SRI MUTHUKUMARAN INSTITUTE OF TECHNOLOGY

(Approved by AICTE, Accredited by NBA and Affiliated to Anna University, Chennai)

Chikkarayapuram (Near Mangadu), Chennai- 600 069.

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

EC8702 - ADHOC AND WIRELESS SENSOR NETWORKS
(REGULATION – 2017)

YEAR: IV **SEM: VII**

UNIT II - SENSOR NETWORKS – INTRODUCTION & ARCHITECTURES

PART – A

1. What is a wireless sensor network?

Wireless Sensor Network (WSN) is an infrastructure-less wireless network that is deployed in a large number of wireless sensors in an ad-hoc manner that is used to monitor the system, physical or environmental conditions

2. Illustrate the characteristic requirements of a wireless sensor network.

- Power consumption constraints for nodes using batteries or energy harvesting
- Chance to cope with node failures (resilience)
- Mobility of nodes
- Heterogeneity of nodes
- Scalability to large scale of deployment
- Capability to withstand harsh environmental conditions
- Simplicity of use
- Cross layer design

3. Define Sensor.

A Sensor is a device that responds and detects some type of input from both the physical or environmental conditions, such as pressure, heat, light, etc. The output of the sensor is generally an electrical signal that is transmitted to a controller for further processing.

4. Give the advantages of WSN.

- Network setups can be carried out without fixed infrastructure.
- Suitable for the non – reachable places such as over the sea, mountains, rural areas or deep forests.
- Flexible if there is random situation when additional workstation is needed.
- Implementation pricing is cheap
- It avoids plenty of wiring.
- It might accommodate new devices at any time.
- It's flexible to undergo physical partitions.
- It can be accessed by using a centralized monitor.

5. Define Life Time of a Sensor Node.

The time until the first node fails is the network lifetime or the time until the network is disconnected into two or more partitions, or the time until 50% of nodes have failed, or the time when for the first time a point in the observed region is no longer covered by atleast a single sensor node.

6. Write the fundamental technologies needed for Wireless Sensor Network.

- Miniaturization of hardware
- Processing and communication
- Sensing equipment

7. What are the Deployment options of Wireless Sensor Network?

Fixed deployment: Well planned deployment of sensor network.
Random deployment: By dropping a large number of nodes from an aircraft over a forest fire.

8. How WSN is used in intelligent buildings?

Buildings waste vast amounts of energy by inefficient Humidity, Ventilation, Air Conditioning. A better real-time monitoring of temperature, airflow, humidity and other physical parameters in a building by means of a WSN can considerably increase the comfort level of inhabitants and reduce the energy consumption.

9. Give few examples of Facility management application of WSN.

- Keyless entry applications where people wear badges that allow a WSN to check which person is allowed to enter which areas of a larger company site.
- Detection of intruders to company sites.
- A wide area WSN could track a Vehicle's position and alert security personnel.
- A WSN could be used in a chemical plant to scan for leaking chemicals.
- These applications require large number of sensors and they should be able to operate a long time on batteries.

10. What are the Hardware components of a Single Node in WSN?

- Controller
- Memory
- Sensors and Actuators
- Communication Devices
- Power Supply Unit

11. What are the characteristics of a transceiver to be taken into account for using in WSN?

The most important characteristics of a transceivers are: Service to upper layer, power consumption and energy efficient state change times and energy, Data rates, Modulations, Transmission power control etc.

12. What is a Sensor? Give its categories.

Sensors are tiny nodes used to obtain information on the environment such as temperature, pressure, humidity or pollutant. Sensors can be roughly categorized into three categories:

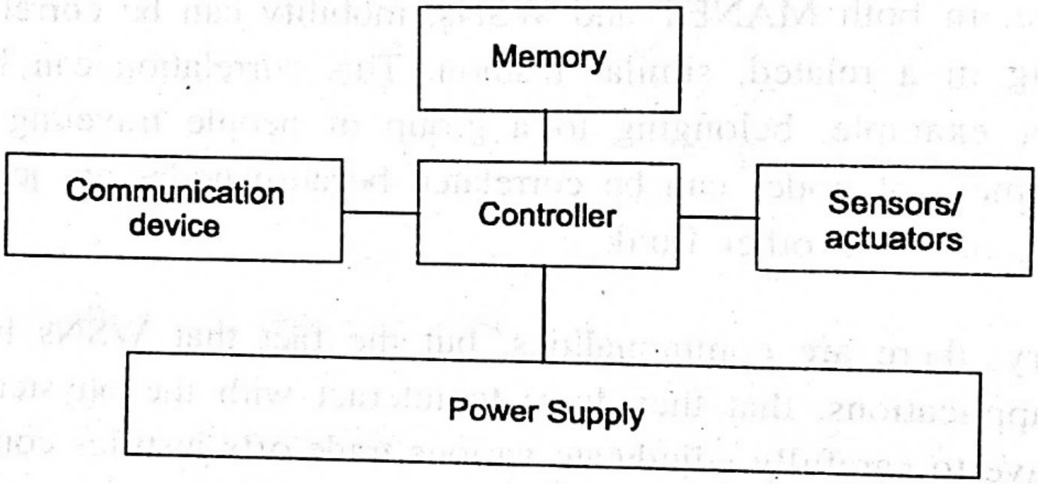
- Passive, Omni directional sensors
- Passive, narrow-beam sensors
- Active sensors.

13. List the components of WSN involved in energy consumption.

- Operation states with different power consumption
- Microcontroller Energy consumption
- Memory Energy consumption

- Radio Transceivers Energy consumption
- Power consumption of Sensor and Actuators

14. Draw the overview of Sensor Node Components.



15. What are the three types of mobility?

In Wireless senor networks, mobility can appear in three main forms:

Node mobility: The wireless sensor nodes themselves can be mobile. The meaning of such mobility is highly application dependent.

Sink mobility: Information sinks can be mobile. While this can be a special case of node mobility, the important aspect is the mobility of an information sink that is not part of the sensor network.

Event mobility: In application like event detection and in particular in tracking applications, the cause of the events or the objects to be tracked can be mobile

16. What is Network lifetime?

The time for which the network is operational or, put another way, the time during which it is able to fulfil its tasks (starting from a given amount of stored energy). It is not quite clear, however, when this time ends.

17. Define Scalability.

The ability to maintain performance characteristics irrespective of the size of the network is referred to as scalability.

18. What is Noise Figure?

The noise figure NF of an element is defined as the ratio of the Signal-to-Noise Ratio (SNR) ratio SNRI at the input of the element to the SNR ratio SNRO at the element's output:

$$NF = SNRI / SNRO$$

It describes the degradation of SNR due to the element's operation and is typically given in dB: NF dB= SNRI dB − SNRO dB.

