Chapter-2 (Single-node architecture)

The basic objective is to discuss the task performed by a node such as computation, storage, communication and sensing/actuation, along with the components needed to perform these tasks.

→ Also the energy consumption of these components is described, i.e. how energy is stored, gathered from the environment and saved by controlling the operation mode of node components.

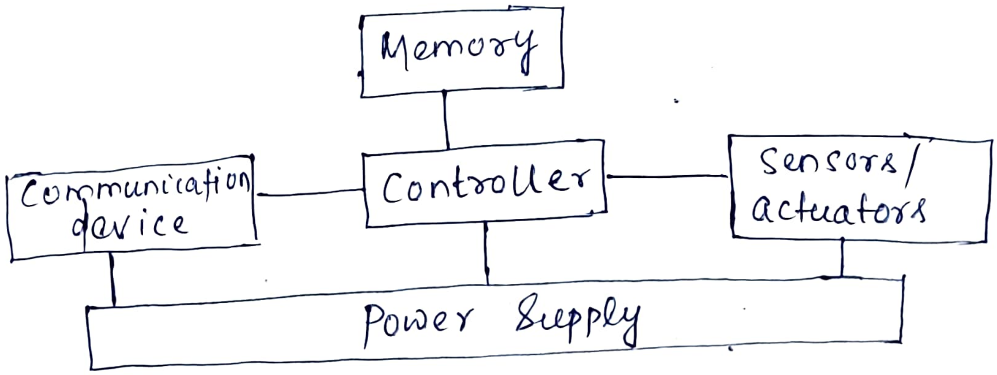
→ All these control is provided by a operating system. Therefore, this chapter provide an understanding about the capabilities and limitations of the nodes in a sensor network.

2.1 Hardware components:

2.1.1 Overview of sensor node hardware:

Selection for hardware components of a sensor node in WSNs depend on the application requirements and factors such as size, cost and energy consumption. Sometimes energy consumption in terms of communication and computation facilities are considered as acceptable quality. In reality the size of sensor node is not important rather convenience, simple power supply and cost are important.

Overview of main sensor node hardware components



The block diagram represents the components of a basic sensor node.

(a) Controller: It process all the data and executes an arbitrary code.

(b) Memory: It is used to store programs and immediate data. Different types of memory is used for programs and data.

Sensors and actuators: It provides an interface with the physical world, i.e. these device can sense or control the physical parameter of the environment.

Communication: with the help of communication the nodes are converted into network. Therefore wireless channel is required for sending and receiving information.

Power supply: Batteries are necessary to provide energy. Sometimes recharging of batteries is obtained from the environment (solar cells).

2.1.2 Controllers:

→ Controller collects data from sensors, processes it, decide the sending of the data, receive the data from other nodes and allow the actuators function ~~the~~.

→ Controller acts as the CPU of the node and executes programs ranging from ~~such as~~ signal processing and communication protocols to application programs.

Types of Processors (Microcontrollers)

The general purpose processor such as desktop computers can be used. However, these processors are overpowered and have excessive energy consumption.

→ The simpler processor useful for embedded systems are commonly referred as microcontrollers. These microcontrollers are suitable in embedded systems because of their flexibility in connecting with sensors, the instructions are amenable to signal processing, and low power consumption, instructions are convenient with builtin memory. They are also freely programmable.

→ Microcontrollers are suitable for WSNs as ~~it~~ it can reduce ~~energy~~ power consumption by entering into sleep states where only part of controller are active. One main difference to general purpose system is that microcontroller based system donot have the feature of memory management unit. Hence limiting the functionality of memory.

Digital Signal Processors (DSPs) :

DSP are the Programmable Processors which are geared w.r.t. to their architecture and the instruction set for processing large vector data. These are more applicable to signal processing scenarios.

→ In WSNs DSP used to process the incoming analog data from wireless commn device and extracts the digital data stream. In broadband wireless commn. DSP are appropriately used.

→ In WSNs requirements, the wireless Commn is simpler, easy to process and signal processing tasks of sensed data is not complicated, therefore DSP are not typically used in a WSN node.

