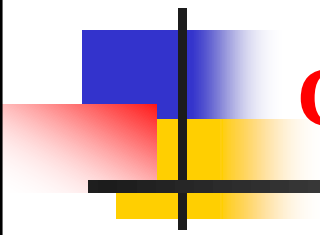


Chapter 5

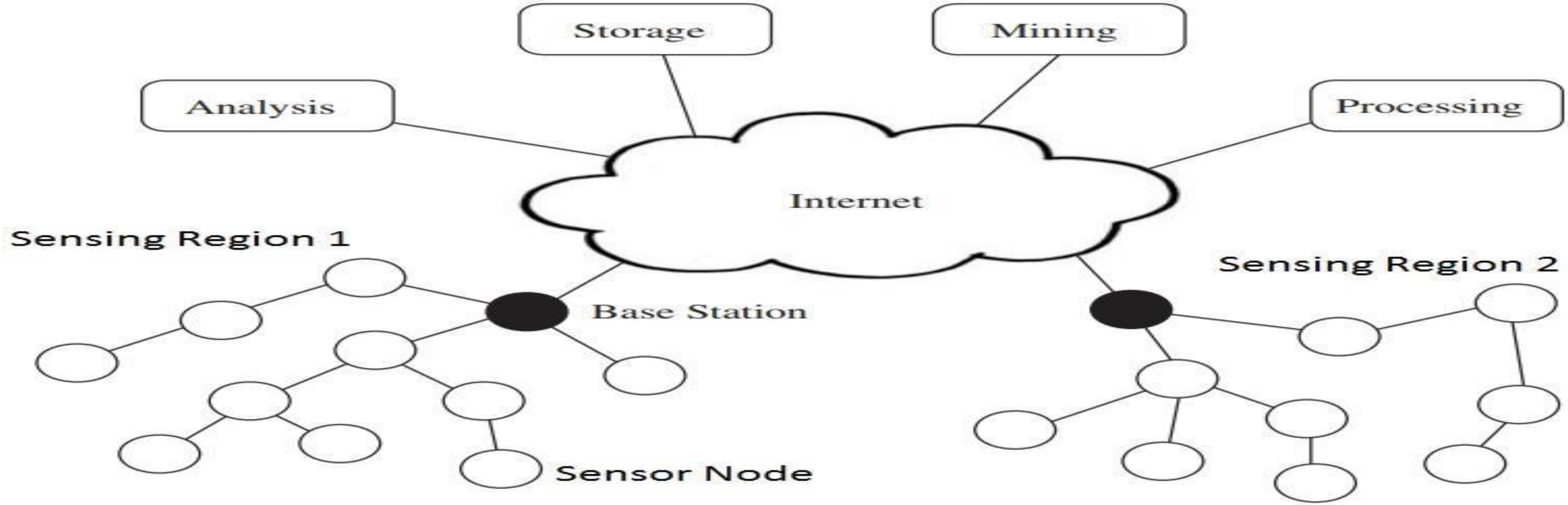
WIRELESS SENSOR NETWORKS

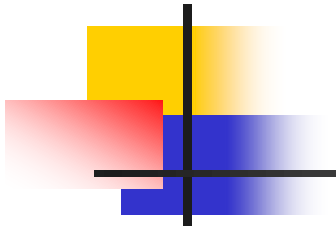
Introduction

- A Sensor is a device used to gather information about a physical process and translate into electrical signals that
can be processed, measured and analyzed.
- The physical process can be any real-world information like temperature, pressure, light, sound, motion, position, flow, humidity, radiation etc.
- A Sensor Network is a structure consisting of sensors, computational units and communication elements for the purpose of recording, observing and reacting to an event or a phenomenon.
- The events can like physical world, an industrial environment, a biological system while the controlling or observing body can be a consumer application, government, civil, military, or an industrial entity
- Such Sensor Networks can be used for remote sensing, medical telemetry, surveillance, monitoring, data collection etc

Wireless Sensor Networks

- A typical sensor network consists of sensors, controller and a communication system. If the communication system in a Sensor Network is implemented using a Wireless protocol, then the networks are known as Wireless Sensor Networks





- According to technologists, Wireless Sensor Networks is an important technology for the twenty first century.
- Recent developments in MEMS Sensors (Micro Electro Mechanical System) and Wireless Communication has enabled cheap, low power, tiny and smart sensors, deployed in a wide area and interconnected through wireless links for various civilian and military applications
- A Wireless Sensor Network consists of Sensor Nodes deployed in large quantities and support sensing, data processing, embedded computing and connectivity

Wireless Sensor Networks (WSNs)

- A sensor network is a wireless network that consists of thousands of very small nodes called *sensors*.

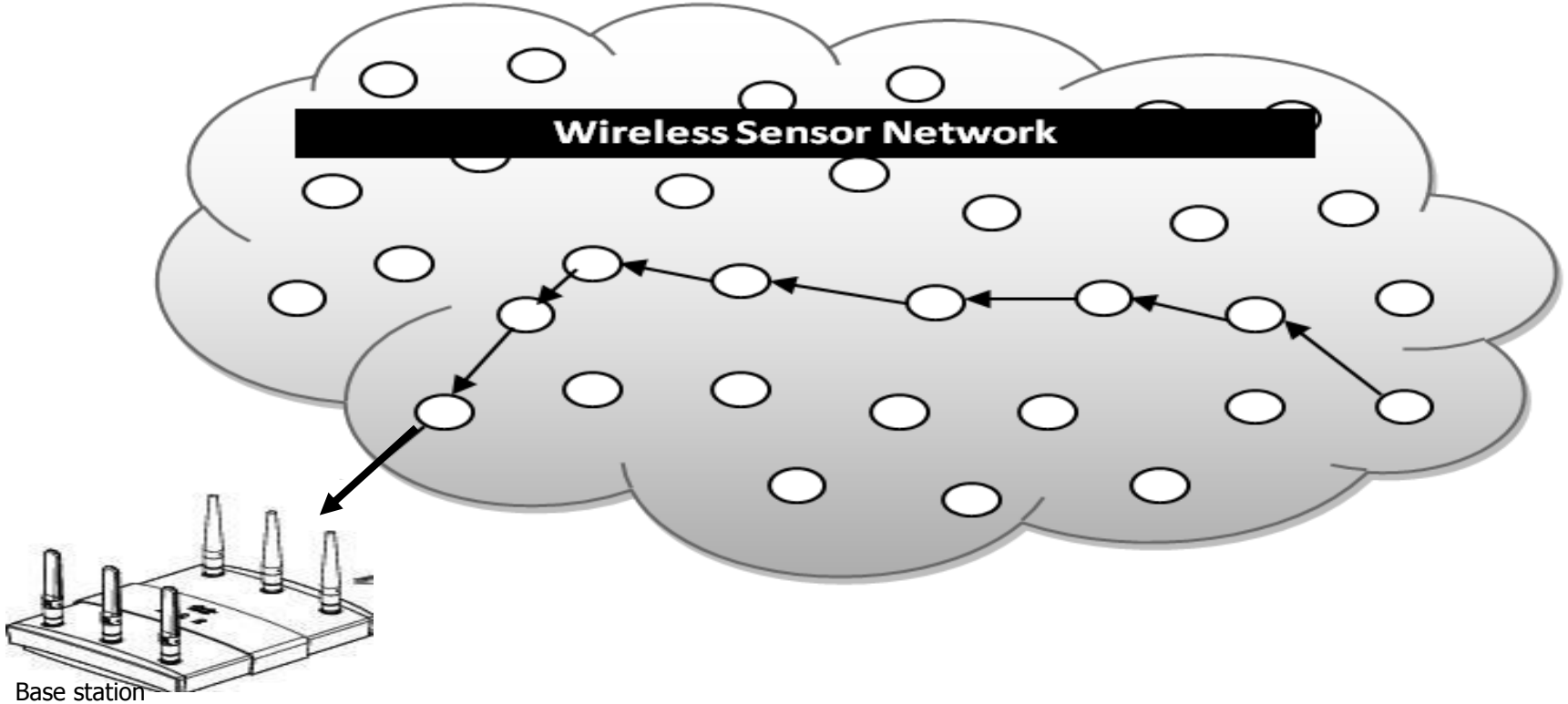


Figure 1: Architecture of wireless sensor networks

Wireless Sensor Networks (cont.)

- WSN **Sensors** are equipped with sensing, limited computation, and wireless communication capabilities.

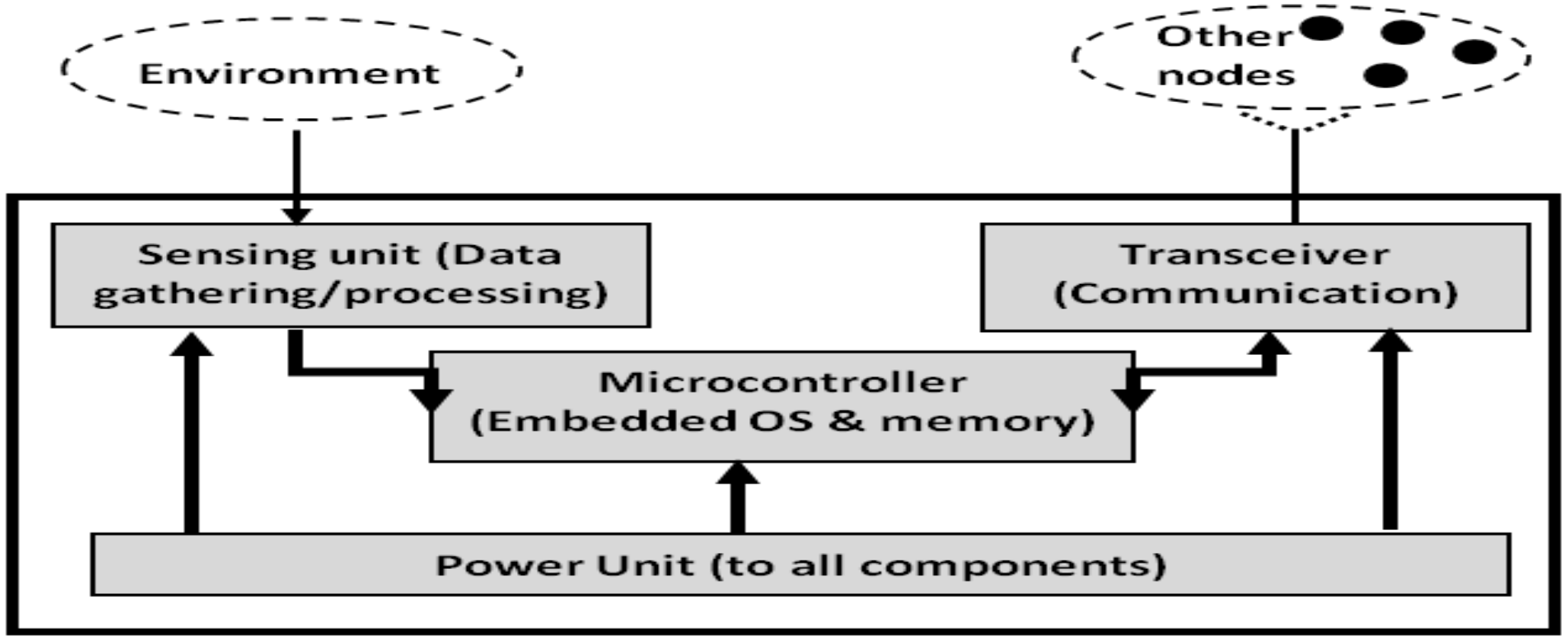


Figure 2: Typical hardware components of a sensor node in wireless sensor networks

Motivation for WSN

- The recent developments in engineering, communication and networking led to new sensor designs, information technologies and wireless systems.
- Such advanced sensors can be used as a bridge between the physical world and the digital world.
- Sensors are used in numerous devices, industries, machines and help in avoiding infrastructure failures, accidents, conserving natural resources, preserving wildlife, increase productivity, provide security etc.
- The use of distributed sensor network contributed by the technological advances in VLSI, MEMS and Wireless Communication.
- With the help of modern semiconductor technology, powerful microprocessors can be developed, smaller in size when compared to the previous generation products. This miniaturization of processing, computing and sensing technologies led to tiny, lowpower and cheap sensors, controllers and actuators.

Introduction

- Wireless Sensor Networks are networks that consists of sensors which are distributed in an ad hoc manner.
- These sensors work with each other to sense some physical phenomenon and then the information gathered is processed to get relevant results.
- Wireless sensor networks consists of protocols and algorithms with self-organizing capabilities.

Comparison with ad hoc networks

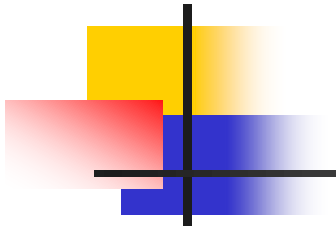
- Wireless sensor networks mainly use **broadcast** communication while ad hoc networks use **point-to-point** communication.
- Unlike ad hoc networks wireless sensor networks are **limited by sensors** limited power, energy and computational capability.
- Sensor nodes may **not have global ID** because of the large amount of overhead and large number of sensors.

WSNs Applications

- WSNs have many advantages over traditional networking techniques.
- They have an ever-increasing number of applications, such as infrastructure protection and security, surveillance, health-care, environment monitoring, food safety, intelligent transportation, and smart energy.

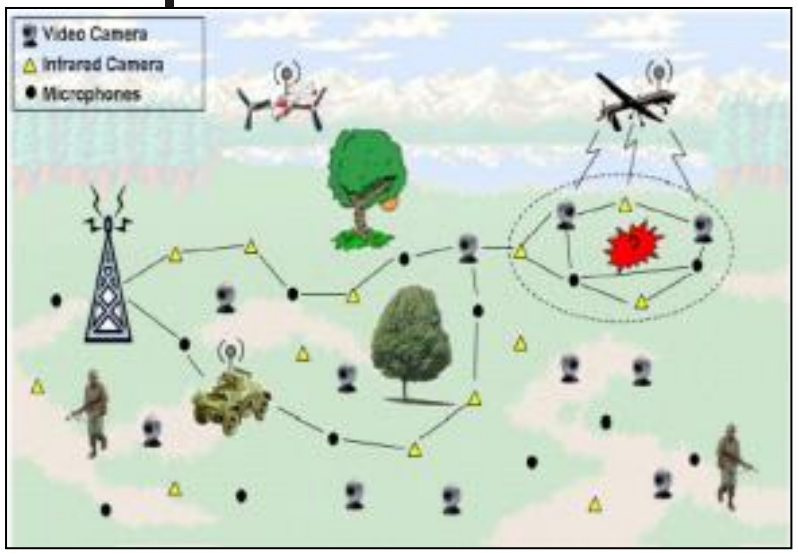
Applications of WSN

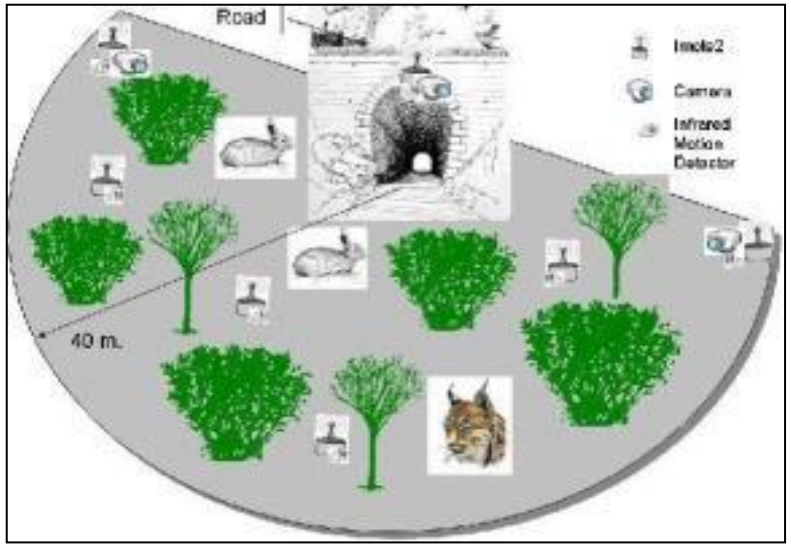
- Air Traffic Control (ATC)
- Heating Ventilation and Air Conditioning (HVAC)
- Industrial Assembly Line
- Automotive Sensors
- Battlefield Management and Surveillance
- Biomedical Applications
- Bridge and Highway Monitoring
- Disaster Management
- Earthquake Detection
- Electricity Load Management