19. Define gain.

The gain is the ratio of the output signal power to the input signal power and is typically given in dB. Amplifiers with high gain are desirable to achieve good energy efficiency.

20. What is the need for multi-hop communication in wireless sensor network?

The need for multi-hop communication arises due to the increase in the size of wireless sensor networks. In such settings, sensors in one domain communicate with sensors in another domain via an intermediate sensor that can relate to both domains. Communication can also occur as a sequence of hops through a chain of pair-wise adjacent sensors.

21. What is event & Sink?

The node that generates data is called source and the information to be reported is called an event. A node which interested in an event is called sink.

22. List the issues and challenges in designing a sensor networks.

- Sensor networks pose certain design challenges due to the following reasons:
- Sensor nodes are randomly deployed and hence do not fit into any regular topology.
- Sensor networks are infrastructure-less.
- Power constraints.
- A sensor network should also be capable of adapting to changing connectivity due to the failure of nodes, or new nodes powering up.

23. What is Receiver sensitivity?

The receiver sensitivity (given in dBm) specifies the minimum signal power at the receiver needed to achieve a prescribed Eb /N0 or a prescribed bit/packet error rate.

24. Define transceivers in WSN.

The essential task is to convert a bit stream coming from a microcontroller (or a sequence of bytes or frames) and convert them to and from radio waves. It is usually convenient to use a device that combines these two tasks in a single entity. Such combined devices are called **transceivers**.

25. Write short notes on memory devices in WSN.

There is a need for Random Access Memory (RAM) to store intermediate sensor readings, packets from other nodes, and so on. While RAM is fast, its main disadvantage is that it loses its content if power supply is interrupted. ROM, PROM, EPROM, EEPROM can be used to store the data.

PART – B

1. IllustratethechallengesandtherequiredmechanismsofaWirelessSensornetwork.

<u>**Characteristic requirements**</u>

In order to perform many applications in WSN, the following characteristics must be taken into consideration.

Type of service

- The service type rendered by a conventional communication network is evident – it moves bits from one place to another. For a WSN, moving bits is only a means to an end, but not the actual purpose.
- Additionally, concepts like *scoping* of interactions to specific geographic regions or to time intervals will become important.
- Hence, new paradigms of using such a network are required, along with new interfaces and new ways of thinking about the service of a network.

Quality of Service

- Traditional quality of service requirements

– usually coming from multimedia-type applications
– like bounded delay or minimum bandwidth are irrelevant when applications are tolerant to latency or the bandwidth of the transmitted data is very small in the first place.

- In some cases, only occasional delivery of a packet can be more than enough; in other cases, very high reliability requirements exist.
- In yet other cases, delay *is* important when actuators are to be controlled in a real-time fashion by the sensor network.

Fault tolerance

- Nodes may run out of energy or might be damaged, or since the wireless communication between two nodes can be permanently interrupted.
- It is important that the WSN as a whole is able to tolerate such faults.

Lifetime

- In many scenarios, nodes will have to rely on a limited supply of energy (using batteries).
- Replacing these energy sources in the field is usually not practicable, and simultaneously, a WSN must operate at least for a given mission time or as long as possible.
- Hence, the **lifetime** of a WSN becomes a very important figure of merit.
- Evidently, an energy-efficient way of operation of the WSN is necessary.
- The lifetime of a network also has direct trade-offs against quality of service: investing more energy can increase quality but decrease lifetime.
- The precise *definition of lifetime* depends on the application at hand. A simple option is to use the time until the first node fails (or runs out of energy) as the network lifetime.
- Other options include the time until the network is disconnected in two or more partitions.

Scalability

- Since a WSN might include a large number of nodes, the employed architectures and protocols must be able scale to these numbers.

Wide range of densities

- In a WSN, the number of nodes per unit area – the *density* of the network – can vary considerably. Different applications will have very different node densities.
- The network should adapt to such variations.

Programmability

- Nodes should be programmable, and their programming must be changeable during operation when new tasks become important.
- A fixed way of information processing is insufficient.

Maintainability

- As both the environment of a WSN and the WSN itself change (depleted batteries, failing nodes, new tasks), the system has to adapt.
- It has to monitor its own health and status to change operational parameters or to choose different trade-offs (e.g. to provide lower quality when energy resource become scarce).

Required mechanisms

- To realize these requirements, innovative mechanisms for a communication network have to be found, as well as new architectures, and protocol concepts.

- A particular challenge here is the need to find mechanisms that are sufficiently specific to the given application to support the specific quality of service, lifetime, and maintainability requirements .
- Some of the mechanisms that will form typical parts of WSNs are:

Multihop wireless communication
- In particular communication over long distances is only possible using prohibitively high transmission power.
- The use of intermediate nodes as relays can reduce the total required power.
- Hence *multihop communication* will be a necessary ingredient.

Energy-efficient operation
- To support long lifetimes, energy-efficient operation is a key technique.
- Energy-efficient data transport between two nodes (measured in J/bit) based on energy-efficient determination of requested information.

Auto-configuration
- A WSN will have to configure most of its operational parameters autonomously, independent of external configuration.
- The total number of nodes and simplified deployment will require that capability in most applications.

Collaboration and in-network processing
- In some applications, a single sensor is not able to decide whether an event has happened.
- But several sensors have to collaborate to detect an event and only the joint data of many sensors provides enough information.
- Information is processed in the network itself in various forms to achieve this collaboration, as opposed to having every node transmit all data to an external network and process it "at the edge" of the network.

Data centric
- In traditional communication networks the transfer of data between two specific devices, each equipped with (at least) one network address – the operation of such networks is thus **address-centric**.
- In **data-centric routing,** the sink which is responsible for gathering data and sending to the base station, issues a query for finding target data stored in the other nodes of WSN.

Locality
- Nodes, which are very limited in resources like memory, should attempt to limit the state that they accumulate during protocol processing to only information about their direct neighbors.

Exploit trade-offs
- WSNs will have to rely to a large degree on exploiting various inherent trade-offs between mutually contradictory goals, both during system/protocol design and at runtime.

2. Explain the technologies used in WSN.

Building such wireless sensor networks has only become possible with some fundamental advances in enabling technologies.

Miniaturization of hardware

- 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.
- This is particularly relevant to microcontrollers and memory chips as such, but also, the radio modems, responsible for wireless communication, have become much more energy efficient.
- Reduced chip size and improved energy efficiency is accompanied by reduced cost, which is necessary to make redundant deployment of nodes.

