Unit-I

Overview Of Wireless Sensor Networks

Wireless Sensor Networks are spatially distributed autonomous (independent) sensors to monitor physical or environmental conditions. such as temperature, sound, pressure, humidity, wind direction and speed, vibration intensity, power line voltage, chemical concentrations, pollutant levels, etc., and to co-operatively pass their data through the N/w to a main central point for appropriate processing.

The development of WSN was motivated by military application such as battlefield surveillance; today such N/ws are used in many industrial and consumer applications, such as industrial process monitoring and control, Machine health monitoring, civil infrastructure and security.

A Sensor N/w consist of multiple detection stations called Sensor Nodes, each of which small, light weight and portable. Every sensor node is equipped with a transducer, micro computer, transceiver and power source. The transducer generates electrical signals based on sensed physical effects and phenomena. The micro computer processes and stores the sensor o/p. The transceiver receives commands from a central computer and transmits data to that computer. The power for each sensor node is derived from a battery.

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Key definitions of Sensor Networks:

Sensor: A transducer that converts a physical phenomenon such as heat, light, sound or motion into electrical or other signal for further processes.

Sensor node: A basic unit in a sensor network, with on-board sensors, processor, memory, wireless modem and power supply. It is often abbreviated as node.

Network topology: A connectivity graph where nodes are sensor nodes and edges are communication links. In a wireless network, the link represents a one-hop connection and the neighbors of a node are those within the radio range of the node.

Routing: The process of determining a network path from a packet source node to its destination.

Geographic routing: Routing of data based on geographical attributes such as locations or regions.

In-network: A style of processing in which the data is processed and combined near where the data is generated.

Collaborative processing: Sensors co-operatively processing data

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from multiple sources in order to serve a high-level task. This typically requires communication among a set of nodes.

State: A snapshot about a physical environment (e.g., the number of signal sources, their locations or spatial extent, speed of movement), or a snapshot of the system itself. (e.g., the Network state).

Uncertainty: A condition of the information caused by noise in sensor measurements, or lack of knowledge in models. The uncertainty affects the system's ability to estimate the state accurately and must be carefully modeled.

Task: There are two kind of tasks

1. High level system task - which may include sensing, communication, processing and resource allocation.
2. Application task: which may include detection, classification, location Localization and tracking.

Detection: The process of discovering the existence of a physical phenomenon. A Threshold detector may used for a detection whenever a physical phenomenon is determined to be significant enough compared with the threshold.

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Classification: The assignment of class labels to a set of physical-phenomena being observed.

Localization and tracking: The estimation of the state of a physical entity such as physical phenomenon. Tracking produces a series of estimates over time.

Value of information or information utility:

A mapping of data to a scalar number, in the context of the overall system task and knowledge. For example, information utility of a piece of sensor data may be characterized by its relevance to an estimation task at hand and computed by a mutual information function.

Resource: Resource include sensors, communication links, processors, on-board memory and node energy reserves.

Sensor tasking: The assignment of sensors to a particular task and the control of sensor state (on/off, pan/tilt) for accomplishing the task.

Node services: There are two services that enable application to discover properties of nodes and the nodes to organize themselves into a useful network.

1. time synchronization, 2. node localization.

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Data storage: Sensor information is stored, indexed and accessed by applications. Storage may be local to the node where the data is generated, Load-balanced across a network or anchored at a few points (warehouses).

Embedded operating system (OS): The run-time system support for sensor network applications. An embedded os typically provides an abstraction of system resources and set of utilities

System performance goal: The abstract characterization of system properties. Examples include scalability, robustness and network Longevity each of which may be measured by a set of evaluation metrics.

Evaluation metric: A measurable ~~quantity~~ quantity that describes how well the system is performing on some absolute scale. An evaluation method is a process for comparing the value of applying the metrics on an experimental system with that of some other bench mark system.

Examples: packet loss, Nlw dwell time — (system)

track loss, false alarm rate,
probability of correct association,
Location error / processing latency
} - (application)

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Advantages of sensor Networks:

It offers unique advantages over traditional centralized approach. Dense Networks of distributed communicating sensors can improve signal to noise ratio by reducing average distance from sensor to target. Increased energy efficiency in communications is enabled by the multihop topology of the Network. The greatest advantages of networked sensings are

* improved robustness
* Scalability.

Decentralized sensing system and Decentralized algorithms are inherently increase robustness and scalability.

Energy Advantage:

WSN maximum uses radio frequency signals, Because of the unique attenuation characteristics of RF signals, and a multihop RF network provides a significant energy saving over a single hop Nlw for the same distance.

Consider the following simple example of an N-hop Netwo Assume the overall distance for transmission is Nr, where r is the one-hop distance. The minimum receiving power at a node is Preceive and power at the transmision node is Psend.

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Then, the RF attenuation model near the ground is given by

$$P_{receive} \propto \frac{P_{send}}{r^{\alpha}}$$

where $r \rightarrow$ transmission distance

$\alpha \rightarrow$ RF attenuation exponent

Due to multipath and other interference effects, α is in the range of 2 to 5.

$$\therefore P_{send} \propto r^{\alpha} P_{receive}$$

Therefore the power advantage of an N-hop transmission versus a single hop transmission over the same distance Nr is

$$\eta_{rf} = \frac{P_{send}(Nr)}{N.\ P_{send}(r)} = \frac{(Nr)^{\alpha} P_{receive}}{N.\ r^{\alpha} P_{receive}} = N^{\alpha-1}$$

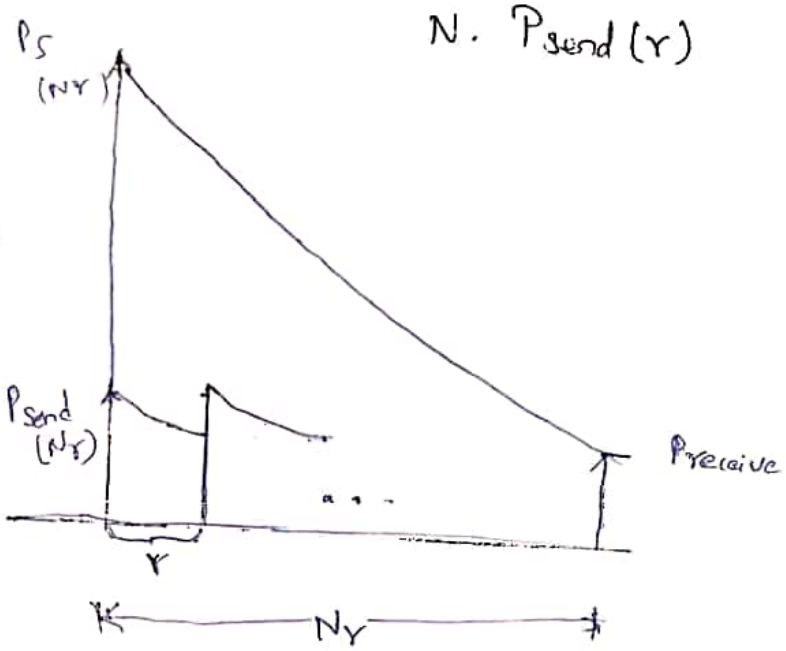


Figure shows the power attenuation for multihop and single hop networks. A larger N gives a larger power saving due to the consideration of RF energy alone.

However this analysis ignores the power usage by other components

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using more no. of nodes increases not only cost, but also the power consumption of these other RF components.

Detection Advantage:

Each sensor has a finite sensing range, determined by the noise floor at the sensor. The sensor networks increase the SNR, because of denser sensor field decreases the average distance from a sensor to the signal source.