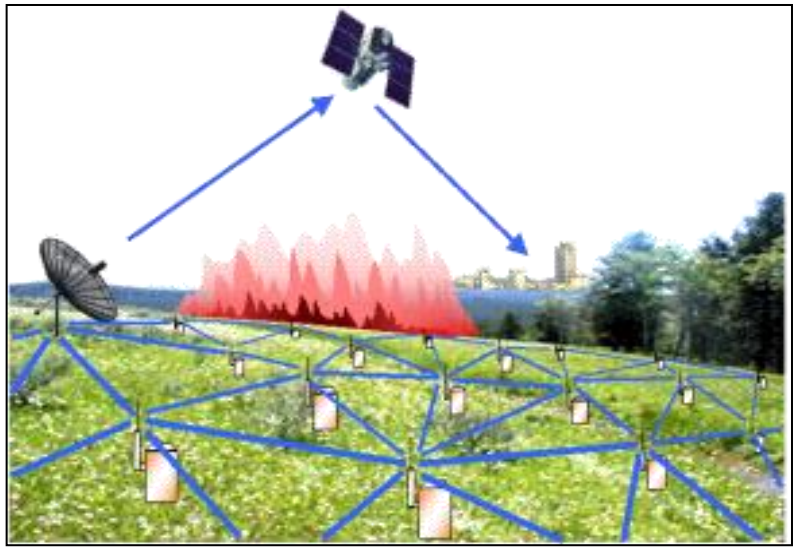


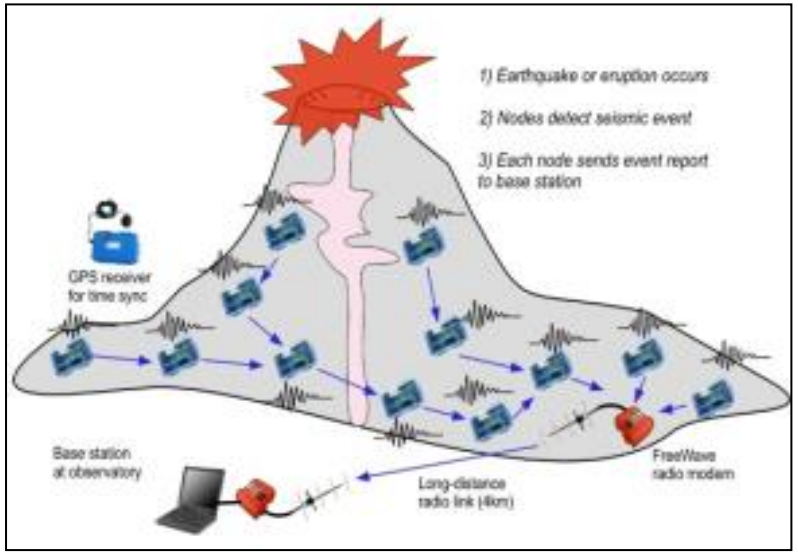
- Environment Control and Monitoring
- Industrial Automation
- Inventory Management
- Personal Health Care
- Security Systems

WSNs Applications









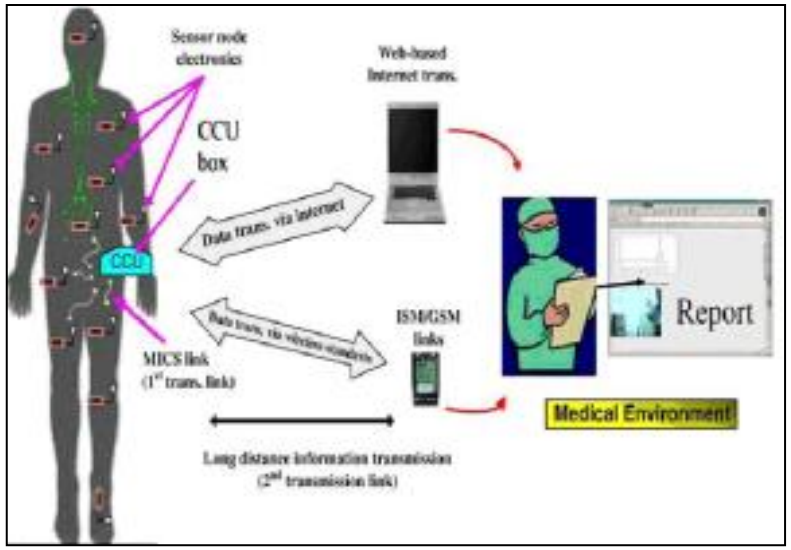


Figure 3: WSNs Applications

Applications of Wireless Sensor networks

The applications can be divided in three categories:

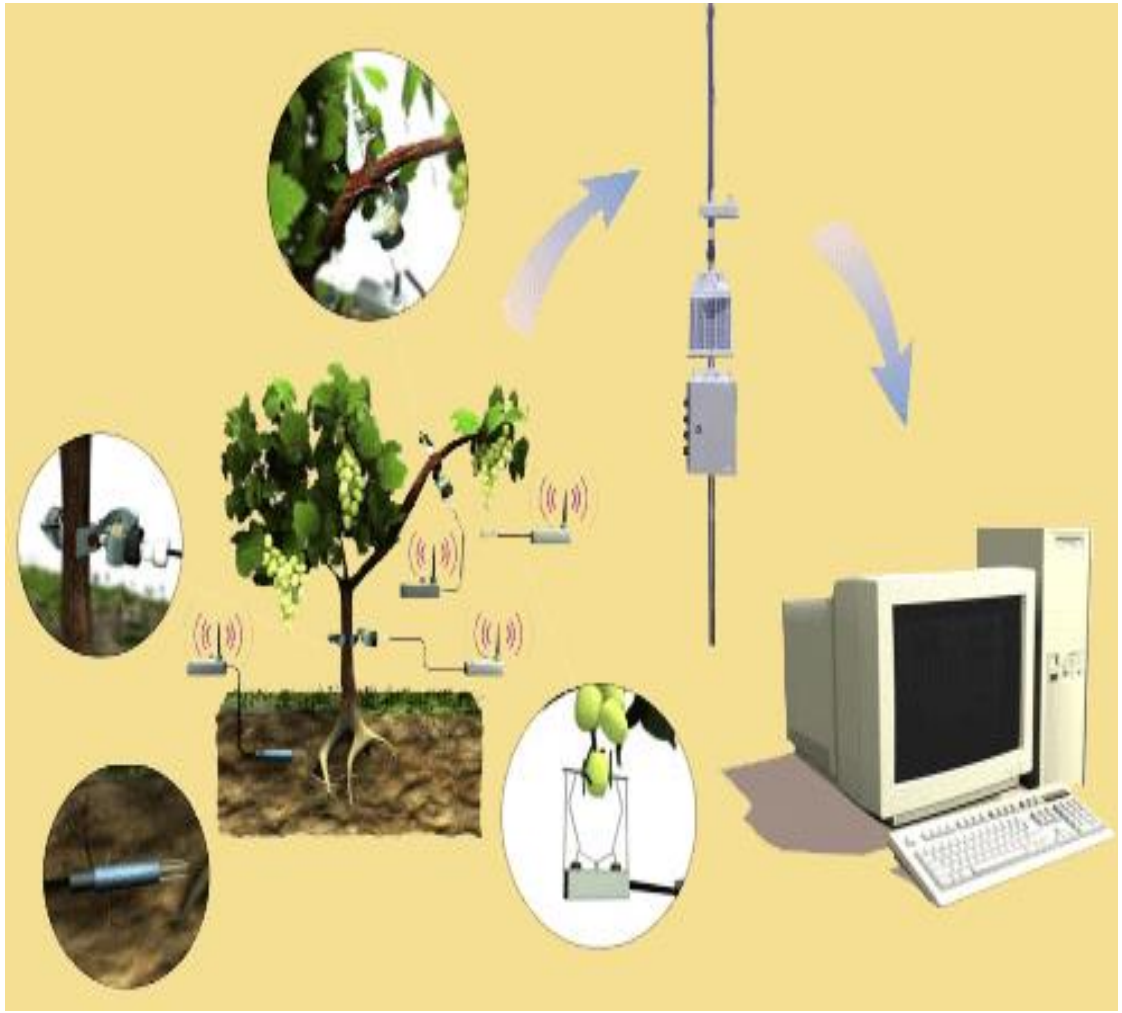
1. Monitoring of objects.
2. Monitoring of an area.
3. Monitoring of both area and objects.

Monitoring Area

- Environmental and Habitat Monitoring
- Precision Agriculture
- Indoor Climate Control
- Military Surveillance
- Treaty Verification
- Intelligent Alarms

Example: Precision Agriculture

- Precision agriculture aims at making cultural operations more efficient, while reducing environmental impact.
- The information collected from sensors is used to evaluate optimum sowing density, estimate fertilizers and other inputs needs, and to more accurately predict crop yields.



Monitoring Objects

- Structural Monitoring
- Eco-physiology
- Condition-based Maintenance
- Medical Diagnostics
- Urban terrain mapping

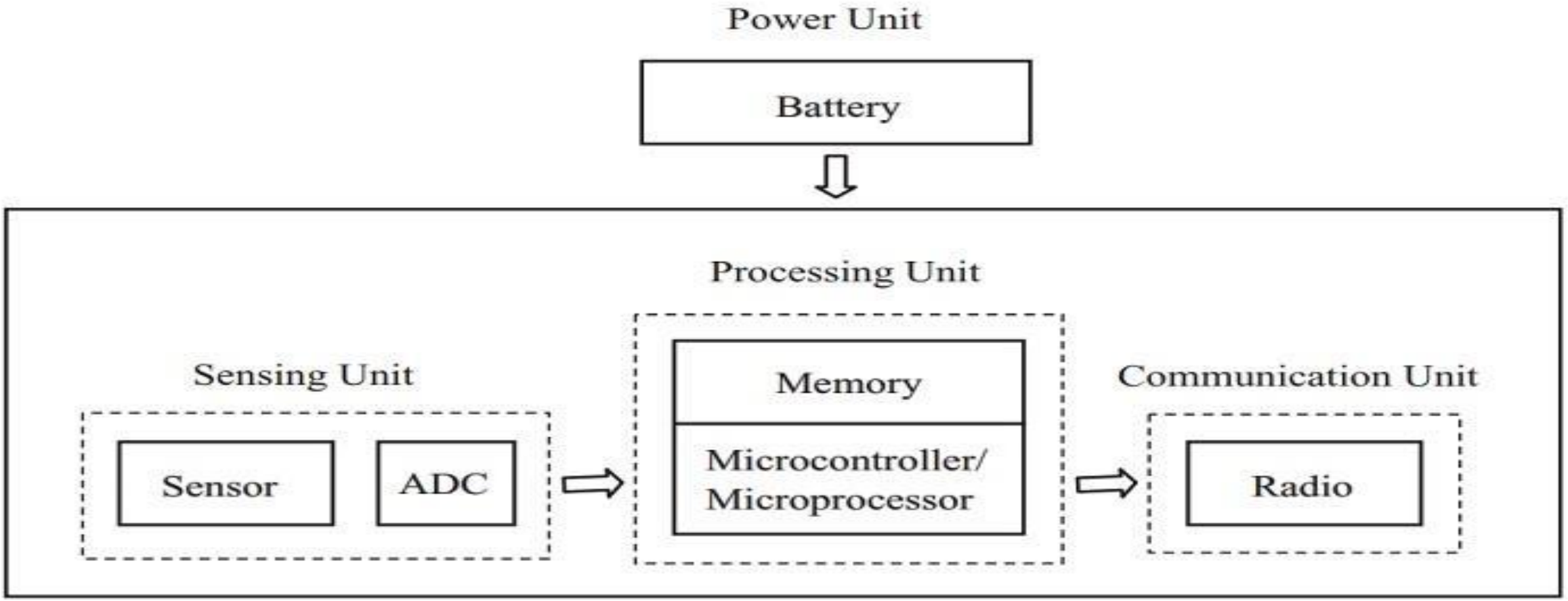
Monitoring Interactions between Objects and Space

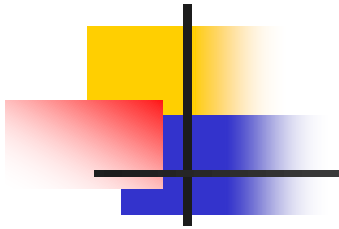
- Wildlife Habitats
- Disaster Management
- Emergency Response
- Ubiquitous Computing
- Asset Tracking
- Health Care
- Manufacturing Process Flows

Elements of WSN

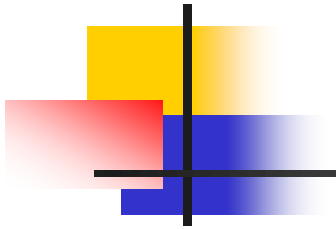
- A typical wireless sensor network can be divided into two elements. They are:
  - Sensor Node
  - Network Architecture
- A Sensor Node in a WSN consists of four basic components. They are:
  - Power Supply
  - Sensor
  - Processing Unit
  - Communication System

- Basic Components of WSN





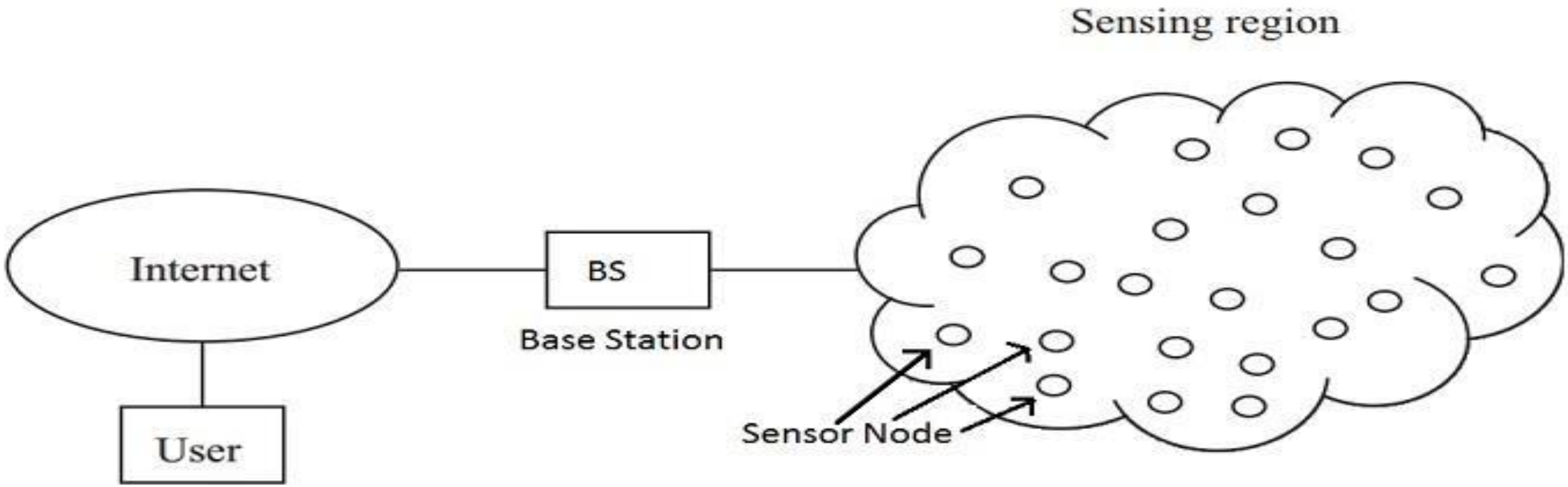
- Elements of WSN (Cont)
- The sensor collects the analog data from the physical world and an ADC converts this data to digital data.
- The main processing unit a microprocessor or a microcontroller, performs an intelligent data processing and manipulation. Communication system consists of radio system, a short-range radio for data transmission and reception.
- As all the components are low-power devices, a small battery like CR-2032, is used to power the entire system.
- A Sensor Node consists of not only the sensing component but also other important features like processing, communication and storage units.