Sensing Equipment

- The actual sensing equipment is the third relevant technology.
- However, it is difficult to generalize because of the vast range of possible sensors.
- The basic parts of a sensor node have to accompanied by power supply.
- This requires, depending on application, high capacity batteries that last for long times, that is, have only a negligible self-discharge rate, and that can efficiently provide small amounts of current.
- Ideally, a sensor node also has a device for **energy scavenging**, recharging the battery with energy gathered from the environment – solar cells or vibration-based power generation.
- Such a concept requires the battery to be efficiently chargeable with small amounts of current, which is not a standard ability.
- Both batteries and energy scavenging are still objects of ongoing research.
- The counterpart to the basic hardware technologies is software.
- The division of tasks and functionalities in a single node is done by the architecture of the operating system or runtime environment.
- This environment has to support simple re-tasking, cross-layer information exchange, and modularity to allow for simple maintenance.
- This software architecture on a single node has to be extended to a network architecture, where the division of tasks between nodes, not only on a single node and also to structure interfaces for application programmers.

3. Explain the applications of WSN in detail.

Some of the most important applications of WSN include:

Disaster relief applications

- A typical scenario is wildfire detection: Sensor nodes are equipped with thermometers and can determine their own location.
- These sensors are deployed over a wildfire, for example, a forest, from an airplane.
- They collectively produce a “temperature map” of the area or determine the perimeter of areas with high temperature that can be accessed from the outside by firefighters equipped with Personal Digital Assistants (PDAs).
- Similarly control of accidents in chemical factories.
- In military applications, where sensors should detect enemy troops rather than wildfires.
- In such an application, sensors should be cheap enough to be considered disposable since a large number is necessary; lifetime requirements are not particularly high.

Environment control and biodiversity mapping

- WSNs can be used to control the environment with respect to chemical pollutants – a possible application is garbage dump sites.

- Another example is the surveillance of the marine ground floor; an understanding of its erosion processes is important for the construction of offshore wind farms.
- Also to gain an understanding of the number of plant and animal species that live in a given habitat (biodiversity mapping).

Intelligent buildings

- Buildings waste vast amounts of energy by inefficient Humidity, Ventilation, Air Conditioning usage.
- A better, real-time, high-resolution monitoring of temperature airflow, humidity, and other physical parameters in a building by means of a WSN
- It can increase the comfort level of inhabitants and reduce the energy consumption.
- In addition, such sensor nodes can be used to monitor mechanical stress levels of buildings in seismically active zones.
- By measuring mechanical parameters like the bending load of girders, it is possible through WSN whether it is still safe to enter a given building after an earthquake. It is a considerable advantage for rescue personnel.
- Similar systems can be applied to bridges. Other types of sensors might be geared toward detecting people enclosed in a collapsed building and communicating such information to a rescue team.

Facility management

- In the management of facilities larger than a single building, WSNs also have a wide range of possible applications.
- Simple examples include keyless entry applications where people wear badges that allow a WSN to check which person is allowed to enter which areas of a larger company site.
- This example can be extended to the detection of intruders.
- Vehicles that pass a street outside of normal business hours. A wide area WSN could track such a vehicle's position and alert security personnel – this application shares many commonalities with corresponding military applications.
- WSN could be used in a chemical plant to scan for leaking chemicals.

Machine surveillance and preventive maintenance

- One idea is to fix sensor nodes to difficult to- reach areas of machinery where they can detect vibration patterns that indicate the need for maintenance.
- Examples for such machinery could be robotics or the axles of trains. Other applications in manufacturing are easily conceivable.
- The main advantage of WSNs here is the cable free operation, avoiding a maintenance problem in itself and allowing a cheap, often retrofitted installation of such sensors.

Precision agriculture

- Applying WSN to agriculture allows precise irrigation and fertilizing by placing humidity/soil composition sensors into the fields.
- Similarly, pest control can profit from a high-resolution surveillance of farm land.
- Also, livestock breeding can benefit from attaching a sensor to each pig or cow, which controls the health status of the animal (by checking body temperature, step counting, or similar means) and raises alarms if given thresholds are exceeded.

Medicine and health care

- The use of WSN in health care applications is a potentially very beneficial.

- Possibilities range from post operative and intensive care, where sensors are directly attached to patients.
- The advantage of doing away with cables is considerable to the long-term surveillance of (typically elderly) patients and to automatic drug administration (embedding sensors into drug packaging, raising alarms when applied to the wrong patient, is conceivable).
- Also, patient and doctor tracking systems within hospitals can be literally life saving.

Logistics

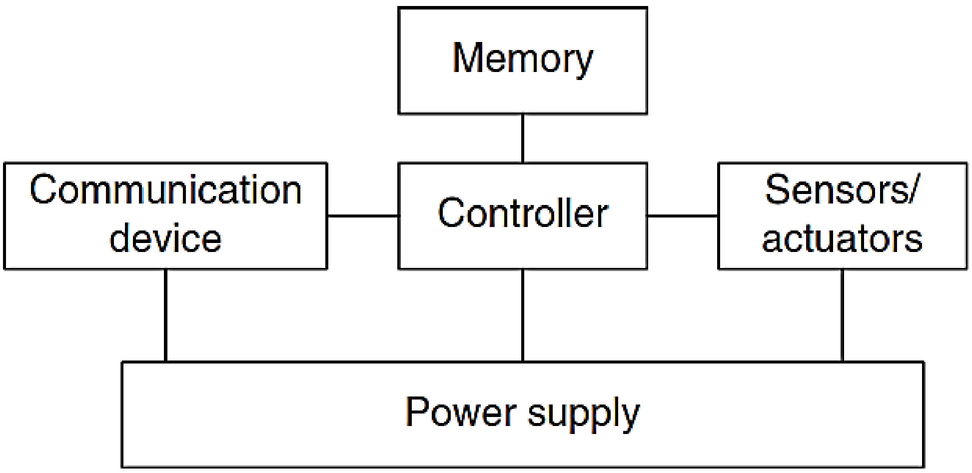
- In several logistics applications, it is possible to equip goods (individual parcels, for example) with simple sensors that allow a simple tracking of these objects during transportation or facilitate inventory tracking in stores or warehouses.

Telematics

- Partially related to logistics applications are applications for the telematics context, where sensors embedded in the streets or roadsides can gather information about traffic conditions. Such a so called "intelligent roadside"
- It could also interact with the cars to exchange danger warnings about road conditions or traffic jams ahead.

4. Explain about the hardware components of sensor nodes.

- Building a wireless sensor network first of all requires the constituting nodes to be developed and available.
- These nodes have to meet the requirements that come from the specific requirements of a given application:
- They might have to be small, cheap, or energy efficient, they have to be equipped with the right sensors, the necessary computation and memory resources, and they need adequate communication facilities.



CONTROLLER

- The controller is the core of a wireless sensor node.
- It collects data from the sensors, processes this data, decides when and where to send it, receives data from other sensor nodes, and decides on the actuator's behavior.
- It is the Central Processing Unit (CPU) of the node.it is representing trade-offs between flexibility, performance, energy efficiency, and costs.