Let us consider the acoustic sensing case in a two-dimension plane, where the acoustic power received at a distance r is

$$P_{receive} \propto \frac{P_{source}}{r^2}$$

The SNR is given by

$$SNR_r = 10 \log \frac{P_{receive}}{P_{noise}}$$

$$= 10 \log P_{source} - 10 \log P_{noise} - 20 \log r.$$

Increase the sensor density by a factor of K reduces the average distance to the target by a factor of $1/\sqrt{K}$. Thus, The SNR advantages of the denser sensor n/w is

$$\eta_{SNR} = SNR_{\frac{r}{\sqrt{K}}} - SNR_r = 20 \log \frac{r}{r/\sqrt{K}} = 10 \log K.$$

Therefore, increase in sensor density factor of K improves the

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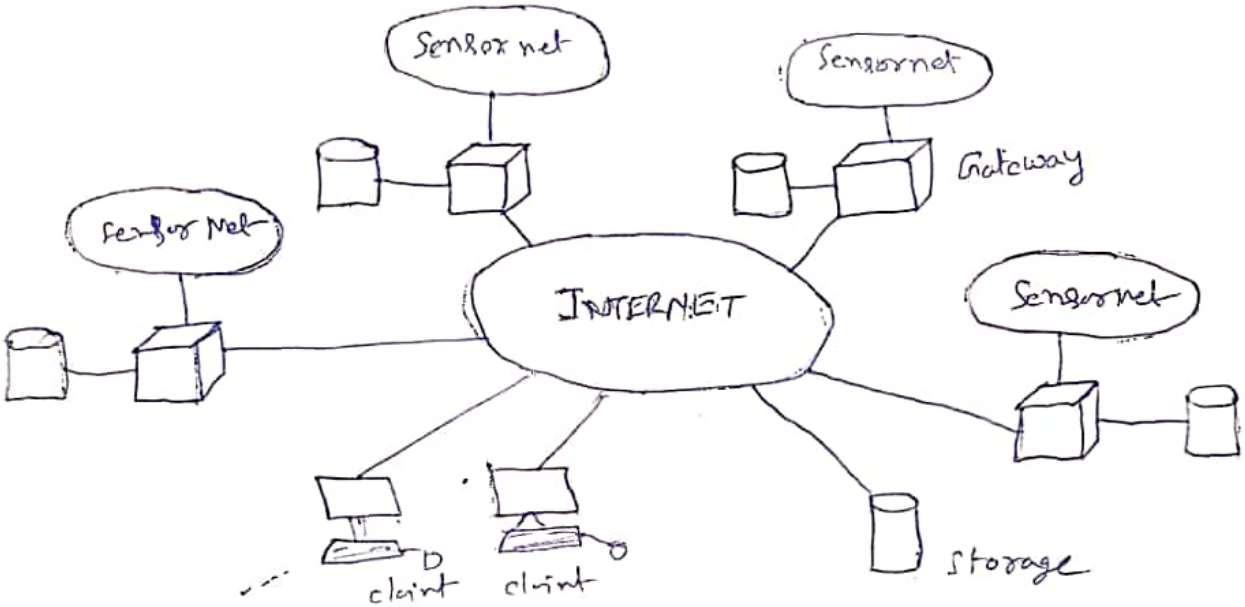
SNR at a sensor by 10 log k db.

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Unique Constraints and Challenges:

A sensor network is subject to a unique set of resource constraints such as finite on-board battery power and limited n/w communication bandwidth. In a typical sensor network, each sensor nodes operates independently and has a microprocessor and a small amount of memory for signal processing and task scheduling. Each node is also equipped with one or more sensing devices such as acoustic microphone arrays, video or still cameras, Infra red (IR), seismic, or magnetic sensor. Each sensor node communicates wirelessly with a few other local nodes with in its radio communication range.

Sensor Network is creating entirely new types of traffic that are quite different from what one finds on the Internet now. Information collected by and transmitted on a sensor network describes conditions of physical environments - for example heat, humidity, press vibration etc.



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Figure shows a sensor networks, it may internetwork with an IP core network via a number of gateways. A gateway routes user queries or commands to appropriate nodes in a sensor net. It also routes sensor data to user who have requested the information. A data storage service may be present at the gateway, in addition to data logging at each sensor.

The storage may serve as an intermediary between user and sensors, providing continuous data storage. Additionally, one or more data storage devices may be attached to the IP network. to collect the data from a number of edge sensor Network and to suppor a variety of user-initiated browsing and search functions.

Challenges of WSN:

Limited hardware: Each node has limited processing, storage and communication capabilities and limited energy supply and bandwidth.

Limited support for networking: The network is peer to peer, with mesh topology and dynamic, mobile and unreliable connectivity. There are no universal routing protocols or central registry services. Each node act both as a router and as an application host.

Limited support for software development: The task are typically real-time and massively distributed, involve dynamic collaboration among nodes, and must handle multiple competing events. Global properties can be specified only via local instructions. Because of

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Coupling between applications and system layers, Software architecture must be designed appropriate to the information processing architecture (H/W architecture).

Life time: Critical to any WSN is the expected life time. In many scenarios, the nodes placed out in the field for months or years. The 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 WSN becomes a very important figure of merit. Evidently, an energy efficient way of operation is necessary in WSN.

Size and cost:

The physical size and cost of each sensor node has a significant and direct impact on the design of WSN. The primary goal of WSN is cost should be as low as possible with all functionalities.

Robustness and Fault tolerance Since nodes may run out of energy or might be damaged or the wireless communication between two nodes can be permanently interrupted. It is important that the WSN as a whole is able to tolerate and adapt to individual node failure. To tolerate node failure, each node must be designed to be as robust as possible.

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Flexibility: Not only will it be necessary for the nodes to process information, but also they will have to react flexibility on changes in their tasks. These 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.

Scalability: Since WSN might include a large number of nodes The employed architectures and protocols must be 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 depending upon application. Even within application, density can vary over time and space because node fail (or) move, So the network should adapt to such variations.

Maintainability: As both the environment of a WSN and the WSN itself change (depleted batteries, failing nodes, New task), the system has to adapt. It has to monitor its own health and status to change operational parameters or to choose different trade-off.

Self-configuration:- A WSN will have to configure most of its operational parameters autonomously, independent of external configuration.

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Applications Of WSN:

- Habitat and Ecosystem Monitoring
- Seismic monitoring
- Civil Structural & health monitoring
- monitoring Ground water Contamination
- Industrial process monitoring
- Border Security and surveillance
- Automated Building climate control.
- Infrastructure Protection (Power grids, water distributi
- Air pollution Monitoring
- Forest fire detection
- Natural disaster prevention

Some typical applications for WSN:

Military applications:

Sensor nodes can be spread across the battlefield or enemy area and be programmed to track and monitor enemy troop movements and can be used to locate their exact positions.

It can also be used to detect the use of biological or chemical weapons and relay this information to commanders, so as to allow sufficient time for soldiers to take defensive action.

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Improved battlefield communication is another benefit of WSN.

Environmental application: Sensor networks are being increasingly used for environmental concerns. Examples :—

→ habitat monitoring of birds and animals without distrubing of their lifestyle. Either fixed the sensor nodes in a large geographic region (or) attaching the sensor directly to the body of the animals to monitor their behaviour

→ water-quality monitoring may also be useful to determine contamination with bacteria or other harmful pollutants.

→ Major application in this category is the spread of sensor nodes across a forest to monitor temperature and give early warning of fire out breaks.

→ Other applications are weather prediction, climate monitoring, distributed computing, pollution tracking, seismic detection, etc...

Medical application:

WSNs can be used in medical application by using the sensor node as a device that can reside on (or) within the human body and perform tasks that are currently done by costly machines. These include glucose monitor for

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insulin levels in diabetic patients;

→ Functioning of the heart monitor for patients with irregular heartbeats (or) coronary diseases;

→ Artificial retinal and cortical implants to electronically transmit information to visually impaired persons.

→ other medical applications include use in telemonitoring of human physiological data, tracking and monitoring doctors and patients inside a hospital.

Medical application sensors have special requirements. They must be safe and biocompatible to human body and not damage the human tissues. The sensor must be designed for long term operation and have enough power so that frequent surgery is avoided.

Industrial applications:

In Industrial area, sensor nodes are fixed to difficult-to-reach area of machinery where they can detect vibration pattern that indicate the need for maintenance.

Some of sensor nodes could be attached to equipment to monitor performance and identify inefficient operation or poorly performing equipment.

Sensing application help automate data acquisition from remote sensor to reduce user intervention.

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Other services include smoke, CO, and H_2O detectors; Equipment management services and preventive maintenance; security services, Lighting control, Material processing systems (heat, gas flow, cooling, chemical), Electric meters, etc.

Urban applications: WSN can be used for various urban applications like transportation, traffic systems, auto-identification by driving license, parking availability, security monitoring in shopping malls, city streets and home security.