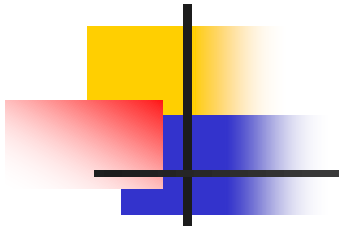


- With all these features, components and enhancements, a Sensor Node is responsible for physical world data collection, network analysis, data correlation and fusion of data from other sensor with its own data.

Network Architecture

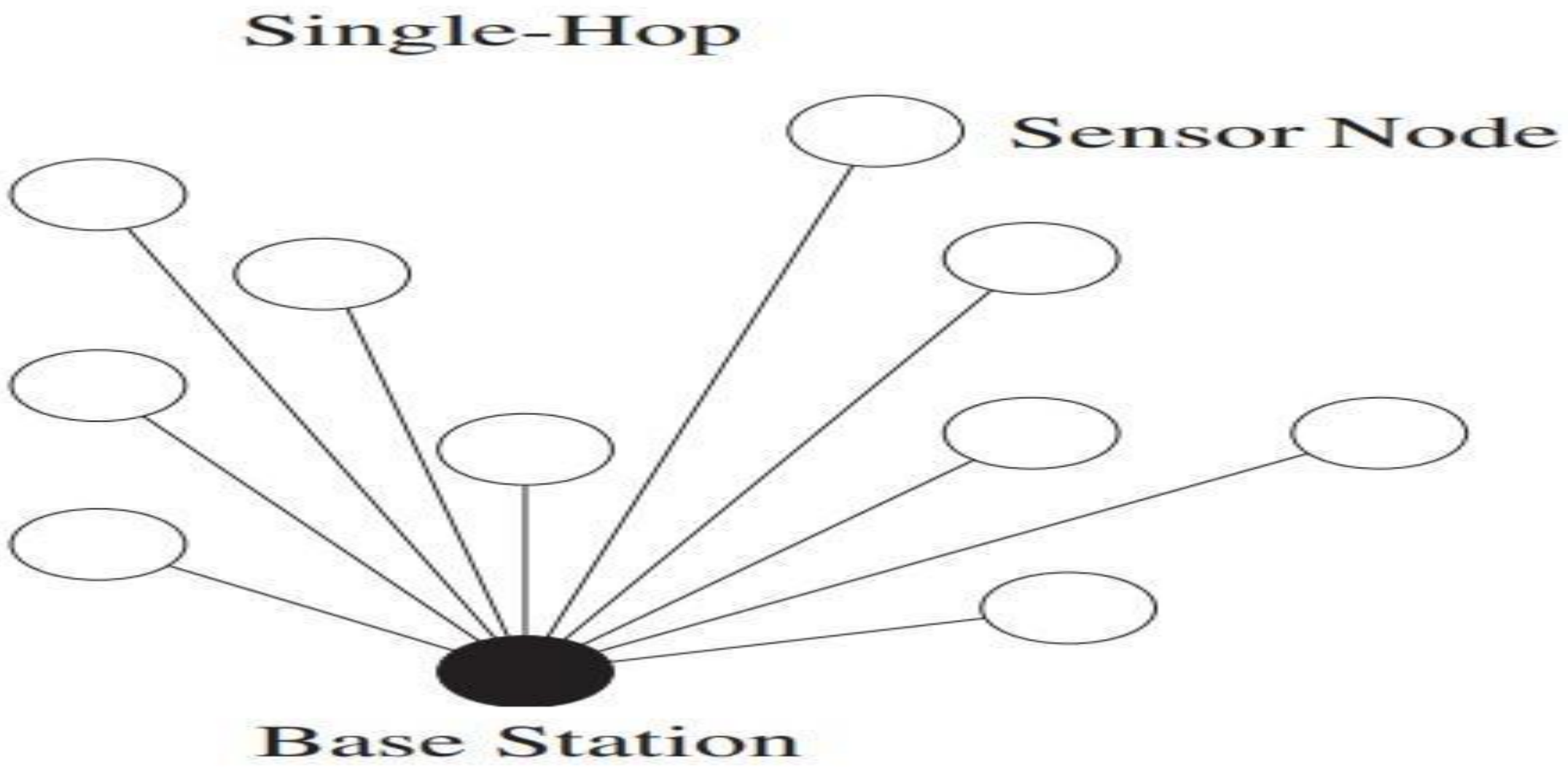
- When a large number of sensor nodes are deployed in a large area to monitor a physical environment, the networking of these sensor nodes is equally important. A sensor node in a WSN not only communicates with other sensor nodes but also with a Base Station (BS) using wireless communication.





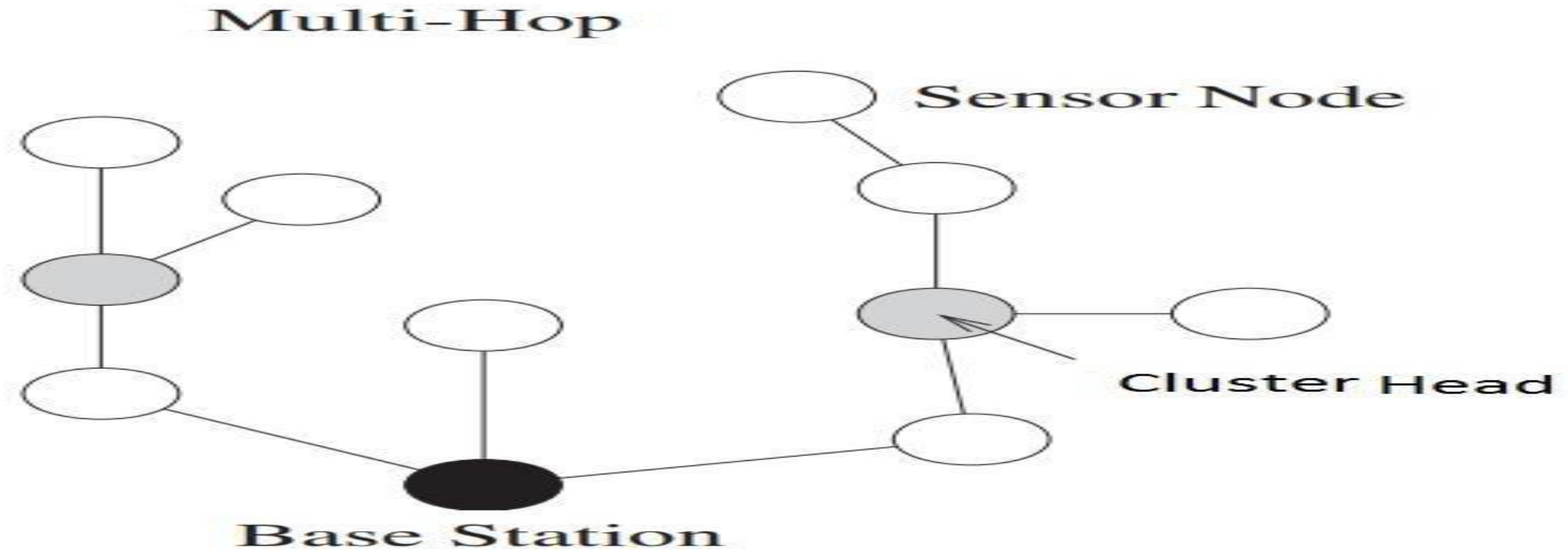
- The base station sends commands to the sensor nodes and the sensor node perform the task by collaborating with each other.
- The sensor nodes in turn send the data back to the base station. A base station also acts as a gateway to other networks through the internet.
- After receiving the data from the sensor nodes, a base station performs simple data processing and sends the updated information to the user using internet.
- If each sensor node is connected to the base station, it is known as Single-hop network architecture.
- Although long distance transmission is possible, the energy consumption for communication will be significantly higher than data collection and computation.

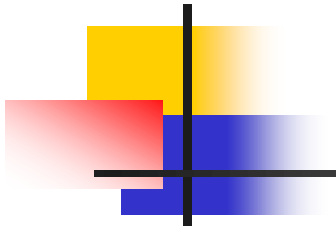
Single Hop Architecture



Multi-hop Architecture

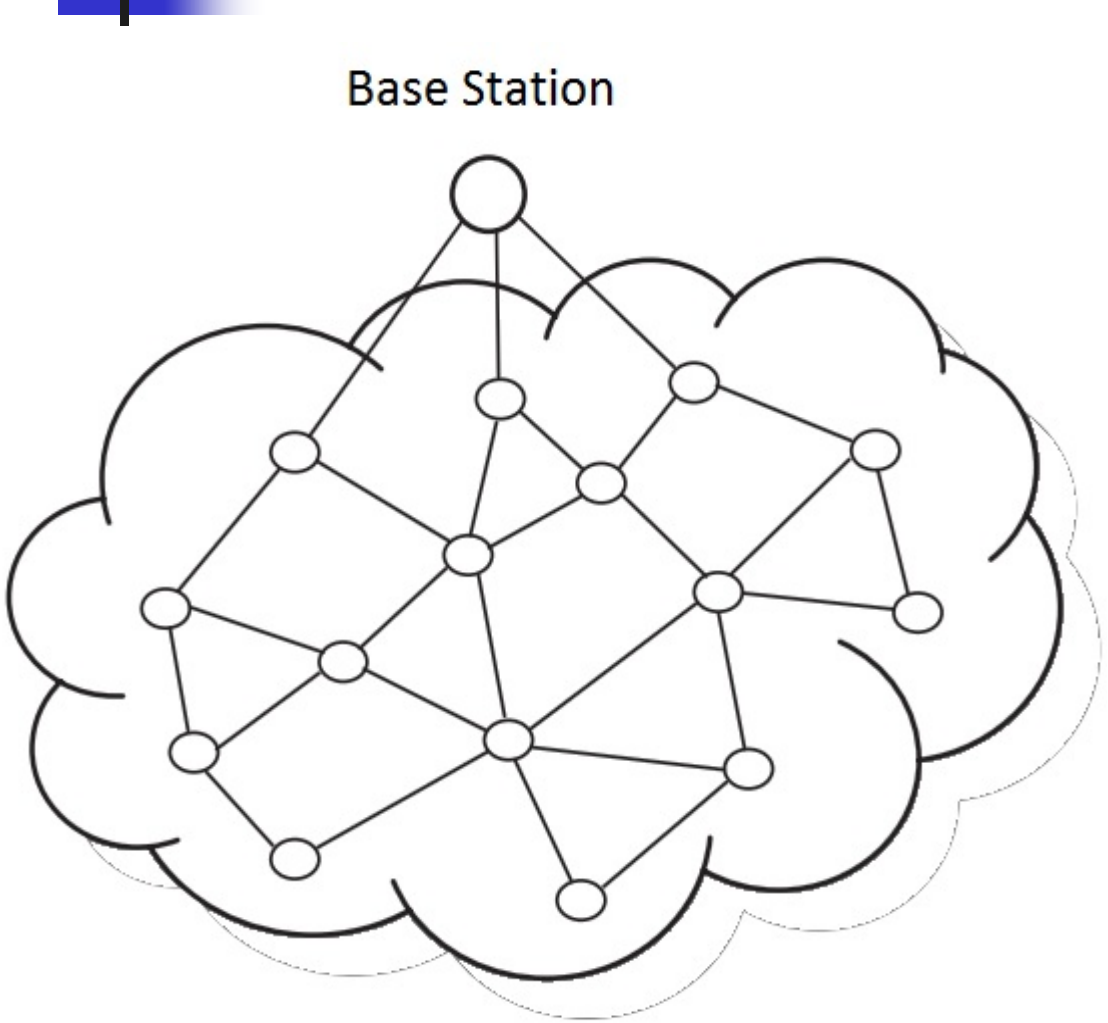
- Hence, Multi-hop network architecture is usually used. Instead of one single link between the sensor node and the base station, the data is transmitted through one or more intermediate node

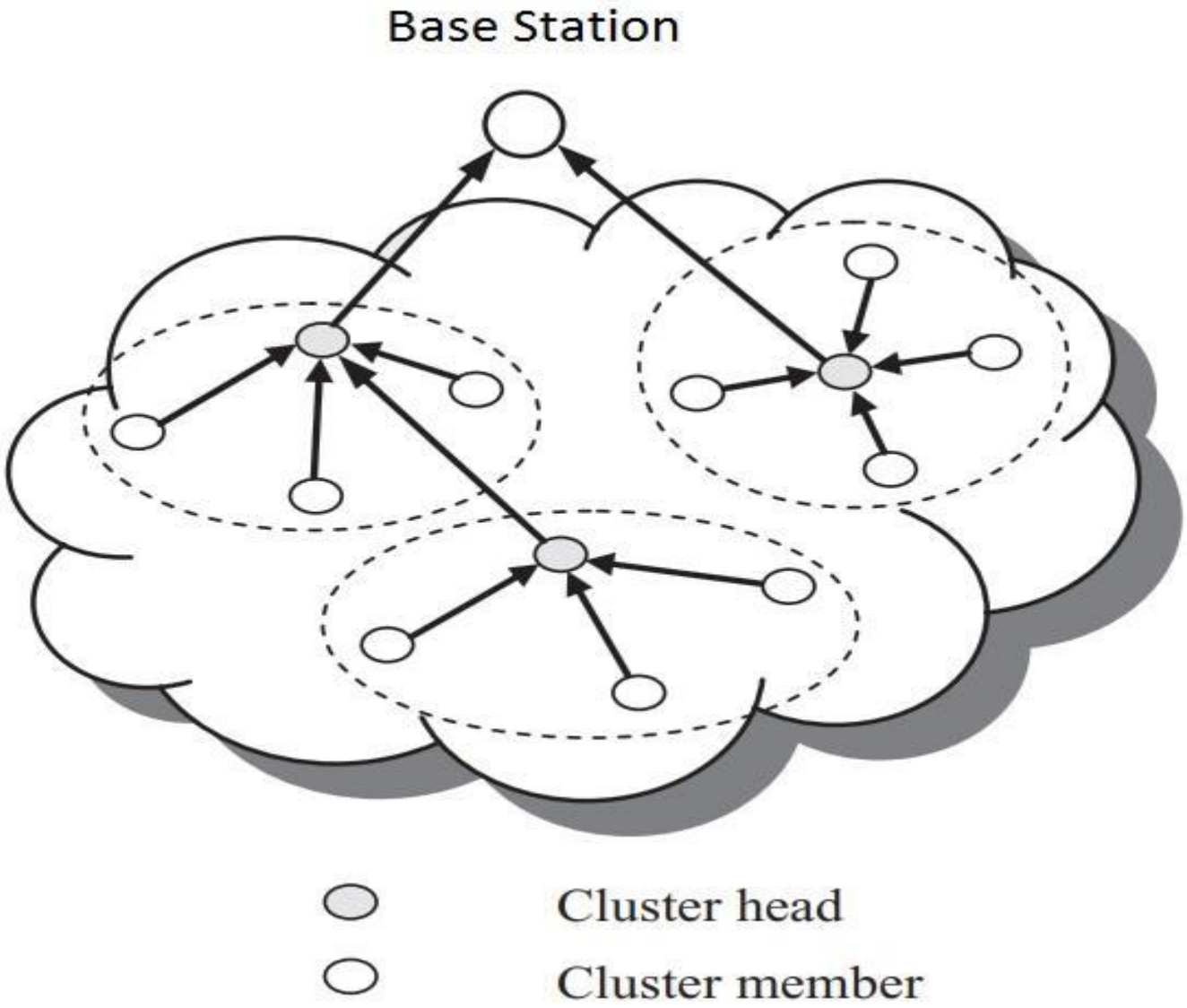




- This can be implemented in two ways. Flat network architecture and Hierarchical network architecture.
- In flat architecture, the base station sends commands to all the sensor nodes but the sensor node with matching query will respond using its peer nodes via a multi-hop path.
- In hierarchical architecture, a group of sensor nodes are formed as a cluster and the sensor nodes transmit data to corresponding cluster heads.
- The cluster heads can then relay the data to the base station