Microcontroller:

- Flexibility suited to embedded systems.
- Instruction set amenable to time-critical signal processing
- Low power consumption
- Have memory built in
- Freely programmable

Digital Signal Processors (DSPs)

- Specialized processor
- Special architecture and their instruction set, for processing large amounts of vectorial data.
- It is used to process data coming from a simple analog, wireless communication device to extract a digital data stream.
- Another option for the controller is Field-Programmable Gate Arrays (FPGAs) or Application-Specific Integrated Circuits (ASICs).
- *FPGA*- Time and energy consumption for reprogrammable.
- *ASIC*- Less flexibility, costly hardware.
- In WSN application, the duties of the sensor nodes do not change over lifetime and where the number of nodes is big enough to warrant the investment in ASIC development is the superior solution.

MEMORY

- There is a need for Random Access Memory (RAM) to store intermediate sensor readings, packets from other nodes, and so on. While RAM is fast, its main disadvantage is that it loses its content if power supply is interrupted.
- ROM, PROM, EPROM, EEPROM can be used to store the data.
- Correctly dimensioning memory sizes, especially RAM, can be crucial with respect to manufacturing costs and power consumption.

COMMUNICATION DEVICE

- The communication device is used to exchange data between individual nodes.
- Radio Frequency (RF)-based communication provides relatively long range and high data rates, acceptable error rates at reasonable energy expenditure, and does not require line of sight between sender and receiver.

Transceivers:

- The essential task is to convert a bit stream coming from a microcontroller (or a sequence of bytes or frames) and convert them to and from radio waves.
- It is usually convenient to use a device that combines these two tasks in a single entity. Such combined devices are called **transceivers**.
- A range of low-cost transceivers is commercially available that incorporate all the circuitry required for transmitting and receiving – modulation, demodulation, amplifiers, filters, mixers, and so on.

Transceiver tasks and characteristics

- To select appropriate transceivers, a number of characteristics should be taken into account.

Service to upper layer

- Most notably to the Medium Access Control (MAC) layer. Sometimes, this service is **packet oriented**; sometimes, a transceiver only provides a **byte interface** or even only a **bit interface** to the microcontroller.

Power consumption and energy efficiency

- Energy efficiency is the energy required to transmit and receive a single bit.
- Transceivers should be switchable between different states, for example, active and sleeping.
- The idle power consumption in each of these states and during switching between them is very important.

Carrier frequency and multiple channels

- Transceivers are available for different carrier frequencies; evidently, it must match application requirements and regulatory restrictions.
- It is often useful if the transceiver provides several carrier frequencies to choose from, helping to alleviate some congestion problems in dense networks.
- Such as FDMA or multichannel CSMA/ ALOHA techniques.

Data rates

- Carrier frequency and used bandwidth together with modulation and coding determine the gross data rate. Typical values are a few tens of kilobits per second.

Modulations -Several of on/off-keying, ASK, FSK, or similar modulations.

Noise figure

- The **noise figure** is defined as the ratio of the Signal-to-Noise Ratio (SNR) ratio SNR*I at* the input of the element to the SNR ratio SNR*O at* the element's output.

$$NF= SNRi/SNRo$$

Receiver sensitivity

- The receiver sensitivity (given in dBm) specifies the minimum signal power at the receiver needed to achieve a prescribed Eb /N0 or a prescribed bit/packet error rate.

Blocking performance

- The blocking performance of a receiver is its achieved bit error rate in the presence of an interferer.

Frequency stability

- The **frequency stability** denotes the degree of variation from nominal center frequencies when environmental conditions of oscillators like temperature or pressure change.

Transceiver operational states

- Many transceivers can distinguish four operational states

Transmit -In the **transmit state**, the transmit part of the transceiver is active and the antenna radiates energy.

Receive -In the **receive state** the receive part is active.

Idle

- A transceiver that is ready to receive but is not currently receiving anything is said to be in an **idle state**.
- In this idle state, many parts of the receive circuitry are active, and others can be switched off.

Sleep

- In the **sleep state**, significant parts of the transceiver are switched off.
- These sleep states differ in the amount of circuitry switched off and in the associated **recovery times** and **startup energy.**

Wakeup Receivers

- To keep this specialized receiver simple, it suffices for it to raise an event to notify other components of an incoming packet; upon such an event, the main receiver can be turned on and perform the actual reception of the packet.
- Such receiver concepts are called wakeup **receivers.**

SENSORS

- **Passive, omnidirectional sensors -**Thermometer, light sensors, vibration, microphones, humidity, mechanical stress or tension in materials
- **Passive, narrow-beam sensors -** Camera, which can “take measurements” in a given direction, but has to be rotated if need be.
- **Active sensors -** a sonar or radar sensor or some types of seismic sensors.

Each sensor node has a certain **area of coverage** for which it can reliably and accurately report the particular quantity that it is observing.

ACTUATORS

- Actuators are just about as diverse as sensors,
- This controls a motor, a light bulb, or some other physical object is not really of concern to the way communication protocols are designed.

POWER SUPPLY OF SENSOR NODES

- **Traditional batteries**
- ✓ The power source of a sensor node is a battery, either non rechargeable (“primary batteries”) or rechargeable (“secondary batteries”).
- **Capacity**
- ✓ They should have high capacity at a small weight, small volume, and low price. The main metric is energy per volume, J/cm3
- **Capacity under load**
- ✓ They should withstand various usage patterns as a sensor node can consume quite different levels of power over time and actually draw high current in certain operation modes.
- **Self-discharge**
- ✓ Their self-discharge should be low; they might also have to last for a long time
- **Efficient recharging**
- ✓ Recharging should be efficient even at low and intermittently available recharge power;
- **Energy scavenging**
- ✓ Energy from a node’s environment must be tapped into and made available to the node – **energy scavenging** should take place.
- **Photovoltaic -**The well-known solar cells can be used to power sensor nodes.
- **Vibrations-** One almost pervasive form of mechanical energy is vibrations.