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Enabling technologies for WSN:

Building such wireless sensor network has only become possible with some fundamental advances in enabling technologies First and foremost among these technologies is the miniaturization of hardware. Smaller feature size in chips have driven down the power consumption of the basic components of a sensor node to a level that the constructions of WSN. This is particularly relevant to microcontrollers and memory chips and also 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 affordable.

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Next to processing and communication, the actual sensing equipment is the third relevant technology. These three 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 are conceivable options. 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 first question to answer here is the principle division of tasks and functionalities in a single node (the architecture of the operating system or runtime environment). This environment has to support simple retasking, 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. Here the question is,

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how to structure interfaces for application programmers. The third part to solve them is the question of how to design appropriate communication protocols.

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Unit - II

ARCHITECTURES

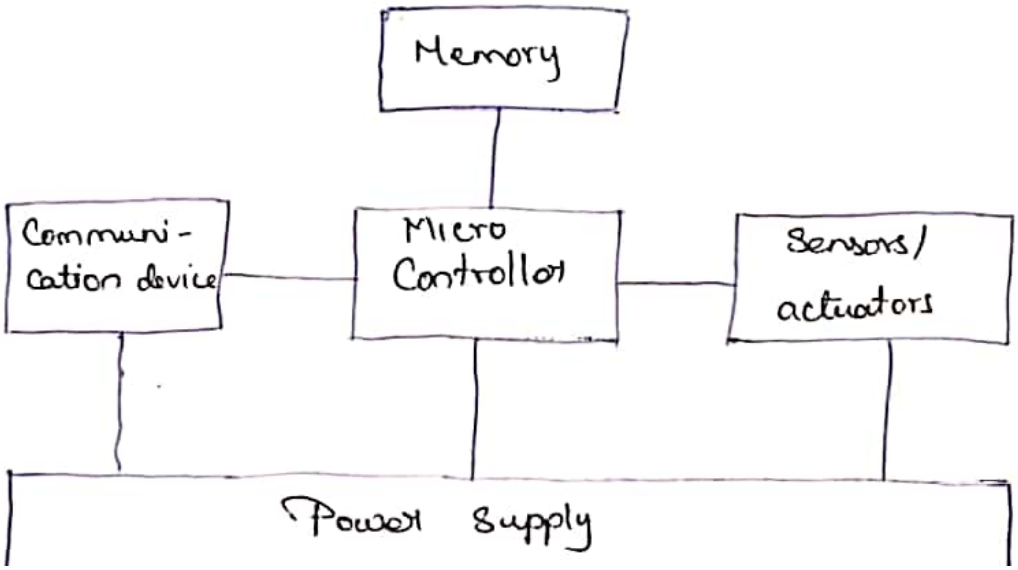
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SINGLE NODE ARCHITECTURE:

The basic part of WSN is node. The principal task of a node is sensing, computing, storage and communication. These nodes have to be small, cheap, or energy efficient. They have to be equipped with right sensors, the necessary computation and memory resources, and they need adequate communication facilities. These hardware components and their composition into a functioning node are described in this section.

HARDWARE COMPONENTS:

A basic sensor node comprises five main components.



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Memory: Memory is used to store programs and intermediat data; usually, different type of memory are used for programs and data.

Sensors and actuators: The actual interface to the physical world Devices that can observe or control physical parameters of the environment.

Communication device: Turning nodes into a network requires a device for sending and receiving information over a wireless channel.

Power Supply: Usually, some form of batteries are necessary to provide energy. Sometimes, some form of recharging by obtaining energy from the environment is available as well (e.g. solar cells).

Each of these components has to operate balancing the trade-off between as small as energy consumption as possible on the one hand and the need to fulfill their tasks on the other hand.

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CONTROLLER:

MICROCONTROLLER VERSUS MICROPROCESSORS, FPGAS, ASIC's:

The controller is the core of a wireless sensor node. It collects data from the sensors, processes this data,

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decides when and where to send it, and decides on the actuator's behaviour. It has to execute various programs, ranging from time critical signal processing and communication protocol to application program; it is the central processing unit (CPU) of the node.

Selection of processor depends upon flexibility, performance, energy efficiency and costs.

Microcontroller:

The microprocessor are general-purpose processor, like those known from desktop computers. These processors are highly overpowered and energy consumption is excessive. But microcontroller is optimized for embedded systems. Some key characteristics why these microcontrollers are particularly suited to embedded systems are their, flexibility, Low power consumption in built memory and freely programmable. Microcontrollers are suitable for WSN. since it do specific operation.

Different processors:

DSPs – It is a specialized case programmable processors. optimized for signal processing tasks, not suitable for WSN.

FPGA's – Field programmable Gate Arrays provide high flexibility but it can take time and energy more. May be good for testing

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COMMUNICATION DEVICE:

Choice of transmission medium:

The communication device is used to exchange of data between individual nodes. In the case of wireless communication which is the transmission medium? - The usual choices are Radio frequencies, optical communication and ultrasound. Of these choices, Radio-Frequency (RF)-base communication is used in WSN Applications. It provides long Range and high data rates, acceptable error rates with energy efficient and no need of Line of sight communication.

Transceivers:

For actual communication, both a transmitter and receiver are required in a sensor node. The transmitter convert the bit stream coming from a microcontroller in to radio waves. The receiver, receives the Radio waves and convert back into bit/byte stream. The combined action of transmitter and Receiver devices are called transceiver. So same device is used for both transmission and Reception. Usually, half duplex mode of operation is used because transmission and reception at the same time on a wireless medium is impractical in most cases.

How to choose Transceiver?

1) Transceiver tasks and characteristics:

*. Service to upper layer: A receiver has to offer certain services to the upper layers, most notably to MAC layer.

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Some times, this service is packet oriented, (or) byte oriented (or) even only bit-oriented interface.

Carrier Frequency and multiple channels:- Transceivers are available for different carrier frequencies (channels), evidently it must match application requirements and regulatory restriction Typically, supported frequency range somewhere in 433 MHz, 2.4 GHz ISM band.

Data rates: Carrier frequency and used bandwidth together with modulation and coding determine the gross data rate.

Range: The range of the transmission is very important. It evidently depends on the Max transmission power, Antenna characteristics, Attenuation caused by environment, carrier frequency, Modulation/coding scheme and bit error rate. It also depends upon the Quality of Receiver and its sensitivity. The approximate value of the range is few meter to several hundreds of meters are available.

II. Energy characteristics:

1) power consumption and energy efficiency: The power consumption is the energy required to transmit/Receive a data. For energy efficiency, transceiver should be switchable between different states like active, sleep, idle etc. The time and energy consumption to change between different states are also very important.

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2) Transmission power Control: Some transceivers can directly provide control over the transmission power to be used. Discrete no. of power levels are available, from which the actual transmission power can be chosen. Max o/p power is usually determined by regulations.

3) power efficiency: The efficiency of radio front end is given as the ratio of radiated power to the over all power consumed by the front end. (which percentage of consumed power is radiated $\simeq \frac{o/p}{i/p}$)

$$\text{Power efficiency} = \frac{\text{radiated power}}{\text{consumed power}}$$

III. Radio Performance:

1) Modulations: The transceiver typically support several Modulation like ASK, FSK or similar modulation (ON/OFF-keying). Depending upon the convenient of experiment, any one of the modulation used.

2) Noise Figure: It is defined as ratio of input signal-to-noise Ratio to O/P signal-to-Noise.

$$NF = \frac{SNR_I}{SNR_O} \quad (or)$$

$$NF(dB) = SNR_I\ dB - SNR_O\ dB.$$

3) gain: The gain is the ratio of the output signal power to the input signal Power. Amplifier with high gain are desirable to achieve good energy efficiency.

4) Receiver sensitivity: The receiver sensitivity specifies the Minimum signal power at the receiver to achieve a given E_b/N_o.

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Blocking Performance: Achieved bit error rate in the presence of an interferer. An important special case is an Adjacent channel interferer that transmits on neighboring frequencies. The Adjacent-channel suppression describes a transceiver's capability to filter out signals from adjacent frequency bands (to reduce Adjacent channel interference) has a direct impact on the observed signal to interference and Noise Ratio (SINR).

