based on the same underlying technology there are some distinguishing features between them. NFC is a subset of RFID technology. Both uses radio waves for data transmission. NFC operates within the High Frequency range of the RFID spectrum. RFID is a much older technology and originated way back in the 1980s. NFC is a newbie and came to picture in 2002. RFID improves upon printed barcodes whereas NFC improves upon QR codes. Both technologies do not need line of sight operation but NFC has added intelligence and is much efficient than RFID. RFID can store and transmit simple Ids whereas NFC transmits multiple data types.

NFC can provide solutions to solve all the challenges faced to implement Internet of Things applications- to connect the unconnected. It provides easy network access and data sharing between IoT devices. It provides secured data transmission within a closed proximity and hence havkers have less chance to hack them. Today, NFC is playing a key role in making the IoT applications more efficient.

6. **Explain WLAN topologies**

WLAN Topologies

The 802.11 standard identifies two main wireless topology modes: infrastructure mode and Independent Basic Service Set (IBSS). IBSS is also knows as ad hoc mode. With the ubiquity of wireless networks, mesh topologies are now common.

Infrastructure Mode

With infrastructure mode, wireless clients interconnect via an AP. Figure illustrates infrastructure mode terminology. Notice that the configuration of the APs to share the same SSID allows wireless clients to roam between BSAs.

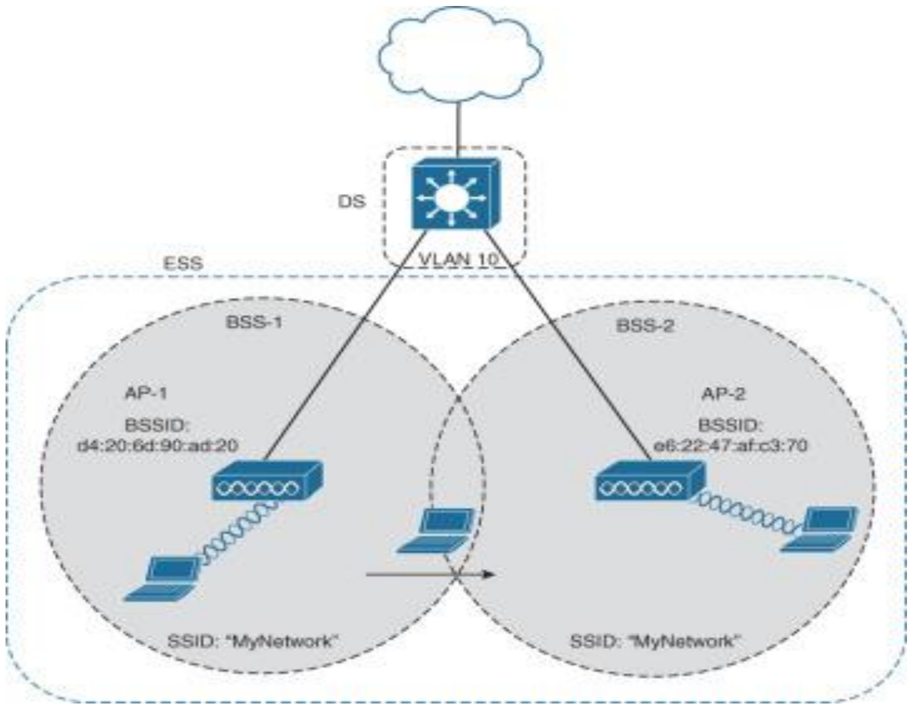


Figure : Example of ESS Infrastructure Mode

Infrastructure mode terminology includes the following:

•Basic service set (BSS): This consists of a single AP interconnecting all associated wireless clients.

•Basic service area (BSA)**:**This is the area that is bound by the reach of the AP's signal. The BSA is also called a *cell* (the gray area inFigure).

•Basic service set identifier (BSSID)**:**This is the unique, machine-readable identifier for the AP that is in the format of a MAC address and is usually derived from the AP's wireless MAC address.

•Service set identifier (SSID)**:**This is a human-readable, non-unique identifier used by the AP to advertise its wireless service.

•Distribution system (DS): APs connect to the network infrastructure using the wired DS, such as Ethernet. An AP with a wired connection to the DS is responsible for translating frames between 802.3 Ethernet and 802.11 wireless protocols.

•Extended service set (ESS)**:**When a single BSS provides insufficient coverage, two or more BSSs can be joined through a common DS into an ESS. An ESS is the union of two or more BSSs interconnected by a wired DS. Each ESS is identified by its SSID, and each BSS is identified by its BSSID.

IBSS, or Ad Hoc Mode

In the 802.11 standard, Independent Basic Service Set (IBSS) is defined as two devices connected wirelessly in a peer-to-peer (P2P) manner without the use of an AP. One device takes the role of advertising the wireless network to clients. The IBSS allows two devices to communicate directly without the need for any other wireless devices, as shown in Figure. IBSSs do not scale well beyond 8 to 10 devices.