Field Programmable Gate Arrays (FPGA) or Application specific integrated Circuits (ASICs) :

FPGA Provide a facility for reprogramming to adapt to a changing set of requirements. This facility is provided in terms of time and energy as it is not practical to reprogram FPGA at the same frequency as microcontrollers.

→ ASIC is specialized processor designed for given application such as high speed routers and switches. The trad-off is loss of flexibility compared to a better energy efficiency and performance. ASIC provide the functionality in hardware which require software development in a microcontroller. Therefore, ASIC results in costlier hardware development for dedicated WSNs applications over lifetime with large number of sensor nodes ASIC development is superior solution. However, looking at the high flexibility and simplicity of microcontrollers these are mostly preferred in current WSNs applications.

Some examples of microcontrollers

Intel strong RAM : It is a high-end Processor and is mostly geared toward handheld devices like PDAs. The SA-1100 model has 32 bit Reduced instruction set computer (RISC) core, runs upto 206 MHZ.

Texas Instruments MSP 430 :

A family of microcontrollers are designated as MSP 430. Unlike Strong ARM it is intended for embedded applications. It runs a 16 bit RISC core at a lower clock frequencies upto 4 MHZ.

-) It comes with wide interconnection possibilities and instructions to handle different peripherals.

-) It has on-chip RAM (2-10 KB), 12 bit A/D converters, and a realtime clock.

Atmel ATmega :

Atmel ATmega 128L is an 8 bit microcontroller, is intended for use in embedded applications and equipped with external interfaces for peripherals.

2.1.3 Memory :

The Random Access Memory (RAM) is required to store intermediate sensor readings, packets from the nodes. But RAM is volatile. Therefore, Program code can be stored in Read-Only Memory (ROM), ~~and~~ Electrically Erasable Programmable Read-only memory (EEPROM), and flash memory. The flash memory is similar to EEPROM allowing data to be erased or written in blocks instead of bytes at a time.

-) Flash memory also serve as intermediate storage of data when RAM is insufficient or when power supply of RAM is off for sometime.

-> The flash memory accounts for long read and write access delays and also it accounts for high energy.

2.1.4 Communication device:

Choice of transmission medium: The commn. device used to exchange data betn. individual sensor nodes. Some examples of wired communication are field bus like Profibus, LON, CAN etc.

LON: Local operating network is an open standard networking platform

CAN: Campus area network is a computer network interconnecting multiple LAN in a limited geographic area.

→ The communication devices for these networks are custom off-the-shelf components.

→ Some communication platform is wireless medium, which includes radio frequencies, optical communication, and ultrasound. From the various wireless medium radio-frequency (RF) based communication is most relevant as it is most suitable for WSNs requirements. It provides long range, high data rates, acceptable error rates at minimum energy expenditure, and doesn't require line of sight (LOS) betn transmitter (TX) and receiver (RX).

LOS: It is the direct path betn TX & RX in which obstructions face. If the object is blocking a direct view betn TX & RX it is considered as obstructed line of sight. Most wireless radio wave transmitted signal in straight lines from transmitter.

→ Typical WSNs communication frequencies lies betn. 433MHz and 2.4 GHz.

Transceivers:

→ For a sensor node to facilitate communication both transmitter and receiver are required in a sensor node. The main task is to convert the bit stream from a microcontroller to and from radiowaves. These combination of transmission and reception of data is carried out by the devices named as transceivers.

→ The preferred operation is half duplex since transmitting and receiving at same time on wireless medium is impractical in many situations. The commercially available transceivers have inbuilt circuits for transmitting and receiving - modulation, demodulation, amplifiers, mixers, filters, etc.

Transceiver tasks and characteristics :

A number of characteristics are taken into account for appropriate transceivers selection.

Service to upper layer :

Receiver has to offer certain services to upper layers i.e the medium access control (MAC) layer. These services are packet oriented, transceivers provides a byte or bit interface to microcontroller.

→ Hence the transceiver must provide an interface that allows the MAC layer to start frame transmissions and send the packets from main memory of sensor node into the transceiver. Hence, the incoming Packets need to be streamed into buffers accessible by the MAC Protocol.

Power consumption and energy efficiency :

Energy efficiency means how much energy is required to transmit and receive a single bit. Also in WSNs transceiver need to be switchable between active and sleeping states. The ideal power consumption in each states and during switching the states is important.