Out of band emission: The inverse to adjacent channel suppression is the out of band emission of a transmitter. To limit disturbance of other system, the transmitter should produce as little as possible of transmission power outside of prescribed bandwidth, centered around the carrier frequency.

Carrier Sense and RSSI: In many medium access control protocols, sensing whether the wireless channel is busy, is a critical information. The receiver has to be able to provide that information in the Received Signal Strength Indicator (RSSI).

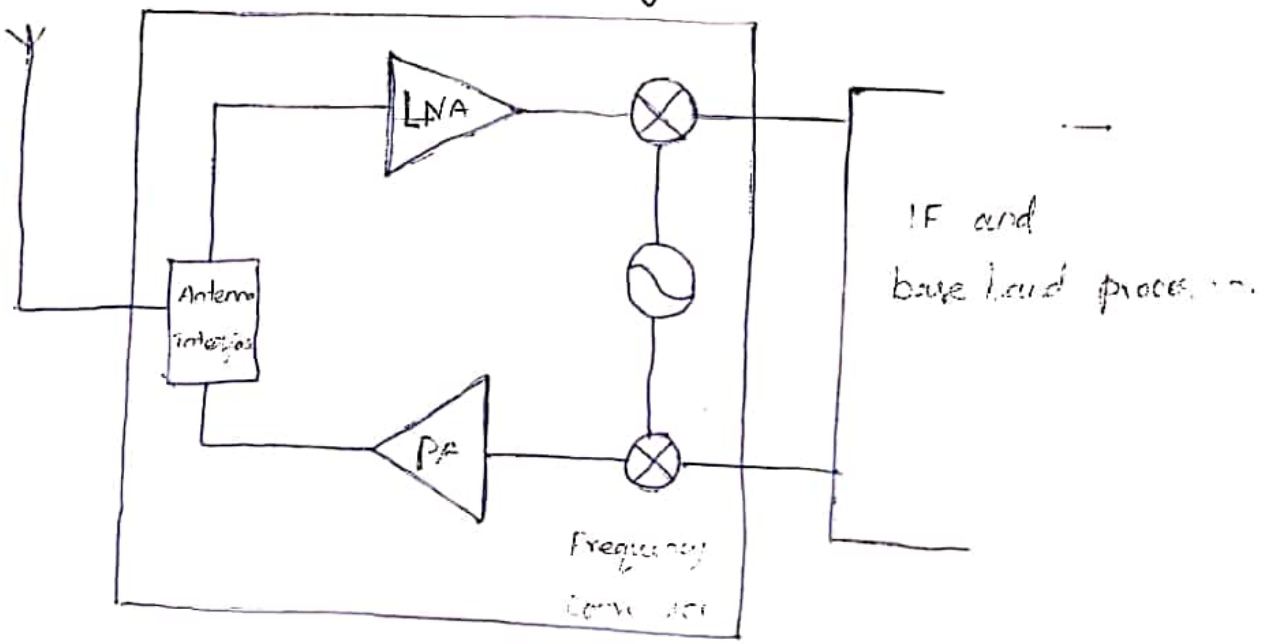
Frequency Stability: The frequency stability denotes the degree of variation from nominal center frequencies when environmental conditions of oscillators like temperature or pressure change. The poor frequency stability can break down communication links.

Voltage Range: Transceivers should operate reliably over a range of supply voltage.

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Transceiver Structure:

A common structure of transceivers is RF front end.



LNA – Low Noise Amplifier ; PA – Power Amplifier.

The RF front end performs analog signal processing in the actual radio frequency band (2.4GHz ISM band). It is the first stage of the interface between EM waves and digital signal processing of the further transceiver stages.

→ The power Amplifier (PA) accepts the upconverted signals from the IF or baseband part and amplifies them for transmission over the antenna.

→ The Low Noise Amplifier (LNA) amplifies incoming signals up to levels suitable for further processing without significantly reducing the SNR.

→ Elements like Local oscillators and Mixers are used for

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Frequency conversion from the RF spectrum to intermediate frequencies (or) to the baseband. The incoming RF frequency signal is multiplied in a Mixer with a fixed-frequency signal from the local oscillator. The resulting signal is nothing but a IF (Intermediate-frequency) signal.

Transceiver operational states:

There are four operational states

1) transmit – In the transmit state, the transmit part of the transmitter is active and the antenna radiates energy

2) Receive – In this state, the receiver part is active.

3) Idle – A transceiver is ready to receive but is not current receive anything is said to be Idle State. In this Idle state many part of the receive circuitry are active and some part can be switched off for energy saving.

4) Sleep – Significant parts of the transceiver are switched off. When circuit is in this Sleep state, It cannot be able to receive immediately. So, Recovery time and Startup energy to leave Sleep state can be significant.

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Examples of Radio Rx Transceivers:

Almost boundless variety available

RFM—TR1000 Family:

This family transceivers are available for 916 or 868 MHz frequency range, 1100 KHz bandwidth, upto 115.2Kbps. The modulation is either ON/OFF (or) ASK; it also provides a dynamically tunable output power. The Maximum power about 1.4mW and It is attractive because of low power consumption.

Chipcon CC1000:

Range 300 to 1000 MHz, FSK Modulation, Provides RSSI and has programmable output power.

Chipcon CC2400:

This is the first commercially available single chip transceiver for IEEE 802.15.4. It operates in 2.4GHz, It requires DSSS Modem, data rate is 250kbps. Higher power consumption than above transceivers.

Infineon TDA 525x family:

It is flexible, single chip and energy-efficient transceivers. The range is 868 MHz, modulation-either ASK or FSK modulation, It has a highly efficient power amplifier, RSSI

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information, and an intelligent power-down feature. It also has excellent blocking performance that makes it quite resistant to interference.

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SENSORS AND ACTUATORS:

SENSORS:

Sensors can be roughly categorized into three

Categories < Active probing – It needs an external supply to Activate
passive probing – Do not require external power.

Passive, omnidirectional sensors: These sensors can measure a physical quantity at the point of the sensor node without actually manipulating the environment by active probing – in this sense – They are passive, at the same time it sense the data in all directional then it is omnidirectional – sensors.

Examples: Light sensors, thermometer, vibration, humidity, pressure, smoke detector and so on.

There is no notion of direction involved in these measurement

Passive, narrow – beam sensor: –

These sensors are passive as well, but have a well defined notion of direction of measurement.

Examples: camera, which can take measurements in a given direction.

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Active sensors: These sensors actively probes the environment. — Example : Radar.

Actuators:

Actuators are just about as diverse as sensor. The meaning of Actuators is a mechanism that puts something into automatic action. In principle, all that a sensor node can do is to open or close a switch or a relay or to set a value in some way. Whether this controls a motor, a light bulb or some other device.

POWER SUPPLY OF SENSOR NODES

The Goal of power supply unit is to provide as much energy as possible at smallest in cost / volume / weight / recharge time and longevity. In WSN, recharging may or may not be an option.

There are two options

1) Primary batteries – not rechargeable
2) Secondary batteries – rechargeable.

Requirements of Batteries:

*) Low self-discharge – For Last for long time.
* Capacity under Load –
*. Efficient recharging at low current. –

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*. Capacity under load - pattern
*. Good relaxation properties (Seeing self-recharging)
*. voltage stability.

Battery examples: Capacity of Battery = energy/volume = J/cm³

Primary batteries:

Chemistry	Zinc-Air	Lithium	Alkaline
Energy (J/cm³)	3780	2880	1200

secondary batteries:

Chemistry	Lithium	NiMHd	NiCd
Energy (J/cm³)	1080	860	650

Energy Scavenging:

Energy Scavenging is a process of gathering the energy from the environments. example: Solar cells.

For Long-Lasting Networks - energy scavenging should take place.

Energy Sources:

Solar cells: It can be used to power sensor nodes. When the light incident on these cells, it produce electric power.

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The available power depends on whether nodes are used outdoor or indoors, and on time of day. The resulting power is somewhere between 10 $\mu W/cm^2$ indoors and 15 mW/cm^2 outdoors.

Temperature gradients:

Differences in temperature can be directly converted to electric energy. Theoretically, even small difference of 5K can produce considerable power. Example: Thermoelectric generator produce 80 $\mu W/cm^2$ at about 1V from a 5 Kelvin temperature difference.