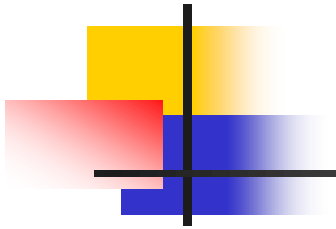
Flat and Hierarchical Network Architectures





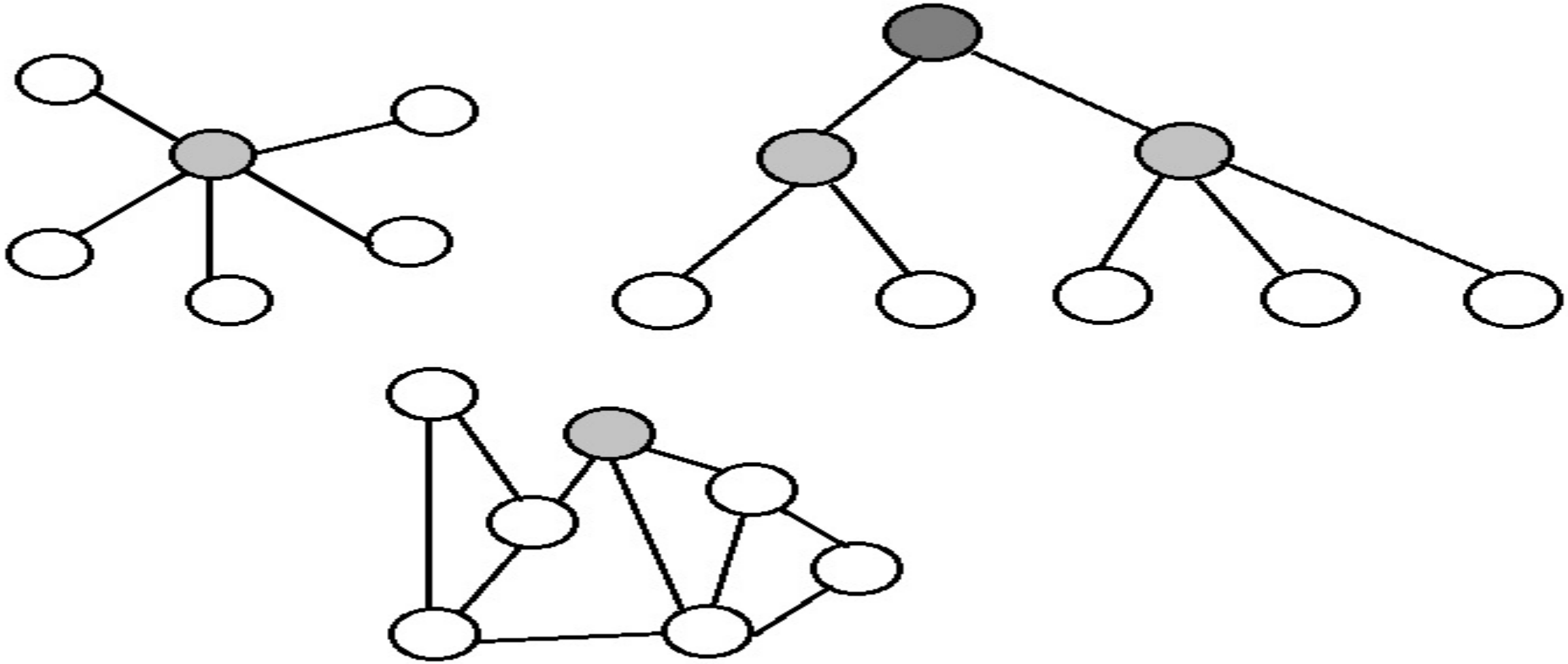
Network Topologies in WSN

- A WSN can be either a single-hop network or a multihop network. The following are a few different network topologies that are used in WSNs.
- Star Topology
  - In star topology, there is a single central node known as hub or switch and every node in the network is connected to this hub. Star topology is very easy to implement, design and expand. The data flows through the hub and plays an important role in the network and a failure in the hub can result in failure of entire network.
- Tree Topology
  - A tree topology is a hierarchical network where there is a single root node at the top and this node is connected to many nodes in the next level and continues. The processing power and energy consumption is highest at the root node and keeps on decreasing as we go down the hierarchical order



- Mesh Topology
  - In mesh topology, apart from transmitting its own data, each node also acts as a relay for transmitting data of other connected nodes. Mesh topologies are further divided into Fully Connected Mesh and Partially Connected Mesh. In fully connected mesh topology, each node is connected to every other node while in partially connected mesh topology, a node is connected one or more neighboring nodes.

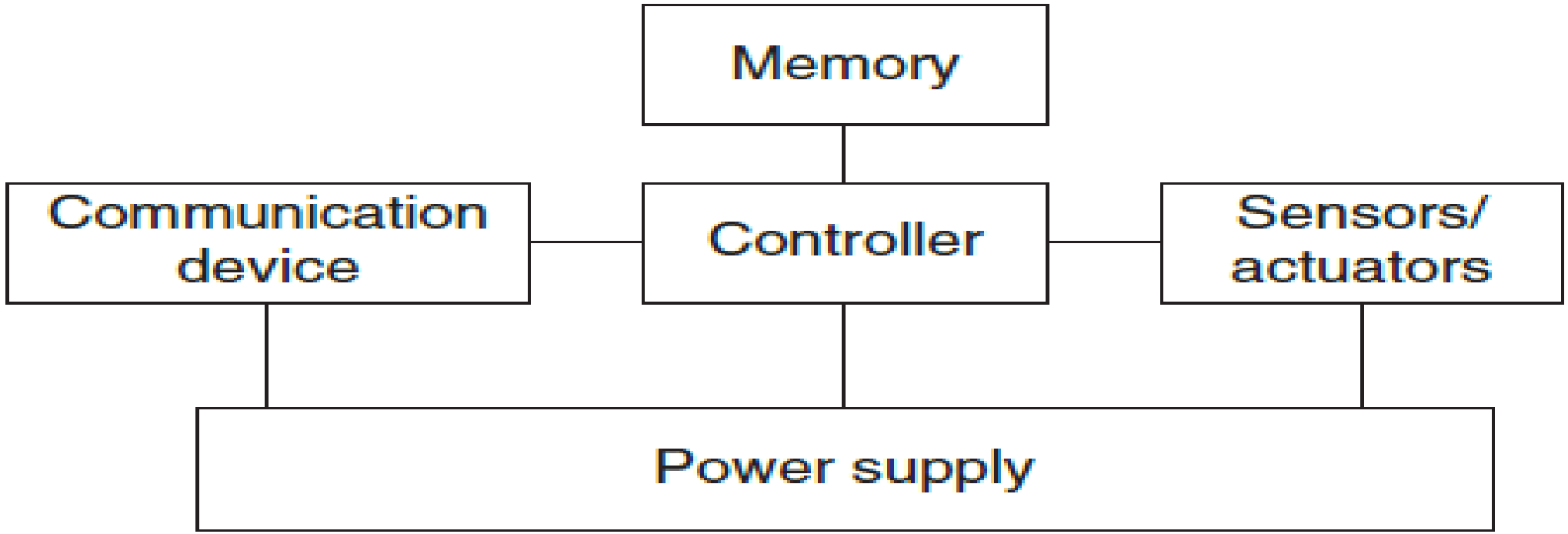
Network Topologies in WSN

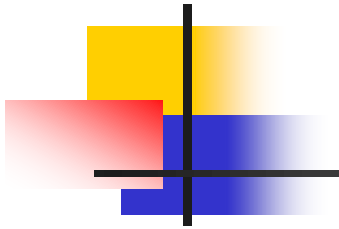


Overview of Sensor Node

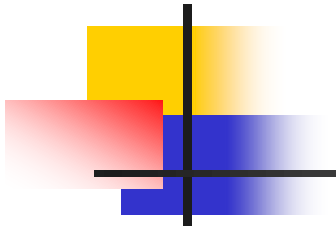
- A basic sensor node comprises five main components are shown in the Figure.
- **Controller:** To process all relevant data
- **Memory:** To store programs and intermediate data.
- **Sensors and actuators:** Actual interface to the physical world to observe or control physical parameters of the environment.
- **Communication:** Device for sending and receiving information over a wireless channel
- **Power supply:** Some form of batteries necessary to provide energy and some form of recharging by obtaining energy from the environment as well

- Basic Components of a Sensor Node

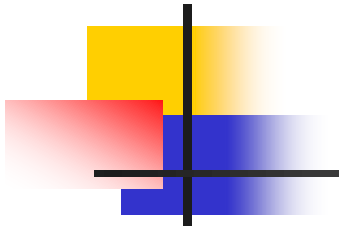




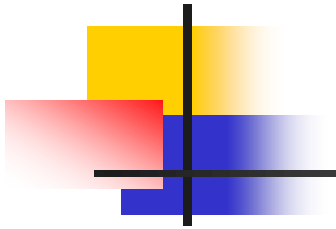
- Controllers: The controller is the core of a wireless sensor node.
  - It is the Central Processing Unit (CPU) of the node
  - It collects data from sensors, processes this data, receives data from other sensor nodes, and decides on the actuator's behavior.
  - It has to execute various programs, ranging from timecritical signal processing and communication protocols to application programs.
  - Such a variety of processing tasks can be performed on various controller architectures, representing trade-offs between flexibility, performance, energy efficiency, and costs.
  - Microcontrollers are suitable for WSNs since they can reduce their power consumption by going into **sleep states** where only parts of the controller are active.
  - One of the main differences to general-purpose systems is that microcontroller-based systems do not include a memory management unit – for example, protected or virtual memory is difficult.



- In a wireless sensor node, DSP can be used to process incoming data. But the advantages of a DSP are not required in a WSN node and they are usually not used.
- Another option for the controller is to use FieldProgrammable Gate Arrays (FPGAs) or ApplicationSpecific Integrated Circuits (ASICs) instead of microcontrollers.



- An FPGA can be reprogrammed in the field to adapt to a changing set of requirements , but this can take time and energy.
- An ASIC is a specialized processor, designed for a given application such as high-speed routers and switches.
- The typical trade-off here is loss of flexibility in return for a considerably better energy efficiency and performance



- Memory
- There is a need for Random Access Memory (RAM) to store intermediate sensor readings, packets from other nodes etc.
- RAM is fast, but it loses its contents if power supply is interrupted.
- The program code can be stored in Read-Only Memory (ROM) or in Electrically Erasable Programmable ReadOnly Memory (EEPROM) or flash memory.
- Flash memory can also serve as intermediate storage of data when the power supply goes off for some time.
- The long read and write access delays of flash memory should be taken into account as well as the high required energy.

- Communication Module
- **1. Choice of transmission medium**
  - The first choice is the transmission medium and usual choices include radio frequencies, optical communication, and ultrasound.
  - Radio Frequency (RF)-based communication is vital requirement of most WSN applications.
  - It provides long range and high data rates, acceptable error rates at reasonable energy expenditure, and does not require line of sight between sender and receiver.
  - For a practical wireless, RF-based system, the carrier frequency has to be carefully chosen. The wireless sensor networks use communication frequencies between about 433 MHz and 2.4 GHz.

2. Transceivers

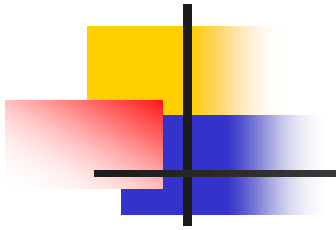
- For actual communication, both a transmitter and a receiver are required in a sensor node to convert a bit stream coming from a microcontroller and convert them to and from radio waves. Such combined devices are called **transceivers**.
- Usually, half-duplex operation is realized since transmitting and receiving at the same time on a wireless medium is impractical in most cases. A range of low-cost transceivers is available that incorporate all the circuitry required for transmitting and receiving, modulation, demodulation, amplifiers, filters, mixers etc..
-

3. Transceiver tasks and characteristics

- The following are the some of the important characteristics of a transceiver which should be taken into account.
  - Service to upper layer
  - Power Consumption and Energy Efficiency
  - Carrier Frequency & Multiple channels
  - Transmission Power Control
  - Data Rates
  - Modulation
  - Noise Figure
  - Power Efficiency
  - Frequency Stability etc

4. Transceiver States

- **Transmit State: T**he transmit part of the transceiver is active and the antenna radiates energy.
- **Receive State: T**he receive part is active.
- **Idle State:** A transceiver that is ready to receive but not currently receiving anything is said to be in an **idle state**.
- **Sleep State: The** significant parts of the transceiver are switched off. There are transceivers offering several different sleep states



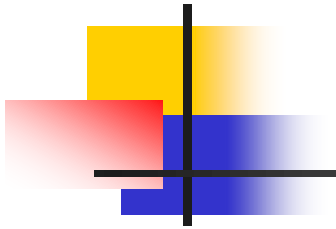
- Sensors & Actuators
- Sensors can be categorized into the following three categories –
- **1. Passive Omni-directional sensors:**
  - They can measure a physical quantity at the point of the sensor node without manipulating the environment by active probing. They obtain the energy directly from the environment – energy is only needed to amplify their analog signal. There is no notion of "direction in these measurements. Typical examples include thermometer, light sensors, vibration, microphones, humidity, chemical sensors etc
- **2. Passive narrow-beam sensors**: They are passive but have a well-defined notion of direction of measurement. A typical example is a camera, which can "take measurements" in a given direction, but has to be rotated if need be.

- **3. Active sensors:** They probe the environment, for example, a sonar or radar sensor or some types of seismic sensors, which generate shock waves by small explosions

Power Supply of Sensor Nodes

1. Traditional batteries

- The power source of a sensor node is a battery, either non-rechargeable (primary batteries) or, if an energy scavenging device is present on the node, also rechargeable (secondary batteries).
- In some form or other, batteries are electro-chemical stores for energy – the chemicals being the main determining factor of battery technology.

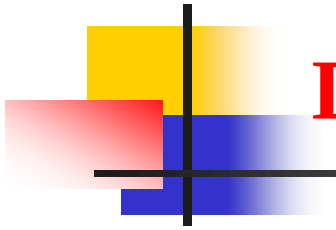


2. Energy scavenging

- Some of the unconventional energy sources like fuel cells, micro heat engines and radioactivity – convert energy from stored secondary form into electricity in a easy way than a normal battery would do.
- The entire energy supply is stored on the node itself – once the fuel supply is exhausted, the node fails.
- The energy from a node's environment must be tapped into and made available to the node – **energy scavenging** should take place.

Characteristics of Wireless Sensor Networks

- Wireless Sensor Networks mainly consists of **sensors. Sensors** are -
  - low power
  - limited memory
  - energy constrained due to their small size.
- Wireless networks can also be deployed in **extreme environmental** conditions and may be prone to enemy attacks.
- Although deployed in an ad hoc manner they need to be **self organized** and **self healing** and can face constant reconfiguration.



Design Challenges

- **Heterogeneity**
  - The devices deployed maybe of various types and need to collaborate with each other.
- **Distributed Processing**
  - The algorithms need to be centralized as the processing is carried out on different nodes.
- **Low Bandwidth Communication**
  - The data should be transferred efficiently between sensors

Continued..

