Implementation of Wireless Sensor Mote

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By

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Certificate

It is certified that the work contained in the thesis entitled "Implementation of Wireless Sensor Mote" by Manish Raghuvanshi (Y3215006) has been carried out under our supervision and this work has not been submitted elsewhere for the award of degree.

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Manish Raghuvanshi

Abstract

The vast potential of Sensor Networks is an emerging area of research in recent years. By networking large numbers of tiny sensor motes, it is possible to obtain data about physical phenomena that was difficult or even sometimes impossible to obtain in conventional ways.

The sensor motes have certain tradeoffs in terms of size, power, cost, code size, and data rate. We have designed a slave sensor mote (10 cm by 8 cm) and a master mote (10 cm by 5.5 cm). The hardware design is simple and cheap, but is larger in terms of size when compared with Mica Mote.

The three components that dominate power dissipation for slave sensor mote are the microcontroller, the radio and the buffers. The current needed to power up the Sensor Mote is measured 77mA, which has been ensured with the optimum use of mote's devices. This current is comparable to Mica Mote. The battery with capacity 580Ah is deployed; hence implemented mote can be used continuously in an application for around 254 days. Zigbee wireless standard was chosen as a communication protocol. The transmission achieved is a real time data transmission with data rate of 250 kbps. This has been ensured with minimum use of radio module's buffers and keeping the backoff exponent of CSMA zero. The signal strength of last packet received is found to be – 77.0553dBm.

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Chapter 1
Introduction

1.1 Thesis Introduction

According to Moore's Law, the number of transistors on a microchip doubles approximately every two years, leading to faster and more powerful computers on our desktops with each generation. At the same time, microprocessors with a given computing capacity are becoming smaller and cheaper with every passing year. While silicon scaling marches on, the same semiconductor manufacturing processes are being utilized to build microscopic mechanical structures that interact with the physical world. This technology, called MEMS (microelectromechanical systems) [1], enables the production of velocity sensors, thermometers, and even low-power radio components that fit on the head of a pin and cost just pennies each. These three hardware ingredients e.g. microprocessors, sensors, and low-power radios--make up a sensor node, or mote.

Efficient design and implementation of wireless sensor network has become an emerging area of research in recent years, due to vast potential of sensor network enables application that connect the physical world to the virtual world. By networking large numbers of tiny sensor motes, it is possible to obtain data about physical phenomena that was difficult or impossible to obtain in conventional ways. In coming years, as advances in micro-fabrication technology allow the continuous drop of the cost of manufacturing sensor motes, increasing deployments of wireless sensor networks are expected with the network eventually growing to large numbers of motes.

1.2 Wireless Sensor Mote

To deploy the wireless sensor network we are required to have the basic unit, which deals in sensing the required data as well, transmit it. This basic unit is known as Wireless

Sensor Node or Mote (WSM). The name Mote is given by the scientists from UC Berkeley, involve in a project, known as Smart Dust. It was a project funded by the Defense Advanced Research Projects Agency's Network Embedded Software Technology program. The aim of the Smart dust project is to shrink the devices down to dust mote size.

The WSM is wireless embedded system. The implementation of the WSM can be divided in two parts.

- Hardware
- Software

Hardware implementation deals in drawing the schematic on the plane paper according to the application, testing the schematic design over the breadboard using the various IC's to find if the design meets the objective, carrying out the PCB layout of the schematic tested on breadboard, finally preparing the board and testing the designed hardware.

The software part deals in programming the microcontroller so that it can control the operation of the IC's used in the implementation. In the present work we have used the Protel design software [28][29] for PCB layout design, the WinAVR software development tool [2] to write and compile the source code, which has been written in the C language. The PonyProg serial device programmer [3] has been used to write this compile code into the microcontroller.

1.3 Need for Wireless Sensor Mote

Wireless Sensor Networks are found to be useful when we talk about the surveillance. It may be surveillance for military application, home appliances, seismic applications, monitoring the wild life, structures monitoring, environment monitoring etc. The advantage of wireless sensor network is that we can use them with ease in the environment where wired system cannot be used or if used we have to be very cautious for example in medical treatment. The sensor motes can also be deployed to monitor patients and assist disabled patients. Some other commercial applications Include *managing inventory, monitoring* *product quality, and monitoring disaster areas*. These areas can be differentiated in three main categories

• Monitoring space,

• Monitoring things, and

• Monitoring the interactions of things with each other and the encompassing space.

The first category includes environmental and habitat monitoring [4], precision agriculture, indoor Climate control [5], surveillance, treaty verification, and intelligent alarms. The second includes structural monitoring [6], ecophysiology and condition-based equipment maintenance and medical diagnostics [7]. The most dramatic applications involve monitoring complex interactions, including wildlife habitats [8], disaster management, emergency response, ubiquitous computing environments, asset tracking, healthcare, and manufacturing process flow.

The wireless Sensor motes (WSM) can be deployed to have more than one sensing capability if the different sensors are put on the same WSM. So we can have different data at the same time i.e. acoustics, seismic, environmental etc. transmitted trough the WSM to the base station. This data can be processed at the base station to get the various kinds of information at the same time.

Finally we can say the Wireless Sensors are a giant leap toward proactive computing, a paradigm where computers anticipate human needs and, if necessary, act on their behalf. Instead of shuttling data between the real world and machines, the human is at the top reaping the benefits of ubiquitous computer. Sensor network and proactive computing has the potential to improve our productivity and enhance safety, awareness, and efficiency at the societal scale.

1.4 Data Transfer between WSM

The transmission of the data can be achieved using Infrared (IR) and radio frequency (RF). IR requires line of sight (LOS) path between the transmitter and receiver and hence is not used frequently. Instead, RF is used in wireless sensor network as it implements a wireless link in which the waves can penetrate a limited number of walls.

A protocol is a set of rules or agreed upon guidelines for communication. When communicating, it is important to agree on how to do so. If one party speaks French and one German the communications will most likely fail. Various communication protocols are used in respect to achieve reliability, integrity, availability, and security of the data. The protocols used in wireless sensor network are Bluetooth, Zigbee, HomeRF, 802.11a, 802.11b, and HyperLan etc.

1.5 Limitations of WSM

The limitations of WSN can be discussed in terms of power, which is to be considered as the crucial factor in deployment of the sensor motes [9]; when WSN has been placed in some areas like in forest or under water we cannot keep them in supervision continuously. So it must have sufficient power to maximize waking lifetime. The power requirements for WSN can be improved by adapting some power management protocol, which is another aspect of study in Wireless Sensor Networking [10]. Apart from that it has limited processing speed, communication bandwidth; storage capacity and problem relating to synchronization of motes [11]. Research has been going on in these areas to get the maximum output by enhancing storage capacity, bandwidth, processing speed and power management. The work presented here discusses process through which we have attempted making a WSM prototype using COTS (common of the self) component. This is the first step before the research in specific theoretical areas can be verified.

Research has been going on to improve the design of WSM but there are several constraints, which have to be considered. Constrained can be divided mainly in two categories software and hardware. Software constrain includes low complexity algorithms, low execution time, adaptation to changes in wireless medium, efficient routing algorithm and medium access protocols [12] etc. These constraints can be considered due to power consumption. The hardware constraint includes availability of the IC's, size of the motes, low power consumption; low production cost, unattended operation and adaptability to the environment [13] etc.

1.6 Thesis Objective

The primary objective is to develop a proof-of-concept model demonstrating the use of a wireless sensor mote to acquire and log data. Data will be logged from a temperature sensor to a master mote connected together via the wireless network. This proof of concept model will contain the modified hardware to support the temperature sensor on a wireless sensor network and the software interface written in C needed to program the interfacing communication mote.

The Research and Development Program of DAE (Department of Atomic Energy, India) announces the robotic application for remote monitoring in the field of Nuclear Engineering [14]. IAEA (International Atomic Energy Agency) is working on Spent fuel management [15] which has always been one of the important stages in the nuclear fuel cycle and it is still one of the most vital problems common to all countries with nuclear reactors. So an advanced version of the model can further be explored in a nuclear environment for integrating into a remote monitoring application. However the WSM implemented in the present work is proof-of–concept model that can be used to monitor the temperature in an office environment.

In the next chapter a comparison has been made between the existing wireless standards such as Bluetooth, Wi-Fi, HyperLan and Zigbee. These wireless communication protocols were seen with respect to the sensor network .The best one is selected from the list of different protocols on the basis of the data rate, power dissipation, range of communication and cost etc.

Chapter 2
Existing Technologies

2.1 Existing Wireless Technologies

There are numerous wireless communications protocols that can be used in WSM. Table 2.1 [18] shows a comparison of several Wireless protocols available, on the basis of their frequency range, technology, performance, range, power consumption etc.

	Technology						
	Bluetooth	HomeRF	802.11b	HiperLAN	802.11a	HiperLAN2	Zigbee
Frequency Band	2.4GHz	2.4GHz	2.4GHz	2.4GHz	5GHz	5GHz	2.4 GHz
Technology	Frequency Hopping Spread Spectrum	Frequency Hopping Spread Spectrum	Direct Sequence Spread Spectrum	Guassian Minimum Shift Keying	Orthogonal Freq. Division Multiplexing	Orthogonal Freq. Division Multiplexing	Direct Sequence Spread Spectrum
Performance	720 Kbps	1.6 Mbps	11 Mbps	23 Mbps	~50 Mbps	~50 Mbps	250 Kbps
Range	<10 meters	50 meters	150 meters	150 meters	50 meters	50 meters	50 meters
Power	Very Low	Medium	Medium	Medium	Medium High?	Medium High?	Low
Relative Cost	Low/ Very Low	Medium/Low	Medium	Medium	High	High	Low
Target Applications	Cable Replacement Wireless Data Wireless Voice Personal Networks	Wireless Data Wireless Voice	Wireless Data	Wireless Data	Wireless Data	Wireless Data	Monitoring Control or Automation Sensor Network

Table 2.1: Comparison of existing Wireless Protocols

As it can be seen, the table presents technologies where the throughput is high. However, in an attempt to make the WSM nodes wireless, this is not the only consideration. It is also noted, that the protocols presented above consume a considerable amount of power.

Bluetooth [20] however, has the feature of low power and hence is explored further. Also, a new and emerging protocol defined as Zigbee [21] (known for its extremely low power protocol consumption stack) is investigated as it is supported by the transceiver used to implement the WSM in the present work.

2.1.1 Bluetooth

The Bluetooth protocol [19] enables short range; low-cost and low power wireless communications between Bluetooth devices. Designed primarily as a cable replace technology, it enables ad-hoc wireless networking, which allows formation of a network without base stations. The Bluetooth radio uses a low-powered transceiver that supports digital wireless communications at the 2.4GHz ISM band .The main features of Bluetooth are

- Uses the spread spectrum, frequency hopping, and full-duplex signal at a nominal rate of 1600 hops/sec.
- Adaptive frequency hopping (AFH) capability
- Data rate supported is up to 3 Mbps
- The operating range depends on the device class:

    Class 3 radios – have a range of up to 1 meter or 3 feet

    Class 2 radios – most commonly found in mobile devices – have a range of 10 meters or 30 feet

    Class 1 radios – used primarily in industrial use cases – have a range of 100 meters or 300 feet

2.1.2 Zigbee

Zigbee is a recently developed two-way wireless communications protocol designed to meet very low power consumption (6 months-2yrs on 2 AA) and low cost (half that of Bluetooth) requirements. Appendix A defines the protocol stack used in Zigbee protocol. The higher protocol layers are being defined by the Zigbee Alliance group while interests in the lower layers of the stack (MAC, PHY and LLC) are being defined by the IEEE 802.11 working group 4 (802.11.4) which is aimed at achieving data throughput of 250kbps in the 2.4GHz band. Protocol features include [21]:

- Service discovery
- Master / Slave topology
- Automatic network configuration
- Dynamic slave device addressing
- Up to 254 (+ master) network nodes
- TDMA slots can be allocated
- Full handshaking for packet transfers (reliable data transfer)
- CSMA/CA channel access mechanism
- Data rate of 20kbps at 868 MHz, 40kbps at 915 MHz and 250kbps at 2.4 MHz
- Power management features

The Zigbee protocol operates in the three different frequency bands (2 .4 GHz ISM world wide, 915MHz USA ISM band and 868MHz -Europe), which employs DSSS [21] for transmission and reception of data. As seen above, different data throughputs can be used however influencing the distance of transmission. Table 2.2 [21] shows this comparison.

