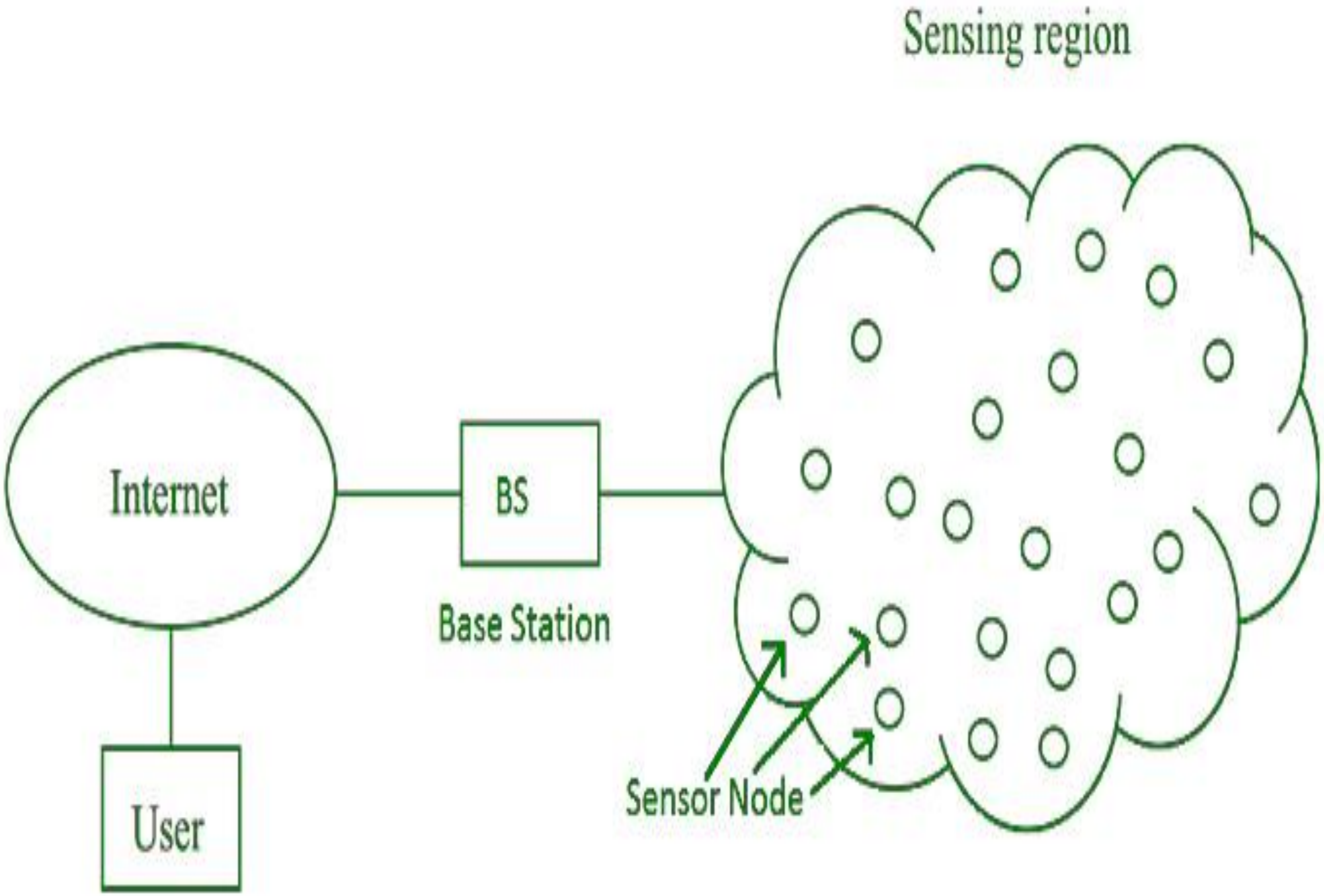
Wireless and Mobile Networks

Dr./ Ahmed Mohamed Rabie

Chapter 2

Wireless Sensor Networks

Wireless sensor networks (WSNs) are interconnected sensor nodes that communicate wirelessly to collect data about the surrounding environment. Although WSNs have gained a lot of popularity, there are some serious limitations when implementing security imposed by resource limitations in memory, computing, battery life, and bandwidth.


Sensing region
Internet
BS
Base Station
User
Sensor Node

Sensor nodes offer a powerful combination of distributed sensing, computing and communication. The ever increasing capabilities of these tiny sensor nodes, which include sensing, data processing, and communicating, enable the realization of WSNs based on the collaborative effort of a number of other sensor nodes. They enable a wide range of applications and, at the same time, offer numerous challenges due to their peculiarities, primarily the stringent energy constraints to which sensing nodes are typically subjected.

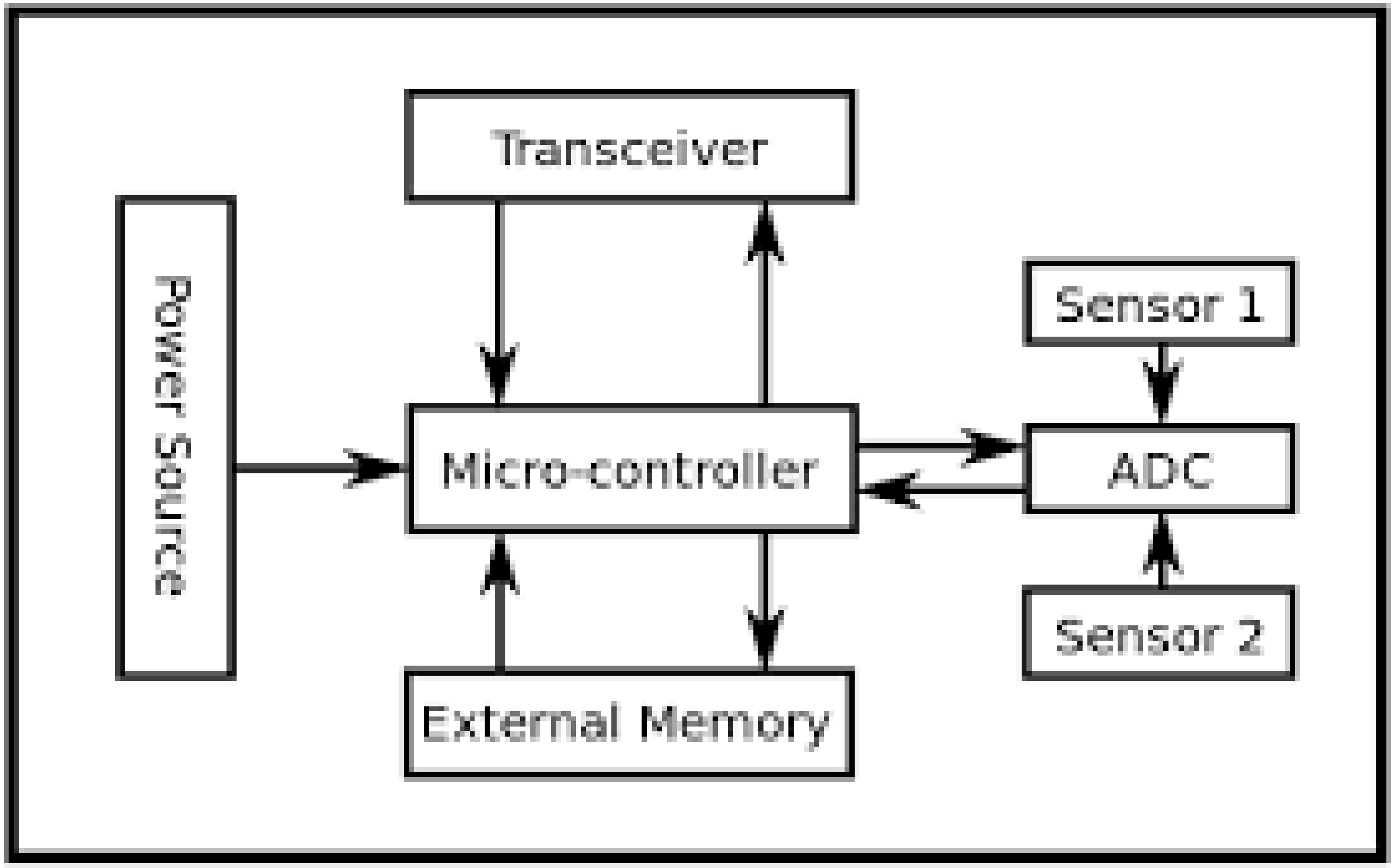
Sensor nodes are used in WSN with the onboard processor that manages and monitors the environment in a particular area. They are connected to the **Base Station** which acts as a processing unit in the WSN System. Base Station in a WSN System is connected through the Internet to share data.