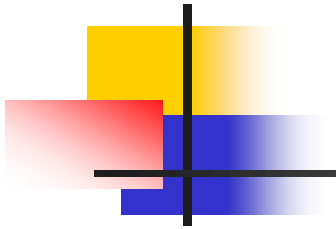
- **Large Scale Coordination**
  - The sensors need to coordinate with each other to produce required results.
- **Utilization of Sensors**
  - The sensors should be utilized in a ways that produce the maximum performance and use less energy.
- **Real Time Computation**
  - The computation should be done quickly as new data is always being generated.

Operational Challenges of Wireless Sensor Networks

- Energy Efficiency
- Limited storage and computation
- Low bandwidth and high error rates
- Errors are common
  - Wireless communication
  - Noisy measurements
  - Node failure are expected
- Scalability to a large number of sensor nodes
- Survivability in harsh environments
- Experiments are time- and space-intensive

Enabling Technologies for WSN

- It has only become possible to build wireless sensor networks with some fundamental advances in enabling technologies.
- First and foremost among these technologies is the miniaturization of hardware.
- Smaller feature sizes in chips have driven down the power consumption of the basic components of a sensor node to a level that the constructions of WSNs can be contemplated.
- This is particularly relevant to microcontrollers and memory chips and the radio modems responsible for wireless communication.

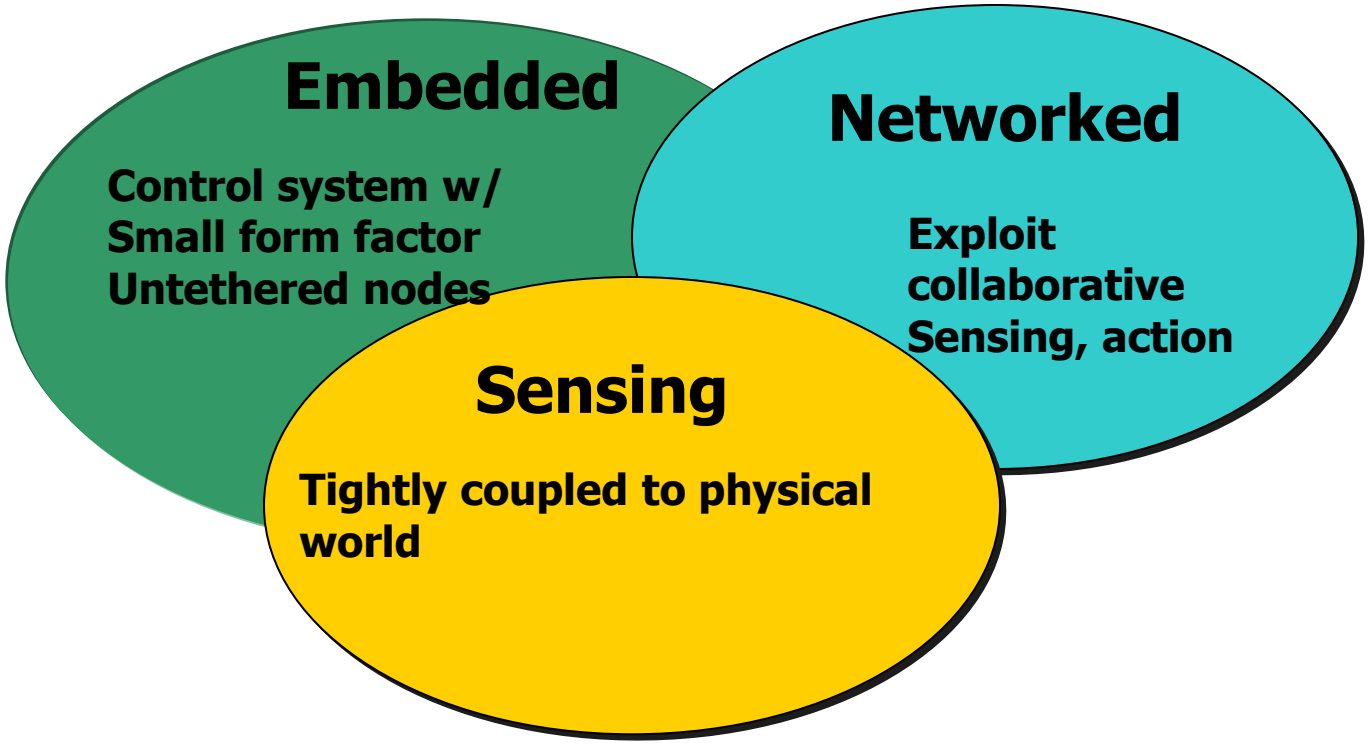


- Reduced chip size and improved energy efficiency is accompanied by reduced cost, which is necessary to make redundant deployment of nodes affordable.
- The actual sensing equipment is the third relevant technology next to processing and communication.
- However, it is difficult to generalize because of the vast range of possible sensors

Enabling Technologies

Embed numerous distributed devices to monitor and interact with physical world

Network devices to coordinate and perform higher-level tasks



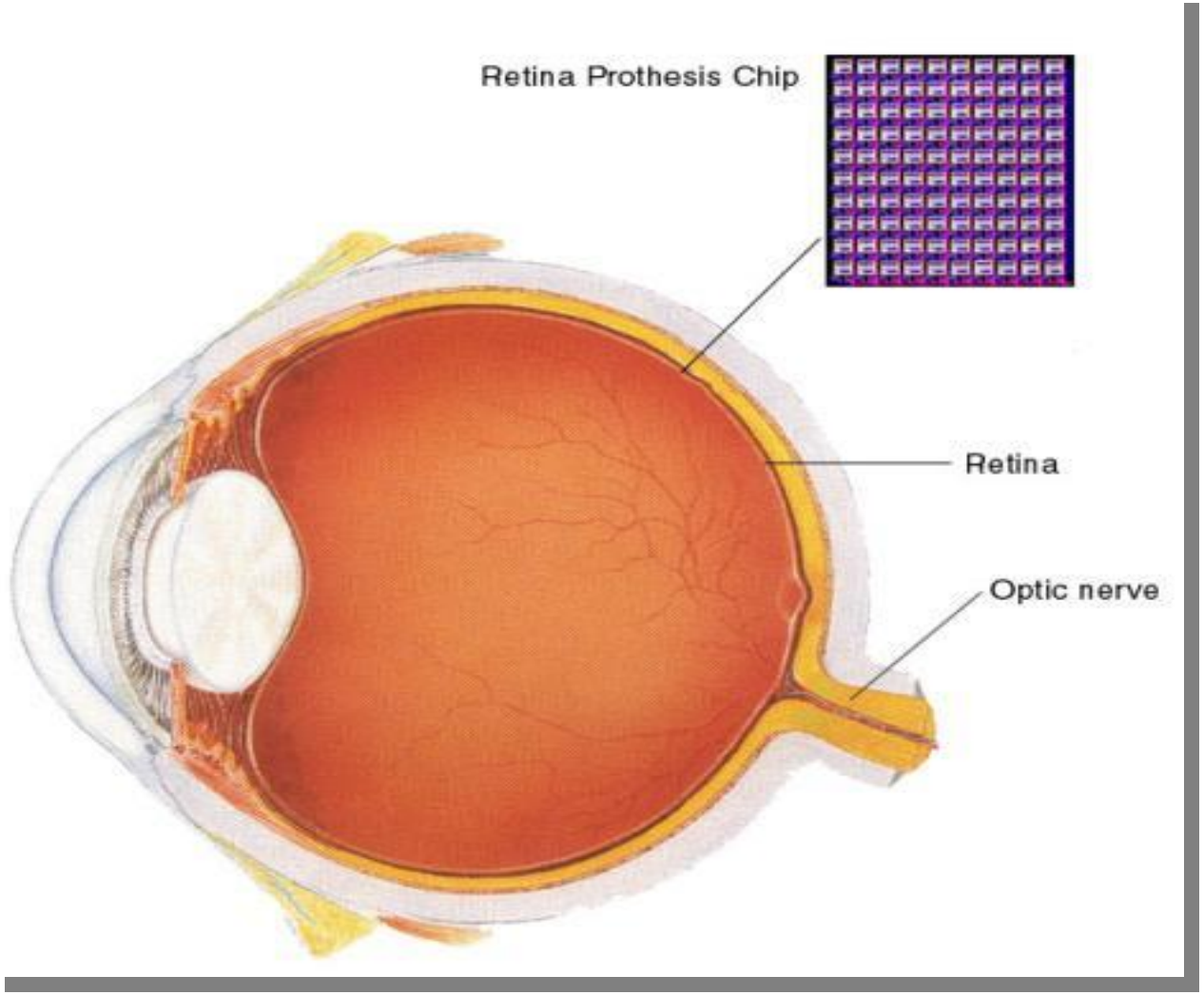
Exploit spatially and temporally dense, in situ, sensing and actuation

Future of WSN - Smart Home / Smart Office

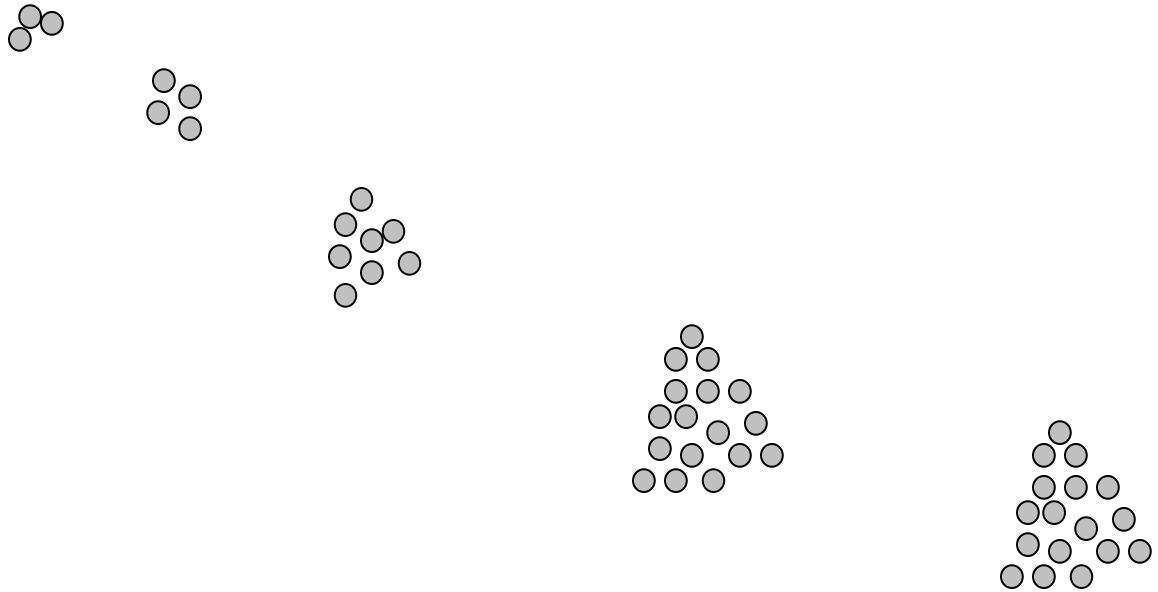
- Sensors controlling electrical devices in the house.
- Better lighting and heating in office buildings.
- The Pentagon building has used sensors extensively.

Biomedical / Medical

- Health Monitors
  - Glucose
  - Heart rate
  - Cancer detection
- Chronic Diseases
  - Artificial retina
  - Cochlear implants
- Hospital Sensors
  - Monitor vital signs
  - Record anomalies



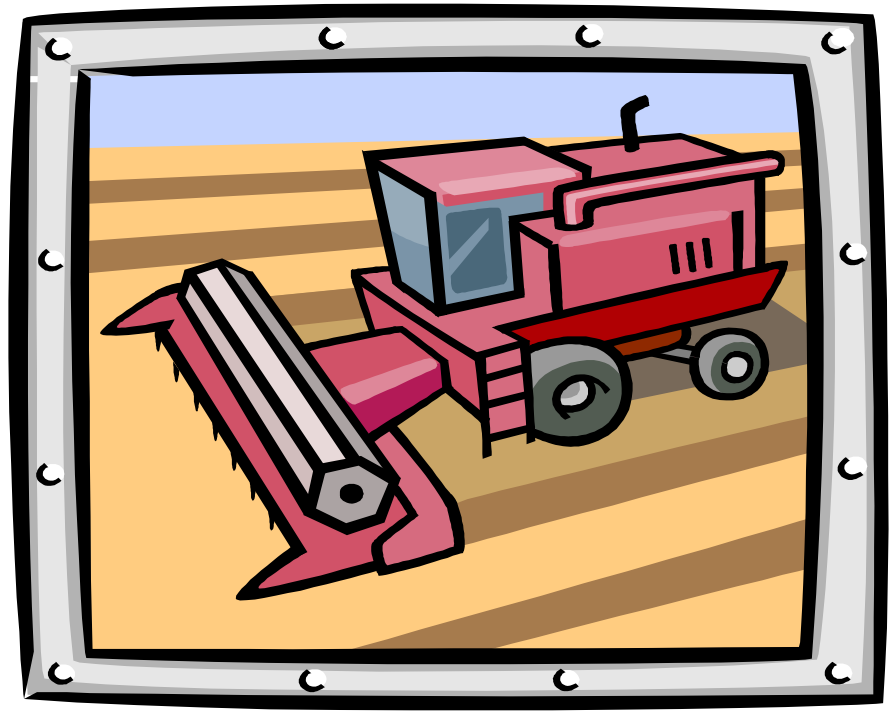
Military



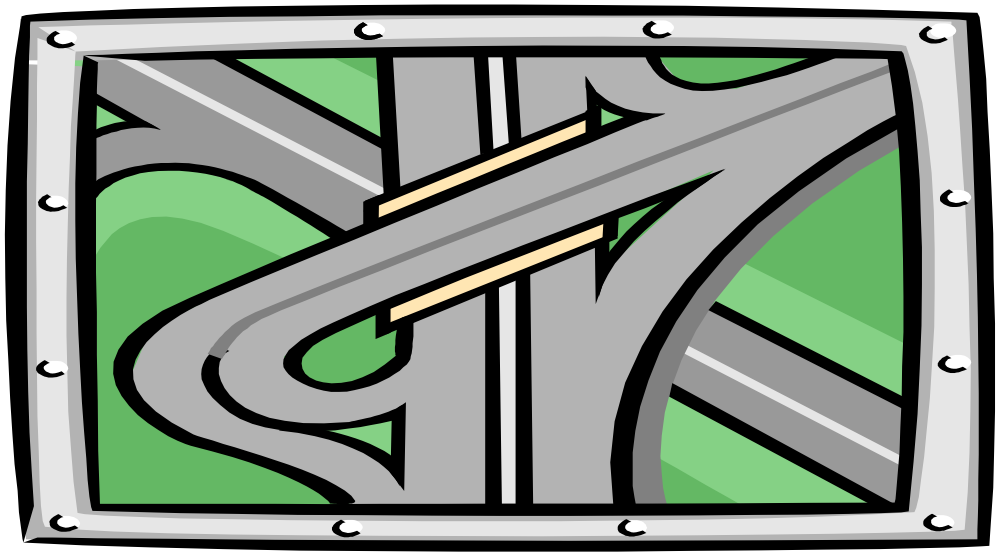
Remote deployment of sensors for tactical monitoring of enemy troop movements.