Bit Rate\Power	0dBm	10dBm	20dBm
250kbps	13m	29m	66m
28kbps	23m	54m	134m

Table 2.2: Data Rate vs. Power for Zigbee

2.2 Existing WSM Systems

A project of interest includes ‘ZebraNet’ [8] system was designed by Department of Electrical Engineering at Princeton University to track the long term animal migrations. As the project name suggests it was used to track the position of the zebra’s .The low power GPS chip is deployed as the sensor to record the position data of the zebras. Another project of interest includes ’PicoRadio’ [17] was developed at the Berkley Wireless research Centre. The goal of the project is to create minimum energy networks of wireless nodes; another project named Smart Dust [16], being developed with similar aims, is running a very simple operating system named TinyOS [23]. TinyOS uses a scheduler for multithreading between tasks. A project known as wireless sensor network system (Wisden) [6] for structural monitoring is a result of the combined effort made by University of Southern California, University of California, Los Angeles and Crossbow Technology Inc. and is used to detect and localize damages in buildings, bridges, ships, and aircraft. Eli S. Leland, Elaine M. Lai, Paul K. Wright at Department of Mechanical Engineering, University of California, Berkeley designed a WSM for monitoring the indoor environment [22]. The important point is that WSM designed in the project is a Self-Powered WSM. The idea used in designing self-powered WSM is that sensor mote will be mounted on a wooden staircase and uses a piezoelectric bimorph to generate electricity from vibrations in the staircase. This generated electricity is the source of power for temperature sensor (thermistor) and wireless radio to transmit temperature readings to the base station. POST [24] is a project to study the marine life history of Pacific salmon. The scientists have been using two kinds of tag one is archival tag and other one is acoustic tag. By deploying any of the two tags researchers have been measuring and storing information on temperature, depth, or light levels. The direction, speed, and timing of movements of individual animals can be reconstructed from the information obtained; Wireless Sensor Networks developed by Alan Mainwaring Joseph, Polastre Robert Szewczyk, David Culler John, Anderson for Habitat Monitoring [24] is used to monitor the seabird nesting behavior and the environment. The WSM are deployed in the ARGO project [17] to observe the temperature, salinity, and current profile of the upper ocean. The goal is a quantitative description of the state of the upper ocean and the patterns of ocean climate variability. Another WSM network is being used to monitor the movement of the animals, and one can think of virtual fences, with an acoustic stimulus being given to animals that cross a virtual fence line [25].

There are many such applications some of them are shown in table 2.3[25], which can be summarized on the basis of deployment, mobility, and energy etc.

The Bluetooth and Zigbee protocols were discussed in detail in this chapter, as they are competing technology for the wireless sensor networks. Zigbee has been found to have more appropriate features to support the wireless sensor network. Some of the existing wireless sensor motes were also discussed. In the next chapter the network architecture and network topology has been discussed with respect to the sensor network.

Heterogeneity	Modality	Infrastructure	Topology	Coverage	Connectivity	Size	Lifetime	QoS
weather stations, burrow nodes, gateways	radio	base station, gateways	star of clusters	dense (every burrow)	connected	tens – hundreds (~100 deployed)	7 months (breeding period)	–
nodes, gateway	radio	base station, GPS	graph	dense (every animal)	sporadic	tens – hundreds	one year	–
nodes, base station	radio	base station, GPS, GSM	star	sparse	connected	tens – hundreds (9 deployed)	several months	–
homogeneous	radio	base station, GPS	graph	dense (every cow)	intermittent	up to hundreds (10 deployed)	days to weeks	–
homogeneous	radio	GPS	graph	sparse (0.5 – 1km apart)	connected	up to hundreds (6 deployed, 50 planned)	several months	–
homogeneous	radio	satellite	star	sparse	intermittent	1300 deployed, 3000 planned	4-5 years	–
sensors, gateway, base station	radio	base station	tree (two-tiered multi-hop)	sparse (20m apart)	connected	up to hundreds (65 deployed)	several months (growth period)	–
sensors, relays, access boxes, warehouse	radio	relays, access boxes	tree (three-tiered multi-hop)	sparse	intermittent	up to hundreds (55 sensors, 4 relays deployed)	years	–
homogeneous	radio	rescuer's PDA	star	dense (every person)	connected	tens – hundreds (number of victims)	days (duration of a hike)	dependability
medical sensors, patient identifier, display device, setup pen	radio, IR light (for setup pen)	ad hoc	single-hop	dense	connected	tens	days to months (hospital stay)	real-time, dependability, eaves-dropping-resistance
sensor nodes, transceivers, central unit	radio (sensor unidirectional)	transceivers	layered multi-hop	sparse (selected outlets)	connected	tens – hundreds	years (building lifecycle)	–
different sensors	radio	ad hoc	star	sparse	connected	tens	hours (duration of assembly)	–
homogeneous	radio	UAV	graph	sparse	intermittent (UAV)	tens – thousands (5 deployed)	weeks – years (conflict duration)	stealth, tamper-resistance, real-time
homogeneous	radio, ultrasound (for localization)	ad hoc	graph	dense	connected	up to hundreds (20 deployed)	months – years	tamper-resistance
homogeneous	radio	ad hoc	graph	redundant (multiple nodes recognize shot)	connected	up to hundreds (60 deployed)	months – years	real-time

Table 2.3: Existing WSM applications

Chapter 3
Wireless Link Criteria

3.1 Architecture

To govern an effective wireless communication there is a requirement of network architecture. Essentially, Network must contain some kind of protocol stack that describes processes required to communicate between motes. A protocol is defined as a set of rules. This facilitates communication [26]. A protocol stack is defined as a collection of protocols layered on top of each other. Figure 3.1 [26] below shows an overview of the flow of implementation in a protocol stack using the OSI Reference Model (OSIRM).

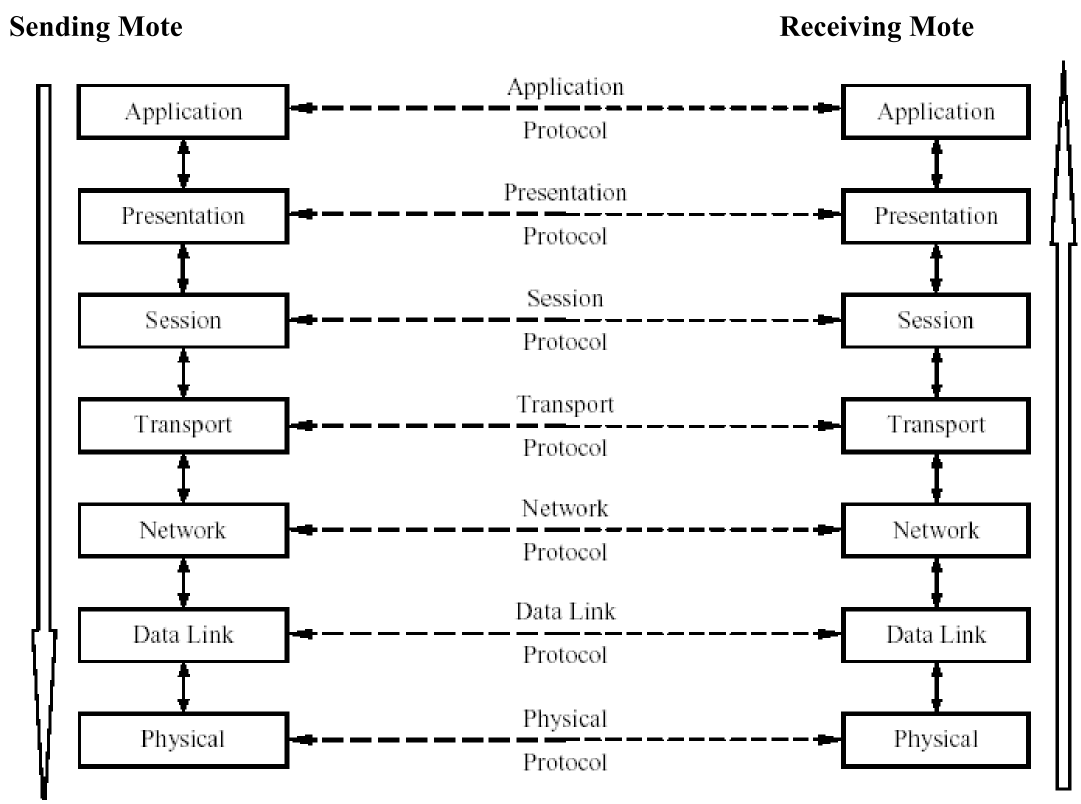


Figure 3.1: OSI Reference Model (OSIRM)

The top four layers in the protocol stack can be applied irrespective of medium being wired or wireless. Communication between the two motes occurs via the protocol stack and across the physical medium. Generally, if a mote 1 sends data (known as the payload), it passes this data to the layers below (starting normally from the Application Layer) where each layer appends a protocol specific header to the payload as shown in the Figure 3.2.

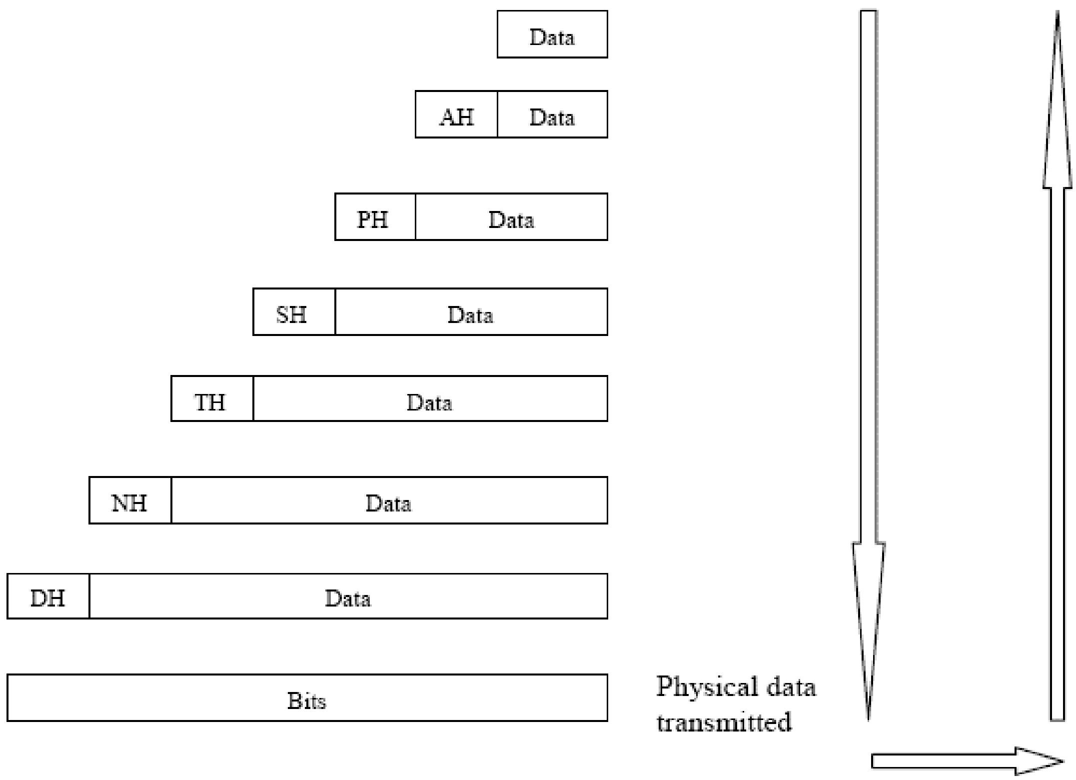


Figure 3.2: Protocol specific Packet

After passing through the stack, the data is sent across the physical medium (with the aid of a transceiver) to mote 2. This packet of data is then passed up the protocol stack where each layer removes its appropriate header. Mote 2 then receives the payload data at the top of the stack (Application Layer) sent by mote 1.

3.2 Network Topology

The thesis work presented here deploys 3 motes, of which there are two defined categories. A PC mote is needed to display the data collected and is also responsible for gathering information from the sensor motes and computing this data to obtain a temperature signal. In order for this to exist, the network topology required by the system must consist of at least two Slave motes and one Master mote. Figure 3.3 illustrates the topology used.

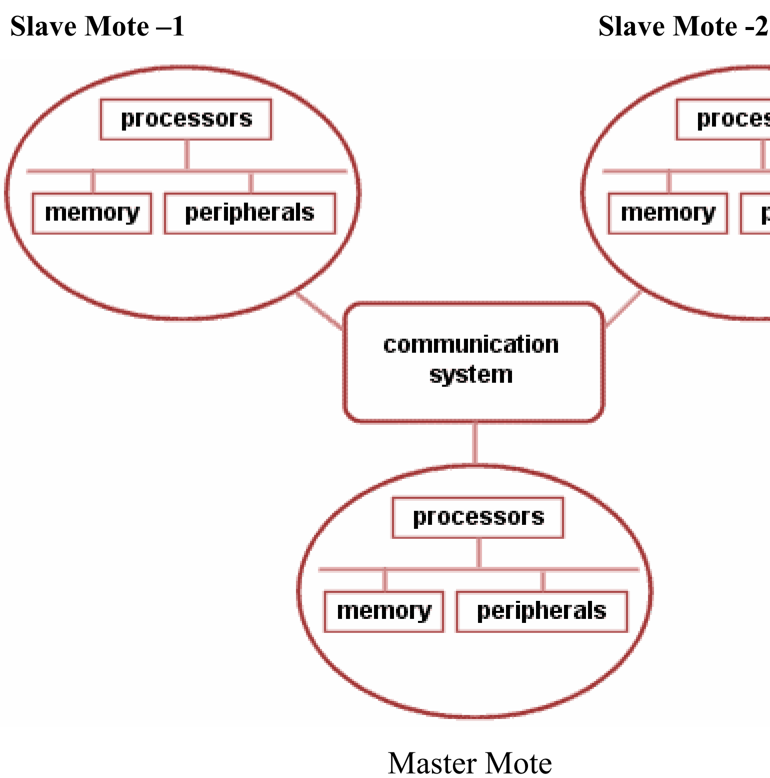


Figure 3.3: Network Topology required

The mote interfaced to PC serves as the Master mote (Base Station) and the motes used to collect and send the data are the Slave motes. The Master mote is used to resynchronize the Slave motes, gather the information sent by them and compute on this information to produce the temperature signal on the PC. The purpose of the Slave motes is to obtain temperature data and transfer this using a protocol stack when required by the Master mote at certain time intervals.