5. Explain the issues and Challenges in designing a sensor networks.

Sensor networks pose certain design challenges due to the following reasons:

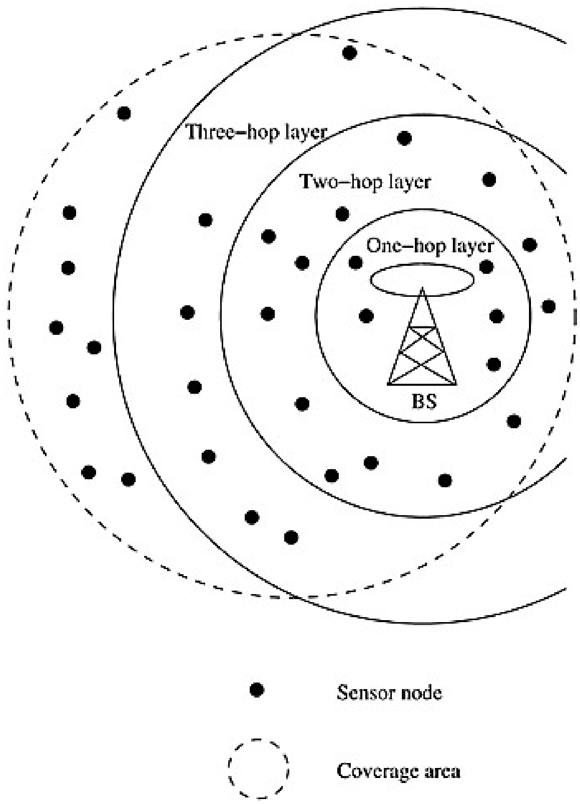
- ✓ Sensor nodes are randomly deployed and hence do not fit into any regular topology. Once deployed, they usually do not require any human intervention n. Hence, the setup and maintenance of the network should be entirely autonomous.
- ✓ Sensor networks are infrastructure-less. Therefore, all routing and maintenance algorithms need to be distributed.
- ✓ Sensors usually rely only on their battery for power, which in many cases cannot be recharged or replaced. Hence, the available energy at the nodes should be considered as a major constraint while designing protocols.
- ✓ Hardware design for sensor nodes should also consider energy efficiency as a primary requirement. The micro-controller, operating system, and application software should be designed to conserve power.
- ✓ Sensor nodes should be able to synchronize with each other in a completely distributed manner, so that TDMA schedules can be imposed and temporal ordering of detected events can be performed without ambiguity.
- ✓ A sensor network should also be capable of adapting to changing connectivity due to the failure of nodes, or new nodes powering up.
- ✓ Provisions must be made for secure communication over sensor networks, especially for military applications which carry sensitive data.

6. Explain the architecture of wireless sensor networks.

- ➢ The design of sensor networks is influenced by factors such as scalability, fault tolerance, and power consumption.
- ➢ The two basic kinds of sensor network architecture are
    - ✓ Layered
    - ✓ Clustered.

Layered Architecture

- ➢ A layered architecture has a single powerful base station (BS), and the layers of sensor nodes around it correspond to the nodes that have the same hop-count to the BS.



Layered architecture

It is used with in-building wireless backbones, and in military sensor-based infrastructure, such as the Multi-Hop Infrastructure Network Architecture (MINA).

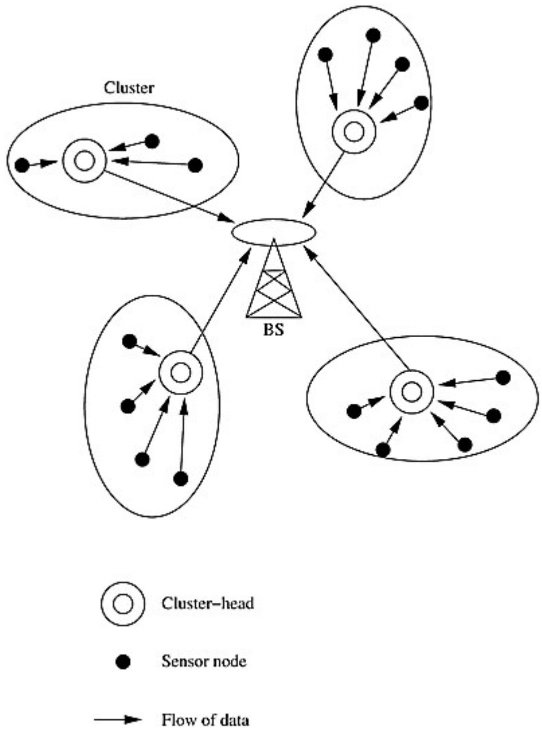
- In the in-building scenario, the BS acts an access point to a wired network, and small nodes form a wireless backbone to provide wireless connectivity.
- The users of the network have hand-held devices such as PDAs which communicate via the small nodes to the BS.
- Similarly, in a military operation, the BS is a data-gathering and processing entity with a communication link to a larger network.
- A set of wireless sensor nodes is accessed by the hand-held devices of the soldiers.

Advantage:

- Each node is involved only in short-distance.
- Low-power transmissions to nodes of the neighboring layers.

Clustered Architecture

- A clustered architecture organizes the sensor nodes into clusters, each governed by a cluster-head. The nodes in each cluster are involved in message exchanges with their cluster-heads, and these heads send message to a BS.
- Clustered architecture is useful for sensor networks because of its inherent suitability for data fusion. The data gathered by all member of the cluster can be fused at the cluster-head, and only the resulting information needs to be communicated to the BS.
- The cluster formation and election of cluster-heads must be an autonomous, distributed process.



Clustered architecture.

7. Explain the Operation States with Different Power Consumption.

Operational states with power consumption

- Energy supply for a sensor node is at a premium: batteries have small capacity, and recharging by energy scavenging is complicated and volatile.
- Hence, the energy consumption of a sensor node must be tightly controlled.
- The main consumers of energy are the controller, the radio front ends, to some degree the memory, and, depending on the type, the sensors.

How to reduce consumption?

- To reduce power consumption of these components comes from chip-level and lower technologies:
- Designing low-power chips is the best starting point for an energy-efficient sensor node.
- Introducing and using multiple states of operation with reduced energy consumption in return for reduced functionality is the core technique for energy-efficient wireless sensor node.
- For a controller, typical states are “active”, “idle”, and “sleep”; a radio modem could turn transmitter, receiver, or both on or off; sensors and memory could also be turned on or off.
- The usual terminology is to speak of a “deeper” sleep state if less power is consumed.

Drawbacks of transition of states:

- Transitions between states take both time and energy.
- The usual assumption is that the deeper the sleep state, the more time and energy it takes to wake up again to fully operational state (or to another, less deep sleep state).
- Hence, it may be worthwhile to remain in an idle state instead of going to deeper sleep states.

