Node Architecture

A basic sensor node comprises five main components such as

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

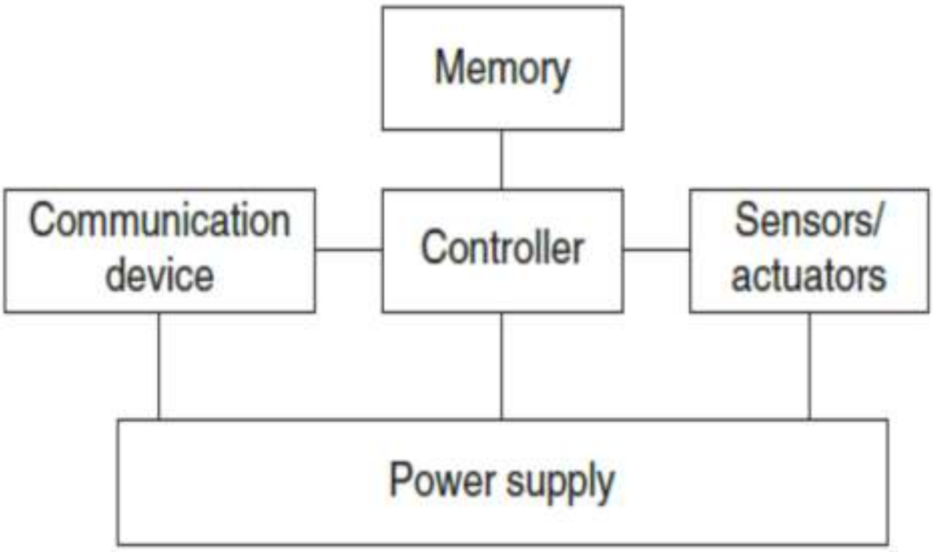

Fig 1.1 Hardware Components of Sensor Node

Controller

A controller to process all the relevant data, capable of executing arbitrary code. The controller is the core of a wireless sensor node. It collects data from the sensors, processes this data, decides when and where to send it, receives data from other sensor nodes, and decides on the actuator's behavior. It is the Central Processing Unit of the node. For general purpose processors applications microcontrollers are used. These are highly overpowered and their energy consumption is excessive. These are used in embedded systems. Some of the key characteristics of microcontrollers are particularly suited to embedded systems are their flexibility in connecting with other devices like sensors and they are also convenient in that they often have memory built in. A specialized case of programmable processor is Digital Signal Processors. They are specifically geared, with respect to their architecture and their instruction set, for processing large amount of vectorial data, as is typically the case in signal processing applications.

Memory

In WSN there is a need for Random Access Memory(RAM) to store intermediate sensor readings, packets from other nodes and so on. While RAM is fast, its main disadvantage is that it loses its content if power supply is interrupted. Program code can be stored in ROM or more typically in Electrically Erasable Programmable Read –Only Memory(EEPROM) OR flash memory. Flash memory can also serve as intermediate storage of data in case RAM is insufficient or when the power supply of RAM should be shut down for some time.

Sensors and Actuators

Sensors

Sensors can be categorized into three

- 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 that is passive.
- Passive, narrow- beam sensors: These sensors are passive as well, but have well defined notion of direction of measurement.
- Active sensors: This sensor actively probes the environment Eg: A sonar or radar sensor or some types of seismic sensors, which generates shock waves by small explosions.

Actuators: Actuators are just about as diverse as sensors, yet for the purposes of designing a WSN that converts electrical signals into physical phenomenon.

Communication Device

- Choice of transmission medium: The communication device is used to exchange data between individual nodes. In some cases, wired communication can actually be the method of choice and is frequently applied in many sensor networklike settings (using field buses like Profibus, LON, CAN, or others). The communication devices for these networks are custom off-the-shelf components. The case of wireless communication is considerably more interesting. The first choice to make is that of the transmission medium – the usual choices include radio frequencies, optical communication, and ultrasound; other media like magnetic inductance are only used in very specific cases. Of these choices, Radio Frequency (RF)-based communication is by far the most relevant one as it best fits the requirements of most WSN applications: It provides relatively long range and high data rates, acceptable error rates at reasonable energy expenditure, and does not require line of sight between sender and receiver
- Transceivers :For actual communication, both a transmitter and a receiver are required in a sensor node. The essential task is to convert a bit stream coming from a microcontroller (or a sequence of bytes or frames) and convert them to and from radio waves.