3.2.1 Master Mote

Figure 3.4 forms the basis of Master Mote design. Note however, the design of this mote is not constrained by size and power limitations as this mote is to be located at the PC. The master mote is similar to the slave mote except it may or may not have a sensor. In the present work sensor has not been used on the master mote. But it is interfaced to the PC to facilitate the information display.

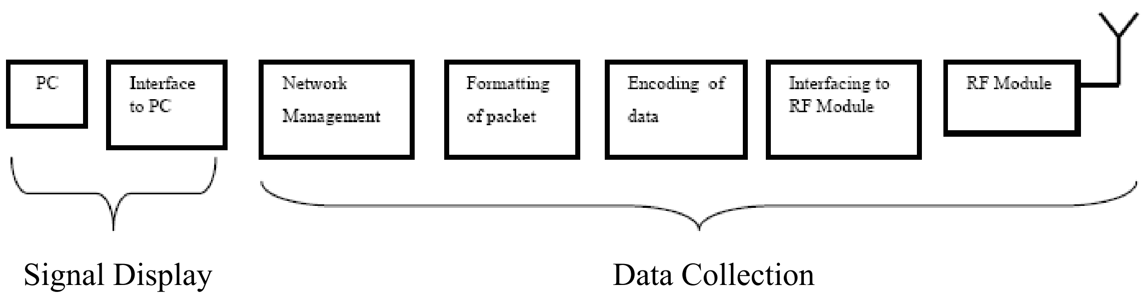


Figure 3.4: Master Mote design

3.2.2 Slave Mote

The Slave mote design is similar to that of the Master mote except power requirement must be minimal as these motes are 'wireless units'. The Slave motes also require memory, as temperature data's are stored before being sent at their respective time slots. The Slave mote should consist of the following as illustrated in Figure 3.5. Temperature Sensor required to acquire temperature data; Microcontroller is used to run the protocol and interface to the wireless module; and a RF transceiver needed to transmit and receive data wirelessly.

Because the Slave mote is a 'stand alone' device and is required to run a protocol stack as well as obtain Temperature data, some power saving protocol [10] need to be implemented to reduce computation overhead and improve system efficiency.

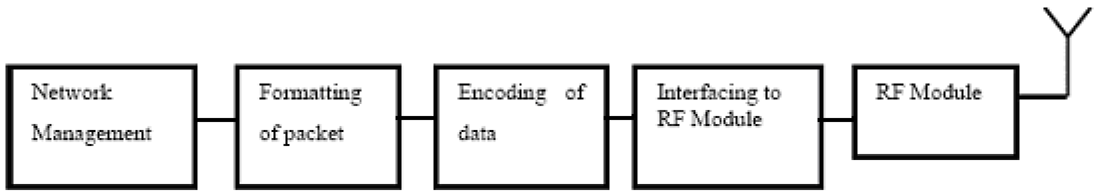


Figure 3.5: Slave Mote design

One of the simplest ways to achieve the power requirements of the sensor mote is to use the two microcontrollers for two different tasks i.e. one for acquiring data and other one to run protocol stack. But in the present work we have used only one microcontroller to reduce the complexity of the system.

3.2.3 Piconet

The term ‘piconet’ is derived from a network configuration in the Bluetooth specifications. A ‘piconet’ is a network of motes where one mote has control of the network (known as the Master) while the remainder motes (known as Slaves) respond to requests sent by the master. For the purposes of this thesis, a piconet [20] is required as in Figure 3.3. Initially, the Master mote will need to send out a message to the Slave motes to notify the motes when to

- Start collecting and storing the temperature data
- Resynchronize the system and
- Require transmitting temperature data.

Once the Master mote has broadcasted its unique packet to the Slave motes, they will begin transmitting temperature data to the Master mote for a certain number of times periodically. Once this has been completed, the Slave motes will sleep they need to resynchronize for next set of data transfer. Hence the motes wait for the next signal broadcasted by the Master Mote.

3.3 Physical Layer

The Physical Layer is required in all stacks as it governs the actual voltages, type of electrical signals, mechanical connections and other items relating to the actual data transmission medium. This includes cabling types, distances and connectors, as well as collision detection for high layer protocols like CSMA/CD. It is used to avoid 'collisions' between motes that may be transmitting simultaneously (although this is not evident in the current system). The Physical Layer also performs the function of transmission and reception of raw data (be it wired or wireless) and involves interfacing to transceiver. The contents of the packet being sent are usually unknown to this layer and the data is seen as bits as in Figure 3.2. A well-designed Physical Layer will facilitate reliable, efficient and accurate communications between motes.

3.3.1 Modulation

In order to send data, modulation is required. Modulation is the process of encoding information in a manner suitable for transmission [27]. It generally involves taking a message (baseband message) signal and using it to modify certain parameters of carrier signal (f_c) resulting in a bandpass signal (f_s) for transmission. Carrier signals generally have very high frequencies when compared to the baseband signal frequency for ease of transmission for severable reasons as given below.

- For low propagation loss and low dispersion of electromagnetic waves as the modulated carrier is usually transmitted as electromagnetic wave.
- To enable the construction of small antennas (usually a quarter of the wavelength).
- To be able to multiplex (i.e. to combine multiple signals for transmission).

The bandpass signal is called the modulated signal and the baseband message signal is known as the modulating signal [27]. Digital modulation techniques offer many advantages over analogue, which include the following.

• Greater noise immunity

• Robustness to channel impairment

• Easier multiplexing

• Greater security

Many modulation schemes exist but for the sensor mote application, digital modulation has been used. These include schemes such as:

• Frequency Shift Keying (FSK) - varying frequency f_c in accordance with the message.

• Amplitude Shift Keying (ASK) - varying amplitude of carrier in accordance with the message.

• Phase Shift Keying (PSK) - varying phase of carrier in accordance with the message.

3.3.2 Spread Spectrum Techniques

Spread Spectrum techniques employ a transmission bandwidth that is several orders of magnitude greater than the minimum required signal bandwidth. While spread spectrum techniques are very inefficient for a single user, the advantage of this technique is that many users can concurrently use the same bandwidth without much interference with one another. Apart from occupying a very large bandwidth, spread spectrum signals are pseudorandom and have a noise-like property when compared with the modulating (digital) signal. Spread spectrum signals are controlled by a pseudo-noise (PN) sequence (produced by a pseudo-noise generator), which is binary sequence that appears random but can be reproduced by the intended receiver. Spread spectrum signals are demodulated at the receiver using a locally generated pseudorandom carrier. Demodulation with the correct PN sequence de-spreads the spread spectrum signal and recovers the original data, whereas demodulation with an incorrect PN sequence results in a very small amount of wideband noise at the receiver output. Spread spectrum techniques have been used in WLANs for three main reasons:

1. To achieve low transmitted power spectral density

2. Secure transmission and

3. To avoid the problem of licensing

There are two techniques involved using Spread spectrum technologies. One of these is Frequency Hopping Spread Spectrum (FHSS). This technique involves periodically changing (hopping) to different transmission frequencies. Another technique known as Direct Sequence Spread Spectrum (DSSS) spreads the signal data by directly multiplying the data pulses with a PN sequence.

Although spread spectrum techniques offer a degree of security and robustness, these techniques are too complicated when the requirement from the network is to periodically send data to a central mote. The transceiver XBee [41] has been used in the present work, which supports the DSSS technique.

In summary Network architecture and topology for sensor network has been discussed. To practically implement the sensor network there is a need of the sensor motes. In order to give a physical realization to the sensor mote devices are required. The next chapter discusses the selection of the devices on the basis of their features, cost, availability, size and resources for hardware implementation of the sensor motes.

Chapter 4

Selection of Devices

4.1 Selection of devices based on their Packages

The basic building blocks in WSM hardware design are

- Processing Unit,
- Sensing Unit,
- Transceiver Unit and
- Power Unit.

They may also have additional application-dependent components such as a *location finding system*, *power generator*, and *mobilizer* [9]

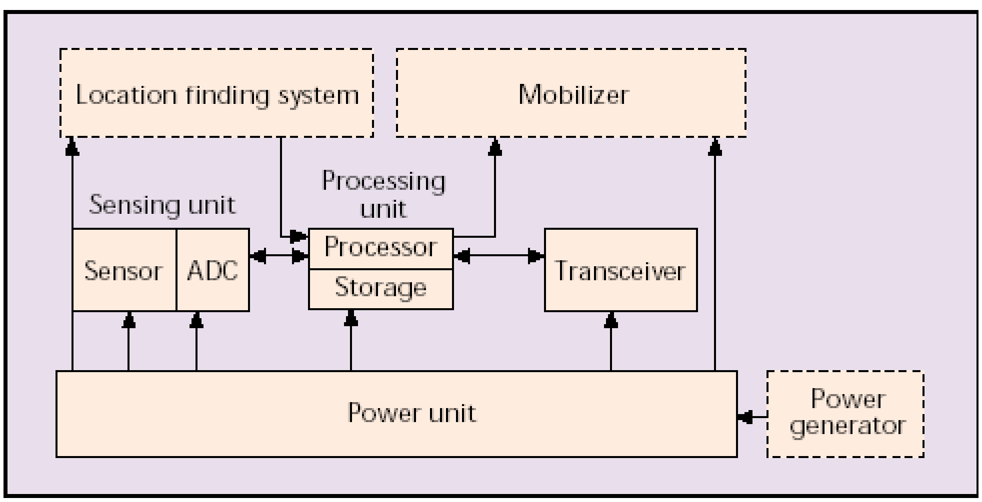


Figure 4.1: Basic building blocks of WSM

Processing unit, Sensing unit, and Transceiver unit are commercially available in the form of IC's. Frequently the power requirements of the WSM system are met through the use of Batteries. Though the battery alone may not be sufficient to carryout a smooth functioning of the WSM, hence power voltage regulators may be added to the circuit. In the present work, initially adapters were used when system was evolving through different stages to reduce the cost and complexity of the system and finally after testing the system the battery will replace the power adapters. Power voltage regulators IC's have been used to achieve the specified voltage supply to different units within the WSM system.

It can be interpreted that basic unit of WSM hardware design is IC. Before implementing the hardware over the PCB there is need to select IC's for each subsystem. The criterion for the selection of an IC's to design a Wireless Sensor Mote (WSM) is based on the [25] [30]

- Size,
- IC's Features,
- Resources,
- Cost and
- Availability.

IC's can be differentiated on the basis of their Packaging. These packages are classified according to the mounting methods of IC's over the PCB as

- Through-Hole Mounting and
- Surface Mounting.

4.1.1 Through-Hole Mounting

Through-hole-mounting is a method for mounting devices on the printed circuit board in which pins on the device are inserted into holes in the board and soldered in place. Some of the packaging technologies, which use this method, are listed in Table 4.1 [31] on the following page.

• *Dual In-line Package (DIP)*

DIP is one of the earliest packaging standards of through-hole mounting which is in use. It has been the main stream of the microelectronics industry since 1968. The popularity of the DIP IC's is due to its larger size compared to SMT devices. For the implementation of hardware on PCB by using IC's of a particular packaging, requires an *infrastructure*. This infrastructure facilitates mounting, soldering, testing, and interconnection to other IC's. Whereas DIP IC's can be easily mounted and soldered on PCB (Printed Circuit Board) manually without the need of industrial infrastructure like the one needed for Surface Mount Devices.

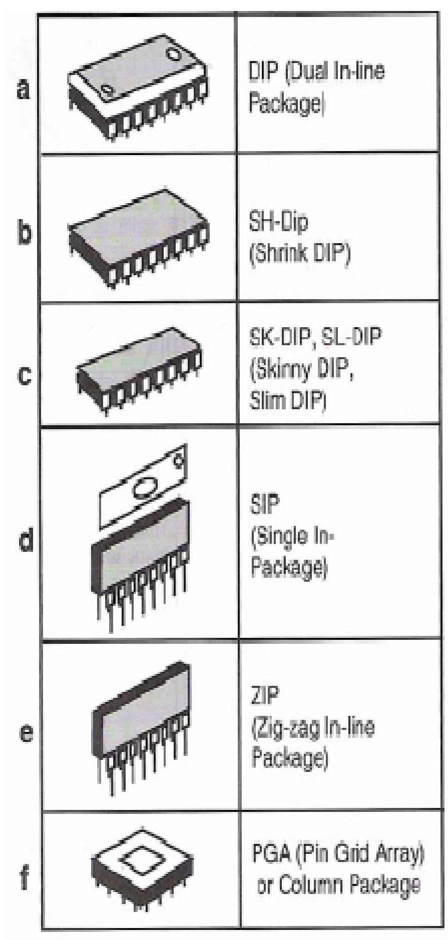


Table 4.1: Through-Hole Packages

The main disadvantage of using DIP is their lower available pin counts. The most common rectangular DIPs have become a limiting factor with pins spaced 2.4 mm apart, on only two sides of the package; hence the physical size of the DIP has become large. But there is always the quest to pack more components in a given space, which leads to miniaturization of IC's in general and WSM in particular. The primary DIPs, which are available in market, can be classified in three categories.

- Plastic
- Cerdip
- Side-brazed Ceramic

In order of increasing cost and decreasing volume:

4.1.2 Surface Mounting

Surface mounting technology was developed in the 1960 and became popular in late 1980. In surface mount technique, components were mechanically redesigned to have small metal tabs or end caps that could be directly soldered to the surface of the PCB. The technology has gained the popularity because of its advantages of miniaturization.