Components of WSN:

- **Sensors**: Sensors in WSN are used to capture the environmental variables and which is used for data acquisition. Sensor signals are converted into electrical signals.
- **Radio Nodes**: It is used to receive the data produced by the Sensors and sends it to the WLAN access point. It consists of a microcontroller, transceiver, external memory, and power source.

- **WLAN Access Point**: It receives the data which is sent by the Radio nodes wirelessly, generally through the internet.
- **Evaluation Software**: The data received by the WLAN Access Point is processed by a software called as Evaluation Software for presenting the report to the users for further processing of the data which can be used for processing, analysis, storage, and mining of the data.

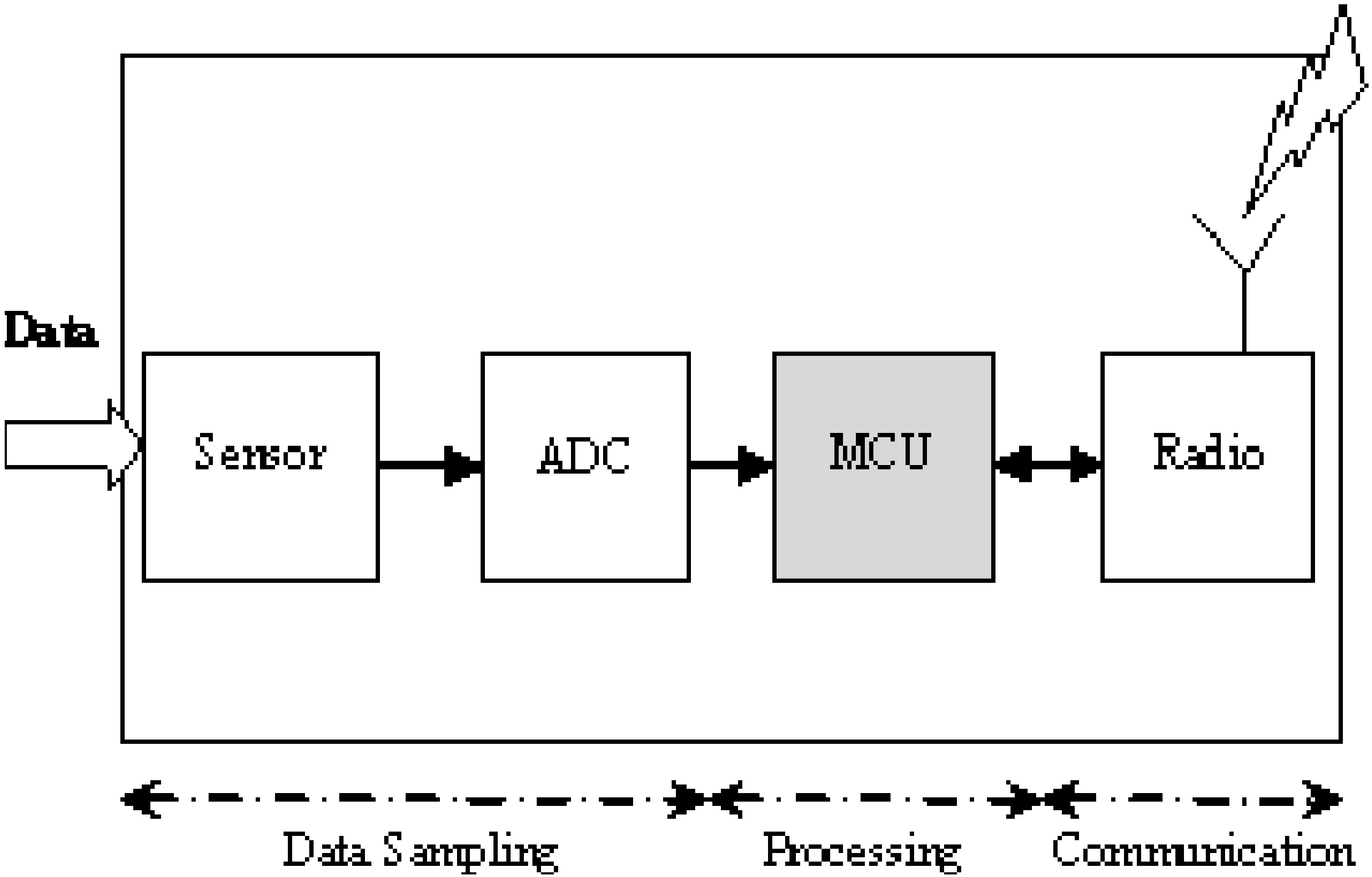
Radio Nodes


Transceiver
Power Source
Sensor 1
Micro-controller
ADC
Sensor 2
External Memory

Sensor Nodes

1- Controller: The controller performs tasks, processes data and controls the functionality of other components in the sensor node. While the most common controller is a microcontroller, other alternatives that can be used as a controller are: a general purpose desktop microprocessor, and digital signal processors. A microcontroller is often used in many embedded systems such as sensor nodes because of its low cost, flexibility to connect to other devices, ease of programming, and low power consumption.