Vibrations:

One form of mechanical energy is vibrations: Walls or windows in building are resonating with cars or trucks passing in the streets, machinery often has low frequency vibrations, and so on. The available energy depends on both amplitude and frequency of the vibration and ranges from about 0.1 $\mu W/cm^3$ – 10000 $\mu W/cm^3$.

Flow of air/ liquid:

Another often-used power source is the flow of air or liquid in wind mills or turbines. The challenge here is again Miniaturization, but some of the work on millimeter scale MEMS gas turbines might be reusable.

The energy scavenging usually has to be combined with secondary batteries and these are not able to provide power

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The 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 end, to some degree the memory and depending upon the type of sensors.

Operation states with different power consumption:

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Hence, it is best to turn it off. Naturally, it should be able to wake up again, on the basis of external stimuli or on the basis of time. Introducing and using multiple states of operation with reduced energy consumption is the core technique for energy-efficient WSN.

These modes can be introduced for all components of a sensor node, in particular for controller, radio front end, memory and sensor. For controller typical states are active, idle, sleep; a radio modem could turn transmitter, receiver or both on or OFF. Sensors and memory could also be turned on or OFF.

If the device went to deeper sleep state, it takes more time and energy to wakeup again to fully operational state. Hence it may be better to in ideal state when compared to sleep state.

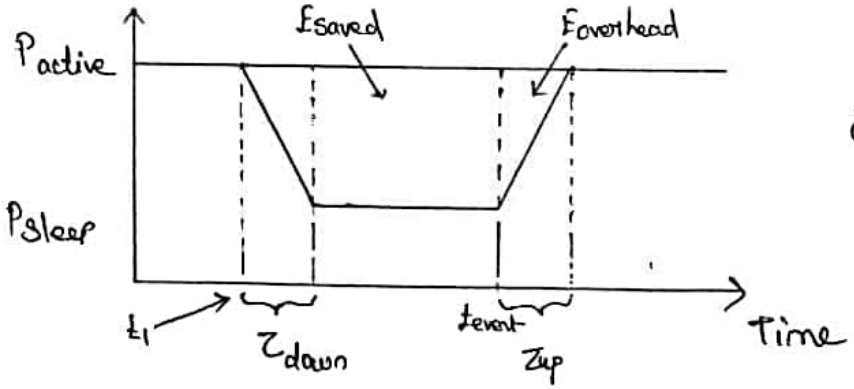


Fig: Micro controller operating states

Fig: Energy savings and overheads for sleep modes.

A time t_1, the decision whether a component (or) the micro controller is to be put into sleep mode should be taken, to reduce power consumption, from P_{active} to P_{sleep}.

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If it remains active and the next event occurs at time t_{event}, then a total energy of $E_{active} = P_{active}(t_{event} - t_1)$ has be spent uselessly idling.

Putting the component into sleep mode, on the other hand, requires a time z_{down} until sleep mode has been reached

The average power consumption during this phase $\gamma = (P_{active} + P_{sleep})/2$

Then, P_{sleep} is consumed until t_{event}.

The total energy is required in sleep mode $= z_{down}(P_{active} + P_{sleep})/2 + (t_{event} - t_1 - z_{down}) P_{sleep}$.

This is opposed to $(t_{event} - t_1) P_{active}$ when remaining active.

The energy saving is thus,

$$E_{saved} = (t_{event} - t_1) P_{active} - (z_{down}(P_{active} + P_{sleep})/2 + (t_{event} - t_1 - z_{down}) P_{sleep})$$

Once the event to be processed occurs, however, an additional overhead of is occured to come back to operational state. So,

$$E_{overhead} = z_{up}(P_{active} + P_{sleep})/2$$

This energy is indeed an overhead since no useful activity can

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, be take place. Clearly, switching to a sleep mode is only beneficial if Eoverhead < Esave. (or) Time to the next event sufficiently large:

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

Careful scheduling of such transitions has been from several perspectives.

—— x ——

Microcontroller energy Consumption:- (Examples)

Intel Strong ARM:

*. In normal mode - 400 mW (power consumption)

*. In Idle mode - 100 mW "

*. In sleep mode - 50 μW

Texas Instruments MSP 430:

fully operation : 1.2 mW

Deepest sleep mode : 0.3 μW

Atmel AT Mega:

operational mode : 15mW

Idle mode : 6mW

sleep mode : 75 μW

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Memory Power Consumption:

From an energy perspective, the most relevant kinds of memory are on-chip memory of microcontroller and Flash memory. Off-chip RAM is rarely if ever used. The power needed to drive on-chip memory is usually included in the power consumption of controller.

Hence, the most Crucial Part: Flash Memory. Infact, the construction and usage of flash memory can heavily influence node lifetime. The relevant metrics are read and write times and energy consumption. Consider the energy consumption, for

read operation – 1.111 nAh,

write operation – 83.333 nAh.

Hence, writing to Flash memory can be a time and energy consuming task that is best avoided if somehow possible.

—x—

Radio Transceiver Power consumption:

A radio transceiver has essentially two task: transmitting and receiving data between a pair of node. The radio transceivers can also be operate in different modes, the simplest ones are being turned on or turned off. For low energy consumption, the transceivers should be turned off most of the

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time and only be activated when necessary. 20

Energy Consumption during transmission:

In principle, the energy consumed by a transmitter is due to two sources: one part is due to RF signal generatic which mostly depends on chosen modulation and target distance and the power radiated by the antenna. Second part is due to electronic components necessary for frequency synthesis, frequency conversion, filters and so on.

The transmitted power is generated by the amplifier of a transmitter. Amplifier power P_{amp} depends on its architecture. and consumed power depends on the power they are to generated.

$$P_{amp} = \alpha_{amp} + \beta_{amp} P_{tx}$$

where

P_{tx} → radiated power

α_{amp}, β_{amp} → Constant depending on model.

The efficiency of the power amplifier

$$\eta_{PA} = \frac{P_{tx}}{P_{amp}} \quad \text{at max output power}$$

In addition to the amplifier, other circuitry has to be powered up during transmission as well. This power is referred to as $P_{to\,Elec}$.

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Time to transmit n bits $= \frac{n}{R * R_{code}}$

where

R = nominal data rate, R_{code} = coding rate.

In addition, the transmitter has to turn on before transmission, startup costs also are incurred. (ie) T_{start}, P_{start}.

Overall transmission Energy,

$$E_{tx}(n, R_{code}, P_{amp}) = T_{start} P_{start} + \frac{n}{R * R_{code}} (P_{tx\,Elec} + P_{amp}$$

It should be pointed out that this equation does not depend on the modulation chosen for transmission.

Energy Consumption during reception:

Similar to transmitter, the receiver can be either turned off or turned on. So Receiver also has startup costs T_{start}, P_{sta}

Time to receive n bit $= \frac{n}{R * R_{code}}$ (same as transmitter)

The Receiver electronic needed power = $P_{rx\,Elec}$

Overall Reception Energy

$$E_{rx} = T_{start} P_{start} + \frac{n}{R * R_{code}} \left(P_{rx\,Elec} + \eta E_{decBit} \right)$$

where E_{decbit} = Energy for decoding bit

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The decoding energy is relatively complicated to model; as it depends on a number of H/w and system parameters.

Computation Vs. Communication:

Directly comparing computation / communication energy cost not possible. But put them into perspective. Then calculate Energy ratio of "sending one bit" Vs. "Computing one instruction". The resultant cost shows that, to communicate one kilobyte = Computing three million Instruction. Hence, try to compute instead of communicate whenever possible.

Power consumption of sensor and actuators:

Providing any guideline about the power consumption of the actual sensors and actuators is impossible because of the wide diversity of these devices.

For some of them - like passive light (or) temperature sensors - consumed very less amount of power. That can be ignored when compared to other devices on wireless node. (0.6 to 1mA level only)

For other, like active sensor - example : sonar, power consumption can be quite considerable, which should be measured in the dimensioning of power sources on the sensor node.

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OPERATING SYSTEMS AND EXECUTION ENVIRONMENTS:

Embedded operating systems:

The traditional tasks of operating system are controlling and protecting the access to resources and managing their allocation to different users. It allows several processes to communicate with each other and also to be executed concurrently.