Surface mount technology save money, because fabrication costs, are less and completely automated fabrication can be done, with pick and place machines. There are less manufacturing errors, because pick and place robotic machines are used to place components rather than human assemblers. Designs are also smaller and use less printed circuit board (PCB). Components can be placed on top and bottom of the board, for even higher density designs. The pin count in the SMT devices is more as compared to Through-Hole technology. Some of the packaging technologies, which use Surface Mounting method, are listed in Table 4.2 [32].

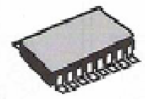
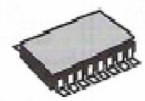
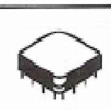
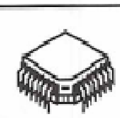
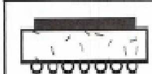
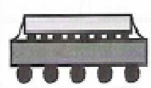
g		SO or SOP (Small Out-Package)
h		CFP (Qued Flat Package)
i		LCC (Leadless Chip Carrier|
j		PLCC, SOJ (Plastic Leader Chip Carrier with Butt Leads)
k		BGA (Ball Grid Array)
l		TAB (Tape Automated Bonding)
m		CSP (Chip Scale Package)

Table 4.2: Surface Mount Packages

- *Small-Outline IC*

Small-outline IC is considered to be one of the earliest members of SMT, which has been categorized into the flatpack packages. The flatpack packages are similar to the DIP packages with the exception that the leads protrude outward to form a flat surface and are mounted on pads, in order to obviate through hole-mounting.

Table 4.3 compares the IC's packages on the basis of their lead configuration,advantages and disadvantages[32].

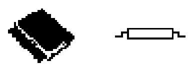
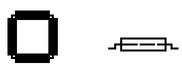
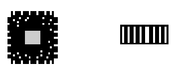
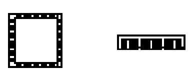
Package Type	Description	Advantages	Disadvantages
Dual-in-Line 	0.100in. Pin Centers 0.125in. Pin Length 0.160in. Body Thickness 0.300in. to 0.900in. Body Width	Capabilities Generally Exist Lowest Implementation Cost Minimum Engineering Effort Well-Established Reliability Database	Pin Count Limited to Less Than 64 I/O Lines Not Surface Mountable
SOIC (Small-Outline IC) 	0.050in. Pin Centers 0.030in. Pin Length (Solderable) 0.098in. Body Thickness 0.155in and 0.300in. Body Width	Surface Mountable Lowest Material Cost Allows Magazine Handling Soldering/Rework (Versus Quad Flat Pack)	Significant Equipment Design and Tooling Handling and Test More Difficult Board Routing/Soldering/ Rework of 0.050in. Pin Centers Reliability Questions
Quad Flat Pack 	0.050in. Pin Centers 0.030in. Pin Length 0.095in. Body Thickness Variable Body Width	Low Materials Cost Solder Joints Visible (Versus Chip Carrier)	Process and Test Modifications Needed Pin-Count Limitations Handling Difficult Board Routing More Complex Soldering/Rework of 0.050in. Centers Reliability Concerns
Chip Carrier 	0.050in. Pin Centers 0.030in. and 0.060in. Standoff 0.100in. Body Thickness JEDEC-Compatible Sizes	High Pin Counts Possible Surface Mountable Less Stressed Than Quad Flat Pack	Development Time and Cost Board Routing/Rework More Difficult Solder-Connect Technology and Joint Reliability
Plastic Chip Carrier 	0.050in. Pin Centers 0.100in. Pin Lengths 0.145in. Body Thickness JEDEC-Compatible Sizes	Surface Mountable Minimum Engineering Effort Low Materials Cost	Technology Compatible With Pin Counts Under 84 Leads Board Routing/Rework of 0.050in. Centers

Table 4.3: Comparison of IC's packages

The distance between the pin centers known as Pitch, decreased drastically in SOIC, QFP, Chip Carrier and Plastic Chip Carrier when compared with the DIP [Table 4.3]. The similar trends can also be seen in the body thickness and the body width. This makes the SMT devices minute in size.

From the above study it can be concluded that there is tradeoff between the miniaturization of hardware and infrastructure required, which facilitates mounting, soldering, testing and interconnection with other IC's of the circuit. In the present work the DIP packages of IC's have been selected, which do not need industrial infrastructure and can be easily mounted, soldered and tested with the help of Soldering Kit. The Soldering kit consists of multimeter, CRO, wire stripper, wire cutter and soldering iron.

Another advantage of using the DIP packages is that the general-purpose printed circuit board can be used for designing the circuit initially, to carryout testing of the WSM circuit. PCB has been designed using the Protel design software [29] after Testing and finalizing the schematic. Finally implementation of hardware is done on PC board. Hence in DIPs there is the flexibility to make the changes in the circuit before carrying out the PCB design. But in case of SMT devices general-purpose printed circuit board cannot be used since the pitch of SMT devices is low [Table 4.3] as compared to general-purpose printed circuit board. So the first step is to carryout the design of PCB according to the schematic circuit diagram. If mounting and soldering of SMT devices over the designed PCB is successful, there might be challenges in testing the functioning of WSM system due to some errors in schematic, and if desired results are not achieved, the PCB design has to be revised according to the changes made in the circuit schematic.

4.2 Selection of the IC's based on their Features

Finalizing the DIP packages of IC's for hardware design, the very next goal is to select the IC's, from the list of various IC's available in the market on the basis of their features such as power consumption, operating voltage, throughput, and current carrying capacity etc. For hardware design of WSM the building blocks are

- Processing Unit,
- Transceiver Unit and
- Sensing Unit.

4.2.1 Processing Unit

The Wireless Sensor Mote (WSM) is expected to communicate with each other as well to Base station, to process and to gather the sensor data. To carry out these tasks WSM must have processing units.

A Microcontroller is a miniature computer. It is an Integrated Chip (IC) that has a Central Processing Unit (CPU), Random Access Memory (RAM), Read Only Memory (ROM) and other components that are also present in a computer. It has been used in WSM as a Processing unit.

There are a large number of commercially available microcontrollers, which allows the flexibility in selecting a microcontroller when implementing a WSM system. Various IC's have been studied to select a microcontroller on the basis of their key features like Bits, Flash, operating voltage, RAM and power consumptions etc. A comparison has been done between the various microcontrollers for a low power wireless application (Table 4.4) [33].

Characteristic	AT90LS8535	ATMega103L	PIC16F8X	MSP430F149	StrongARM SA-1100
Bits	8	8	8	16	32
Flash	8	128	68	60	
RAM	512B	4KB	1B	2048B	
ADC	10 bit	10 bit		12 bit	
Timers	3	3	1	3	
Operating Voltage	4-6V	2,7-3,6V	2-6V	1.8-3.6V	3-3,6V
Power Active	6.4 mA	5.5mA	2mA @5V, 4 MHz	400 uA @3V	230mW @133MHz
Power Idle Mode	1.9 mA	1,6mA		1,3uA	50mW@133MHz
Power-down Mode	<1uA	<1uA	<1uA	<0.1uA	Typical 25uA

(a)

Characteristic	Atmel AT91M42800A	MC68HC05PV8A	80C51RD+	EM6603	DragonBall MC9328MX1
Bits	16/32	8	8	4	16
Flash			64kB		
RAM	8KB	192B	1024B	96x4B	128KB
ADC	0	8bit	0	0	13 bit
Timers	6	1	1	1	2
Operating Voltage	2.7-3.6 V	3.3-5.0 V	2.7- 5.5 V	1.2-3.6 V	1.62 to 3.3 V
Power Active		4.4mA	16mA @16MHz	1.8uA @32KHz	90mA @96MHz
Power Idle Mode		1.95mA	4mA @16MHz	0.35 uA	0.16 mW
Power-down Mode		485uA	50uA @16MHz	0.1uA	

(b)

Table 4.4: Comparisons of Microcontrollers

From the study of microcontroller it can be concluded that Microcontroller MSP430F149 is a good option [33] for sensor nodes since it is 16-bit 8 MIPS, providing more computational power, and also ultra-low power. It is equipped with a full set of analog and digital processors. It has embedded debugging and in-system flash programming through a standard JTAG interface, and is supported by a wide range of development tools including gcc and IAR Embedded Workbench.

Table 4.5 shows a comparison of microcontroller, which can be used in the present work on the basis of their key features. Microchip's PIC is used to educational purpose, but it is not applicable where energy is crucial. 8051 is available from anyone anywhere, but has low performance, being used only for historical reason. Other microcontrollers like Motorola's MC68HC908 [35], Dallas's DS80C310 [36] and Texas Instrument's MSP430 are more popular for an industrial application subject to their sizes where an industrial infrastructure is available. Besides, for such a proof-of-concept model availability is one of the criterions other than the key features, which play a vital role in selection of a particular device.

Characteristic	Atmega 16	DS80C 310	MC68HC908	AT89C52
Bits	8	8	8	8
Flash	16 K		32,256 B	8 K
RAM	1 K	256 B	512 B	2 K
ADC	8 bit	0	0	0
Timers	3	3	2	3
Operating Voltage	4.5-5.5 V	4-5.5 V	3.5 V	3-6.6 V
Power active	1.1 mA@1MHz	30mA	14 mA @ 8 MHz	
Power idle Mode	0.35mA	1.5mA	3.7 mA @ 8MHz	
Power down Mode	0.1μA	1μA	1.35 μA @ 8MHz	100μA

Table 4.5: Microcontrollers Comparison

Atmel's AVR series microcontrollers are popular for their low power consumption, which is a critical factor when choosing a microcontroller for WSM system. These IC's are easily available and can be found in DIP packages; hence Atmel's AVR series ATmega16 [37] and AT89C52 [34] are the best choice. ATmega16 [37] has been selected in the present work on account of its low cost.

4.2.2 Transceiver Unit

The WSMs have to communicate with each other as well to the base station wirelessly. For wireless communication WSMs require a transceiver, which transmit the data from slave mote to master mote or vice versa and between the slave mote if requires. Basically this unit is combination of transmitter and the receiver.

The selection of commercially available transceivers can be done on the basis of their key features like type of modulation, carrier frequency, operating voltage, throughput, transmitted power, current in receiving/transmitting mode etc. One more important factor that contributes in selecting a transceiver is the communication standard they support. Broadly two kinds of standards- Bluetooth and Zigbee can be considered for wireless application. Marcos Augusto et al. [33] compared commercially available Bluetooth devices (Table 4.6) for selection of transceivers for the wireless sensor application.

	TR1000	CC1000	LMX3162	Philstar PH2401
Modulation Type	OOK/ASK	FSK		GFSK
Carrier Frequency	916,5 MHz	300 to 1000 MHz	2.45GHz	2,4 GHz
Operating Voltage	3V	2.1 V to 3.6 V	3.0 –5.5 V	1.8 V
Current Transmit mode	12mA	16.5mAat 868MHz, 0dBm	50mA	<20mA
Current Receive Mode	3.8 mA @115.2 kbps 1.8 mA @ 2.4kbps	9.6 mA at 868MHz	27mA	<20mA
Throughput	OOK 30 kbps ASK 115.2 kbps	up to 76.8 kbit/s		IMbit/s
Receiver Sensitivity	-97dBm @115.2 kbps	-110 dBm at 2.4 kBaud	-93dBm	-84dBm
Transmitter Power	0dBm	-20 to 10 dBm	-7.5dBm	+2dBm

Table 4.6: Comparison of Bluetooth Transceivers

From the Table 4.6 it can be concluded that the throughputs of the Bluetooth devices are high for a sensor node. It increases the complexity of the sensor node when receiving the data and hence is not a good solution for a sensor node [33].

Identifying the wireless communication components as the largest power consumer, it has been suggested to integrate 802.15.4 (Zigbee) compliant radios with the wireless sensing units. Zigbee is the first wireless protocol standard that is designed exclusively for wireless sensor networks [21]. As such, the protocol is written with power in mind; Zigbee consumes a fraction of the power needed for other wireless protocols such as Bluetooth and 802.11 variants. Hence Zigbee compliant transceivers have been further explored.

Characteristic	AT86RF210	MC13193	CC2420	XBee
Modulation Type	DSSS BPSK	DSSS O-QPSK	DSSS	DSSS
Carrier Frequency	850-930MHz	2.4GHz	2.4GHz	2.4GHz
Operating Voltage	1.8-3.6V	2-3.4V	2.1-3.6V	2.8-3.4V
Current Transmit Mode		3μA	17.4mA	45mA
Current Receive Mode	14.5mA	3μA	18.8mA	50mA
Throughput	20Kbps@868MHz 40Kbps@915MHz	250Kbps	250Kbps	250Kbps
Receiver Sensitivity	-95dB	-92dB	-95dB	-92dB
Transmitter Power	6-12dBm	0dBm	-24dBm	0dBm

Table 4.7: Comparison of Zigbee Transceivers

Atmel's AT86RF210 [38], Freescale Semiconductor's MC13193 [39], Chipcons's CC2420 [40] and Maxtream's XBee [41] transceiver IC's are Zigbee devices which have been compared in Table 4.7 and it is inferred that ZigBee specification supports data transmission rates of up to 250 Kbps. ZigBee's technology is slower than Wi-Fi (11 Mbps) and Bluetooth (1 Mbps) but it consumes significantly less power which makes it more suitable for wireless applications.

Most of the above devices are fabricated using surface mount technology. Atmel's AT86RF210 [38] and Freescale semiconductor's MC13193 [39] are fabricated in QFN package while Chipcon's CC2420 [40] is put on in QLP Package. Maxstream's XBee [41] is found to have 2.0 mm of pitch, which is comparable to DIP IC's pitch of 2.5 mm, easy to mount and soldered manually. Besides, it is easily available; hence it has been selected for the present work.