A general purpose microprocessor generally has a higher power consumption than a microcontroller, therefore it is often not considered a suitable choice for a sensor node. Digital Signal Processors may be chosen for broadband wireless communication applications, but in Wireless Sensor Networks the wireless communication is often modest: i.e., simpler, easier to process modulation and the signal processing tasks of actual sensing of data is less complicated. Therefore, the advantages of DSPs are not usually of much importance to wireless sensor nodes.


Data
Sensor
ADC
MCU
Radio
Data Sampling
Processing
Communication

2- Transceiver: Sensor nodes often make use of ISM band, which gives free radio, spectrum allocation and global availability. The possible choices of wireless transmission media are radio frequency (RF), optical communication (laser) and infrared. Lasers require less energy , but need line-of-sight for communication and are sensitive to atmospheric conditions. Infrared, like lasers, needs no antenna but it is limited in its broadcasting capacity. Radio frequency-based communication is the most relevant that fits most of the WSN applications.

WSNs tend to use license-free communication frequencies: 173, 433, 868, and 915 MHz; and 2.4 GHz. The functionality of both transmitter and receiver are combined into a single device known as a transceiver. Transceivers often lack unique identifiers. The operational states are transmit, receive, idle, and sleep. Current generation transceivers have built-in state machines that perform some operations automatically.

Most transceivers operating in idle mode have a power consumption almost equal to the power consumed in receive mode. Thus, it is better to completely shut down the transceiver rather than leave it in the idle mode when it is not transmitting or receiving. A significant amount of power is consumed when switching from sleep mode to transmit mode in order to transmit a packet.

3- External memory: From an energy perspective, the most relevant kinds of memory are the on-chip memory of a microcontroller and Flash memory—off-chip RAM is rarely, if ever, used. Flash memories are used due to their cost and storage capacity. Memory requirements are very much application dependent. Two categories of memory based on the purpose of storage are: **user memory** used for storing application related or personal data, and **program memory** used for programming the device. Program memory also contains identification data of the device if present.

4- Power source: A wireless sensor node is a popular solution when it is difficult or impossible to run a mains supply to the sensor node. However, since the wireless sensor node is often placed in a hard-to-reach location, changing the battery regularly can be costly and inconvenient. An important aspect in the development of a wireless sensor node is ensuring that there is always adequate energy available to power the system. The sensor node consumes power for sensing, communicating and data processing.

More energy is required for data communication than any other process. The energy cost of transmitting 1 Kb a distance of 100 meters (330 ft.) is approximately the same as that used for the execution of 3 million instructions by a 100 million instructions per second/W processor. Power is stored either in batteries or capacitors. Batteries, both rechargeable and non-rechargeable, are the main source of power supply for sensor nodes.

Current sensors are able to renew their energy from solar sources, Radio Frequency(RF), temperature differences, or vibration. Two power saving policies used are Dynamic Power Management (DPM) and Dynamic Voltage Scaling (DVS). DPM conserves power by shutting down parts of the sensor node which are not currently used or active. A DVS scheme varies the power levels within the sensor node depending on the non-deterministic workload. By varying the voltage along with the frequency, it is possible to obtain quadratic reduction in power consumption.

Classification of WSN

The **classification of WSNs** can be done based on the application but its characteristics mainly change based on the type. Generally, WSNs are classified into different categories like the following.

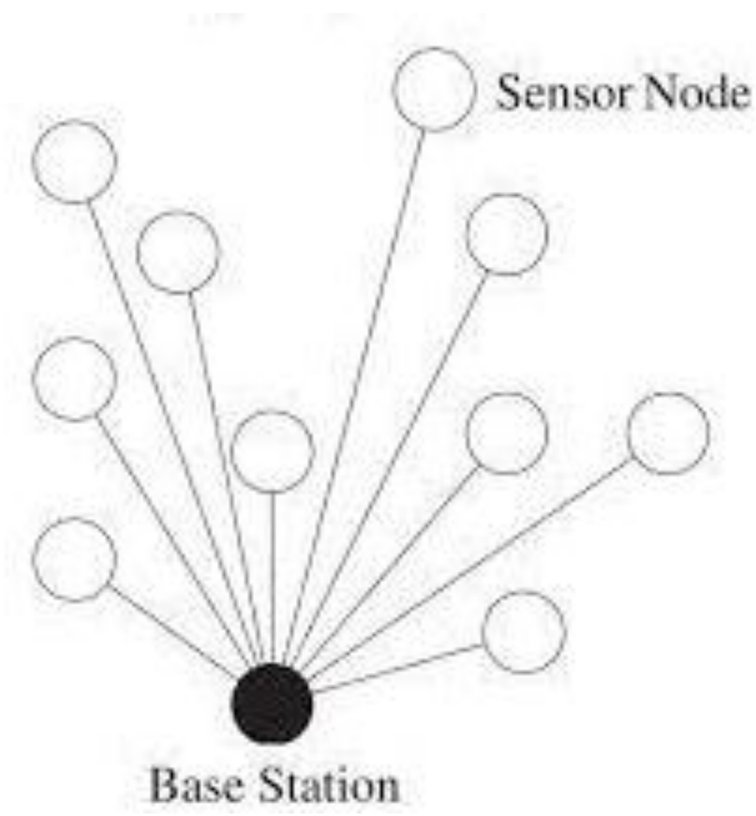
- Static & Mobile
- Deterministic & Nondeterministic
- Single Base Station & Multi Base Station
- Static Base Station & Mobile Base Station
- Single-hop & Multi-hop WSN
- Self Reconfigurable & Non-Self Configurable
- Homogeneous & Heterogeneous.

Static & Mobile WSN: All the sensor nodes in several applications can be set without movement so these networks are static WSNs. Especially in some applications like biological systems uses mobile sensor nodes which are called mobile networks. The best example of a mobile network is the monitoring of animals.

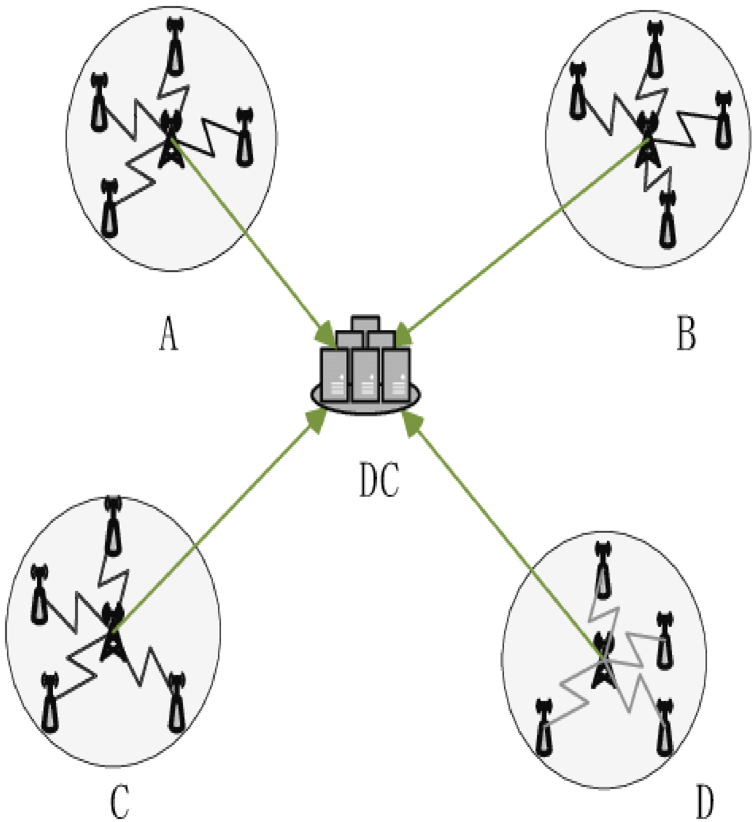
Deterministic & Nondeterministic WSN: In a deterministic type of network, the sensor node arrangement can be fixed and calculated. This sensor node's pre-planned operation can be possible in simply some applications. In most applications, the location of sensor nodes cannot be determined because of the different factors like hostile operating conditions & harsh environment, so these networks are called non-deterministic that need a complex control system.