- Transceiver Structure A fairly common structure of transceivers is into the Radio Frequency (RF) front end and the baseband part:
  - The radio frequency front end performs analog signal processing in the actual radio frequency band, whereas the baseband processor performs all signal processing in the digital domain and communicates with a sensor node’s processor or other digital circuitry. Between these two parts, a frequency conversion takes place, either directly or via one or several Intermediate Frequencys (IFs). The boundary between the analog and the digital domain is constituted by Digital/Analog Converters (DACs) and Analog/Digital Converters (ADCs). The RF front end performs analog signal processing in the actual radio frequency band, for example in the 2.4 GHz Industrial, Scientific, and Medical (ISM) band; it is the first stage of the interface between the electromagnetic waves and the digital signal processing of the further transceiver stages. Some important elements of an RF front ends architecture are sketched in Figure:

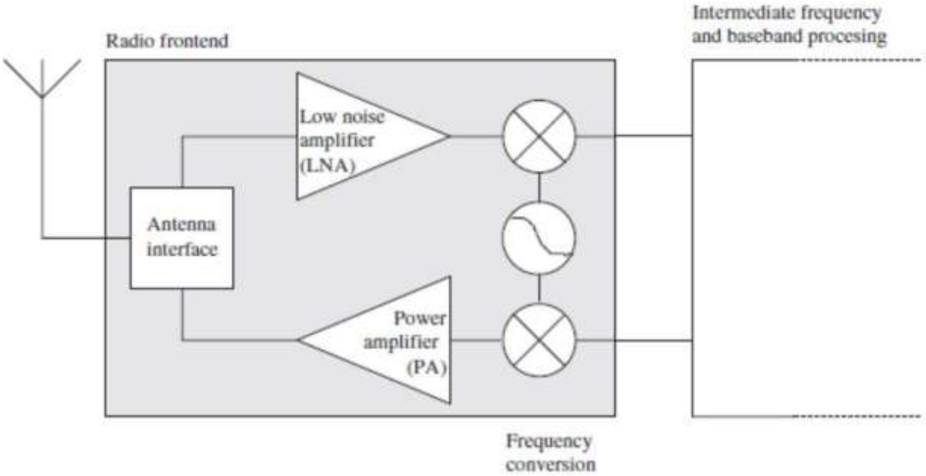

Fig 1.2.1 RF Front end

  - The Power Amplifier (PA): It accepts upconverted signals from the IF or baseband part and amplifies them for transmission over the antenna.
  - The Low Noise Amplifier (LNA): It amplifies incoming signals up to levels suitable for further processing without significantly reducing the SNR [470]. The range of powers of the incoming signals varies from very weak signals from nodes close to the reception boundary to strong signals from nearby nodes; this range can be up to 100 dB. Without management actions, the LNA is active all the time and can consume a significant fraction of the transceiver’s energy.

- **Transceiver tasks and characteristics**: To select appropriate transceivers, a number of characteristics should be taken into account. The most important ones are:
  1. Service to upper layer: A receiver has to offer certain services to the upper layers, most notably to the Medium Access Control (MAC) layer. Sometimes, this service is packet

oriented; sometimes, a transceiver only provides a byte interface or even only a bit interface to the microcontroller. In any case, the transceiver must provide an interface that somehow allows the MAC layer to initiate frame transmissions and to hand over the packet from, say, the main memory of the sensor node into the transceiver (or a byte or a bit stream, with additional processing required on the microcontroller). In the other direction, incoming packets must be streamed into buffers accessible by the MAC protocol.

2. Power consumption and energy efficiency: The simplest interpretation of energy efficiency is the energy required to transmit and receive a single bit. Also, to be suitable for use in WSNs, transceivers should be switchable between different states, for example, active and sleeping. The idle power consumption in each of these states and during switching between them is very important.
3. Carrier frequency and multiple channels: Transceivers are available for different carrier frequencies; evidently, it must match application requirements and regulatory restrictions.
4. State change times and energy: A transceiver can operate in different modes: sending or receiving, use different channels, or be in different power-safe states.
5. Data rates: Carrier frequency and used bandwidth together with modulation and coding determine the gross data rate.
6. Modulations: The transceivers typically support one or several of on/off-keying, ASK, FSK, or similar modulations.
7. Coding: Some transceivers allow various coding schemes to be selected.
8. Transmission power control: Some transceivers can directly provide control over the transmission power to be used; some require some external circuitry for that purpose. Usually, only a discrete number of power levels are available from which the actual transmission power can be chosen. Maximum output power is usually determined by regulations.
9. Noise figure: The noise figure, NF of an element is defined as the ratio of the Signal-to-Noise Ratio (SNR) ratio SNRI at the input of the element to the SNR ratio SNRO at the element’s output. It describes the degradation of SNR due to the element’s operation and is typically given in dB.
10. Gain: The gain is the ratio of the output signal power to the input signal power and is typically given in dB. Amplifiers with high gain are desirable to achieve good energy efficiency.
11. Power efficiency: The efficiency of the radio front end is given as the ratio of the radiated power to the overall power consumed by the front end; for a power amplifier,

the efficiency describes the ratio of the output signal’s power to the power consumed by the overall power amplifier.