A schematic circuit diagram was drawn of WSM. The different selected IC's were mounted and soldered over a general purpose PCB according to the schematic circuit diagram. XBee transceiver's IC of pitch 2 mm cannot be mounted to general-purpose PCB of pitches 2.5 mm. So at first a PCB has been designed using Protel software [29] for XBee transceiver. Then it has been mounted and soldered over the designed PCB and finally PCB was placed over the general-purpose PCB.

4.2.3 Sensor Unit

The Sensor unit in WSM senses, or detects a signal or physical condition with incorporation of sensors. The processing unit uses the sensors data sensed by the sensors. Processing unit stores the data, process it if necessary and transmit it to the base station. Hence the Sensor unit translates between the physical world and the abstract world of processing unit.

Sensor may be classified in two categories according to the data transferred by them to processing unit

- Analog Sensor and
- Digital Sensor.

Analog sensor gives an output as analog signal while a digital sensor gives output as digital signal.

The sensor is a kind of transducer that converts one form of energy into other form of energy. They use the energy transferred to them converting it into analog signal or digital signal. Sensor may be classified according to the energy transferred to them:

4.2.3.1 Thermal energy

- Temperature sensors: thermometers , thermocouples temperature sensitive resistors (thermistors), bi-metal thermometers and thermostats
- Heat sensors: bolometer, calorimeter

4.2.3.2 Mechanical sensors

- pressure sensors: altimeter, barometer, barograph, pressure gauge
- gas and liquid flow sensors: flow sensor, anemometer, flow meter, gas meter, water meter, mass flow sensor
- mechanical sensors: acceleration sensor, position sensor, strain gauge

4.2.3.3 Optical and radiation sensors

- Electromagnetic time-of-flight. Generate an electromagnetic impulse, broadcast it, then measure the time a reflected pulse takes to return. Commonly known as - RADAR (Radio Detection and Ranging) are now accompanied by the analogous LIDAR (Light Detection and Ranging. See following line), all being electromagnetic waves. Acoustic sensors are a special case in that a pressure transducer is used to generate a compression wave in a fluid medium (air or water)
- Light time-of-flight. Used in modern surveying equipment, a short pulse of light is emitted and returned by a retro reflector. The return time of the pulse is proportional to the distance and is related to atmospheric density in a predictable way.

4.2.3.4 Acoustic sensors

- Sound sensors: microphones, hydrophones, seismometers.

In wireless sensor mote the selection of sensor is done according to the application. In the present work there has been an implementation of a proof-of-concept model for WSM. Data will be logged from a temperature sensor to a master mote connected together via the wireless network. This proof of concept model will contain the modified hardware to support the temperature sensor on a wireless sensor network and the software interface written in C needed to program the communication mote interface. Hence our sensor of interest is temperature sensor from the various sensors available commercially.

The temperature sensors can be classified broadly in two categories Contact Sensors and non-contact Sensors. Contact temperature sensors are required to be in contact of the object to measure its temperature and no contact temperature sensors measure the thermal radiant power of the Infrared or Optical radiation that they receive from a known or calculated area on its surface. In the present work there is requirement of non-contact temperature sensor to measure the temperature of the office environment

Some of the commercially available temperature sensors IC's have been studied on the basis of their key features like supply voltage, supply current, package, range of temperature they can measure etc. Table 4.8 compares Analog Device's AD7818 [42], National Semiconductor's LM94022 [43], Dallas Semiconductor's DS1620 [44] and Phillips's NE1617A [45] temperature sensors IC's.

Characteristic	AD7818	LM94022	NE1617A	DS1620
ADC Bits	10	0	8	9
Temperature Range (° C)	-55 -125	-50-150	0-125	-55-125
Supply Current	2mA	5.4μA	70μA	1mA
Supply Voltage	2.7-5.5V	1.5-5.5V	3-5.5V	2.7-5.5V
Conversion Time	9μA		170ms	750ms
Package	SOIC	Extreme Small SC70 5 Pin	QSOP 16-Pin	DIP/SOIC 8- Pin

Table 4.8: Comparison of Sensor IC's

A mote gets the power from the battery, which has to be charged regularly. Some times the motes have to be operated unattended. Hence power is critical factor for the wireless sensor mote [10]. So the supply current is the important factor when selecting an IC for wireless sensor mote.

From the above table 4.8 it can be concluded that temperature sensor IC LM94022 [45] manufactured by National Semiconductor is best to use in wireless application considering its supply current 5.4 μA which is lowest among all IC's . But it is manufactured in SC70 package, too small to mount and soldered manually. Hence cannot be used in the present work.

DS1620 [44] can be an appropriate choice considering its DIP package, digital output and supply current, which is found to be 1 mA. Hence it has been selected as a temperature sensor unit for the WSM in the present work.

4.3 Power Unit

The limitations of the WSM can be discussed in terms of the Power, which is to be considered as the crucial factor in deployment of the sensor motes [9]; sometime WSM remain unattended in some applications. So it must have sufficient power to maximize working lifetime. The power requirements can be improved by adapting some power management protocol, which is another aspect of study in Wireless Sensor Networking [10]. Generally the battery is source of power in WSM. Though the battery alone may not be sufficient to carryout a smooth functioning of the WSM, hence power voltage regulators may be added to the circuit. The batteries can be classified in two categories Chargeable and Rechargeable. They are also classified according to electrochemical material used for electrode such as NiCd, NiZn, AgZn, NiMh, and Lithium-Ion.

Batteries are not good choice when system is evolving through different stages, as they would be lasting for few days and will contribute unnecessary additional cost to development of the system. Once system is tested and finalized they can be used. In addition to that it will reduce the complexity of the system. In the present work, during the initial stage adapters were used instead of batteries to carryout the testing and modifications in the circuit of WSM.

A battery can be classified on the basis of its key features and specifications

- Electrochemistry

Capacity:

The capacity of a cell is defined as how many milli-amp-hours (mAh) of current the cell can store and subsequently deliver.

Example:

If a cell is rated at 1000 mAh, then it can deliver the following:

2000 mA of current for 1/2 hour

1000 mA of current for 1 hour

500 mA of current for 2 hours

200 mA of current for 5 hours

Energy Density:

The energy density of a cell is a measure of how much energy can be stored in the cell per unit volume or per unit weight.

E (watt-hours) = cell voltage x capacity rating

Energy density per unit volume is called the "volumetric energy density" and is expressed in terms of watt-hours/liter (wh/l).

Energy density per unit weight is called the "gravimetric energy density" and is expressed in terms of watt-hours/kilogram (wh/kg).

- Battery Mechanical Specifications
  - Volume
  - Weight

➢ Internal vs. External Battery Pack

- Battery Environmental Specifications

➢ Operating / Storage Temperature

➢ Drop Specifications

➢ Vibration / Mechanical Shock

➢ Water Resistance

A comparison of batteries has been done on the basis of primary/secondary and volumetric density in Table 4.9 [33].

Battery	Recharge able?	Volumetric density(Wh/l)	Environmental or Health concerns
Alkaline-MnO2	No	347	
Silver Oxide	No	500	
Li/MnO2	No	550	
Zinc Air	No	1150	
Sealed Lead Acid	Yes	90	Yes
NiCd	Yes	80-105	Yes
NiMH	Yes	175	No
Li-ion	Yes	200	Yes
Li-Polymer	Yes	300-415	

Table 4.9: Comparisons of Batteries

K.A. Cook and A.M. Sastry, University of Michigan, has done the research how to choose a power supply battery for Wireless Integrated Microsystems-Environmental Monitor Testbed (WIMS-EMT). The goal of WIMS-EMT is the realization of a wristwatch-sized device capable of sampling ambient pressure, temperature, humidity, and air quality. They have used the three approaches [46] to select the batteries from the list of commercially available batteries:

(1) Specification of a single, aggregate power supply, resulting in a single battery electrochemistry and cell size;

Characteristic	Alkaline	Alkaline	Alkaline	Nickel-Cadmium	Lead-Acid
Voltage	9V	1.5V	1.5V	1.2V	6V
Volume	23ml	8ml	55.9ml		128ml
Capacity	580Ah	2.8Ah		1.08Ah	1.3Ah
Weight	49g	27g	141g	23g	300g
Energy Density (Wh)	5.22	4.2		1.296	5.1
Volumetric Density (Wh/l)	226	525			39.8
Gravimetric Density (Wh/Kg)	106	155		56	17
Rechargeable	No	No	No	Yes	Yes
Manufacturer	Duracell	Duracell	Panasonic	Panasonic	Panasonic

Table 4.10: Comparisons of Batteries

(2) Specification of several power supplies, by a priori division of power sources by power range;

(3) Specification of an arbitrary number of power "bundles," based on available space in the device.

And it has been shown that second approach provided the best results of mass (0.032 kg) and volume (0.028 L) among the three approaches. The second and third approaches provided the best battery lifetime results; both systems produced lifetimes in excess of 2000 hrs.

Panasonic and Duracell's Alkaline, Nickel cadmium, Lead Acid batteries are commonly used in day-to-day life and easily available in the market. Table 4.10 shows a comparison of Panasonic and Duracell's batteries on the basis of voltage, capacity, geometry and volumetric density etc. Following the algorithm [46] developed by K.A. Cook and A.M.

Sastry, University of Michigan, a suitable choice in the present application can be interpreted. The alkaline battery of Duracell (part number: MN1604) has been selected.

In summary it can be concluded that certain tradeoffs are being made in selection of the devices before implementing the hardware on PCB. These tradeoffs are mainly between the Size, IC's Features, Resources, Cost, and Availability. In the next chapter there is a description of hardware and software implementations using selected devices. Hardware implementation concerns with the integration of the devices on the PCB, which gave a physical realization for the sensor motes. While software implementation describes the firmware, which makes them to interact with each other.

Chapter 5
Implementation

5.1 Hardware Development

5.1.1 Slave mote

The Slave mote is responsible for collecting and processing the data. It consists of the following component:

- Microcontroller
- Temperature sensor
- Transceiver
- Power Supply

5.1.1.1 Microcontroller

The Atmega16 [37] microcontroller is low power CMOS 8-bit RISC microcontroller. The on-chip ISP Flash allows the program memory to be reprogrammed in-system through an SPI serial interface and can operate with operating voltage levels from 2.0V to 5.0V. Table [5.1] summarizes features available to the Atmega16.

The program memory of microcontrollers is used to store and execute the compiled C, or assembly code (machine language). The program memory is of *Flash* type, which has many advantages over other types of memory. Most important of all, it is rapidly erasable and programmable. The flash memory has the endurance of at least 10,000 write/ erase cycles. This is useful for reducing the time between “burning” and evaluation of the compiled code.

Atmega16	Value	Units
Operating Frequency	0-8	MHz
FLASH Program Memory	16K	Bytes
Data Memory	1K	Bytes
EEPROM Data Memory	512	Bytes
Serial Communication	2	
ADC	Yes	10 bit A/ D module
Instruction Set	131	Instructions
Timers	3	

Table 5.1: Key Features of Atmega16 microcontroller

The EEPROM can be compared to a PC's hard disk. Its most important feature is that, unlike RAM, it can retain its memory contents even after the power has been turned off. In microcontroller applications it is used for saving initialization or calibration information. It is important to point out that the EEPROM also has two main disadvantages. Unlike RAM memory, this kind of memory has a limited life expectancy. The memory gets "worn out" after around 100,000 read/ write cycles.

Therefore the program should be written so that it makes little use of the EEPROM, and if possible, no use at all. The second disadvantage is that the "write time" can be *5ms*, but since programs rarely write to the EEPROM, if ever, this does usually not pose a problem.

The clock speed basically decides how fast the code gets executed. By executing powerful instruction in single clock, the microcontroller achieves the throughputs approaching 1 MIPS per MHz. This means that, at least theoretically, at 16MHz the microcontroller is executing 16 MIPS.

The I/ O ports are essential to a microcontroller for its ability to *control*. The Atmega16 delivers four ports with 8 pins each, a total of 32 I/ O pins. Any pin can be configured as an input or an output, and this pin assignment does not have to remain static but can change dynamically in runtime.

5.1.1.2 Interfacing the MaxStream's Xbee with microcontroller

The MaxStream's ZigBee/ XBee RF modules [41] have many characteristics that are desired in wireless communication. MaxStream offers two different versions of wireless modules, the XBee And the XBee-Pro. Both of these modules have the same set of instructions and operate in the same manner, but the XBee-Pro offers over more than double the range of XBee. In the present work, to measure the office temperature Xbee is selected. Transmit power output is rated at 1mW with an operating frequency of 2.5GHz with operating current running around 45-50 mA and RF data rate of 250k bps.

While XBee-Pro edition runs at a 10mW output power, enabling it to transmit much further. The implementation of adding wireless to any design can be accomplished easily with the MaxStream XBee module. The XBee module is extremely effective in terms of short-range wireless communication. The XBee module is low power, small, and easy to integrate into any project with short-range wireless communication.