Single Base Station & Multi Base Station: In a single base station network, a single base station is used and it can be arranged very close to the region of the sensor node. The interaction between sensor nodes can be done through the base station. In a multi-base station type network, multiple base stations are used & a sensor node is used to move data toward the nearby base station.

Single Base Station

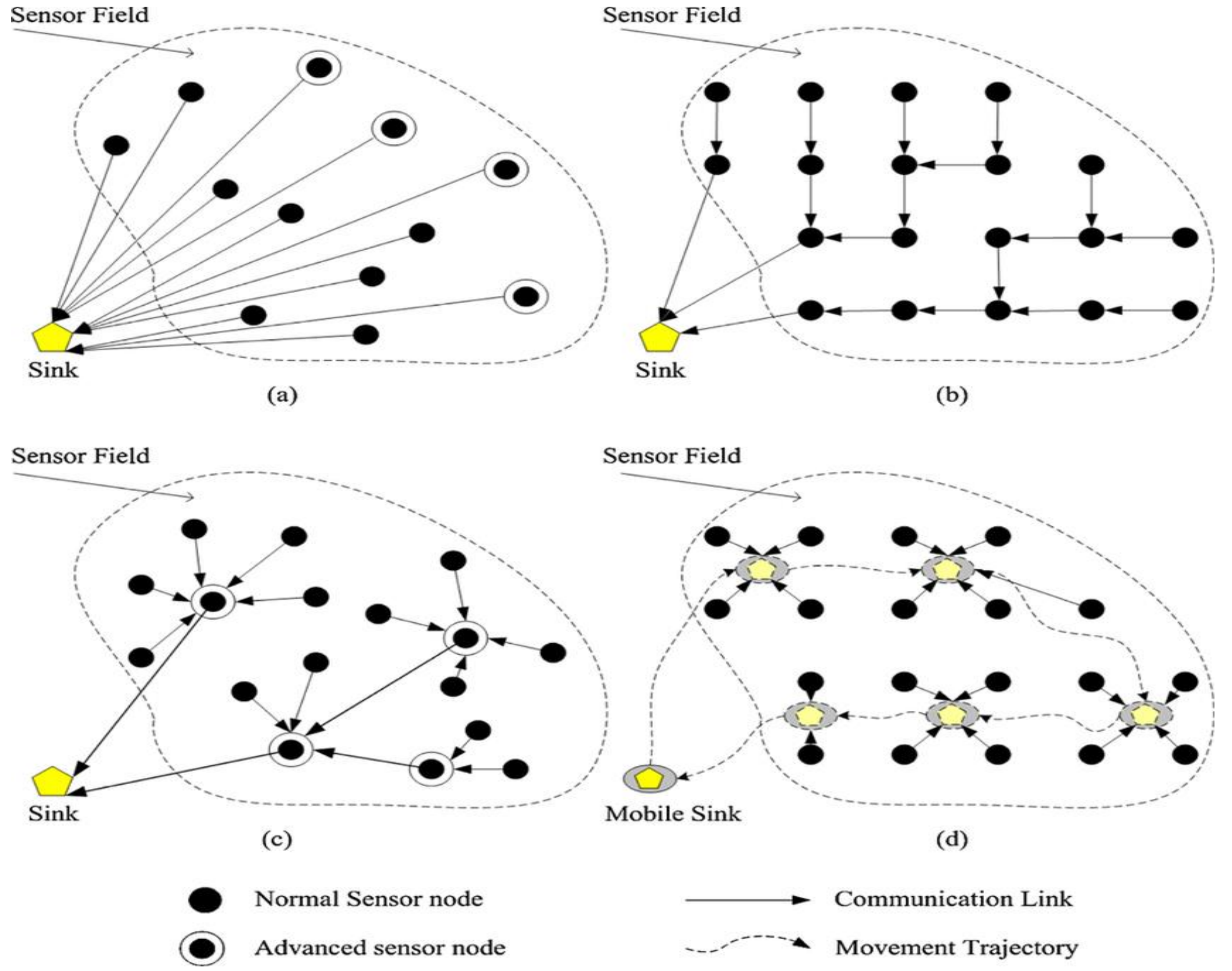


Multi Base Station



Static Base Station & Mobile Base Station: Base stations are either mobile or static similar to sensor nodes. As the name suggests, the static type base station includes a stable position generally close to the sensing area whereas the mobile base station moves in the region of the sensor so that the sensor nodes load can be balanced.

Single-hop & Multi-hop WSN: In a single-hop type network, the arrangement of sensor nodes can be done directly toward the base station whereas, in a multi-hop network, both the cluster heads & peer nodes are utilized to transmit the data to reduce the energy consumption.