Industrial & Commercial

- Numerous industrial and commercial applications:
  - Agricultural Crop Conditions
  - Inventory Tracking
  - In-Process Parts Tracking
  - Automated Problem Reporting
  - Theft Deterrent and Customer Tracing
  - Plant Equipment Maintenance Monitoring



Traffic Management & Monitoring



- Future cars could use wireless sensors to:
  - Handle Accidents
  - Handle Thefts

✓Sensors embedded in the roads to:

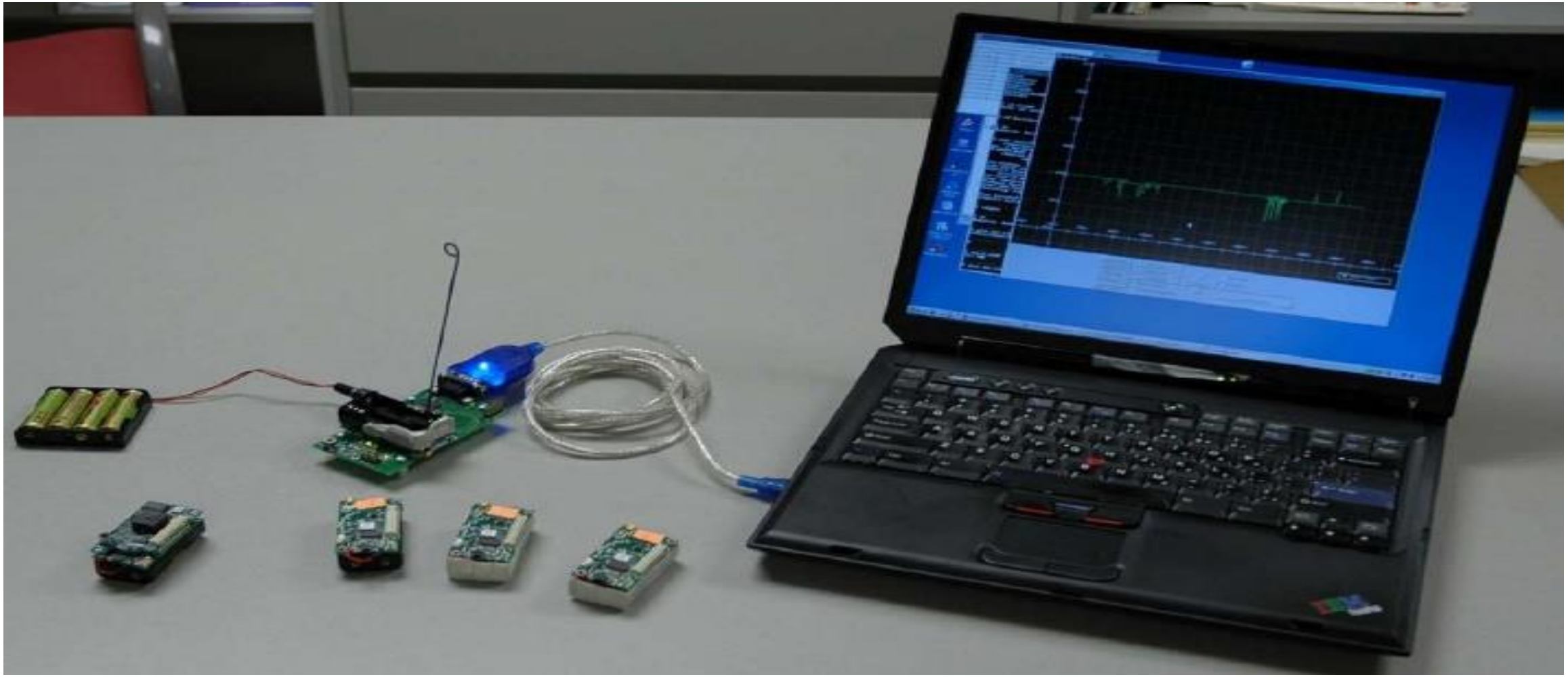
- –Monitor traffic flows
- –Provide real-time route updates

One More Example of Sensor Board - MTS400/420

- Besides the functions of MTS 300, it mainly adds GPS functionality

  - Further Reading
    - http://firebug.sourceforge.net/gps_tests.htm

Hardware Setup Overview



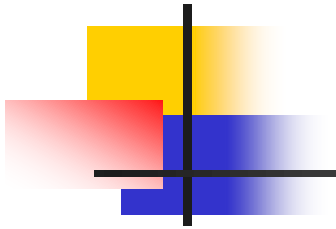
Sensor Network Algorithms

- Directed Diffusion – Data centric routing
- Sensor Network Query Processing
- Distributed Data Aggregation
- Localization in sensor networks
- Multi-object tracking/Pursuer Evader
- Security

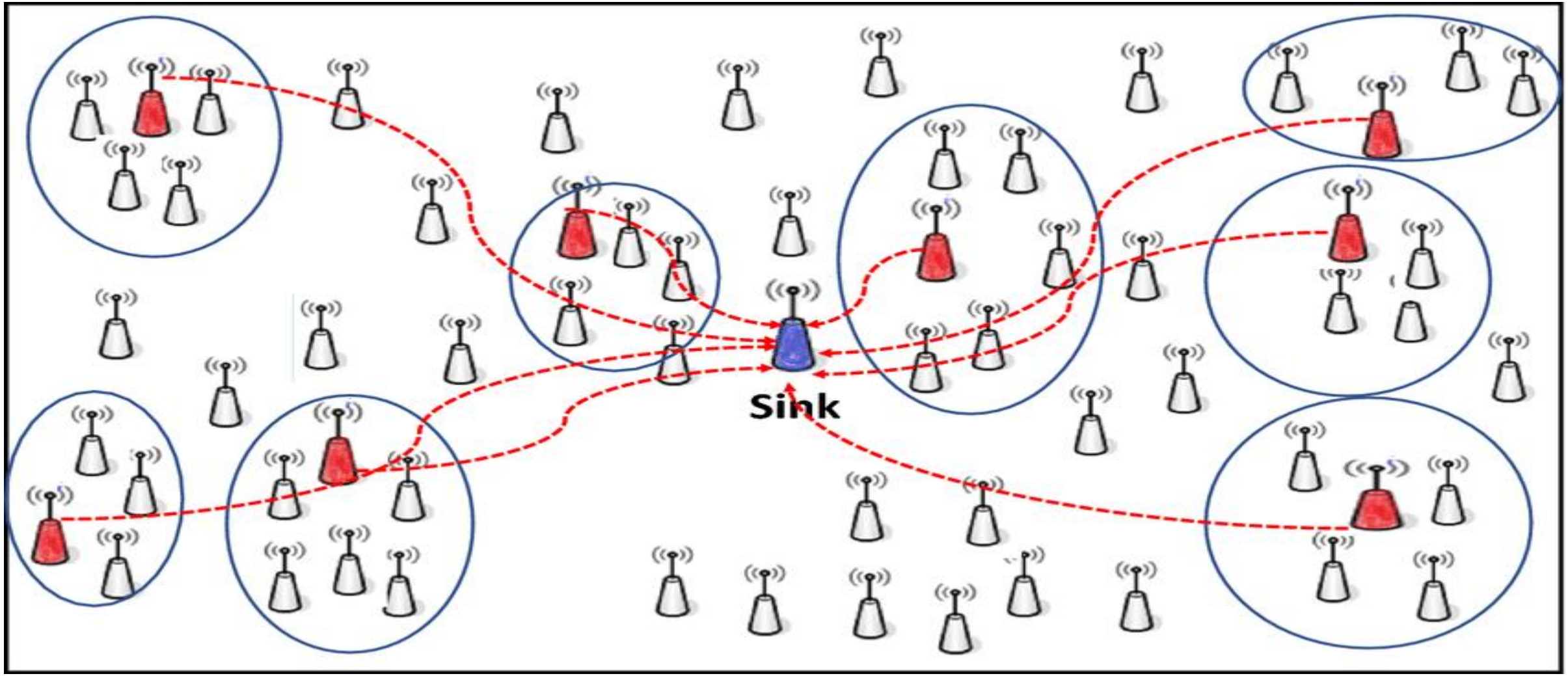
- **Wireless Sensor Networks (WSNs):**
  - WSN Consists of a large number of sensor nodes, densely deployed over an area.
  - Sensor nodes are capable of collaborating with one another and measuring the condition of their surrounding environments (i.e., Light, temperature, sound, vibration).
  - The sensed measurements are then transformed into digital signals and processed to reveal some properties of the phenomena around sensors.
- **Components of a Sensor Node:**
  - In any wireless sensor network, sensor node consists of four basic components, a sensing unit, a processing unit, a transceiver unit, and a power unit. They may also have additional application dependent components such as a location finding system, power generator and mobilize

Types of Wireless Sensor Networks

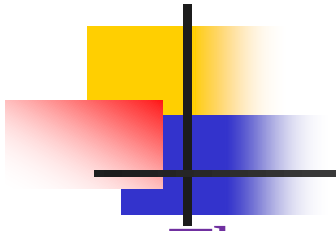
- The types of networks are decided based upon the environment so that they can be deployed underwater, underground, on land and so on. Different types of WSNs include:
  - Terrestrial WSNs
  - Underground WSNs
  - Underwater WSNs
  - Multimedia WSNs
  - Mobile WSNs



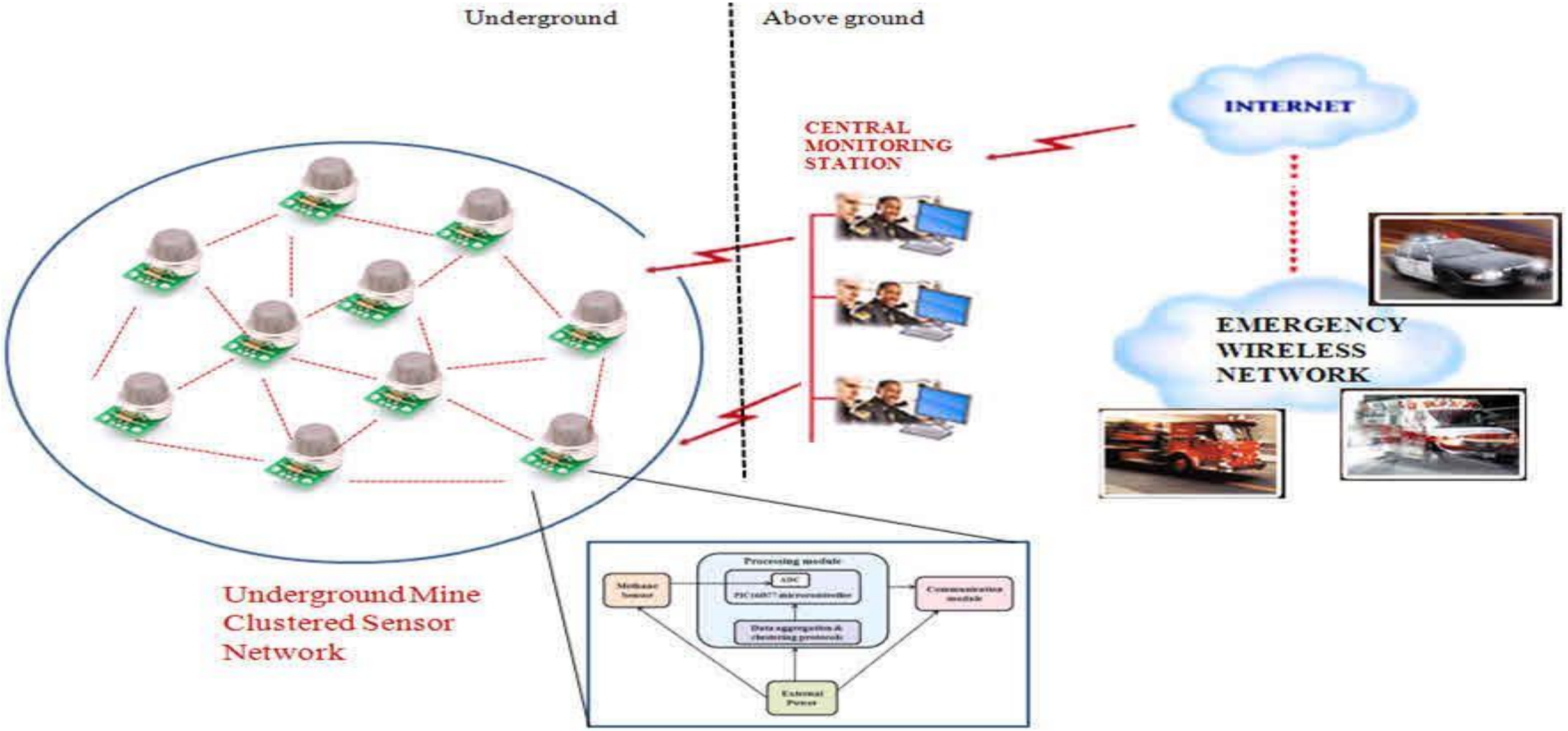
- Terrestrial WSN’s
- Terrestrial WSNs are capable of communicating base stations efficiently and consist of hundreds to thousands of wireless sensor nodes deployed either in an unstructured or structured manner.
- In an unstructured mode, the sensor nodes are randomly distributed within the target area dropped from a fixed plane.
- The preplanned or structured mode considers optimal placement, grid placement, and 2D, 3D placement models. In this WSN, the battery power is limited but equipped with solar cells as a secondary power source.
- The energy conservation of these WSNs is achieved by using low duty cycle operations, minimizing delays, and optimal routing, and so on.

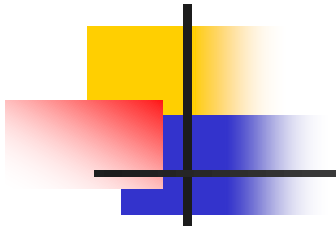

Sink

- Underground WSN
- The underground wireless sensor networks are more expensive than the terrestrial WSNs in terms of deployment, maintenance, and equipment cost considerations and careful planning.
- The WSNs networks consist of several sensor nodes hidden in the ground to monitor underground conditions.
- To relay information from the sensor nodes to the base station, additional sink nodes are located above the ground.
- The underground wireless sensor networks deployed into the ground are difficult to recharge.