Pin #	Name	Direction	Description
1	VCC	-	Power supply
2	DOUT	Output	UART Data Out
3	DIN / CONFIG	Input	UART Data In
4	CD* / DOUT_EN* / DO8*	Output	Carrier Detect, TX_enable or Digital Output 8
5	RESET	Input	Module Reset
6	PWM0 / RSSI	Output	PWM Output 0 or RX Signal Strength Indicator
7	[reserved]	-	Do not connect
8	[reserved]	-	Do not connect
9	DTR / SLEEP_RQ / DI8	Input	Pin Sleep Control Line or Digital Input 8
10	GND	-	Ground
11	RF_TX* / AD4* / DIO4*	Either	Transmission Indicator, Analog Input 4 or Digital I/O 4
12	CTS* / DIO7*	Either	Clear-to-Send Flow Control or Digital I/O 7
13	ON / SLEEP	Output	Module Status Indicator
14	VREF*	Input	Voltage Reference for A/D Inputs
15	Associate / AD5* / DIO5*	Either	Associated Indicator, Analog Input 5 or Digital I/O 5
16	RTS* / AD6* / DIO6*	Either	Request-to-Send Flow Control, Analog Input 6 or Digital I/O 6
17	COORD_SEL* / AD3* / DIO3*	Either	Analog Input 3, Digital I/O 3 or Coordinator Select
18	AD2* / DIO2*	Either	Analog Input 2 or Digital I/O 2
19	AD1* / DIO1*	Either	Analog Input 1 or Digital I/O 1
20	AD0* / DIO0*	Either	Analog Input 0 or Digital I/O 0

Table 5.2: Xbee Module Pin Specification

The interfacing of Xbee transceiver with the Atmega16 [37] microcontroller can be achieved by connecting the required pins. There are some considerations that must be taken into account to accommodate the needs of the XBee First, the pitch of the headings on the XBee is 2.0 mm and will not fit into general purpose PC Boards required for prototyping designs. To overcome this, a PC Board [Fig 5.1] is designed using Protel CAD software for Xbee. Mounted and soldered the Xbee over the designed PC Board. It has been placed over the general purpose PC Board and required pins are connected to the pins of Atmega16 microcontroller.

Second, XBee is designed to operate at 3.3V, whereas Atmega16 microcontrollers run at higher voltages. Voltage regulation can be easily accounted for by using a LM317 voltage regulator [47]. Figure 5.2 shows the schematic circuit diagram, to ensure regulated voltage supply to XBee module.

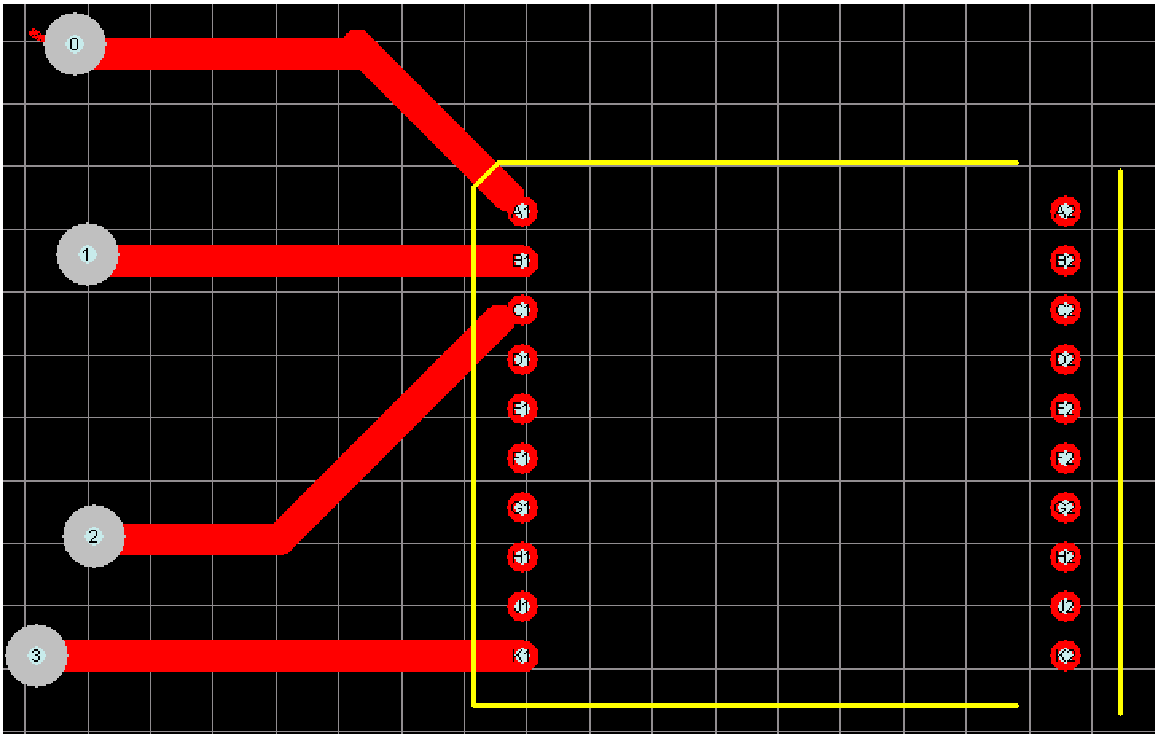


Figure 5.1: PCB design for XBee Transceiver Module

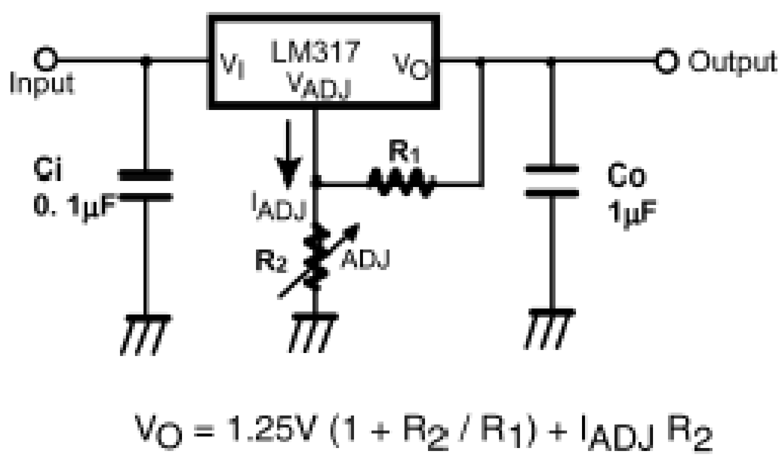


Figure 5.2: LM317

The interface between the Atmega16 and the XBee can be accomplished quite easily because both communicate with a serial UART interface. To communicate directly with the XBee module there are only four pins [Table 5.2] that need to be connected:

Din (3), Dout (2), VDD (1) and GND (10). Pin 2 from the XBee needs to be connected to the Rx (14) pin of the microcontroller. Pin 3 from the XBee needs to be connected to the Tx (15) pin of the microcontroller. A schematic diagram without voltage regulation can be seen in Figure 5.3. The Atmel's microcontroller can be configured to transmit and receive serial data.

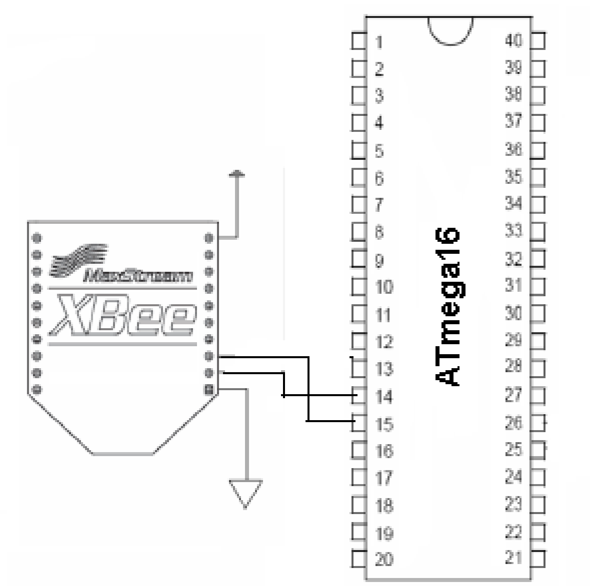


Figure 5.3: Interfacing of Xbee with Microcontroller

5.1.1.3 The Temperature Sensor

To get the temperature reading we use the Dallas DS1620 integrated circuit. It is an 8-pin chip, which has a built in system that measures the temperature and converts the reading into a 9 bit binary value. It has an accuracy of 0.5 degrees C and a range of -55 to 125 degree C. The temperature reading is updated about once per second. A digital interface is included in the chip, which facilitates to connect a microcontroller to the chip and send it commands and receive the temperature data back from the chip. It has three alarm outputs, so the device can also act as a thermostat. The DS1620, which incorporates a 3-wire interface, is controlled using an Atmega16 Microcontroller. The DS1620 is connected directly to the I/ O port on Atmega16 microcontroller, and low-level software drivers handle the 3-wire handshaking and temperature readings. The temperature is received in the microcontroller as 2 bytes. The second byte only contains a sign bit to signify whether the temperature is above or below 0 degrees Celsius.

DS1620 operates in wide range of voltage supply 2.7-5.5 V. The operating voltage of 5 V can be achieved with the incorporation of LM317. Using the circuit [Figure 5.2], the supply voltage of 5 V can be obtained through the adapter-12 V initially and finally through the battery of 9 V.

Pin	Symbol	Name	I/O/PWR	Description
1	DQ	Data input/output	I/O	3-wire port data
2	CLK/$\overline{CONV}$	Clock	I	3-wire port clock
3	RST	Reset	I	3-wire port reset
4	GND	Ground	PWR	System ground
5	T_{COM}	High/low combination trigger	O	Goes high when temperature exceeds TH; will reset to low when temperature falls below TL
6	T_{Low}	Low temp trigger	O	Goes high when temperature falls below TL
7	T_{High}	High temp trigger	O	Goes high when temperature exceeds TH
8	V_{DD}	Supply voltage	PWR	System power range is 2.7 V to 5.5 V

Table 5.3: DS1620 Pin Specifications

The thermostat outputs of the DS1620 allow it to directly control heating and cooling devices. THIGH is driven high if the device exceeds a predefined limit set within the TH Register. The output THIGH can be used to indicate that a high temperature tolerance boundary has been met or exceeded, or it can be used as part of a closed loop system to activate a cooling system and deactivate it when the system temperature reaches to a lower value. TLOW is driven high when the temperature of the device falls below the limit set in the TL Register. TLOW remains active until the DS1620's temperature becomes greater than the value stored in the low temperature register, TL. TCOM is driven high when the temperature exceeds the limit set in the TH Register and remains high until the device temperature falls below that set in the TL Register. In this way, any amount of user-defined temperature hysteresis can be obtained. This characteristic of DS1620 can be used to test it. By increasing the temperature above THIGH as specified in TH or decreasing the temperature below specified TLOW and checking the TCOM accordingly.

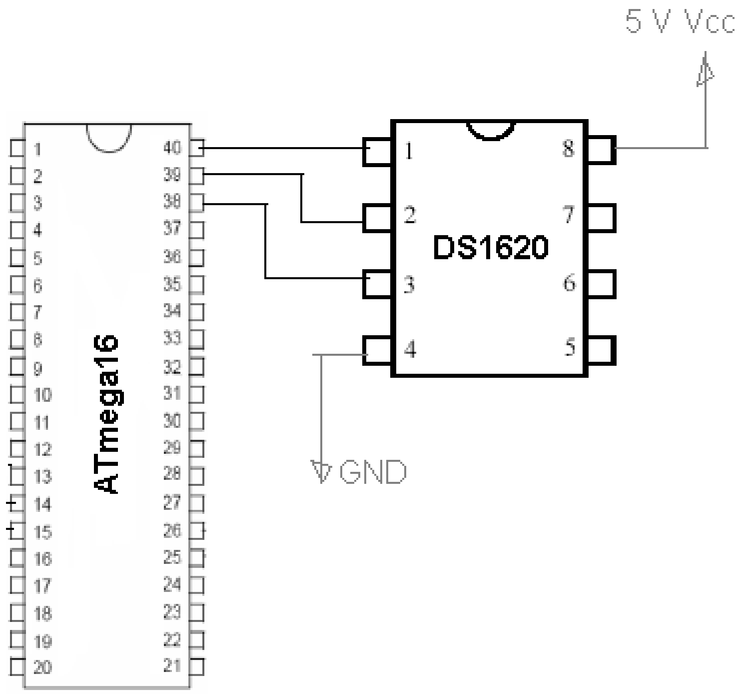


Figure 5.4: Interfacing DS1620 with microcontroller

5.1.1.4 Interfacing the DS1620 with Microcontroller

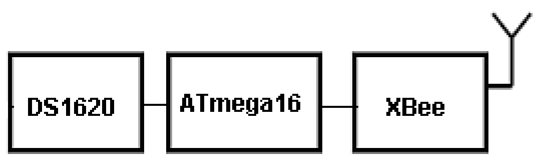
The 3-wire bus comprise of three signals. These are the REST-bar (reset) signal, the CLK (clock) signal, and the DQ (data) signal. All data transfers are initiated by driving the RST- bar input high. Driving the RST-bar input low terminates the communication. A clock cycle is a sequence of a falling edge followed by a rising edge. For data inputs, the data must be valid during the rising edge of the clock cycle. Data bits are output on the falling edge of the clock and remain valid through the rising edge. When reading data from the DS1620, the DQ pin goes to a high-impedance state while the clock is high. Taking RST-bar low during a communication cycle will cause DQ to go to a high-impedance state, thus ending the communication. Data over the 3-wire interface is sent with LSB first. Figure 5.4 illustrates the device connection to the microcontroller programmable input/ output port.