Carrier frequency and multiple channels !

Depending on the application requirements transceivers need to be available for different carrier frequencies. In dense networks transceiver must be able to Provide different carrier frequencies (channels) that overcomes the congestion problems. Certain examples of 'sub bands' for MAC Protocols (FDMA or multichannel CSMA/ ALOHA are used.

FDMA : frequency division multiple access

CSMA : The carrier sense multiple access is a MAC Protocol for a sensor node to verify whether the data traffic is absent before sending a data on a shared transmission medium.

ALOHA: Advocates of Linux open-source Hawaii Association
Protocol functions within OSI (open systems Interconnection)
MAC layer.

State change times and energy:

As transceivers operate in both sending and receiving modes through different channels, therefore the time and energy required to change between the states are important figure of merit. The turnaround time betn sending & receiving is important for MAC.

Data rates:

The data rate is determined by combining used modulation, carrier frequency, and coding. Typical data rates for WSNs are few tens of kilobits/sec. The data rate can be made different by changing the type of modulation or changing the symbol rate.

Modulations:

The supported modulations are ASK, FSK etc. For real time deployment scenario the different modulations are available at runtime.

Coding: The transceivers required to allow different coding.

Transmission Power control:

Transceivers require either direct or external control over its transmission power. A discrete power levels are used for power transmission through regulation of power.

Noise figure: It is defined as the ratio of signal to noise power (SNR) at the i/p of device to SNR at o/p of device.

$$NF = \frac{(SNR)_I}{(SNR)_o}$$

It represents the amount of degradation in device's operation & is expressed in dB.

$$(NF)_{dB} = (SNR)_I\big|_{dB} - (SNR)_o\big|_{dB}$$

Gain : Gain is the ratio of o/p signal power to i/p signal Power and is expressed in dB. To acheive high energy efficiency high gain amplifiers are used.

Power efficiency : It is defined as the ratio of radiated power to the overall Power consumed by the font end. for Power amplifier efficiency defined as the ratio of o/p signal Power to the power consumed by the Power amplifier.

Receiver sensitivity : It is expressed in dBm and specifies the minm. signal Power at the receiver needed to achieve desired E_b/N_0 or a Prescribed bit/packet error rate.

Range : Range of transmitter depends on maxm transmission power, antenna characteristics, attenuation caused by the environment, which in turn depends on the carrier frequency, modulation/coding scheme and the acceptable bit error rate at the receiver.

Blocking Performance : It is defined for a receiver as its achieved bit error rate in presence of interferer. The important special case is adjacent channel interferer that transmits on neighboring frequencies. Adjacent channel suppression is the transceiver's ability to filter out signals from adjacent frequency bands. It has direct impact on observed signal to interference and noise ratio (SINR).

Out of band emission : It is the inverse of adjacent channel suppression of a transmitter. The transmitter used to produce a little ~~power~~ transmission Power outside its prescribed bandwidth to limit the disturbance of other systems or of the WSN.

Carrier sense and RSSI : In medium access ~~c~~ control Protocols, sensing of the wireless channel ~~and~~ or carrier is essential to check whether it is busy due to another node transmission. The receiver need to Provide this information. The IEEE 802.15.4 standard distinguishes the following modes:

→ The underlying signal does not respond accurately with the modulation and spectral characteristics even if the received energy is above threshold.

→ A carrier has been detected, i.e. some signal which complies with the modulation.

→ Carrier is detected and energy is present.

Also the receiver provide an useful Received Signal Strength Indicator (RSSI) information, which indicates the strength at which incoming data packet has received from a transmitter with known transmitter power.

Frequency Stability: It denotes the degree of frequency variation from nominal center frequencies when there is variation in environmental temperature and pressure change. A poor frequency stability can break communication links. An example is when one sensor node is kept in sunlight whereas its neighbor is in shade.

Voltage range: Transceivers need to operate reliably over a range of supply voltages. Otherwise voltage stabilization circuitry is required.