Programming Paradigms and application programming Interfaces:

The different programming paradigms are,

1. Concurrent programming paradigm
2. Process - based programming Paradigm
3. Event based programming paradigm.

Concurrent Programming:

Programming paradigm that support concurrent execution plays a significant role for wireless sensor networks, Because they have to handle data coming from arbitrary sources such as multiple sensors or radio transceiver at arbitrary point in time.

Consider an example of sequential programming paradigm which shows the need of concurrent programming paradigm.
A system could poll a sensor to decide whether data is available.

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If the data is available then it should be processed in a correct way Afterwards, it must poll the transceiver to know the packet availability. If the packet is available then it should be processed immediately. This can be shown in figure below:

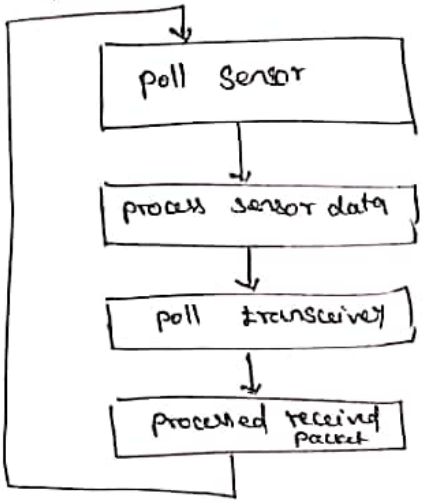


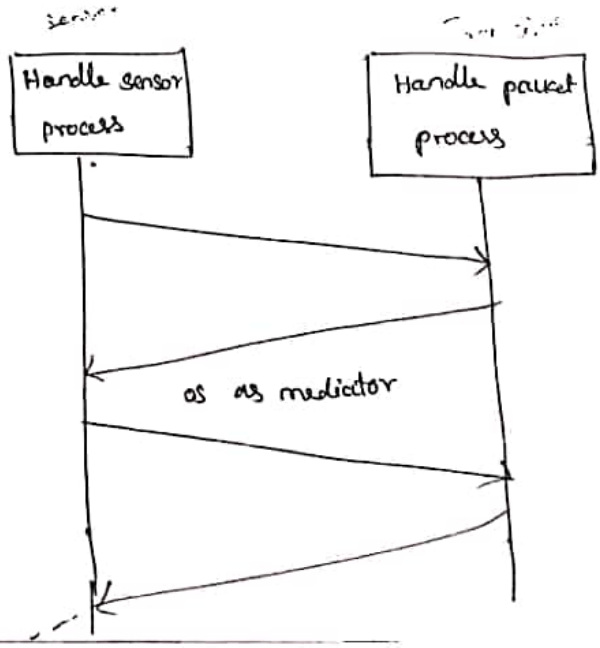
Fig: sequential programming model.

This sequential process can have risk of missing data while a packet is processed (or) missing a packet when sensor information is processed. This risk is particularly large if the processing of sensor data or incoming packets takes large amount of time.

Hence, a simple, sequential programming model is clearly insufficient.

Process - based Programming Paradigm:

Basically modern general purpose operating system allows execution of multiple processes concurrently upon a single CPU. so this will supports the concurrency in a sensor node. This can be shown in figure



first some particular time period It process sensor data. If time elapse, It switch to handle transceiver packet process upto some particular time period. After that once again it goes to handle sensor process and so on.

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In this execution model there are some granular mismatch. Equating individual protocol function or layers with individual processes would have a high overhead in switching from one process to another.

This problem is particularly severe if often tasks have to be executed that are small with respect to overhead incurred for switching between tasks is usual in sensor networks.

Event-based Programming paradigm:

The event based programming model is preferable because it overcomes the problems of process-based programming paradigm. In this, the system is allow to wait until an event occurs. The event can be data availability at sensor nodes, packet arrival or the expiration of a timer.

An event can be handled by a short sequence of instruction which stores the name of event and its necessary information. The actual information processing of these event should not be performed in event-handler routines. Instead it is decoupled from the actual appearance of events and processed separately.

This event-based programming model is shown in figure

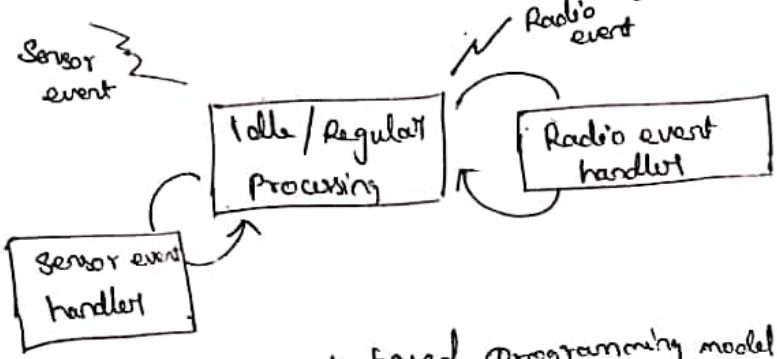


Fig: Event based programming model.

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The event handler can be sensor event handler and radio event handler. Such an event handler can interrupt the processing of any normal code, but it is very simple and short, it can be run in any situation without disturbing other code. The event handlers execute sequentially without interrupting each other.

Interfaces to operating systems:

In addition to programming models, the interfaces provided to the operating systems are used to inquire the internal state of the system. They are also used to set the internal state of the system. This interface must be accessible by both the application programs and the protocol stack and must be tied with both of them. The application programming interface consist of functional interface, object abstraction and also detailed behavioral semantics. Abstraction indicates wireless links, nodes etc. and the function indicate state inquiry and manipulation, accessing hardware and setting of policies.

Structure of operating system and protocol stack:

The structuring of communication protocols was done traditionally by using layered approach. In this approach, the protocols are stacked on each layer and that layer only using the functions of each protocols. This layer approach has great benefits in keeping the entire protocol stack manageable, and promoting modularity and reuse.

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For the purposes of WSN, however, it is not clear whether such a strictly layered approach will be sufficient. 2.4

Example:

Consider the information that specify the strength of received signal by a communication path partner. This information at physical layer can be used for the following.

1. To provide support to Networking protocol to decide about routing changes.
2. To compute location information by estimating distance from the signal strength. (or) to assit link layer protocols either in channel adaptive or hybrid FEC/ARQ schemes.

Thus only single information source can be used for benefitting various other protocols which are not directly linked with this source of information. However this type of information exchange is cross-layer information exchange which is responsible to weaken the restrictions of layered approach.

So, WSN use "component model" as communication protocol in order to structure the protocol stack. The advantage of this model is that it breaks the monolithic layers into small self contained components or modules or building blocks. These components only fulfill one well-defined function.

This component model not only solve some of the structuring problems for protocol stack, it also fits naturally with

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an event-based approach to programming WSN. Wrapping of Hardware, communication primitives, in network processing functionalities all can be conveniently designed and implemented as components.

NETWORK ARCHITECTURE

Sensor network scenarios: There are two types. They are Types of sources and sinks:

Source: 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 operatio

Sink: A sink, on the other hand, is the entity where information is required. A sink can either be a sensor network, or sensor/actuator node or it can even be a node/entity outside the network.

Single hop versus multihop networks:

The single hop network is simple and beneficial because it provides direct communication between a source and sink. The main drawback of single hop network is that it covers only a limited distance, because of which it is difficult for it to be used in wireless sensor network. The reason is WSN covers a lot of ground or that operate in difficult radio environments with strong attenuation.