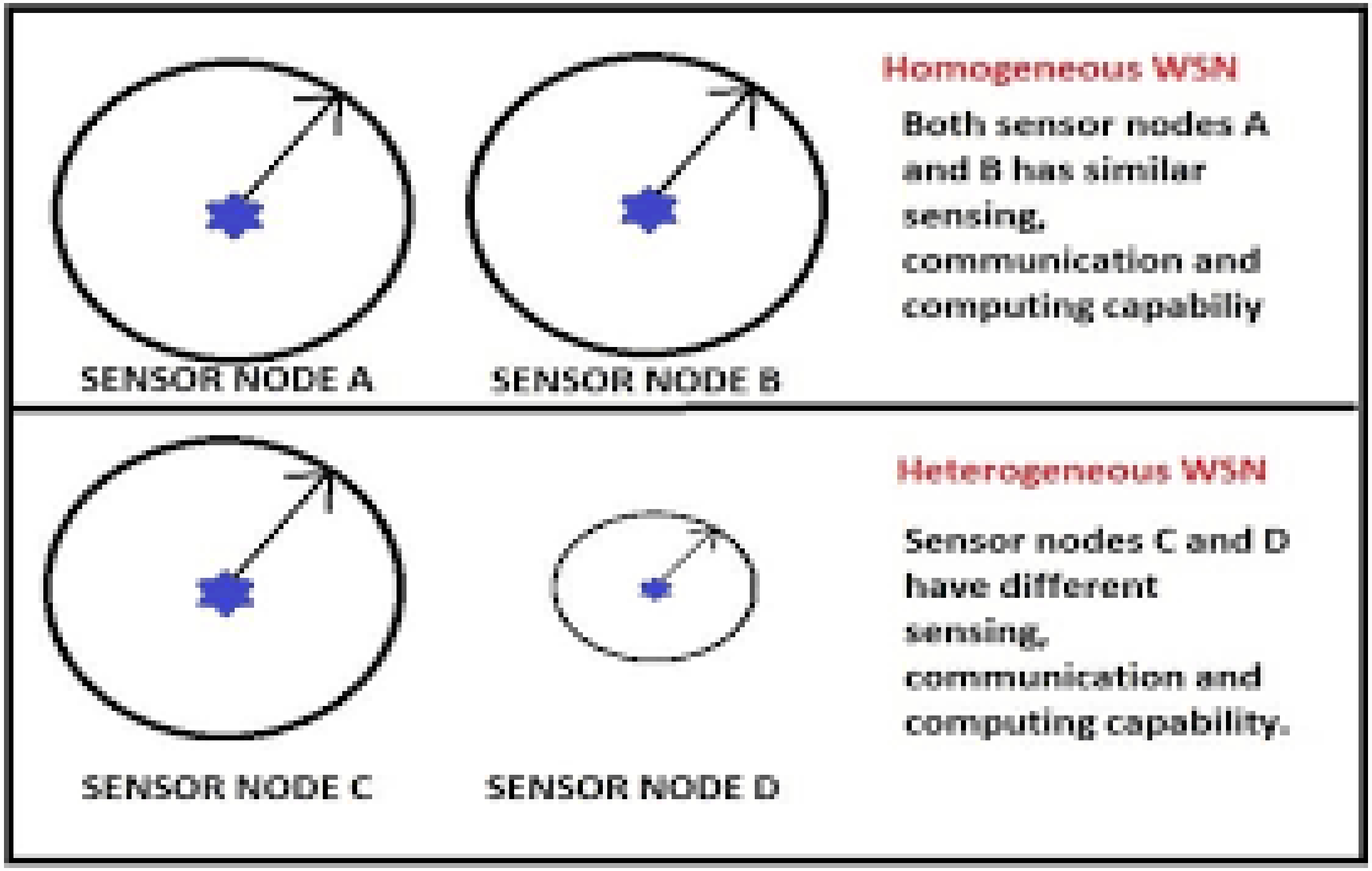


Sensor Field
Sink
(a)
Sensor Field
Sink
(b)
Sensor Field
Sink
(c)
Sensor Field
Mobile Sink
(d)
Normal Sensor node
Advanced sensor node
Communication Link
Movement Trajectory

Self Reconfigurable & Non-Self Configurable

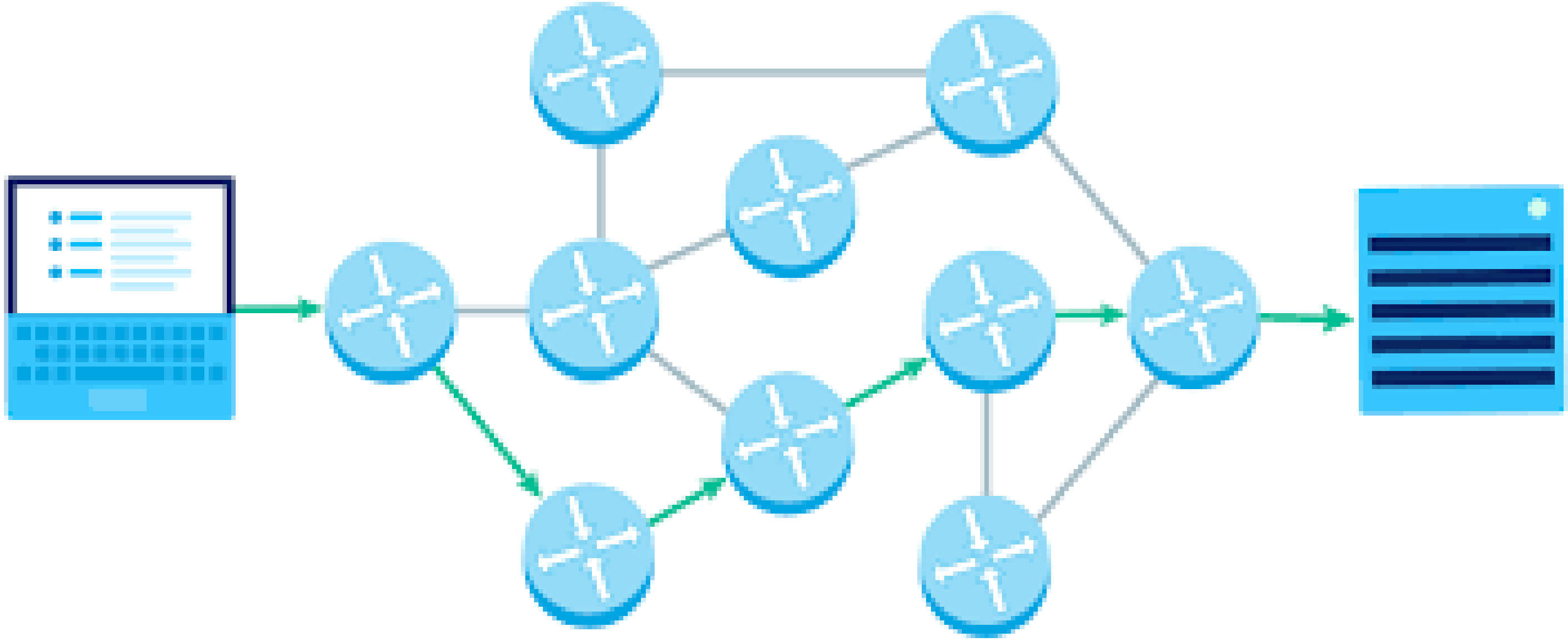
In a non self configurable network, the arrangement of sensor networks cannot be done by them within a network & depends on a control unit for gathering data. In wireless sensor networks, the sensor nodes maintain and organize the network and collaboratively work by using other sensor nodes to accomplish the task.

Homogeneous and Heterogeneous: In a homogeneous wireless sensor network, all the sensor nodes mainly include similar energy utilization, storage capabilities & computational power. In the heterogeneous network case, some sensor nodes include high computational power as well as energy necessities as compared to others. The processing & communication tasks are separated consequently.