12. Receiver sensitivity: The receiver sensitivity (given in dBm) specifies the minimum signal power at the receiver needed to achieve a prescribed Eb/N0 or a prescribed bit/packet error rate.
13. Range: The range is considered in absence of interference; it evidently depends on the maximum transmission power, on the antenna characteristics, on the attenuation caused by the environment, which in turn depends on the used carrier frequency, on the modulation/coding scheme that is used, and on the bit error rate that one is willing to accept at the receiver. It also depends on the quality of the receiver, essentially captured by its sensitivity. Typical values are difficult to give here, but prototypes or products with ranges between a few meters and several hundreds of meters are available.
14. Blocking performance: The blocking performance of a receiver is its achieved bit error rate in the presence of an interferer.
15. Out of band emission: The inverse to adjacent channel suppression is the out of band emission of a transmitter. To limit disturbance of other systems, or of the WSN itself in a multichannel setup, the transmitter should produce as little as possible of transmission power outside of its prescribed bandwidth, centered around the carrier frequency.
16. Carrier sense and RSSI: In many medium access control protocols, sensing whether the wireless channel, the carrier, is busy (another node is transmitting) is a critical information. The receiver has to be able to provide that information. The precise semantics of this carrier sense signal depends on the implementation
17. Voltage range: Transceivers should operate reliably over a range of supply voltages. Otherwise, inefficient voltage stabilization circuitry is required.

Power Supply Of Sensor Nodes

For untethered wireless sensor nodes, the power supply is a crucial system component. There are essentially two aspects:

a) First, storing energy and providing power in the required form
b) Second, attempting to replenish consumed energy by “scavenging”.

Storing energy: Batteries

- Traditional batteries The power source of a sensor node is a battery, either non-rechargeable (“primary batteries”) or, if an energy scavenging device is present on the node, also rechargeable (“secondary batteries”).
- **Capacity**: They should have high capacity at a small weight, small volume, and low price. The main metric is energy per volume, J/cm3.

- **Capacity under load** : They should withstand various usage patterns as a sensor node can consume quite different levels of power over time and actually draw high current in certain operation modes.
- Self-discharge Their self-discharge should be low; Zinc-air batteries, for example, have only a very short lifetime (on the order of weeks.
- Efficient recharging: Recharging should be efficient even at low and intermittently available recharge power.
- Relaxation: Their relaxation effect – the seeming self-recharging of an empty or almost empty battery when no current is drawn from it, based on chemical diffusion processes within the cell – should be clearly understood. Battery lifetime and usable capacity is considerably extended if this effect is leveraged.
- DC–DC Conversion Unfortunately, batteries (or other forms of energy storage) alone are not sufficient as a direct power source for a sensor node. One typical problem is the reduction of a battery’s voltage as its capacity drops. A DC – DC converter can be used to overcome this problem by regulating the voltage delivered to the node’s circuitry. To ensure a constant voltage even though the battery’s supply voltage drops, the DC – DC converter has to draw increasingly higher current from the battery when the battery is already becoming weak, speeding up battery death. Also, the DC – DC converter does consume energy for its own operation, reducing overall efficiency.

Energy scavenging

Some of the unconventional energy stores described above – fuel cells, micro heat engines, radioactivity – convert energy from some stored, secondary form into electricity in a less direct and easy to use way than a normal battery would do. The entire energy supply is stored on the node itself – once the fuel supply is exhausted, the node fails.

- Photovoltaics The well-known solar cells can be used to power sensor nodes. The available power depends on whether nodes are used outdoors or indoors, and on time of day and whether for outdoor usage. Different technologies are best suited for either outdoor or indoor usage. The resulting power is somewhere between 10 μW/cm2 indoors and 15 mW/cm2 outdoors. Single cells achieve a fairly stable output voltage of about 0.6 V (and have therefore to be used in series) as long as the drawn current does not exceed a critical threshold, which depends, among other factors, on the light intensity. Hence, solar cells are usually used to recharge secondary batteries.
- Temperature gradients: Differences in temperature can be directly converted to electrical energy.
- Vibrations: One almost pervasive form of mechanical energy is vibrations: walls or windows in buildings are resonating with cars or trucks passing in the streets, machinery often has low frequency vibrations, ventilations also cause it, and so on. The available energy depends on both

amplitude and frequency of the vibration and ranges from about 0.1 µW/cm3 up to 10, 000 µW/cm3 for some extreme cases (typical upper limits are lower).

- Pressure variations Somewhat akin to vibrations, a variation of pressure can also be used as a power source.