5.1.1.5 Schematic Circuit Diagram

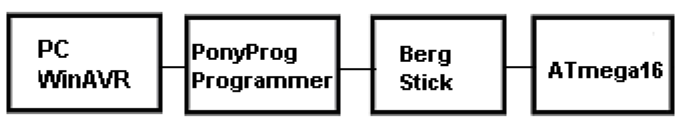
The schematic circuit diagram of the slave mote can be divided in three sections:

- Interfacing Section
- Software Section
- Power Supply Section

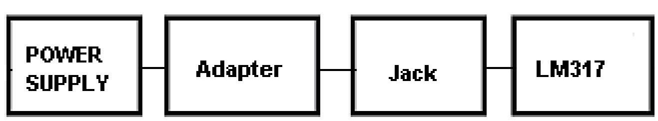
Figure 5.5 shows the block diagram for the different sections. A detailed schematic is drawn in the Appendix 3.



Interfacing Section



Software Section



Power Supply

Figure 5.5: Block Diagram

5.1.2 Master mote

The function of master mote is to gather the data process and display it if required by the application. The master mote implemented in the present work has the following component to carry out its functions.

- Personnel Computer
- Xbee Transceiver Module
- MAX232 Driver/ Receiver
- DB9 Connector

The master mote design is easy as compared to the slave mote. The idea of not using a microcontroller at master mote is that PC can be used as a processor in place of microcontroller. Besides it will be helpful to demonstrate the temperature data collected at master node. Fig. 5.6 shows the block diagram for Master Mote.

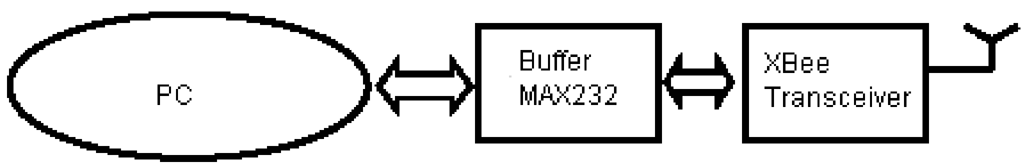


Figure 5.6: Block Diagram of Master Mote

5.1.2.1 Personnel Computer

The PC has been used to display temperature data collected by the DS1620 and sent through wirelessly with the help of ZigBee compliant- Xbee transceiver module from the slave mote. The Xbee module on the master mote receives these data's and transfers to PC using RS-232 communication. The PC uses the software drivers to communicate with the devices.

5.1.2.2 Interfacing the XBee module with PC

In order to set the computer side up with the XBee module, serial communications needs to be setup. MAX232 [48] and DB9 connector has been used to set up a serial communication between the PC and Xbee.

The MAX232 [48] is a line drivers/ receiver, which is intended for all EIA/ TIA-232E and V.28/ V.24 communications interfaces. [Figure 5.7] it has a double charge pump voltage doubler and a +10V to –10V voltage inverter. The voltages outputs are used to generate the RS-232 [Datasheet Xbee module page 27-30].

Serial cable has been used to connect the MAX232 to PC. Serial cable has male/ female DB9 connector [Table 5.4]. Pins 13 and 14 on the MAX232 have been connected to pin 3 and pin 2 respectively at DB9 port in order to transfer information to a computer. Pin 11 on the MAX232 chip connects to the Tx pin-2 on the XBee device while pin 12 connects to an Rx pin-3 [Figure 5.8]. The voltage supply of 5 V for MAX232 can be achieved through the schematic circuit [Figure 5.2].

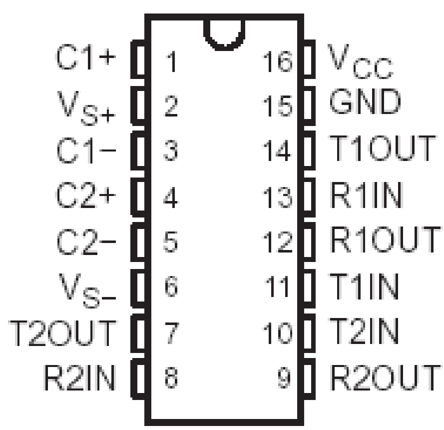


Figure 5.7: MAX232 Pin Configuration

Pin	Signal Description	Function	Signal Direction At Device
1	DCD	Data Carrier Detect	Input
2	RD	Receive Data	Input
3	TD	Transmit Data	Output
4	DTR	Data Terminal Ready	Output
5	SG	Signal Ground	
6	DSR	Data Set Ready	Input
7	RTS	Request to Send	Output
8	CTS	Clear to Send	Input
9	RI	Ring Indicator	Input

Table 5.4: DB9 Pin Specifications

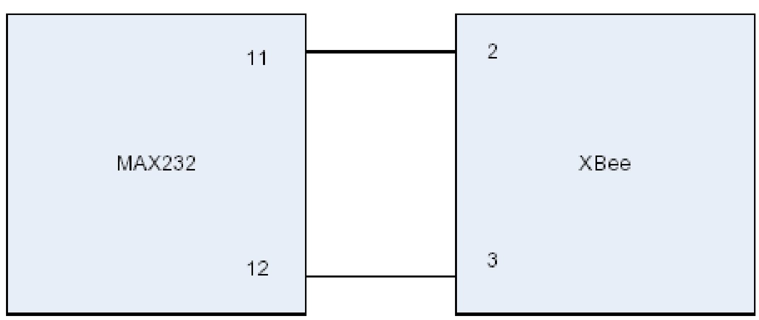


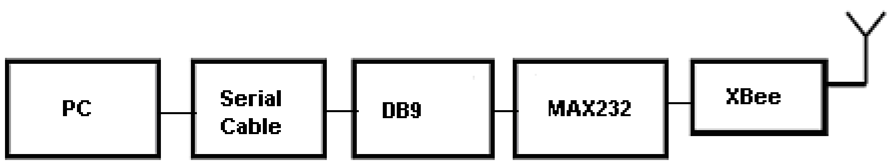
Figure 5.8: Interfacing of MAX232 and XBee Module

In relation to the XBee module, the DIN pin is where data will come in from the computer while the DOUT pin is where information can be transferred back over to the computer once received from another XBee module. The XBee module can only input voltage levels between 2.8V and 3.4V, therefore if a 5V MAX232 chip is used, arrangements will need to be made in order to adjust the levels so as not to burn out the module.

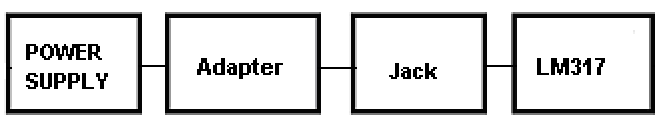
5.1.2.3 Schematic Circuit Diagram

The hardware implementation of the master mote can be divided in two different sections as shown in Fig. 5.9

- Interfacing Section
- Power Supply Section



Interfacing Section



Power Supply Section

Figure 5.9: Block Diagram

The Jack has been placed/ soldered over the PCB. The power supply of 12V adapter is given to the main circuit board by connecting the pin of adapter to main circuit through jack. The LM317 [47] voltage regulator then uses the power supply. A detailed Schematic Circuit Diagram [Appendix 2] has been drawn to demonstrate the connections between different devices.

5.2 Software development

Microcontroller has been programmed to test the hardware as well to achieve the goal of WSM application, which involved the following steps [Fig 5.10]:

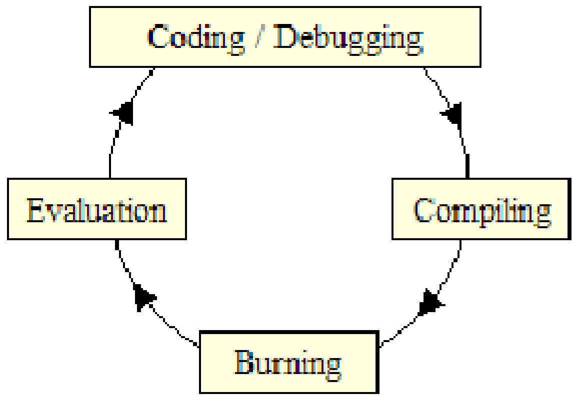


Figure 5.10: Software Developments

5.2.1 Coding / Debugging

• *Coding / Debugging in a high-level language (such as C, or Java) or assembler*.

A compiler for a high level language helps to reduce production time. To program the microcontrollers the WinAVR [2] was used. Although inline assembly was possible, the programming was done strictly in the C language. The source code has been commented to facilitate any occasional future improvement and maintenance.

WinAVR is a suite of executable, open source software development tools for the Atmel AVR series of RISC microprocessors hosted on the Windows platform. It includes the GNU GCC compiler for C and C++. WinAVR contains all the tools for developing on the AVR. This includes avr-gcc (compiler), avr-gdb (debugger) etc.

Test Source Code has been written in C Language to test the microcontroller. An LED will blink as soon as microcontroller's Flash memory is burned with the test program. Using XTU software setting on COM port of PC Xbee module has been checked.

The application source code is written in C language. This protocol generates the real time temperature data. When master mote request for the data, slave mote sends it back to master mote as soon as it gets the query. Master mote displays it over the PC's monitor.

5.2.1.1 Transceiver (XBee)

The system used for the communication between the master mote and slave mote used in the present work is Zigbee compliant MaxStream's XBee transceiver. The XBee takes data and decides where it should be sent. This involves looking at the data type and the destination to determine whether the data should be sent over the radio or serial port. The XBee module is responsible for encapsulating the data in the required packet format for sending it to another XBee, or to the serial port. XBee's UART protocol performs tasks, such as timing and parity checking, that are needed for data communications. As soon as serial data enters the RF module through the DI pin (pin 3), the data is processed. Similarly When RF data is received, the data enters the DO buffer and is sent out the serial port to a host device. It has been seen that the data transmitted over the communication link is uncorrupted. A traditional approach called as data warehousing is made to collect the data from the sensor mote. Data extracted from sensor mote is stored on base station.

5.2.1.2 Sensor (DS1620)

The interfacing of sensor with Atmega16 is done using the 3-Wire communication [44] through 3-wire communication protocol. The application calls a method to read a value, which starts the conversion and then returns. As soon as sensor gets a query for data it starts conversion and sends it to XBee transceiver through processing unit (microcontroller).

5.2.2 Compiling

- *Compiling the code into machine language.*

The compilation of the C program converts it into machine language file (.hex). This is the only language the microcontroller will understand, because it contains the original program code converted into a hexadecimal format. During this step there were some warnings about eventual errors in the program.

5.2.3 **Burning**

Burning the machine language (hex) file into the microcontroller's program memory is achieved with a dedicated programmer, which attaches to a PC's peripheral. PC's serial port has been used for the purpose. In the present work the PonyProg programmer [3] has been used to burn the machine language file into the microcontroller's program memory.

PonyProg [3] is serial device programmer *software* with a user-friendly GUI framework available for Windows95/98/ME/NT/2000/XP and Intel Linux. Its purpose is reading and writing every serial device. It supports I^2C Bus, Microwire, SPI eeprom, and the Atmel AVR and Microchip PIC microcontroller. The microcontrollers were programmed in approximately two seconds with a high speed-programming mode. The program memory, which is of *Flash* type, has, just like the EEPROM, a limited lifespan. On the AVR microcontroller family it may be reprogrammed up to a thousand times without any risk of data corruption.

5.2.4 **Evaluation**

If the system performs all the required tasks and behaves as expected the software development phase is over. If not, the whole procedure will have to be repeated again.

One of the difficulties of programming microcontrollers is the limited amount of resources the programmer has to deal with. In PCs resources such as RAM and processing speed are basically limitless when compared to microcontrollers. In contrast to a PC, the code on microcontrollers should be as low on resources as possible.

In summary, the physical realization of sensor mote through hardware implementation is made and a firmware has been discussed to make the integrated devices to interact with each other. In the next chapter the sensor motes has been evaluated in terms of their size, power, cost etc. The firmware developed has also been discussed in terms of the code size. Further the implemented system is compared with the existing technologies such as Mica Motes [50].

Chapter 6
System Evaluation

The system has been integrated and tested to function properly. The goal of real time temperature data transmission between the Master Mote and the Slave Mote is achieved. The wireless transmission results are given in figure 6.1. The results have been obtained through Docklight [51]. It shows the variation in temperatures when soldering iron is placed near the temperature sensor for few seconds and then removed.

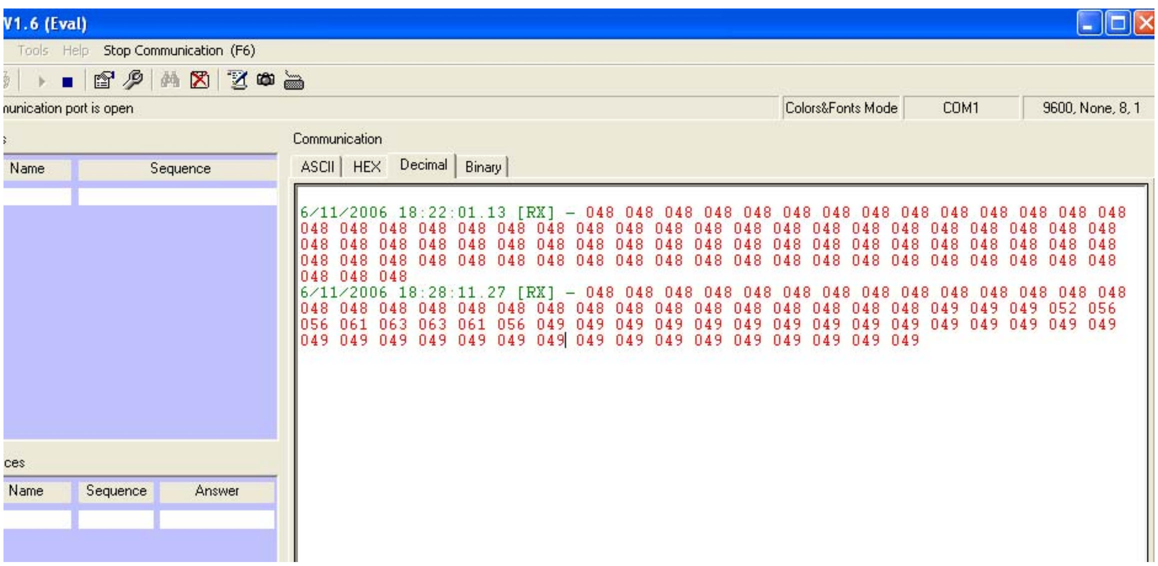


Figure 6.1: Data displayed using Docklight

The data collected at Master Mote (Base station) is found accurate without any distortion. The system works without error because of reception of sufficient power. The signal strength of last packet received is found to be –77.0553dBm. This value is in the range of -40 dBm and the RF module's receiver sensitivity of -92dBm. The received power can also be computed using the Friis transmission formula under line-of-sight conditions, i.e.

$$P_{Rx} = P_{Tx} \frac{G_{Tx} \cdot G_{Rx} \cdot \lambda^2}{16 \cdot \pi^2 \cdot d^2 \cdot L}$$

Here,

G_{Tx} = transmitter antenna gain,

G_{Rx} = receiver antenna gain,

λ = wavelength (same units as d),

d = distance separating Tx (Sensor Mote) and Rx (Master Mote) antennas, and

L = system loss factor (125.89).