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To overcome such drawback of single hop network, multihop network can be used. This network uses relay stations which helps in taking multiple hops from source to sink. In addition to this, it also improves the energy efficiency of communication. The multihop networks which operate in the fashion of store and forward Technique A node in this network need to receive the packet correctly and then forward it to its destination.



fig: single hop

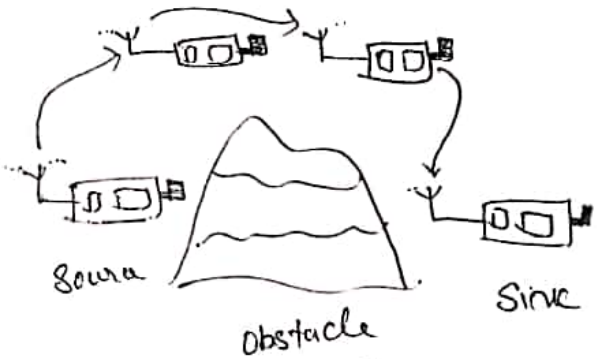
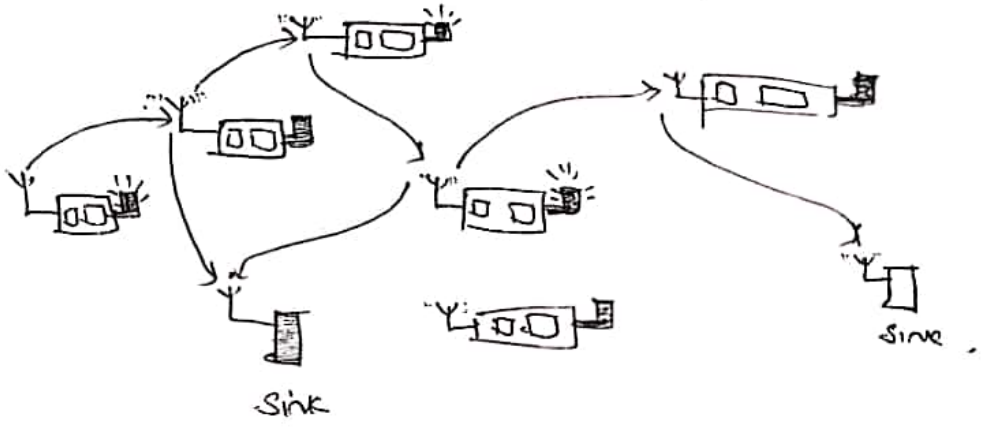


fig: multihop

Multiple Sinks and Source:

So far, only network coith a single source and a single sink have been illustrated. In many cases, there are multiple source and/or multiple sink presents. In the most challenging case, multiple source can send information to multiple sinks, where either all or some of the information has to reach all or some of the sinks.



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Three types of mobility:

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

Node mobility:

Node in WSNs are mobile which indicate that they are highly dependent on application. In the face of node mobility, the network has to reorganize itself frequently enough to be able to function correctly. However, the trade-off among the frequency and speed of node movement will oppose the energy that is used for maintaining the level of functionality in the network.

Sink mobility:

The information sink 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.

For example, a human user requested information while in an in an intelligent building. In simple case, such a requester can interact with the WSN at one point and complete its interactions before moving on. Whether the requester is allowed interaction with any node or only with specific nodes is a design choice for the appropriate protocol layers.

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. Here, while the requester would likely communicate only with node in its vicinity, it might have moved to some other place.

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Event mobility:

In application like event detection and tracking, the cause of the events or the object to be tracked can be mobile. In such case, adequate number of sensors will cover the event everytime. It is observed that the sensor will wake up at the object observes the objects and then goes back to sleep mode. The event source which moves, in the network is accompanies with area of activity in the network. This is called frisbee model.

Optimization Goals and Figure of Merit:

1) Quality of Service:

A WSN generally move bits from one place to another place and hence require better quality of service (QoS), especially in the context of multimedia applications. The quality of service may be either low-level, networking-device-observable attribute - bandwidth, delay, jitter, packet loss rate. or a high level, user-observable attribute like the quality of a voice communication/ video transmission. while the first kind off attribute is applicable to a certain level to WSN, and the second one clearly is not, but is really the more important one to consider. The high level attribute in WSN depends on the following,

* Delay in event detection - Delay b/w event detection and reporting.
* Error in classification
* probability of detecting an Event - what is the probability actually the event occur.
* Tracking accuracy

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*. Approximation accuracy

*. Missing reports. — The probability of undelivered reports.

2) Energy efficiency:

The energy is a precious resource in wireless sensor networks. and so, Energy efficiency is the most important attribute in optimizing goals. The amount of energy used affects the quality of service to a great extent. The common aspects consider under this section are,

Energy per correctly received bit :

It is the energy required to transmit a single bit of information from source to the destination. (considering all sources).

Energy per reported (unique) event:

It is the energy required to report a particular event. which may be unique for various sources. (Redundant information about an already known event does not provide additional informatio

Delay/energy trade-offs:

In case of urgent events, increased amount of energy will be required for fast processing. The trade-off between the delay and extra energy investment should be observed.

3) Lifetime of network: The time for which the network is operational (or) able to fulfill its tasks.

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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.

Time for partition: When does the first partition of the network occur which produce two or more disconnected part. 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:

Usually, with redundant network deployment and sensors that can observe a region instead of just the very spot where the node is located, each point in the deployment region is observed by multiple sensor nodes. The definition of Loss of coverage would be 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.

If partition occurs, Network is unable to report an event. This is due to an event not being noticed because the responsible sensor is dead or because a partition between source and sink has occur.

It should be noted that simulating network lifetime can be a difficult statistical problem.

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3) Scalability :

It is measure of density of the network. The ability to maintain performance characteristics irrespective of the size of the network is referred to as scalability. A WSN comprises of a very large number of nodes and therefore scalability is a very important aspect. Scalability is affected generally by addresses or routing table entries that have to be maintained. These information should be restricted by limiting the resource of sensor nodes. A considerable amount of research has been invested into highly scalable architectures and protocols.

4) Robustness :

Wireless sensor networks should be robust. They should not fail just because of node failure or link damage. However, it is difficult to evaluate the robustness since it's depends on failure of nodes and communication limitations.

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GATEWAY CONCEPTS:

The need for gateways:

Gateway provide a physical connection to the internet in order to enable the WSNs exchange the data with other information devices such as mobile devices. This is relatively straight forward on the physical, MAC and link layer – either the mobile device / gateway is equipped with radio transceiver or the fewer nodes present in the wireless sensor network support standard wireless communication network Technologies such as IEEE 802.11. Both the options are beneficial on the basis of application and the typical use case.

The Logical design of gateway is quite challenging. A gateway. can be considered as the simple router between internet and sensor network which could imply the use of internet protocols inside the sensor network. This option is well and not ignore lightly but WSNs will require specific, heavily optimized protocols Thus, a simple router will not suffice as a gateway.

The remaining possibility is therefore to design the gateway as an actual application-level gateway; on the basis of application level information, it will have to decide its own action. The problem associated with gateways can be estimated according to the source from where the communication is created.

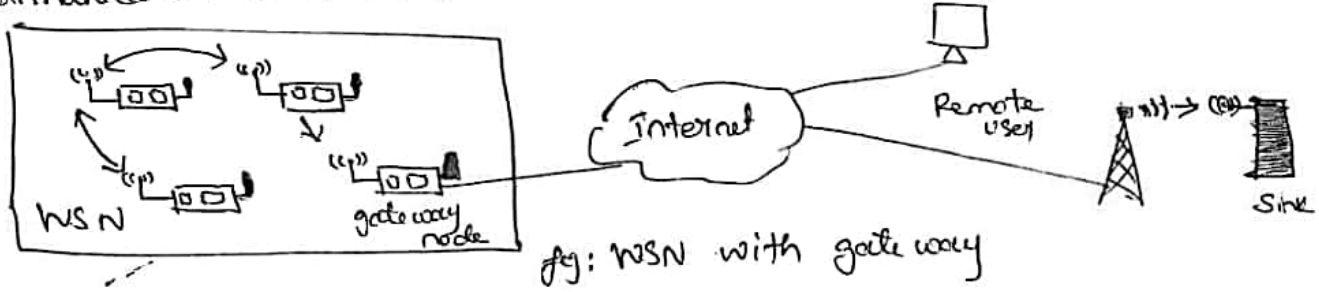


fig: WSN with gateway

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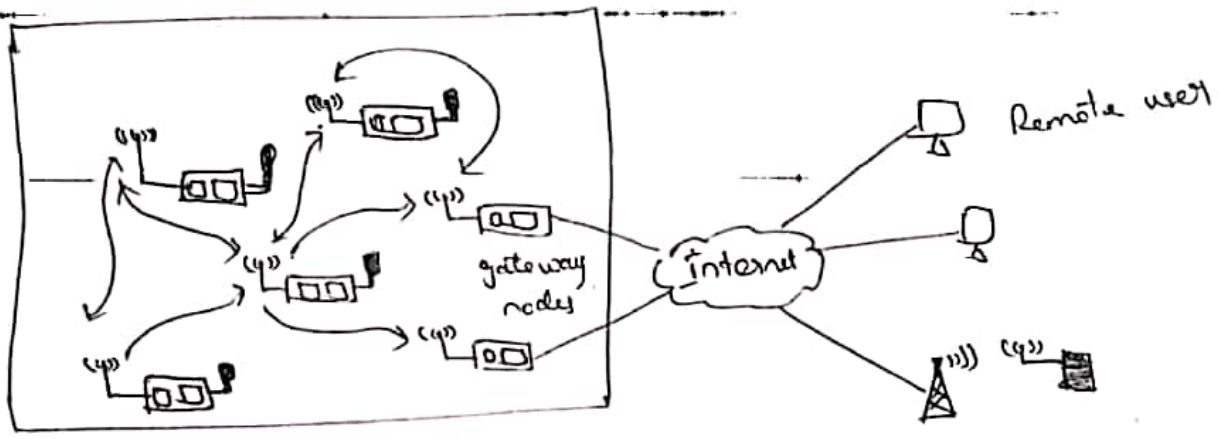