Energy Consumption of Sensor Nodes

Operation states with different power consumption

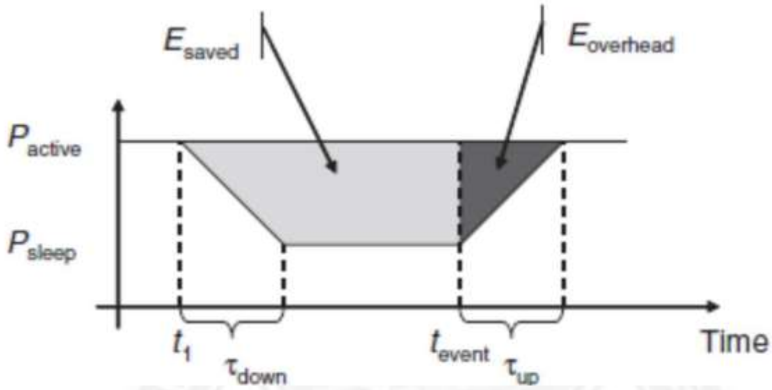

Fig 1.2.2 Energy Savings and Overheads for skeed Modes

Figure illustrates this notion based on a commonly used model. At time t1, the decision whether or not a component (say, the microcontroller) is to be put into sleep mode should be taken to reduce power consumption from Pactive to Psleep. If it remains active and the next event occurs at time tevent, then a total energy of Eactive = Pactive (tevent − t1) has be spent uselessly idling. Putting the component into sleep mode, on the other hand, requires a time τdown until sleep mode has been reached; as a simplification, assume that the average power consumption during this phase is (Pactive + Psleep)/2. Then, Psleep is consumed until tevent. In total, τdown(Pactive + Psleep)/2 + (tevent − t1 − τdown)Psleep energy is required in sleep mode as opposed to (tevent − t1)Pactive when remaining active. The energy saving is thus

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

Once the event to be processed occurs, however, an additional overhead of

$$E_{overhead} = \tau_{up}(P_{active} + P_{sleep})/2,$$

is incurred to come back to operational state before the event can be processed, again making a simplifying assumption about average power consumption during makeup. This energy is indeed an overhead since no useful activity can be undertaken during this time. Clearly, switching to a sleep mode is only beneficial if Eoverhead < Esaved or, equivalently, if the time to the next event is sufficiently large:

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

Microcontroller energy consumption

- **Basic power consumption in discrete operation states**: Embedded controllers commonly implement the concept of multiple operational states as outlined above; it is also fairly easy to control. Some examples probably best explain the idea. Dynamic voltage scaling A more sophisticated possibility than discrete operational states is to use a continuous notion of functionality/power adaptation by adapting the speed with which a controller operates. The idea is to choose the best possible speed with which to compute a task that has to be completed by a given deadline. One obvious solution is to switch the controller in full operation mode, compute the task at highest speed, and go back to a sleep mode as quickly as possible. The alternative approach is to compute the task only at the speed that is required to finish it before the deadline. The rationale is the fact that a controller running at lower speed, that is, lower clock rates, consumes less power than at full speed. This is due to the fact that the supply voltage can be reduced at lower clock rates while still guaranteeing correct operation. This technique is called Dynamic Voltage Scaling (DVS).
- **Memory**: From an energy perspective, the most relevant kinds of memory are on-chip memory of a microcontroller and FLASH memory – off-chip RAM is rarely if ever used. In fact, the power needed to drive on-chip memory is usually included in the power consumption numbers given for the controllers. Read times and read energy consumption tend to be quite similar between different types of FLASH memory. Writing is somewhat more complicated, as it depends on the granularity with which data can be accessed (individual bytes or only complete pages of various sizes). One means for comparability is to look at the numbers for overwriting the whole chip. Considerable differences in erase and write energy consumption exist, up to ratios of 900:1 between different types of memory. Hence, writing to FLASH memory can be a time- and energy-consuming task that is best avoided if somehow possible. For detailed numbers, it is necessary to consult the documentation of the particular wireless sensor node and its FLASH memory under consideration.
- **Radio transceivers**: A radio transceiver has essentially two tasks: transmitting and receiving data between a pair of nodes. To accommodate the necessary low total energy consumption, the transceivers should be turned off most of the time and only be activated when necessary – they work at a low duty cycle. But this incurs additional complexity, time and power overhead that

has to be taken into account. To understand the energy consumption behavior of radio transceivers and their impact on the protocol design, models for the energy consumption per bit for both sending and receiving are required.

- **Power consumption of sensor and actuators**: Providing any guidelines about the power consumption of the actual sensors and actuators is next to impossible because of the wide diversity of these devices. For some of them – for example, passive light or temperature sensors – the power consumption can perhaps be ignored in comparison to other devices on a wireless node. For others, in particular, active devices like sonar, power consumption can be quite considerable and must even be considered in the dimensioning of power sources on the sensor node, not to overstress batteries, for example. To derive any meaningful numbers, requires a look at the intended application scenarios and the intended sensors to be used.