Homogeneous WSN
Both sensor nodes A and B has similar sensing, communication and computing capabiliy
SENSOR NODE A
SENSOR NODE B
Heterogeneous WSN
Sensor nodes C and D have different sensing, communication and computing capability.
SENSOR NODE C
SENSOR NODE D

Routing Protocols in WSN

The routing protocol is a process to select suitable path for the data to travel from source to destination. The process encounters several difficulties while selecting the route, which depends upon, type of network, channel characteristics and the performance metrics. The data sensed by the sensor nodes in a (WSN) is typically forwarded to the base station that connects the sensor network with the other networks (may be internet) where the data is collected, analyzed and some action is taken accordingly.



In very small sensor networks where the base station and motes (sensor nodes) so close that they can communicate directly with each other than this is single-hop communication but in most WSN application the coverage area is so large that requires thousands of nodes to be placed and this scenario requires multi-hop communication because most of the sensor nodes are so far from the sink node (gateway) so that they cannot communicate directly with the base station. The single-hop communication is also called direct communication and multi-hop communication is called indirect communication.

In **multi-hop communication** the sensor nodes not only produce and deliver their material but also serve as a path for other sensor nodes towards the base station. The process of finding suitable path from source node to destination node is called routing and this is the primary responsibility of the network layer.

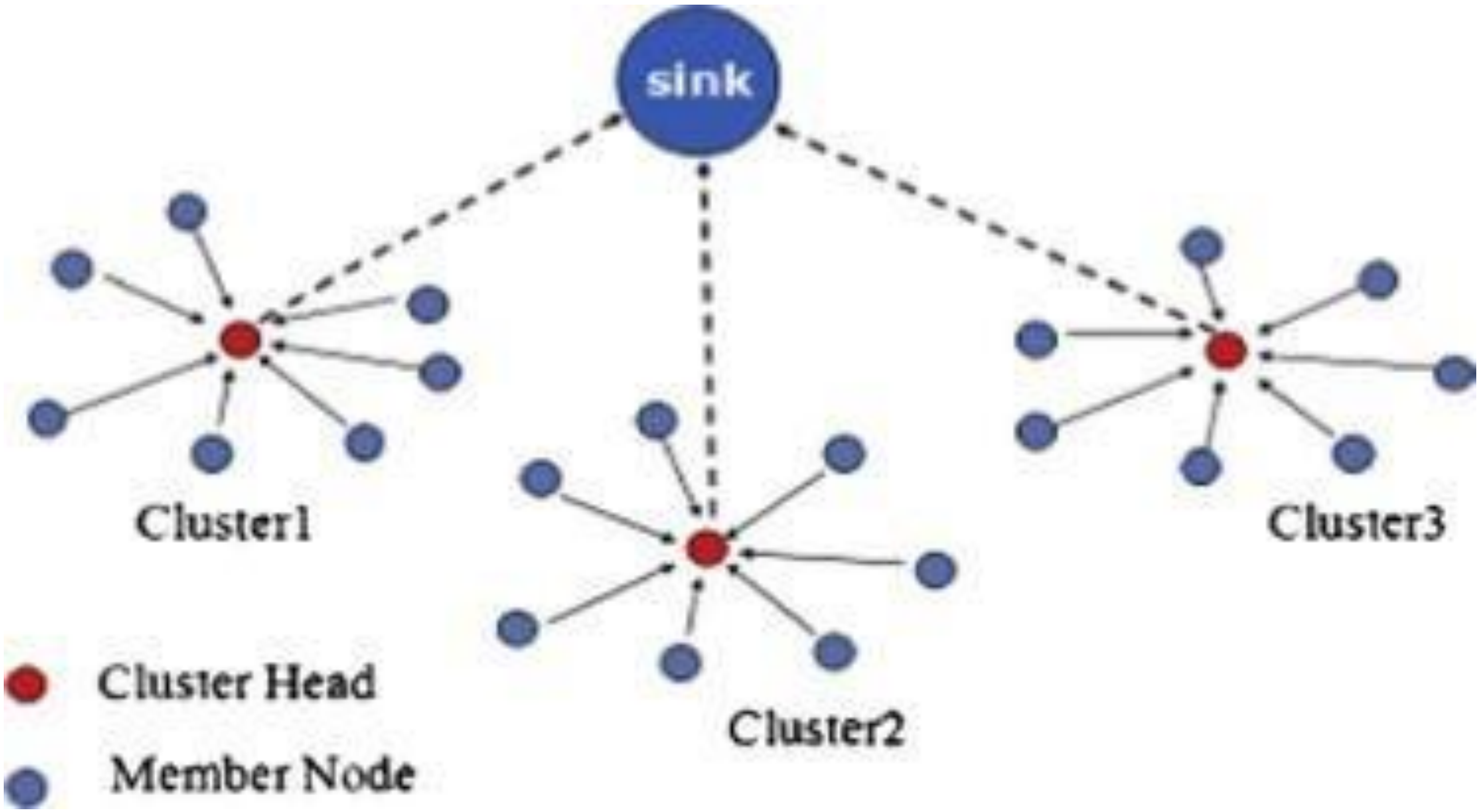
Routing Protocols Classifications


WSN Routing Protocols
Node Centric
Routing protocol
Data Centric
Routing Protocol

The routing protocols define how nodes will communicate with each other and how the information will be disseminated through the network. **There are many ways to classify the routing protocols of WSN**:-

- Node Centric
- Data Centric

1- Node centric In node centric protocols the destination node is specified with some numeric identifiers and this is not expected type of communication in Wireless sensor networks. Low energy adaptive clustering hierarchy (LEACH) is a routing protocol that organizes the cluster such that the energy is equally divided in all the sensor nodes in the network. In LEACH protocol several clusters are produced of sensor nodes and one node defined as cluster head and act as routing node for all the other nodes in the cluster.