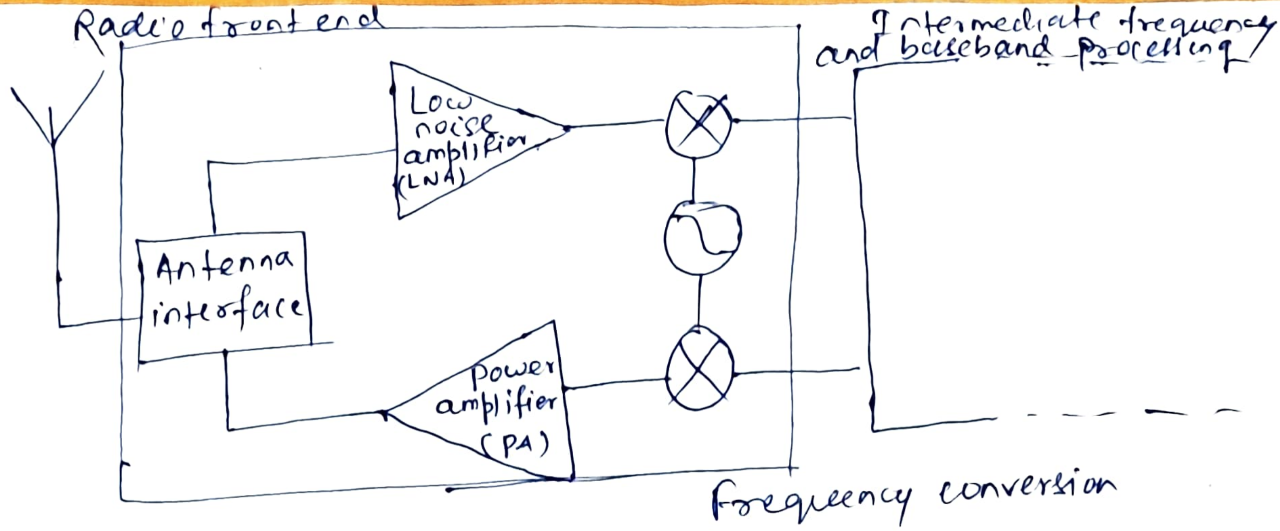
Transceiver Structure:

The common structure of transceivers is into the RF ~~font~~ front end and the baseband part.

→ RF front end performs analog signal processing in actual radio frequency band whereas baseband processor performs signal processing in digital domain and communicate with sensor node's processor or other digital circuitry.

→ There is a frequency conversion between these two parts either directly or through one or more intermediate frequencies (IFs). The boundary between analog and digital domain is constituted by DACs and ADCs.

→ The RF front end performs analog signal processing in actual radio frequency band, in the 2.4 GHz industrial, Scientific and Medical (ISM) band. It is the first stage of interface betn. the electromagnetic waves and the digital signal processing of the further transceiver stages.



→ Power amplifier (PA) accepts the signal from the IF or baseband part and amplifies before transmission over antena.

→ LNA amplifies signals suitable for further processing without reducing the SNR. The LNA is active all the time and consume significant fraction of transceiver energy.

→ Local oscillators or voltage-controlled oscillators and mixers are used for frequency conversion from the RF spectrum to intermediate frequencies or to the baseband.

Transceiver operational states

Transmit : In transmit state the transmit part of transceiver is active and antenna radiates energy.

Receive : In this state the receiver part is active.

Idle : In this state the transceiver is ready to receive but not receiving anything. In ideal state many parts of the receive circuitry are active and others are switched off. for example the (synchronization circuit) where some elements concerned with aquisition are active, while those concerned with tracking can be switched off and activated only when acquisition found something.

Sleep : In this state significant parts of transceiver are switched off. Sleep states differ in amount of circuitry switched off and in the associated recovery times and startup energy. for complete sleep mode (power off) of transceiver, the startup cost include complete configuration & initialization of radio, whereas for 'lighter' sleep modes, ~~the~~ certain transceiver parts is configured and the operational state is remembered.

Advanced radio concepts:

Some of the advanced concepts for radio communication are as follows.

Wakeup radio:

To effectively mange power ~~operati~~ operations of the receiver, the receiver need to power on only if a packet/data starts arrive at it. For this a receiver need to raise an event to notify a packet, this specialized receiver structure does not need power but can detect ~~the~~ packet arrival. After receiving the event the main receiver is turned on and perform actual reception of the packet. Such receiver concept are called wakeup receivers. Their main purpose is to wake up the main receiver without requiring power to do so.