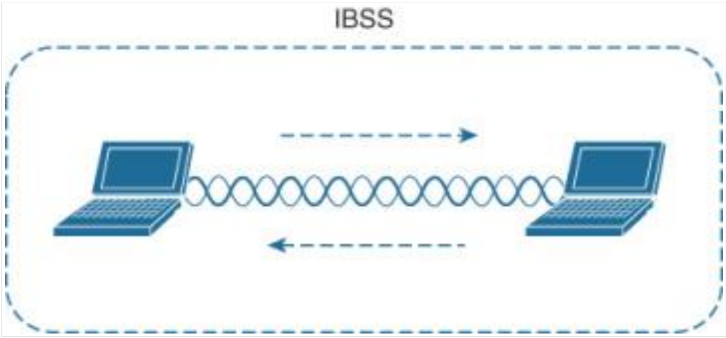


Figure : 802.11 Independent Basic Service Set

Mesh

Having a wired DS connecting all APs is not always practical or necessary. Instead, APs can be configured to connect in mesh mode. In this mode, APs bridge client traffic between each other, as shown in Figure.

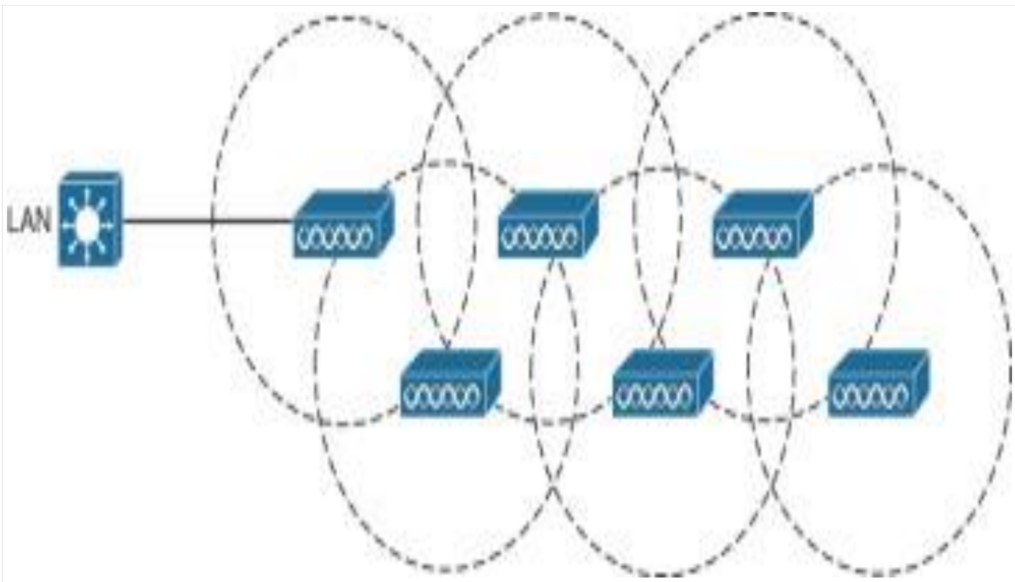


Figure: Example of a Wireless Mesh Network

Each AP in the mesh maintains a BSS on one channel used by wireless clients. Then the APs bridge between each other using other channels. The mesh network runs its own dynamic routing protocol to determine the best path to the wired network.

Wireless Technologies

Wireless technologies can be classified in different ways depending on their range. Each wireless technology is designed to serve a specific usage segment. The requirements for each usage segment are based on a variety of variables, including Bandwidth needs, Distance needs and Power.

Wireless Wide Area Network (WWAN)

This network enables you to access the Internet via a wireless wide area network (WWAN) access card and a PDA or laptop.

These networks provide a very fast data speed compared with the data rates of mobile telecommunications technology, and their range is also extensive. Cellular and mobile networks based on CDMA and GSM are good examples of WWAN.

Wireless Personal Area Network (WPAN)

These networks are very similar to WWAN except their range is very limited.

Wireless Local Area Network (WLAN)

This network enables you to access the Internet in localized hotspots via a wireless local area network (WLAN) access card and a PDA or laptop.

It is a type of local area network that uses high-frequency radio waves rather than wires to communicate between nodes.

These networks provide a very fast data speed compared with the data rates of mobile telecommunications technology, and their range is very limited. Wi-Fi is the most widespread and popular example of WLAN technology.

Wireless Metropolitan Area Network (WMAN)

This network enables you to access the Internet and multimedia streaming services via a wireless region area network (WRAN).

These networks provide a very fast data speed compared with the data rates of mobile telecommunication technology as well as other wireless network, and their range is also extensive.