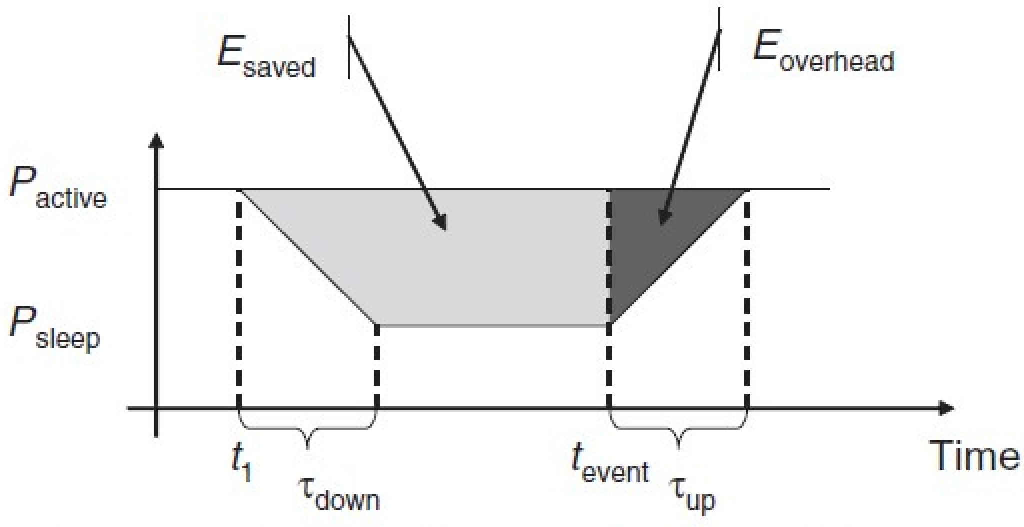


Figure Energy savings and overheads for sleep modes

- Figure illustrates this notion based on a commonly used model.
- At time t1, the decision whether or not a component (say, the microcontroller) is to be put into sleep mode should be taken to reduce power consumption from Pactive to Psleep.
- If it remains active and the next event occurs at time tevent,
  - ✓ then a total energy of Eactive = Pactive(tevent − t1) has be spent uselessly idling.
- Putting the component into sleep mode, on the other hand, requires a time τdown until sleep mode has been reached; as a simplification, assume that the average power consumption during this phase is (Pactive + Psleep)/2.
- Then, *Psleep*is consumed until *tevent.*
- In total, τdown(Pactive + Psleep)/2 + (tevent − t1 − τdown)Psleep energy is required in sleep mode as opposed to (tevent − t1)Pactive when remaining active.
- The energy saving is thus
  Esaved=(tevent− t1)Pactive− (τdown(Pactive+ Psleep)/2 + (tevent− t1 − τdown)Psleep).
- Once the event to be processed occurs, however, an additional overhead of is incurred to come back to operational state before the event can be processed, again making a simplifying assumption about average power consumption during makeup. This energy is indeed an overhead since no useful activity can be undertaken during this time.

Eoverhead= τup(Pactive+ Psleep)/2,

- switching to a sleep mode is only beneficial if E*overhead*<E*saved*or, equivalently, if the time to the next event is sufficiently large:

$$(t_{event} - t_1) > \frac{1}{2}\left(\tau_{down} + \frac{P_{active} + P_{sleep}}{P_{active} - P_{sleep}}\tau_{up}\right).$$

Microcontroller Energy Consumption

Basic power consumption in discrete operation states:

Intel StrongARM

The Intel StrongARM provides *three sleep modes:*

- In *normal mode*, all parts of the processor are fully powered. Power consumption is up to 400 mW.
- In *idle mode*, clocks to the CPU are stopped; clocks that pertain to peripherals are active.

- Any interrupt will cause return to normal mode. Power consumption is up to 100 mW.
- In *sleep mode*, only the real-time clock remains active. Wakeup occurs after a timer interrupt and takes up to 160 ms. Power consumption is up to 50 ⇄W.

Texas Instruments MSP 430

- The MSP430 family features a wider range of operation modes:
- One fully operational mode, which consumes about 1.2 mW (all power values given at 1 MHz and 3 V).
- There are four sleep modes in total.
- The deepest sleep mode, LPM4, only consumes 0.3 µW, but the controller is only woken up by external interrupts in this mode.
- In the next higher mode, LPM3, a clock is also still running, which can be used for scheduled wake ups, and still consumes only about 6 µW.

Atmel ATmega

- The Atmel ATmega 128L has six different modes of power consumption, which are in principle similar to the MSP 430.
- Its power consumption varies between 6 mW and 15 mW in idle and active modes and is about 75µW in power-down modes.

Dynamic voltage scaling

- A more sophisticated possibility than discrete operational states is to use a continuous notion of functionality/power adaptation by *adapting the speed* with which a controller operates.
- The idea is to choose the best *possible speed* with which to compute a task that has to be completed by a *given deadline.*
- One obvious solution is to switch the controller in full operation mode, compute the task at highest speed, and go back to a sleep mode as quickly as possible.
- *The alternative approach is to compute the task only at the speed that is required to finish it before the deadline. The rationale is the fact that a controller running at lower speed, that is, lower clock rates, consumes less power than at full speed. This is due to the fact that the supply voltage can be reduced at lower clock rates while still guaranteeing correct operation. This technique is called Dynamic Voltage Scaling (DVS).*
- This technique is actually beneficial for CMOS chips: reducing the voltage is a very efficient way to reduce power consumption.
- Power consumption also depends on the frequency *f*, hence

$$P \propto f \cdot V^2_{DD}.$$

- Consequently, dynamic voltage scaling also reduces energy consumption

Memory

- From an energy perspective, the most relevant kinds of memory are on-chip memory of a microcontroller and FLASH memory – off-chip RAM is rarely if ever used.
- In fact, the power needed to drive on-chip memory is usually included in the power consumption numbers given for the controllers.
- Hence, the most relevant part is FLASH memory – in fact, the construction and usage of FLASH memory can heavily influence node lifetime.
- The relevant metrics are the read and write times and energy consumption.
- Writing is somewhat more complicated, as it depends on the granularity with which data can be accessed.

Radio Transceivers

- A radio transceiver has essentially two tasks: transmitting and receiving data between a pair of nodes.
- Similar to microcontrollers, radio transceivers can operate in different modes,

- The simplest ones are being turned on or turned off. To accommodate the necessary low total energy consumption.
- The transceivers should be turned off most of the time and only be activated when necessary – they work at a low **duty cycle**.

Modeling energy consumption during transmission

- In principle, the energy consumed by a transmitter is due to two sources:
  - ✓ One part is due to RF signal generation, which mostly depends on chosen modulation and target distance and hence on the transmission power P_{tx}, that is, the power radiated by the antenna.
  - ✓ A second part is due to electronic components necessary for frequency synthesis, frequency conversion, filters, and so on.

Modeling energy consumption during reception

- Similar to the transmitter, the receiver can be either turned off or turned on.
- While being turned on, it can either actively receive a packet or can be idle, observing the channel and ready to receive.
- Evidently, the power consumption while it is turned off is negligible. Even the difference between idling and actually receiving is very small and can, for most purposes, be assumed to be zero.

8. Explain the Sensor Network Scenarios with neat diagram.

Types of sources and sinks

- Several typical interaction patterns found in WSNs – event detection, periodic measurements, function approximation and edge detection, or tracking.
- A source is any entity in the network that can provide information, that is, typically a sensor node; it could also be an actuator node that provides feedback about an operation.
- A sink, on the other hand, is the entity where information is required.
- There are essentially three options for a sink: it could belong to the sensor network as such and be just another sensor/actuator node or it could be an entity outside this network.
- For this second case, the sink could be an actual device, for example, a handheld or PDA used to interact with the sensor network.
- It could also be merely a gateway to another larger network such as the Internet, where the actual request for the information comes from some node "far away" and only indirectly connected to such a sensor network.
- These main types of sinks are illustrated by below figure, showing sources and sinks in direct communication.