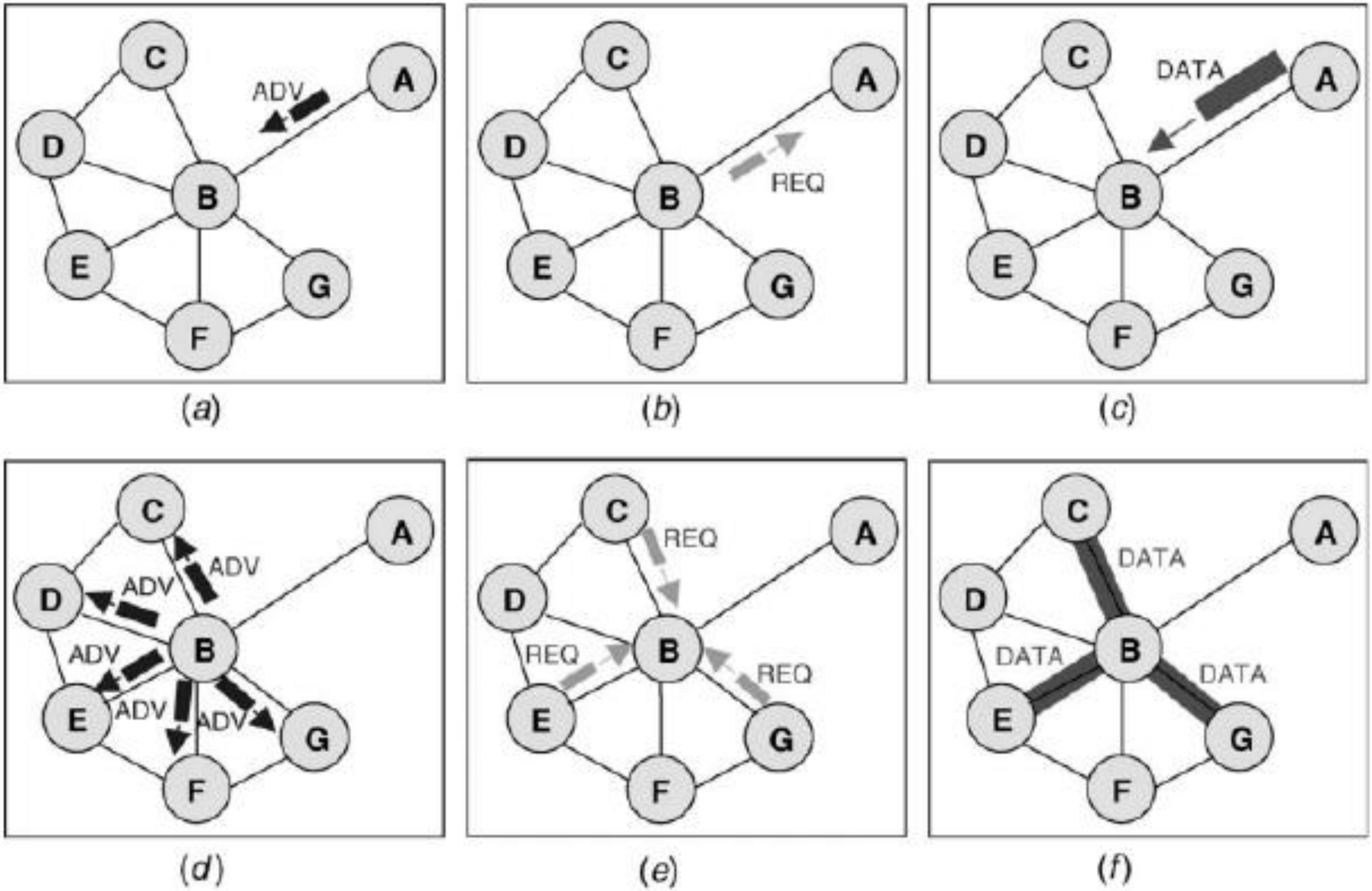

sink
Cluster1
Cluster2
Cluster3
Cluster Head
Member Node

As in routing protocols **the cluster head** is selected before the whole communication starts and the communication fails if there is any problem occurs in the cluster head and there is much chances that the battery dies earlier as compare to the other nodes in cluster as the fix cluster head is working his duties of routing for the whole cluster. LEACH protocol apply randomization and cluster head is selected from the group of nodes so this selection of cluster head from several nodes on temporary basis make this protocol more long lasting as battery of a single node is not burdened for long. Sensor nodes elect themselves as cluster head with some probability criteria defined by the protocol and announce this to other nodes.

2- Data centric: In data-centric routing protocol, whenever a sink requires any data it sends a query message to the different part of the sensor network field. After receiving this query message sensors node replies and sends data to the sink. In data-centric protocol attribute based naming is used which specifies the properties of the data.

In data-centric routing, the sink sends queries to certain regions which might be done using clusters or may be a certain nodes in the routing path and waits for data from the sensors located in the selected regions. Since data is being requested through queries, attribute-based naming is necessary to specify the properties of data.

Sensor protocols for information via negotiation SPIN The idea behind SPIN is to name the data using high-level descriptors or meta-data. Before transmission, metadata are exchanged among sensors via a data advertisement mechanism, which is the key feature of SPIN. Each node upon receiving new data, advertises it to its neighbors and interested neighbors, i.e. those who do not have the data, retrieve the data by sending a request message.



C
A
ADV
D
B
E
G
F
(a)
C
A
D
B
REQ
E
G
F
(b)
C
DATA
A
D
B
E
G
F
(c)
C
A
ADV
ADV
D
B
ADV
E
ADV
ADV
G
F
(d)
C
REQ
A
D
B
REQ
REQ
E
G
F
(e)
C
A
DATA
D
B
DATA
DATA
E
G
F
(f)

There are three messages defined in SPIN to exchange data between nodes. These are: ADV message to allow a sensor to advertise a particular meta-data to their neighboring sensors, REQ message contains a request message for the specific data and DATA message that carry the actual data from the neighboring nodes to the node which sends the ADV message. summarizes the steps of the SPIN method. Later the node B will send the ADV message to the all its neighboring nodes and the process will repeat as done for the node A.

WSN Challenges

There are some **major design challenges in wireless sensor networks** due to lack of resources such as energy, bandwidth and storage of processing.

1- Energy efficiency: Wireless sensor networks are mostly battery powered. Energy shortage is a major issue in these sensor networks especially in aggressive environments such as battlefield etc. The performance of sensor nodes is adversely affected when battery is fallen below a pre-defined battery threshold level. Energy presents a main challenge for designers while designing sensor networks.