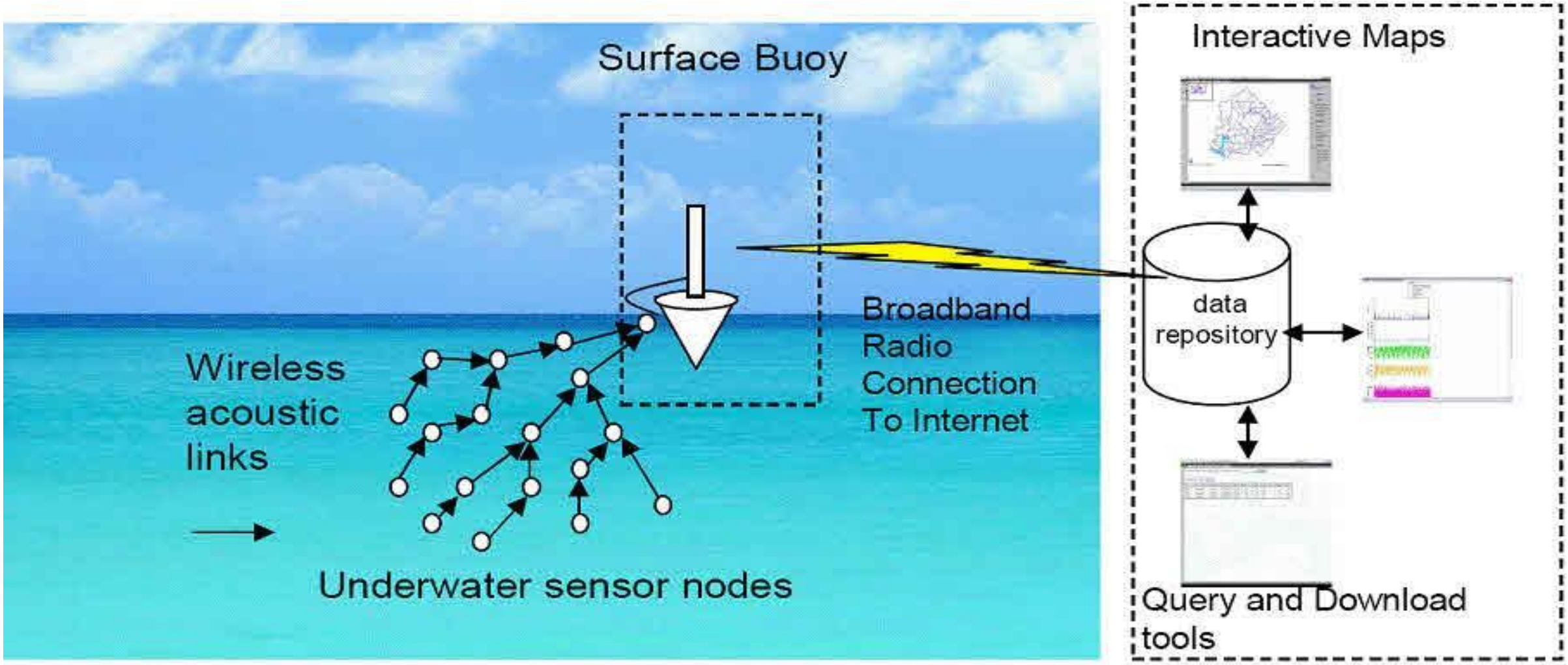


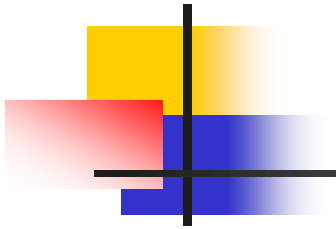
- The sensor battery nodes equipped with limited battery power are difficult to recharge
- In addition to this, the underground environment makes wireless communication a challenge due to the high level of attenuation and signal loss


Underground
Above ground
INTERNET
CENTRAL MONITORING STATION
EMERGENCY WIRELESS NETWORK
Underground Mine Clustered Sensor Network
Processing module
ADC
Communication module
External Power

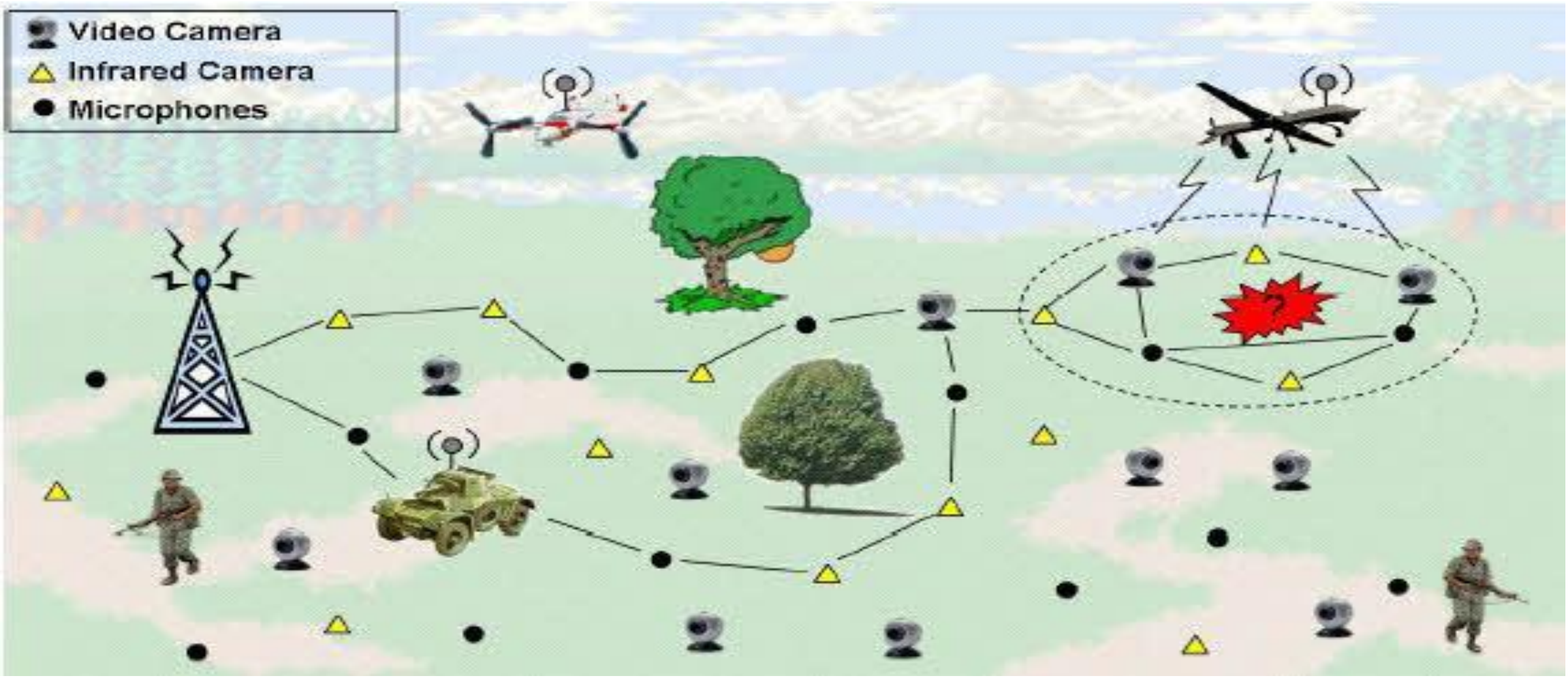


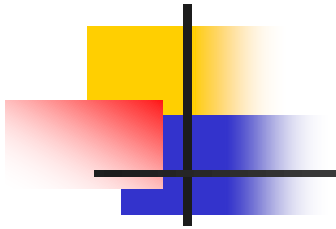
- Under Water WSN
- More than 70% of the earth is occupied with water. These networks consist of several sensor nodes and vehicles deployed underwater.
- Autonomous underwater vehicles are used for gathering data from these sensor nodes. A challenge of underwater communication is a long propagation delay, and bandwidth and sensor failures.
- Underwater, WSNs are equipped with a limited battery that cannot be recharged or replaced.
- The issue of energy conservation for underwater WSNs involves the development of underwater communication and networking techniques


Surface Buoy
Interactive Maps
Broadband
Radio
Connection
To Internet
data
repository
Wireless
acoustic
links
Underwater sensor nodes
Query and Download
tools

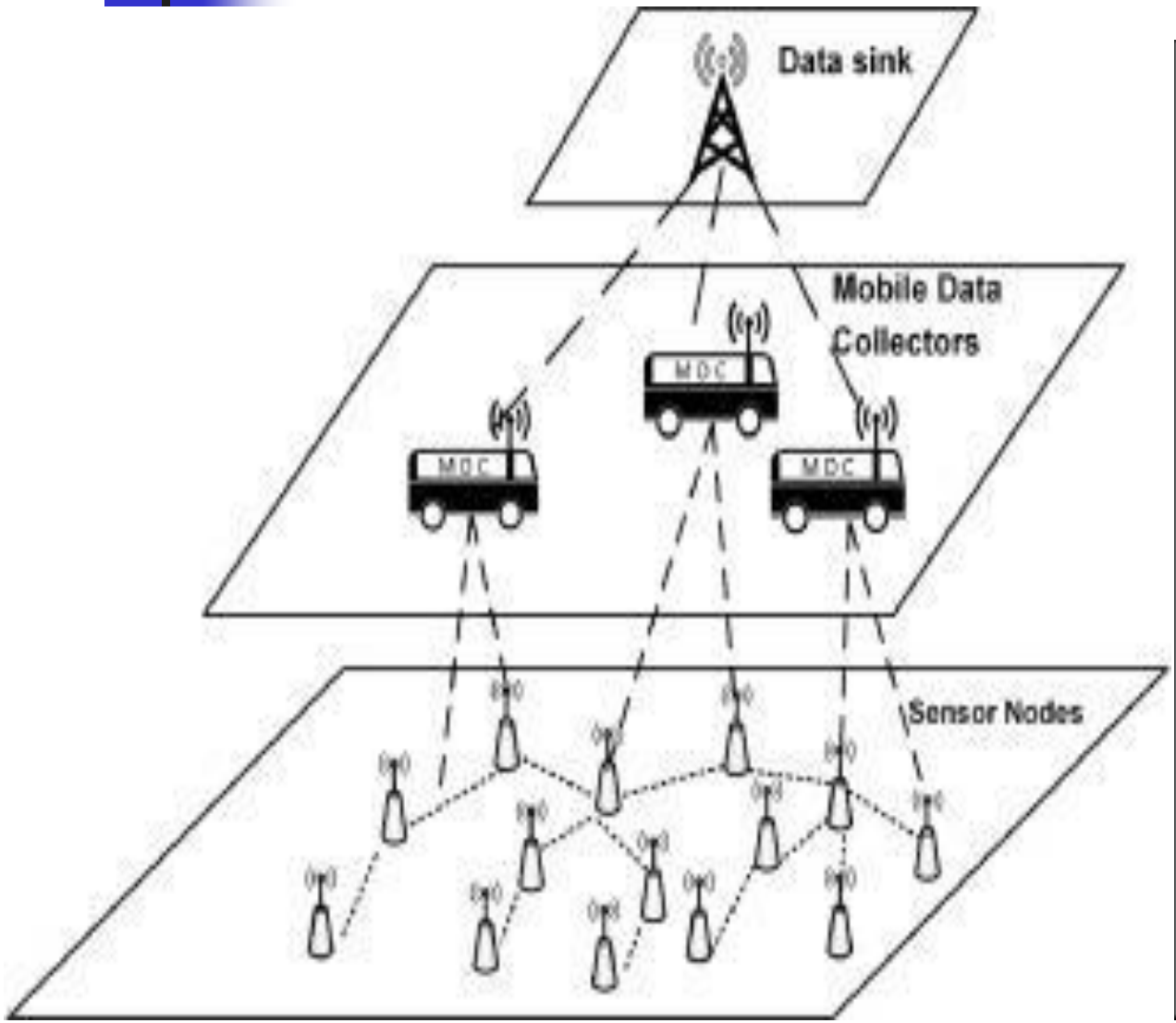


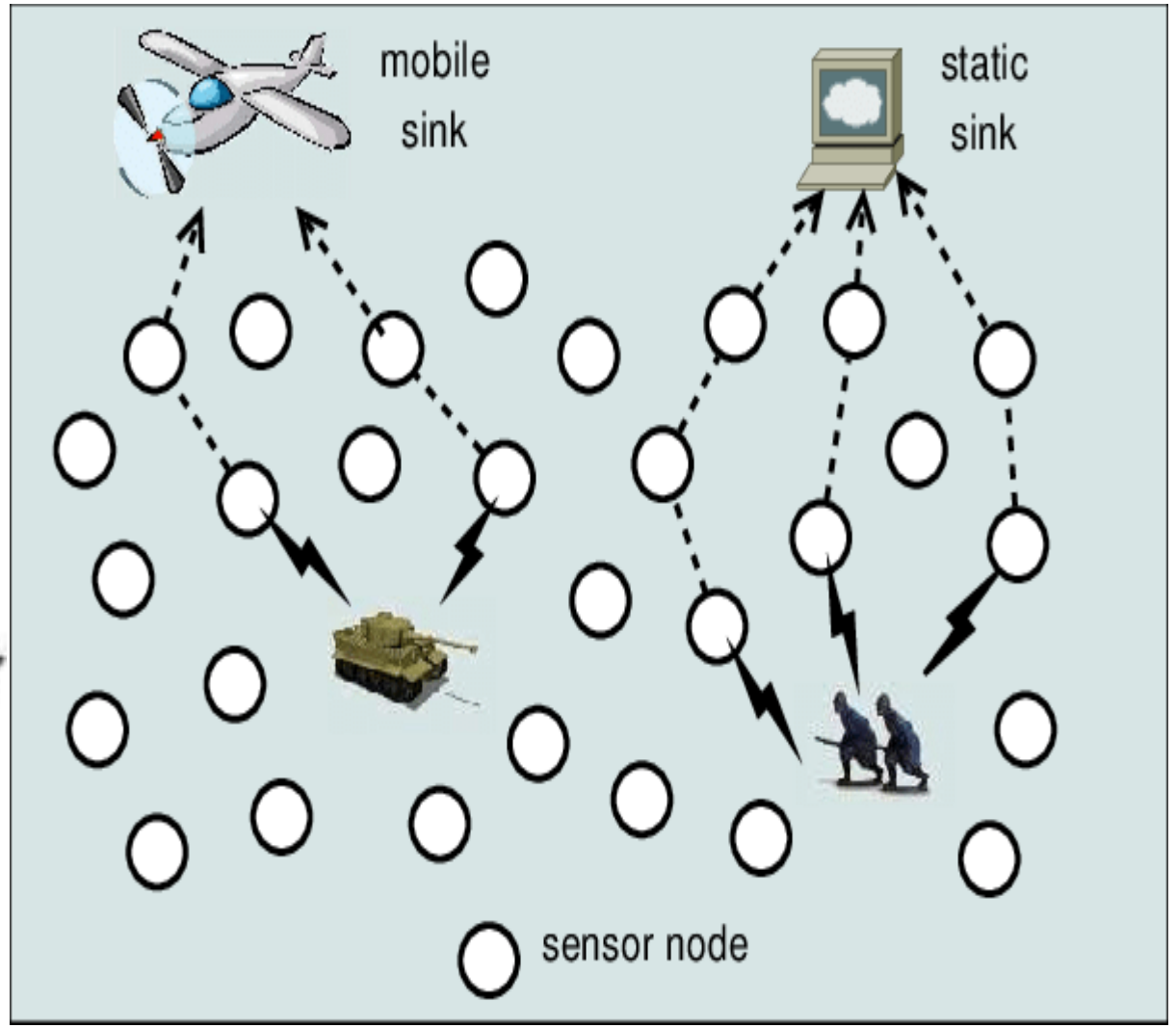
- Multimedia WSN
- Multimedia wireless sensor networks have been proposed to enable tracking and monitoring of events in the form of multimedia such as imaging, video, and audio.
- These networks consist of low-cost sensor nodes equipped with microphones and cameras.
- These nodes are interconnected with each other over a wireless connection for data compression, data retrieval, and correlation.
- The challenges with the multimedia WSN include high energy consumption, high bandwidth requirements, data processing, and compressing techniques.
- In addition to this, multimedia contents require high bandwidth for the content to be delivered properly and easily.

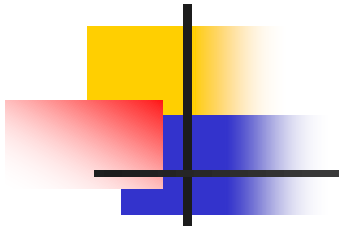

Video Camera
Infrared Camera
Microphones



- Mobile WSN
- These networks consist of a collection of sensor nodes that can be moved on their own and can be interacted with the physical environment.
- The mobile nodes can compute sense and communicate. Mobile wireless sensor networks are much more versatile than static sensor networks.
- The advantages of MWSN over static wireless sensor networks include better and improved coverage, better energy efficiency, superior channel capacity, and so on.


Data sink
Mobile Data Collectors
MDC
MDC
MDC
Sensor Nodes

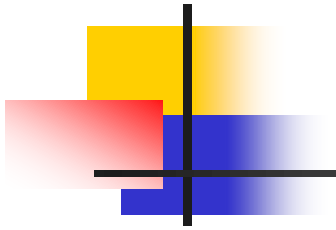

mobile sink
static sink
sensor node



- **Challenges in WSN:**
  - **Energy:** Power consumption can be allocated to three functional domains: sensing, communication, and data processing, each of which requires optimization. The sensor node lifetime typically exhibits a strong dependency on battery life. The constraint most often associated with sensor network design is that sensor nodes operate with limited energy budgets.
  - **Limited bandwidth:** Bandwidth limitation directly affects message exchanges among sensors, and synchronization is impossible without message exchanges. Sensor networks often operate in a bandwidth and performance constrained multi-hop wireless communications medium. These wireless communications links operate in the radio, infrared, or optical range.