Single-hop versus multihop networks

- The inherent power limitation of radio communication follows a limitation on the feasible distance between a sender and a receiver.

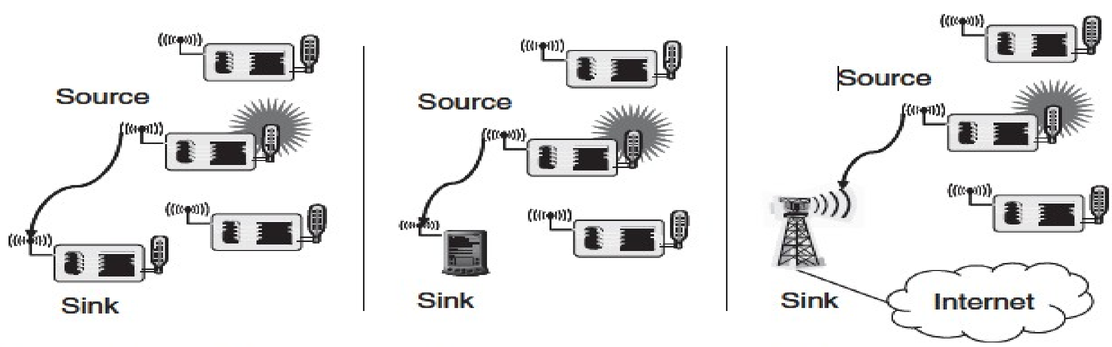


Figure 3.1 Three types of sinks in a very simple, single-hop sensor network

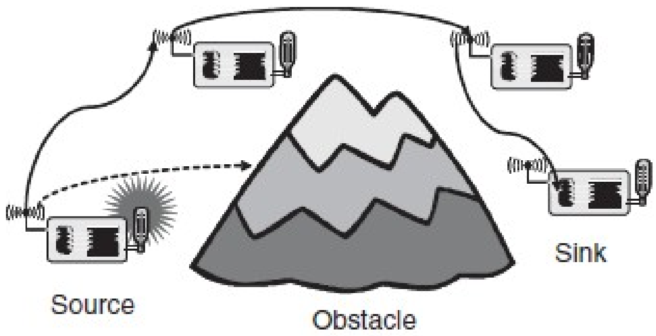


Figure 3.2 Multihop networks: As direct communication is impossible because of distance and/or obstacles, multihop communication can circumvent the problem

- Because of this limited distance, the direct communication between source and sink is not always possible, specifically in WSNs, which are intended to cover a lot of ground (e.g. in environmental or agriculture applications) or that operate in difficult radio environments with strong attenuation (e.g. in buildings).
- To overcome such limited distances, an obvious way out is to use relay stations, with the data packets taking multi hops from the source to the sink.
- This concept of multihop networks for WSNs as the sensor nodes themselves can act as such relay nodes.
- Depending on the particular application, the likelihood of having an intermediate sensor node at the right place can actually be quite high.
- While multihopping is the solution to overcome problems with large distances or obstacles, it has been claimed to improve the energy efficiency of communication.
- The attenuation of radio signals is at least quadratic in most environments (and usually larger), it consumes less energy to use relays instead of direct communication.
- When targeting for a constant SNR at all receivers, the *radiated* energy required for direct communication over a distance d is $cd\alpha$ (c some constant, $\alpha \geq 2$ the path loss coefficient).
- Using a relay at distance $d/2$ reduces this energy to $2c(d/2)\alpha$.
- But this calculation considers only the radiated energy, not the actually *consumed* energy – in particular, the energy consumed in the intermediate relay node.
- Only for large d does the radiated energy dominate the fixed energy costs consumed in transmitter and receiver electronics.
- The concrete distance where direct and multihop communication are in balance depends on a lot of device-specific and environment-specific parameters.
- It should be pointed out that only multihop networks operating in a **store and forward** fashion. In such a network, a node has to correctly receive a packet before it can forward it somewhere.

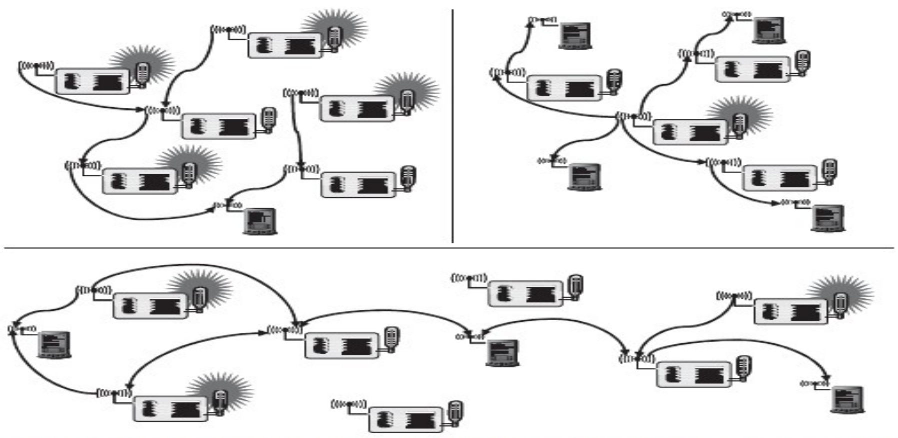


Figure 3.3 Multiple sources and/or multiple sinks. Note how in the scenario in the lower half, both sinks and active sources are used to forward data to the sinks at the left and right end of the network

Multiple sinks and sources

- In many cases, there are multiple sources and/or multiple sinks present.
- In the most challenging case, multiple sources should send information to multiple sinks, where either all or some of the information has to reach all or some of the sinks. The above figure illustrates these combinations.

Three types of mobility

- In wireless sensor networks, mobility can appear in three main forms:

Node mobility

- The wireless sensor nodes themselves can be mobile. The meaning of such mobility is highly application dependent.
- In examples like environmental control, node mobility should not happen; in livestock surveillance (sensor nodes attached to cattle, for example), it is the common rule.
- In the face of node mobility, the network has to reorganize itself frequently enough to be able to function correctly.
- It is clear that there are trade-offs between the frequency and speed of node movement on the one hand and the energy required to maintain a desired level of functionality in the network on the other hand.

Sink mobility

- The information sinks can be mobile.
- The important aspect is the mobility of an information sink that is not part of the sensor network, for example, a human user requested information via a PDA while walking in an intelligent building.
- In a simple case, such a requester can interact with the WSN at one point and complete its interactions before moving on.