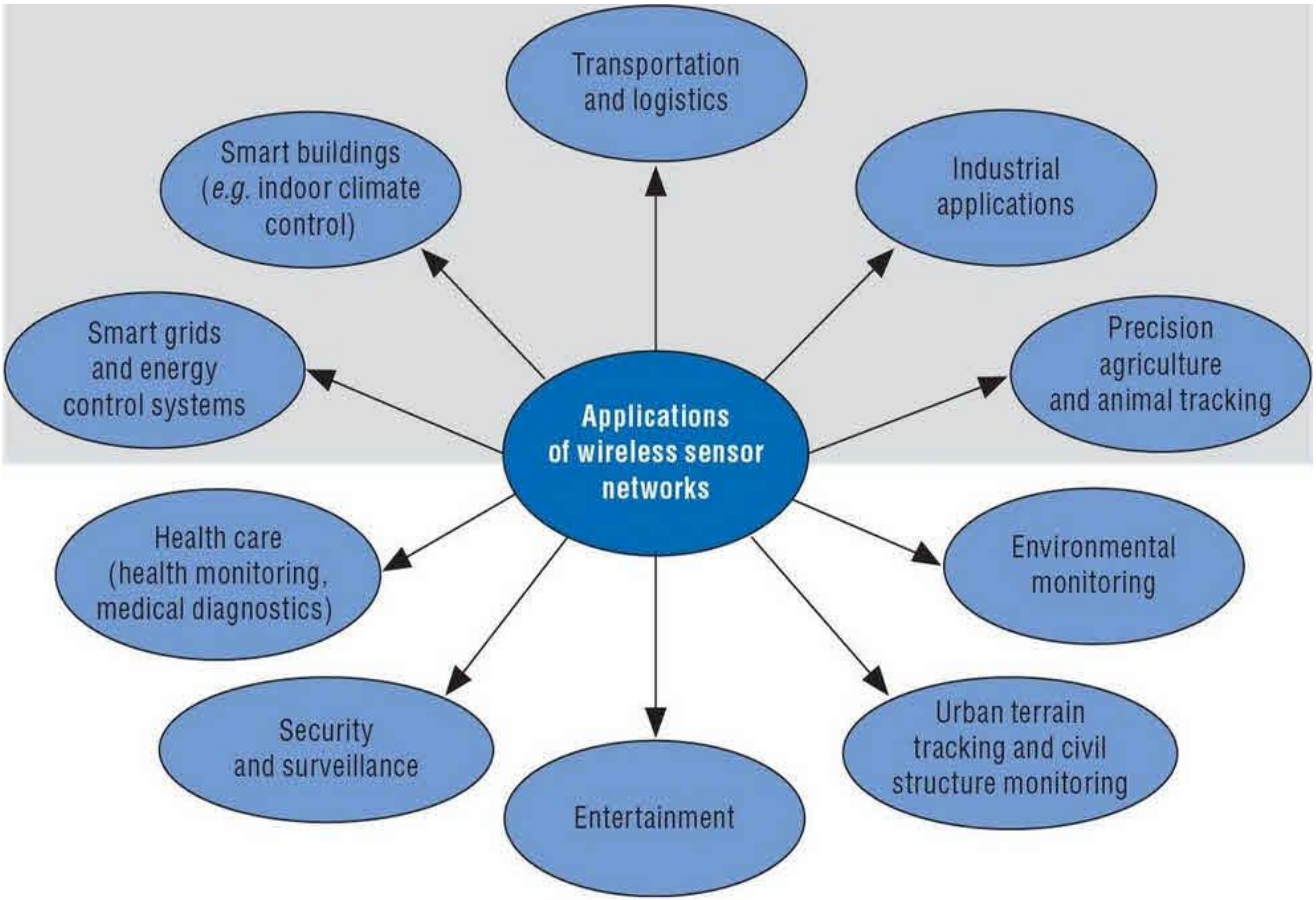
2- Delay: Some applications require instant reaction or response without any substantial delay such as temperature sensor or alarm monitoring etc. So, the routing protocol should offer minimum delay. The time needed to transmit the sensed data is required to be as little as possible in above cited WSN applications.

3- Scalability: As sensors are becoming cheaper day by day, hundreds or even thousands of sensors can be installed in wireless sensor network easily. So, the routing protocol must support scalability of network. If further nodes are to be added in the network any time then routing protocol should not interrupt this.

4- Complexity: The complexity of a routing protocol may affect the performance of the entire wireless network. The reason behind is that we have inadequate hardware competences and we also face extreme energy limitations in wireless sensor networks.

5- Sensor location: Another major challenge that is faced by wireless sensor network designers is to correctly locate of the sensor nodes. Most routing protocols use some localization technique to obtain knowledge concerning their locations. Global positioning system (GPS) receivers are used in some scenario.

WSN Applications


Transportation and logistics
Smart buildings (*e.g.* indoor climate control)
Industrial applications
Smart grids and energy control systems
Precision agriculture and animal tracking
Applications of wireless sensor networks
Health care (health monitoring, medical diagnostics)
Environmental monitoring
Security and surveillance
Entertainment
Urban terrain tracking and civil structure monitoring

1- Area monitoring: Area monitoring is a common application of WSNs. In area monitoring, the WSN is deployed over a region where some phenomenon is to be monitored. A military example is the use of sensors to detect enemy intrusion; a civilian example is the geo-fencing of gas or oil pipelines.

2- Health care monitoring: There are several types of sensor networks for medical applications: implanted, wearable, and environment-embedded. Implantable medical devices are those that are inserted inside the human body. Wearable devices are used on the body surface of a human or just at close proximity of the user. Environment-embedded systems employ sensors contained in the environment. Possible applications include body position measurement, location of persons, overall monitoring of ill patients in hospitals and at home.

Devices embedded in the environment track the physical state of a person for continuous health diagnosis, using as input the data from a network of depth cameras, a sensing floor, or other similar devices. Body-area networks can collect information about an individual's health, fitness, and energy expenditure. In health care applications the privacy and authenticity of user data has prime importance. Especially due to the integration of sensor networks, with IoT, the user authentication becomes more challenging; however, a solution is presented in recent work.

3- Habitat Monitoring: Wireless sensor networks have been used to monitor various species and habitats.

4- Environmental/Earth sensing: There are many applications in monitoring environmental parameters, examples of which are given below. They share the extra challenges of harsh environments and reduced power supply.

5- Air quality monitoring: Experiments have shown that personal exposure to air pollution in cities can vary a lot. Therefore, it is of interest to have higher temporal and spatial resolution of pollutants and particulates. For research purposes, wireless sensor networks have been deployed to monitor the concentration of dangerous gases for citizens. However, sensors for gases and particulate matter suffer from high unit-to-unit variability, cross-sensitivities, and (concept) drift. Moreover, the quality of data is currently insufficient for trustworthy decision-making, as field calibration leads to unreliable measurement results, and frequent recalibration might be required. A possible solution could be blind calibration or the usage of mobile references.

6- Forest fire detection: A network of Sensor Nodes can be installed in a forest to detect when a fire has started. The nodes can be equipped with sensors to measure temperature, humidity and gases which are produced by fire in the trees or vegetation. The early detection is crucial for a successful action of the firefighters; thanks to Wireless Sensor Networks, the fire brigade will be able to know when a fire is started and how it is spreading.

7- Landslide detection: A landslide detection system makes use of a wireless sensor network to detect the slight movements of soil and changes in various parameters that may occur before or during a landslide. Through the data gathered it may be possible to know the impending occurrence of landslides long before it actually happens.

Water quality monitoring

8- Water quality: monitoring involves analyzing water properties in dams, rivers, lakes and oceans, as well as underground water reserves. The use of many wireless distributed sensors enables the creation of a more accurate map of the water status, and allows the permanent deployment of monitoring stations in locations of difficult access, without the need of manual data retrieval.

9- Natural disaster prevention: Wireless sensor networks can be effective in preventing adverse consequences of natural disasters, like floods. Wireless nodes have been deployed successfully in rivers, where changes in water levels must be monitored in real time.

10- Machine health monitoring: Wireless sensor networks have been developed for machinery condition-based maintenance (CBM) as they offer significant cost savings and enable new functionality. Wireless sensors can be placed in locations difficult or impossible to reach with a wired system, such as rotating machinery and untethered vehicles.

11- Data logging: Wireless sensor networks also are used for the collection of data for monitoring of environmental information. This can be as simple as monitoring the temperature in a fridge or the level of water in overflow tanks in nuclear power plants. The statistical information can then be used to show how systems have been working. The advantage of WSNs over conventional loggers is the "live" data feed that is possible.

12- Water/waste water monitoring: Monitoring the quality and level of water includes many activities such as checking the quality of underground or surface water and ensuring a country's water infrastructure for the benefit of both human and animal. It may be used to protect the wastage of water.