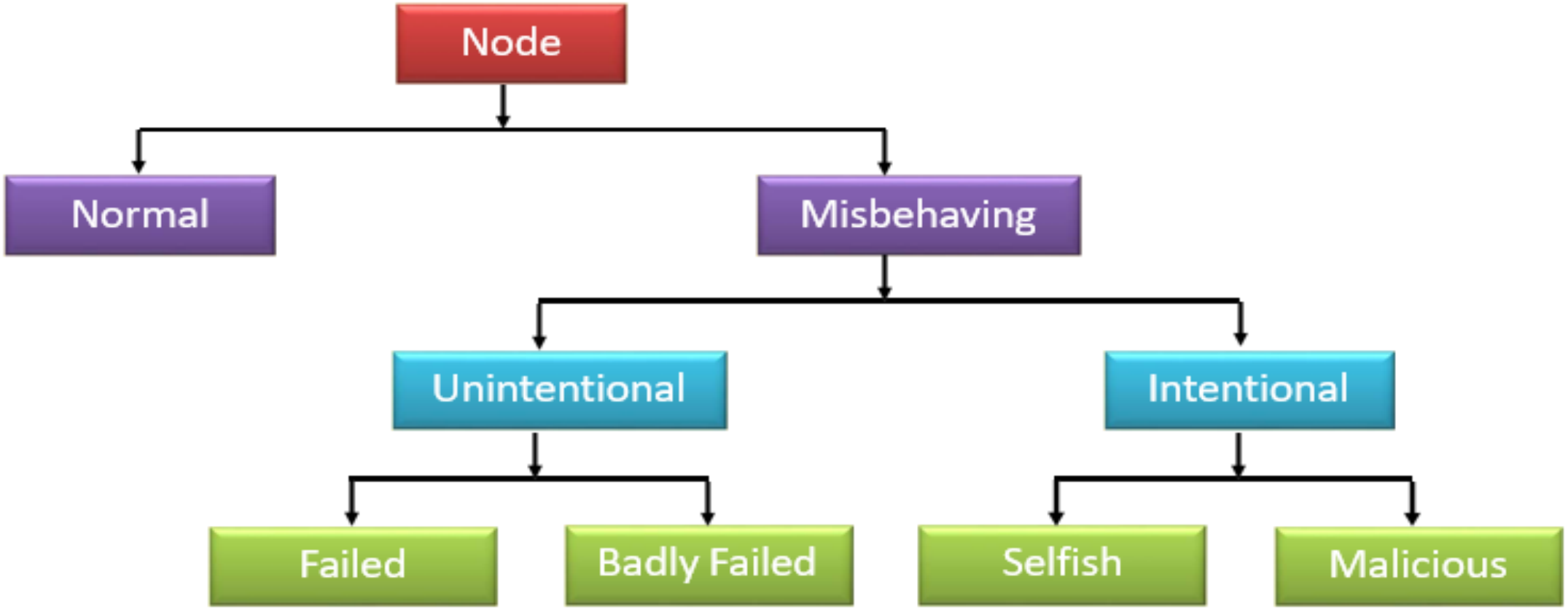
- **Node Costs**: A sensor network consists of a large set of sensor nodes. It follows that the cost of an individual node is critical to the overall financial metric of the sensor network. Clearly, the cost of each sensor node has to be kept low for the global metrics to be acceptable.
- **Deployment Node**: A proper node deployment scheme can reduce the complexity of problems. Deploying and managing a high number of nodes in a relatively bounded environment requires special techniques. Hundreds to thousands of sensors may be deployed in a sensor region.
- **Security:** One of the challenges in WSNs is to provide high security requirements with constrained resources. Many wireless sensor networks collect sensitive information. The remote and unattended operation of sensor nodes increases their exposure to malicious intrusions and attacks. The security requirements in WSNs are comprised of node authentication and data confidentiality. To identify both trustworthy and unreliable nodes from a security stand points, the deployment sensors must pass a node authentication examination by their corresponding manager nodes or cluster heads and unauthorized nodes can be isolated from WSNs during the node authentication procedure.

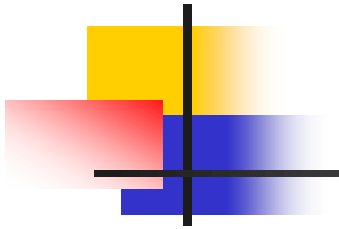
- **SENSOR WEB**
  the sensor web is a type of sensor network that is especially well suited for environmental monitoring. The sensor web is also associated with a sensing system which heavily utilizes the World Wide Web.
- **Sensor Web Enablement (SWE)**
  Sensor Web Enablement (SWE) is a suite of standards developed and maintained by Open Geospatial Consortium. SWE standards enable developers to make all types of sensors, transducers and sensor data repositories discoverable, accessible and usable via the Web.



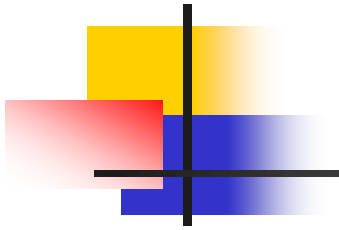
- **SWE Standards include:**
  - Sensor Observation Service
  - Sensor Planning Service
  - Observations and Measurements
  - Sensor Model Language
  - Sensor Things API
- **Cooperation in Wireless Ad Hoc and Sensor Networks**
  - Nodes communicate with other nodes with the help of intermediate nodes.
  - The intermediate nodes act as relays.
  - Wireless nodes are energy-constrained.
  - Nodes may or may not cooperate.
  - Two extremities for Cooperation:
    - **Total cooperation:** if all relay requests are accepted, nodes will quickly exhaust limited energy.
    - **Total non-cooperation:** if no relay requests are accepted, the network throughput will go down rapidly.

- Node Behaviour in WSNs:





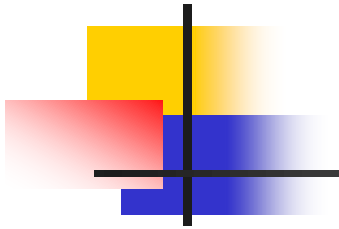
- Normal nodes work perfectly in ideal environmental conditions.
- Failed nodes are simply those that are unable to perform an operation; this could be because of power failure and environmental events.
- Badly failed nodes exhibit features of failed nodes but they can also send false routing messages which are a threat to the integrity of the network.
- Selfish nodes are typified by their unwillingness to cooperate, as the protocol requires whenever there is a personal cost involved. Packet dropping is the main attack by selfish nodes.
- Malicious nodes aim to deliberately disrupt the correct operation of the routing protocol, denying network service if possible.



- **Dynamic Misbehaviour (Dumb behaviour):**
  - Detection of such temporary misbehaviour in order to preserve normal functioning of the network – coinage and discovery of dumb behaviour.
  - In the presence of adverse environmental conditions (high temperature, rainfall, and fog) the communication range shrinks.
  - A sensor node can sense its surroundings but is unable to transmit the sensed data
  - With the resumption of favourable environmental conditions, dumb nodes work normally.
  - Dumb behaviour is temporal in nature (as it is dependent on the effects of environmental conditions)

- **Self-Management of Wireless Sensor Networks:**
  - A WSN is deployed with the intention of acquiring information.
  - The sensed information is transmitted in the form of packets.
  - Information theoretic self-management (INTSEM) controls the transmission rate of a node by adjusting a node's sleep time.
  - Benefits:
    - Reduce consumption of transmission energy of transmitters.
    - Reduce consumption of receiving energy of relay nodes.

- **Social sensing WSN**
- Social Sensing-based Duty Cycle Management for Monitoring Rare Events in Wireless Sensor Networks.
- WSNs are energy-constrained Scenario:
  - Event monitoring using WSNs.
  - WSNs suffer from ineffective sensing for rare events.
  - Event monitoring or sensing, even if there is no event to monitor or sense.
  - Example: Submarine monitoring in underwater surveillance



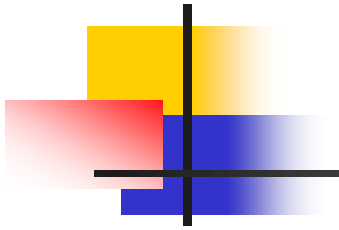
- Challenges:
  - Distinguish rare events and regular events.
  - Adapt the duty-cycle with the event occurrence probability.
- Contribution:
  - Probabilistic duty cycle (PDC) in WSNs.
  - Accumulates information from the social media to identify the occurrence possibility of rare events.
  - Adjusts the duty cycles of sensor nodes using weak estimation learning automata

- **Applications of WSNs:**

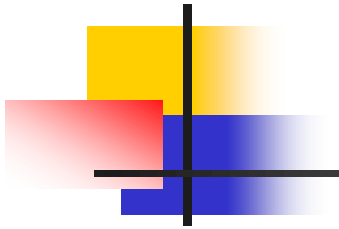
  1. Mines

  - Fire Monitoring and Alarm System for Underground Coal Mines Bord-and-Pillar Panel Using Wireless Sensor Networks.
  - WSN-based simulation model for building a fire monitoring and alarm (FMA) system for Bord & Pillar coal mine.
  - The fire monitoring system has been designed specifically for Bord & Pillar based mines.
  - It is not only capable of providing real-time monitoring and alarm in case of a fire, but also capable of providing the exact fire location and spreading direction by continuously gathering, analysing, and storing real time information.

- **2. Healthcare**
  - Wireless Body Area Networks
  - Wireless body area networks (WBANs) have recently gained popularity due to their ability in providing innovative, cost-effective, and user-friendly solution for continuous monitoring of vital physiological parameters of patients.
  - Monitoring chronic and serious diseases such as cardiovascular diseases and diabetes.
  - Could be deployed in elderly persons for monitoring their daily activities
- 3.Internet of Things (IOT)
- 4. Surveillance and Monitoring for security, threat detection
- 5. Environmental temperature, humidity, and air pressure
- 6. Noise Level of the surrounding
- 7. Landslide Detection

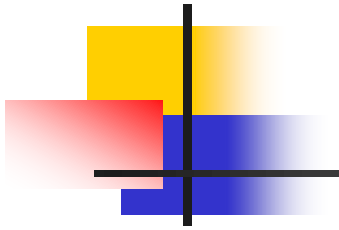


- **Wireless Multimedia Sensor Networks (WMSNs)**
  - Incorporation of low-cost camera (typically CMOS) to wireless sensor nodes
  - **Camera sensor (CS) nodes:** capture multimedia (video, audio, and the scalar) data, expensive and resource hungry, directional sensing range
  - **Scalar sensor (SS) nodes:** sense scalar data (temperature, light, vibration, and so on), omni- directional sensing range, and low cost
  - WMSNs consist of a smaller number of CS nodes and large number of SS nodes
- **WMSNs Application**
  - In security surveillance, wild-habitat monitoring, environmental monitoring, SS nodes cannot provide precise information
  - CS nodes replace SS nodes to get precise information
  - Deployment of both CS and SS nodes can provide better sensing and prolong network lifetime



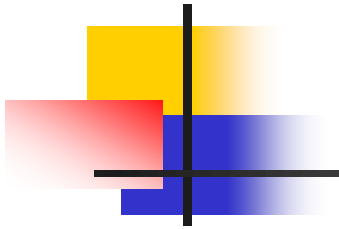
- **Nanonetworks:**
  - Nanodevice has components of sizes in the order nano-meters.
  - Communication options among nanodevices
    - Electromagnetic
    - Molecular
- **Molecular Communication:**
  - Molecule used as information
  - Information packed into vesicles
  - Gap junction works as mediator between cells and vesicles
  - Information exchange between communication entities using molecules

- **Electromagnetic-based Communication**
  - Surface Plasmonic Polariton (SPP) generated upon electromagnetic beam
  - EM communication for Nanonetworks centres around 0.1-10 Terahertz channel
- **Underwater Acoustic Sensor Networks**
  - In a layered shallow oceanic region, the inclusion of the effect of internal solitons on the performance of the network is important.
  - Based on various observations, it is proved that non-linear internal waves, i.e., Solitons are one of the major scatters of underwater sound.
  - If sensor nodes are deployed in such type of environment, inter-node communication is affected due to the interaction of wireless acoustic signal with these solitons, as a result of which network performance is greatly affected.

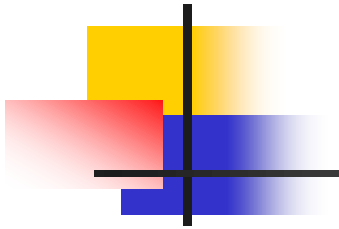


- The performance analysis of UWASNs renders meaningful insights with the inclusion of a mobility model which represents realistic oceanic scenarios.
- The existing works on performance analysis of UWASNs lack the consideration of major dominating forces, which offer impetus for a node's mobility.

- **WSN Coverage:**
  - Coverage – area-of-interest is covered satisfactorily.
  - Connectivity – all the nodes are connected in the network, so that sensed data can reach to sink node.
  - Sensor Coverage studies how to deploy or activate sensors to cover the monitoring area.
    - Sensor placement
    - Density control
  - Two modes:
    - Static sensors
    - Mobile sensors

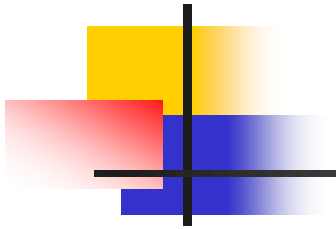


- Determine how well the sensing field is monitored or tracked by sensors.
- To determine, with respect to application-specific performance criteria,
  - in case of static sensors, where to deploy and/or activate them
  - in case of (a subset of) the sensors are mobile, how to plan the trajectory of the mobile sensors.
- These two cases are collectively termed as the coverage problem in wireless sensor networks.
- The purpose of deploying a WSN is to collect relevant data for processing or reporting.
- Two types of reporting:
  - event driven: e.g., forest fire monitoring
  - on demand: e.g., inventory control system

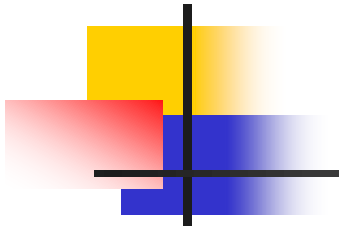


- Objective is to use a minimum number of sensors and maximize the network lifetime
- The coverage algorithm proposed are either centralized or distributed and localized
- Distributed: Nodes compute their position by communicating with their neighbours only.

- Centralized: Data collected at central point and global map computed
- Localized: Localized algorithms are a special type of distributed algorithms where only a subset of nodes in the WASN participate in sensing, communication, and computation.



- **Stationary Wireless Sensor Networks**
  - Sensor nodes are static.
  - Advantages:
    - Easy deployment
    - Node can be placed in an optimized distance-Reduce the total number of nodes
    - Easy topology maintenance
  - Disadvantages:
    - Node failure may result in partition of networks
    - Topology cannot be change automatically



- **Mobile Wireless Sensor Networks**
  - MWSN is Mobile Ad hoc Network (MANET)
  - Let us remember from previous lectures: -
  - MANET-Infrastructure less network of mobile devices connected wirelessly which follow the self-CHOP properties
    - Self-Configure
    - Self-Heal
    - Self-Optimize
    - Self-Protect
  - Wireless Sensor Networks-
    - Consists of a large number of sensor nodes, densely deployed over an area.
    - Sensor nodes are capable of collaborating with one another and measuring the condition of their surrounding environments (i.e., Light, temperature, sound, vibration).

- **Components of MWSN:**
  - **Mobile Sensor Nodes:** Sense physical parameters from the environment When these nodes come in close proximity of sink, deliver data.
  - **Mobile Sink:** Moves in order to collect data from sensor nodes. Based on some algorithm sink moves to different nodes in the networks.
  - **Data Mules:** A mobile entity Collects the data from sensor nodes and Goes to the sink and delivers the collected data from different sensor nodes