→ In actual sense wakeup happens for every packet, i.e the main receiver will only wake up when incoming packet is actually destined for the node by using proper address information at the start of the packet.

→ Wakeup receiver are used to simplify design problems of WSNs, permanent packet receive with low average traffic. The realization of reliable, well-performing wakeup receiver has not yet achieved.

Spread-spectrum transceivers:

Traditional tranceiver concepts that are based on ASK, FSK have limited performance in presence of interference signals. These problems are overcome by using spread-spectrum transceivers. However, these transceivers have more cost and complexity and being less preferred in WSNs.

Ultrawideband communication (UWB)

UWB communication uses a very large bandwidth to directly transmit the digital sequences as short impulses. Therefore UWB spectrum ranges from few Hz to several GHz. As it uses short impulses they have small transmitter power which may vanish in presence of noise.

-) Again UWB commn. can easily penetrate obstacles such as doors due to it high data rate over short distances, which are impermeable to narrowband radio waves. Though high data rate is not that necessary in WSNs but it helps in reducing the on-time of the transceivers.

-) All the above desirable feature of UWB communication need to be balanced against the difficulties in building low-cost and low-power transceivers. Moreover, UWB transmitter are very simple since it doesnot require oscillators, related circuits that are used in transmitters for carrier frequency based transmitter. However, the UWB receivers requires complex timing synchronization. Therefore, UWB transceivers have not been used in prototype for wireless nodes.

-) In some low bitrate and short range applications. UWB is an alternate for IEEE 802.15.4a

Non radio frequency wireless communication

Though in most WSNs applications radiowaves are used as commn. medium there are sm nonradio commn. such as optical commn., ultrasound commn. are also considered.

-> the optical link betn sensor nodes provides a very small energy per bit to generate and detect the optical light. The LED's are considered as high efficiency transmitters. Another advantage of optical transceiver is its simplicity in circuit design and smaller size than radio frequency counterpart. However, the optical commn. has disadvantages that commn betn transmitter and receiver is the line of sight commn and their commn is influenced by weather conditions.

-> In some wireless environment the radio wave and optical commn is not used as they are unable to penetrate such medium (water). So Applications such as surveillance of marine ground floor erosion to help in construction of offshore wind firms, where ultrasound is an attractive communication medium, as ultrasound travels a long distance at comparatively low power.

Examples of radio transceivers

Most commonly used standard radio transceivers that are ~~ar~~ used for WSN prototype nodes ~~are~~ are single-chip solutions, integrating transmitter and receiver functionality, require small external part with low power consumption. Some of these transceivers are:

RFM TR1000 family

-) Available for 916 MHz ~~to~~ & 868 MHz frequency range.
-) Intended for short range radio commn. with rate upto 115.2 kbps.
-) Uses on-off or ASK modulation, with dynamic tunable o/p power.
-) Provide RSS information.
-) Low power consumption in both send and receive, especially in sleep mode.

Hardware accelerators: (Mica motes)

-) Mica motes use RFM TR1000 transceiver and also contain hardware accelerators.
-) Provides low level interface, giving microcontroller tight control over frame formats, MAC protocol, & so on.

Chipcon CC1000 and CC2420 family:

-) CC1000 operates in wide freq. range betn. 300 and 1000 MHz, with programmable o/p power.
-) CC2420 implements the physical layer as prescribed by IEEE 802.15.4 with required support for this standard MAC protocol. This transceiver operates in the 2.4 GHz band and ~~ac~~ uses the DSSS modem, at a data rate of 250 kbps, with low power consumption

Infineon TDA 525x family:

-) ~~Th~~ This family provides single-chip, flexible, energy efficient transceivers.
-) It is 868-870 MHz transceiver that provide both ASK & FSK modulation with efficient power amplifier, RSSI information, a tunable crystal oscillator, data filter and an intelligent power down service.
-) It has excellent blocking performance to interference.

IEEE 802.15.4/ Ember EM2420 RF transceiver:

-) It is a low rate WPAN works with three different freq. bands and uses DSSS technique.