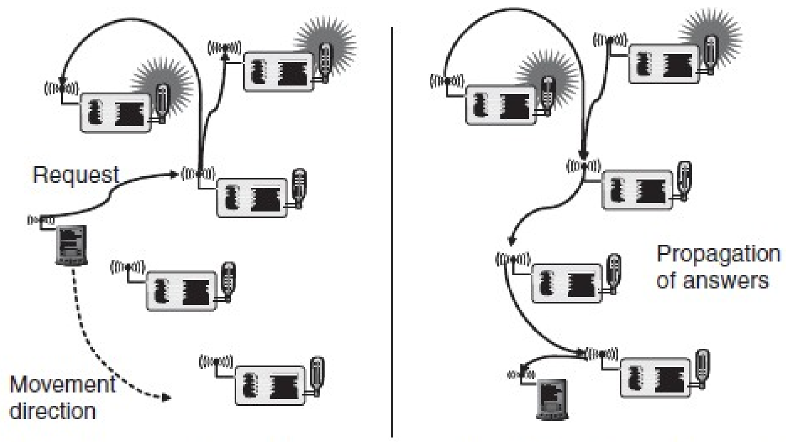


Figure 3.4 A mobile sink moves through a sensor network as information is being retrieved on its behalf

- A mobile requester is particularly interesting, however, if the requested data is not locally available but must be retrieved from some remote part of the network.
- Hence, while the requester would likely communicate only with nodes in its surrounding area, it might have moved to some other place.
- The network, possibly with the assistance of the mobile requester, must make provisions that the requested data actually follows and reaches the requester despite its movements.

Event mobility

- In applications like event detection and in particular in tracking applications, the cause of the events or the objects to be tracked can be mobile.
- In such scenarios, it is important that the observed event is covered by a sufficient number of sensors at all time.

- Hence, sensors will wake up around the object, engaged in higher activity to observe the present object, and then go back to sleep.
- As the event source moves through the network, it is accompanied by an area of activity within the network – this has been called the *frisbee* model.

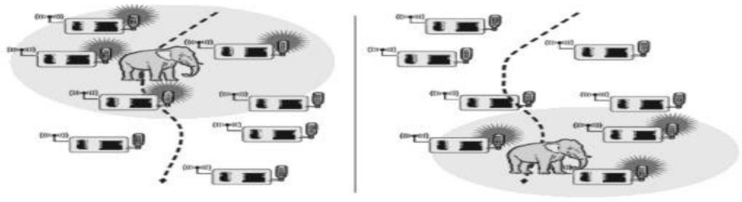


Fig.2.10 Detection of an event – an elephant that moves through the network along with the event source

9. Explain the optimization goals and figure of merit.

- For all these scenarios and application types, different forms of networking solutions can be found.
- The challenging question is how to optimize a network, how to compare these solutions, how to decide which approach better supports a given application, and how to turn relatively imprecise optimization goals into measurable figures of merit?

1. Quality of service

- WSNs differ from other conventional communication networks mainly in the type of service they offer. These networks essentially only move bits from one place to another.
- Possibly, additional requirements about the offered Quality of Service (QoS) are made, especially in the context of multimedia applications.
- Such QoS can be regarded as a low-level, networking-device-observable attribute – bandwidth, delay, jitter, packet loss rate – or as a high-level, user-observable, so-called subjective attribute like the perceived quality of a voice communication or a video transmission.
- But just like in traditional networks, high-level QoS attributes in WSN highly depend on the application. Some generic possibilities are:

Event detection/reporting probability

- What is the probability that an event that actually occurred is not detected or, more precisely, not reported to an information sink that is interested in such an event? For example, not reporting a fire alarm to a surveillance station would be a severe shortcoming.

Clearly, this probability can depend on/be traded off against the overhead spent in setting up structures in the network that support the reporting of such an event (e.g. routing tables) or against the run-time overhead (e.g. sampling frequencies).

Event classification error

- If events are not only to be detected but also to be classified, the error in classification must be small.

Event detection delay

- The delay between detecting an event and reporting it to any/all interested sinks.

Missing reports

- In applications that require periodic reporting, the probability of undelivered reports should be small.

Approximation accuracy

- For function approximation applications (e.g. approximating the temperature as a function of location for a given area), what is the average/maximum absolute or relative error with respect to the actual function? Similarly, for edge detection applications, what is the accuracy of edge descriptions; are some missed at all?

Tracking accuracy

- Tracking applications must not miss an object to be tracked, the reported position should be as close to the real position as possible, and the error should be small.

2. Energy efficiency

- Energy is a precious resource in WSN that energy efficiency should therefore make an evident optimization goal.
- It is clear that with an arbitrary amount of energy; most of the QoS metrics can be increased.
- Hence, putting the delivered QoS and the energy required to do so into perspective should give a first, reasonable understanding of the term energy efficiency.
- The most commonly considered aspects are:

Energy per correctly received bit

- How much energy, counting all sources of energy consumption at all possible intermediate hops, is spent on average to transport one bit of information (payload) from the source to the destination? This is often a useful metric for periodic monitoring applications.

Energy per reported (unique) event

- Similarly, what is the average energy spent to report one event? Since the same event is sometimes reported from various sources, it is usual to normalize this metric to only the unique events.

Delay/energy trade-offs

- Some applications can increase energy investment for a speedy reporting of such events. Here, the trade-off between delay and energy overhead is interesting.

Network lifetime

- The time for which the network is operational or, put another way, the time during which it is able to fulfill its tasks. It is not quite clear, however, when this time ends.

Time to first node death

- When does the first node in the network run out of energy or fail and stop operating?

Network half-life

- When have 50% of the nodes run out of energy and stopped operating. Any other fixed percentile is applicable as well.

Time to partition

- When the first partition of the network in two (or more) disconnected parts occur.
- This can be as early as the death of the first node or occur very late if the network topology is robust.

Time to loss of coverage

- A possible figure of merit is thus the time when for the first time any spot in the deployment region is no longer covered by any node's observations.

Time to failure of first event notification

- A network partition can be seen as irrelevant if the unreachable part of the network does not want to report any events in the first place.
- This can be due to an event not being noticed because the responsible sensor is dead or because a partition between source and sink has occurred.

3. Scalability

- The ability to maintain performance characteristics irrespective of the size of the network is referred to as scalability.

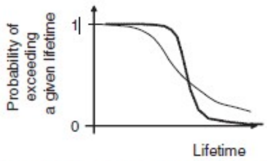


Figure 3.6 Two probability curves of a node exceeding a given lifetime – the dotted curve trades off better minimal lifetime against reduced maximum lifetime

4. Robustness

- WSN should exhibit an appropriate robustness.
- They should not fail just because a limited number of nodes run out of energy, or because their environment changes, these failures have to be compensated by finding other routes.