fig: WSN to internet communication

There are various gateways present in the network which makes it difficult for the sensor node to choose the require route/gateway in order to reach the destination. Besides this, complexity arises when there are various gateways each capable of enabling communication between the nodes and IP networking. This problem can be overcome by constructing an IP overlay network above the sensor network.

But, even after constructing an IP overlay, there is a possibility of few problems to arise. It is quite difficult for the sensor nodes to identify the address of the internet host to which the message is to be sent. However, it becomes necessary for the sensor node to include enough information (IP address and port number) in its own packets, even if it does not have the necessity to process IP protocols. This information is then retrieved by the gateway and translate it into IP packets. The gateway here, performs the task identical to the network address translation (NAT) device.

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Internet to WSN Communication:

When an internet based entity tries to access services of WSN, it must be capable to communicate with WSN. If the requesting terminal be a direct part of the WSN and no particular treatment is necessary.

If the requesting entity/terminal is very fast and is unable to communicate with any of the sensor nodes, and thus requiring the assistance of gateway. To continue the communication, the below information is required.

i) Whether any sensor network exists at the desired location
ii) Existence of gateway node
iii) Access to actual services.

Once the requesting terminal has obtained above information, problem is clearly, addressing an individual sensor. because an individual sensor node does not even have IP address.

The requesting terminal can send the properly formatted request to this gateway, which acts as an application-level gateway or a proxy for individual/set of sensor nodes that can answer this response request; the gateway translates this request into the proper intra-sensor network protocol interactions. It is assumed that there exists an application level protocol which can be used by remote requester and gateway. It is more suitable for communication over the internet than the actual sensor network protocol and it is more convenient for the remote terminal to use. Then a gateway can mask - for example, a data centric data exchange within the network behind an identity-centric exchange used in an Internet.

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Such an application level protocol not much clearly provides solution for our problem. So, so-called Web service protocols are also function with application level protocol, which provide describe services and the way they can be accessed.

WSN tunneling :

WSN tunneling is a process

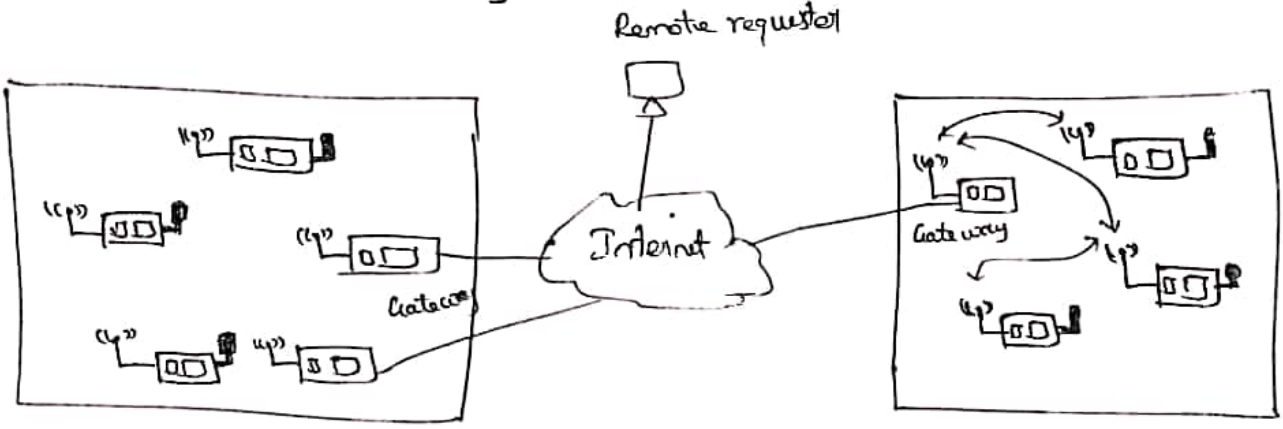


fig : Internet to WSN communication

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WSN tunneling :

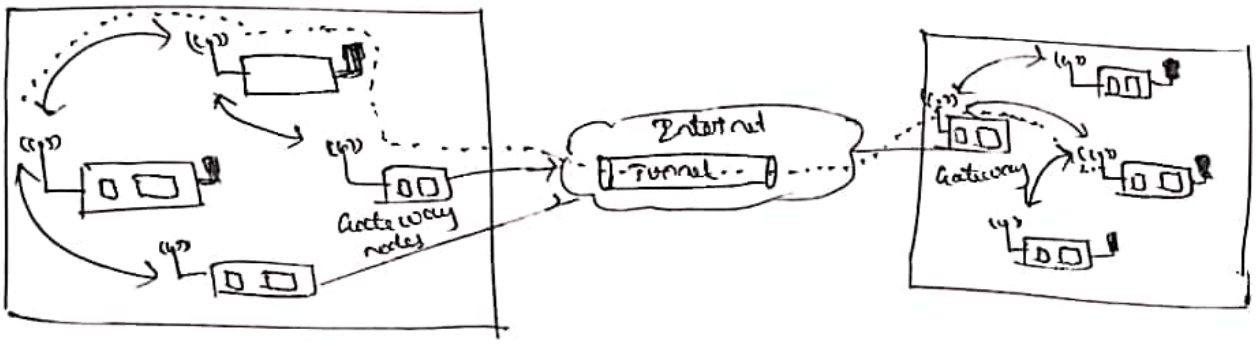
In addition to these describing actual interaction between a WSN and Internet terminals, the gateways can also act as simple extensions of one WSN to another WSN.

WSN tunneling is a process where a large virtual network is created from various separate parts in which all protocols messages are transferred from one WSN to the another WSN; simply using internet as transport network.

This can be attractive, but care has to be taken not to

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confuse the virtual link between two gateway nodes with a real link. Because it may confuse the protocols that are dependent on the physical properties of communication link. It is not necessary for these tunnels to be in the form of fixed nlw connection; even mobile node carried by people can be considered as means for intermediate of WSNs.



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Previous Question paper Answers: (Additional topics)

1) Discuss briefly about the advanced concepts for radio communication

Some of the advanced radio concepts:

1) Spread - spectrum Transceivers (SST):

SST overcomes the interface problems in ASK or FSK. However they face complex hardware and high price issues due to which they failed to gain much importance in WSNs.

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2) Ultrawide - band communication:

Ultra wide band (UWB) is large bandwidth that transmits digital sequence as short impulses. These impulses are spread over a large spectrum ranging from a few hertz to several GHz. However, such a large bandwidth can overlap with the spectrum of conventional ratio system. Since it is widely spread, a small transmission power is sufficient. UWB communication are impermeable to narrow band radio waves. They are capable of measuring the distance accurately

3) Wakeup Radio :

A node is said to be a wakeup receivers when it is turned on only when the packets starts towards it. It is necessary to turn on the node when it is only waiting for the packet.

The purpose of the wakeup receivers is to wakeup only the necessary receiver without wasting much of the power. The wakeup receivers overcomes the problems related to WSNs.

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Explain 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.

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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 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.

This technique is actually beneficial for CMOS chips. As the actual power consumption P depends quadratically on the supply voltage V_{DD}, reducing the voltage is very efficient way to reduce power consumption. Power consumption is also depends upon frequency. Hence $P \propto f \cdot V_{DD}^2$. Consequently, dynamic voltage scaling also reduces energy consumption

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