National Semiconductor LMX3162 :

→ LMX3162 operates at 2.4GHz band and offers six different radiated power levels from 0dBm upto 20dBm.
→ A data transmission rate of 1Mbps with FSK modulation is used.

Conexant RDSSS9M

→ This transceiver consists of RF part working on ISM band betn. 902 and 928MHz.
→ DSSS is used, a data rate of 100 kbps used.

Sensors and actuators :

Sensors are broadly categorized into passive, omnidirectional; passive, narrow-beam, and active sensors.

Passive omnidirectional : These sensors measure physical quantity at the sensor node without manipulating the environment. Some of these sensors are self powered, i.e they obtain the energy from the environment
→ In these sensors there is no notion of 'direction' involvement in the measurement. eg: thermometer, light sensors, vibration, humidity

Passive, narrow-beam sensors:

These sensors are passive but have a well-defined notion of direction of measurement. for example camera, which take measurements in a given direction, but can be rotated as per requirement.

Active sensors : These sensors actively probes the environment. for example, Sonar or radar sensor, which generate shock waves by small explosions.
* Most theoritical work in WSN considers passive sensors.

Actuators

these are the devices that can open or close a switch, or relay or to set some threshold value in some way by a control actuating signal. whether actuator control a motor, light bulb, or other object it is not the concern for the communication protocol design.

Power supply of sensor nodes

for untethered wireless sensor nodes power supply is achieved either by storing energy & providing power or replenishing consumed energy by 'scavenging' from some node - external power source over time. Power storing is conventionally done by batteries.

Storing energy: Batteries

The power source of a sensor node is a battery, either nonrechargable ("Primary batteries") or if an energy scavenging device is present on the node also rechargable ("secondary batteries")

Requirements on batteries

Capacity: Must have high capacity, small weight, small volume, and low price. The performance metric is Joule/volume (J/cm^3).

capacity per load: As sensor nodes acquire different power levels for different operation modes over time and at times draws high current in certain operations, batteries must withstand these varying conditions.

Self discharge: Batteries have to last for long time, therefore self discharge should be low.

efficient recharging: Batteries must efficiently rechargable even at low or intermittently ~~to~~ available recharge power.

Relaxation: The self recharging of an empty battery should be understood. The battery lifetime and usable capacity is significantly extended through chemical diffusion process (Relaxation). It is also possible to use multiple batteries in parallel & 'schedule' the discharge from one battery to another, depending on relaxation properties & power requirements of operation to be supported.

unconventional energy store: fuel cells are an electro-chemical storage of energy, that directly produces electrical energy by oxidizing hydrogen or hydrocarbon fuels also act one form of energy reservoirs. Also radioactive substances act as energy store. "Gold caps" a high quality and high capacity capacitor can also store large amount of energy.

DC-DC conversion: Battery voltage generally reduces as its capacity drops. To ensure a constant voltage even though the battery's supply voltage drops, the DC-DC converter is used.

Energy scavenging:

Some unconventional energy stores such as fuelcells, radio activity convert energy from stored secondary form into electricity. To ensure long lasting nodes for WSNs the Lomeded stores cannot be used because for example if fuel supply is exhausted the node failure occurs. Therefore, energy from a node's environment must be tapped into and made available to node. This is referred as energy scavenging. Some approaches are:

Photovoltaics:

The solar cells can be used to power the sensor nodes. The available power depend on the indoor or outdoor applications for which sensor nodes are deployed. A single cell provide stable o/p voltage of 0.6V and hence can be used in series as long as drawn current is with in the threshold value. Therefore, solar cells are used to recharge secondary battery. [Recharging circuit, solarcell efficiency are open questions.]

Temperature gradients:

Gradient of temperature means temperature difference. This can be directly converted into electrical energy. Theoritically, a small difference of 5k can produce considerable power.

Vibrations: One ~~most~~ pervasive form of mechanical energy is vibrations. The walls & windows of buildings vibrate due to ~~many~~ near by motion of vehicles, functioning of machines. The amplitude and frequency of vibration leads to available energy. Converting vibrations into electrical energy can be accomplished through electromagnetic, electrostatic or piezoelectric effects.