For distance d=10m the data rate of 250 kbps has been achieved for transmission of the temperature data from the wireless sensor Mote to the base station.

The PCB layout has been done for the slave mote as well for master mote with the help of Protel design software [28]. Since the WSM incorporates the Zigbee transceiver, which operates at 2.4 GHz (UHF), grounding is essential for signal shielding. At RF frequencies, tracks on a PCB act as inductors rather than providing resistance. Hence, track lengths were minimized and ground planes were used to shield signals.

Also, decoupling couplers play an important role as transistors within ICs are constantly switching and require a regular source charge without having to draw this from the power supply. These also insured power supply inputs are smooth.

Through careful trial and selection of capacitors and resistors, hardware of master mote and slave mote is implemented. The dimensions of slave sensor mote and master mote are 10 cm by 8 cm and 10cm by 5.5cm respectively. Figure 6.2 and Figure 6.3 shows the physical hardware structure of master mote and slave mote respectively. The hardware implemented is simple in design when compared with other existing wireless sensor motes. The system frequency has been used and hence crystal was not required which contributes to the simplicity of the schematic design. It has been implemented with the DIP so it has larger size as compared to existing technology.

The digital output of the temperature sensor facilitates not to use the inbuilt ADC of the processor, hence the power is being saved further the code size has been reduced as temperature sensor is directly interfaced to the processor. There is no need to use the external EEPROM, as processor's EEPROM is sufficient to write the code in it, this further saves the power and reduce the code size, contributing to the simplicity of the hardware as well to the software implementation.

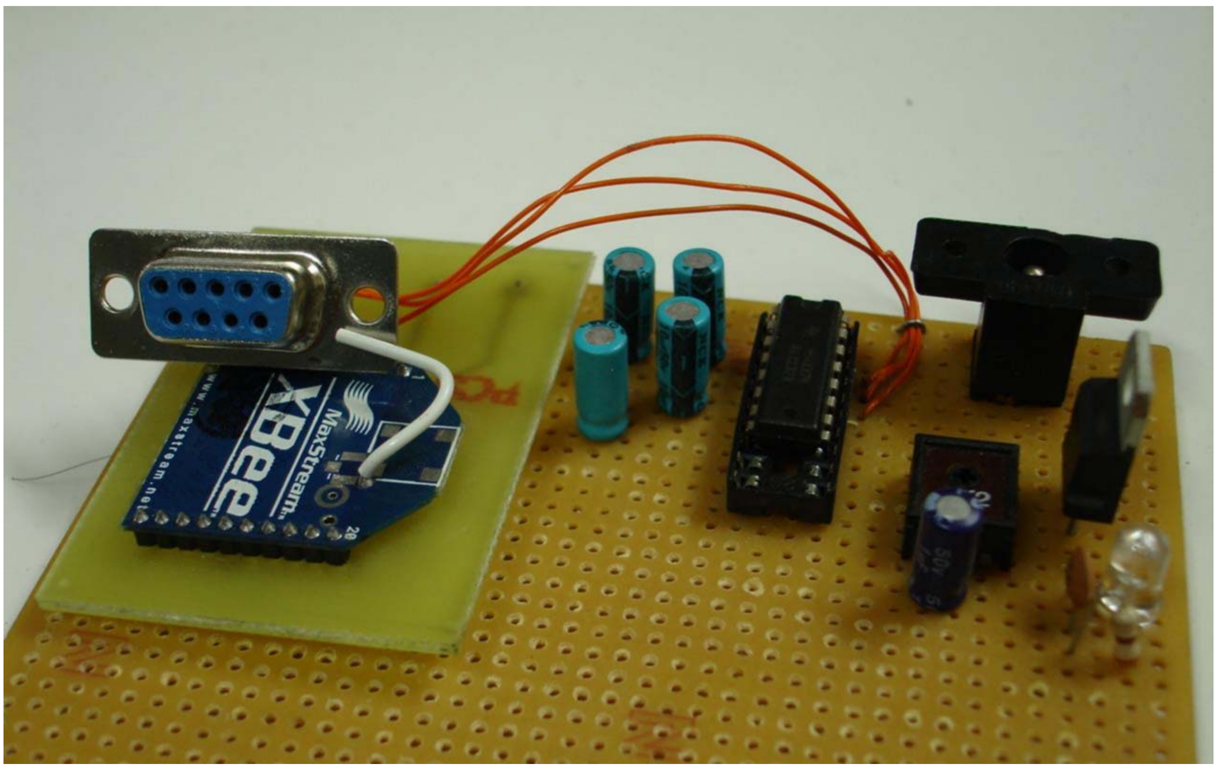


Figure 6.2: Master Mote

Zigbee compliant MaxStream's XBee transceiver module has been programmed such as the power consumption is reduced, the real time data transmission is achieved and the information reached to the base station is synchronized well with time. This can be concluded from several factors:

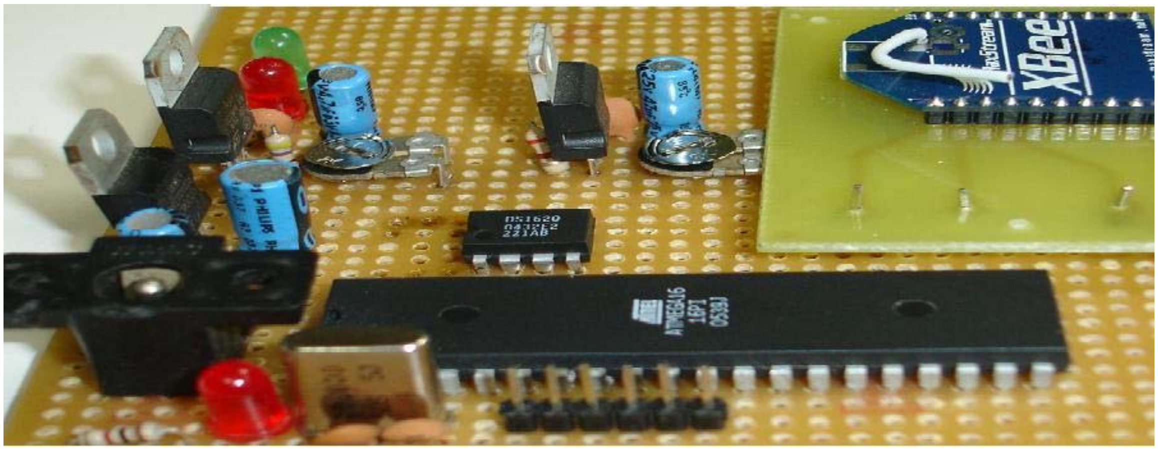


Figure 6.3: Slave Mote

With a small number of sensors that are effectively off most of the time, the probability of a channel being free is greater than 99 %[49]. In the present work a single sensor mote has been used to transfer the temperature data so it would be economical to keep CSMA off i.e. Backoff exponent is kept zero. RF transmission commences as soon as data is detected in the DI (data in from host) buffer .The radio module starts transmission either after ‘p’ number of bytes are received or after a fixed time interval whichever happens earlier. The ‘p’ is a programmable parameter of the module. The maximum value of ‘p’ can be 100 bytes. The sensor mote has been programmed to transmit characters as soon as they arrive instead of buffering them into one RF packet, i.e. ‘P’ has been set to zero.

The Master Mote and Slave Mote design components are summarized along with prices in Table 6.1. It can be seen, motes are cheap as only few components are required for implementation. Table 6.2 shows current consumption for Master Mote and Slave Mote. Master mote consumes 82mA of current. Even though power was not a design issue for the Master Mote, it is evident this device requires little power.

The Slave Mote total current consumption is found to be 77mA. It must be noted that inbuilt ADC on the microcontroller is not used so there is fair amount of power saving. Table 6.2 shows the break up of the current consumption for the Slave Node.

Mote Design	Cost
Master Mote	
Transceiver XBee	$ 46
Miscellaneous (Driver, Connector, cable)	$ 5
Total	$ 51
Slave Mote	
Microcontroller Atmega16	$13
Transceiver XBee	$ 46
Temperature Sensor DS1620	$ 0 sample
Miscellaneous (Programmer, Voltage Regulator etc)	$ 16
Total	$ 75

Table 6.1: Cost Slave and Master Mote

The results obtained for power dissipation are shown in Table 6.2. The three components that dominate power dissipation for slave sensor mote are the microcontroller, the radio and the buffers. The battery chosen for the present application is Duracell's Alkaline Battery. The capacity of the battery is 580Ah; hence it can be used continuously in the application for around 254 days. The code size to run different integrated parts like sensor and transceiver has been listed in the table 6.4.

Mote Design	Current Consumption
Master Mote	
Transceiver XBee	58mA
Miscellaneous (Driver, Connector, cable)	11mA
Total	69mA
Slave Mote	
Microcontroller Atmega16 (Active)	17mA
Transceiver XBee	58mA
Temperature Sensor DS1620	2mA
Total	77mA

Table 6.2 Current Consumption in Master and Slave Mote

Mica2 sensor mote and MicaZ [50], which uses the TinyOS over the AVR platform, has been compared in terms of code size and power with the present work .The current consumption of Mica Mote is found around 67mA while with that of present work is around 77mA. The code size of the Mica Mote for radio application has been found 9.5 KB while for the present work it has been found 296B. It can be seen from the above data that power consumption of the motes is comparable while code size of the implemented sensor mote is much less than when compared to Mica Mote. The increase in code size in Mica Mote is due to TinyOS [23].

Application	Code Size
Initialization	252B
Sensor Application	226B
Transceiver Application	44B
Total	522B

Table 6.3: Code Size

TinyOS is a new platform designed specifically for sensor motes. It provides a developer library for controlling radio and serial communication, and for operating various sensor boards connected to a mote. TinyOS is programmed largely in the nesC language, which was designed expressly for efficiently capturing the semantics of programming for small-embedded devices. The biggest advantage of TinyOS is that application level code is independent of the underlying mote platform, thus changing platforms requires simply recompiling the application source code for the appropriate platform. Using the nesC programming language and TinyOS operating system allowed the sensor application to be developed very rapidly.

ATmega128 and ATmega103 support the TinyOS architecture while Atmega16 do not support it due to memory limitations. The present work can be implemented by using the any of the microcontroller, which supports TinyOS. The limitation of the present work can be seen with respect to TinyOS. As Atmega16 does not support TinyOS every time interfacing any sensor to it the software driver has to be written. In terms of power system is comparable to existing technology, which supports TinyOS while in code size the present system is superior to the existing technology. The power consumption in the sensor network has been reduced by keeping the motes active with small duty cycle i.e. 1% .In the present system the data can be monitored at certain interval of time hence power will be saved and battery life can be improved. The present system utilizes minimum of the resources of microcontroller e.g. timer, Interrupts etc. also, the external devices are not used e.g. EEPROM this contributes to the power savings.

It can be concluded that the motes implemented in the present work are comparable to the existing technology in terms of power but in terms of size and ease of application modeling it lacks the same flexibility as in Mica Motes. Further these motes can be developed using SOIC devices so as to reduce the size. Using the implemented motes a sensor network can be developed and used to compare the different parameters with that of network of the mica motes.

Chapter 7
Future Development

It is evident that a lot of work and improvements in all facets of the system are required before the ultimate goal of a miniature completely wireless Sensor Motes system can be achieved. This section seeks to detail some of the important improvements required and recommends ways to go about implementing them.

7.1 Improvements

7.1.1 Power Consumption

The system in the present application monitors the real time temperature in an office environment. It can be configured to measure the temperature after certain interval of time that will improve battery life and save the fair amount of power.

Power consumption of the slave nodes is quite high for a battery-powered system. The future goal of tiny circuitry will also require a tiny power source and tiny power consumption figures. Thus, it is a high priority to minimize power consumption. The use of low power devices like the LMC6464 micro-power op-amp, which only consumes 20μA of quiescent current per amplifier, is recommended. A very low power instrumentation amplifier can be implemented with three of the four amplifiers on the LMC6464 and it is suggested that this be tried. The use of power management features with the microcontroller and transceivers and the possible sharing of crystals between processor and transceiver should be done. To reduce power consumptions of the Slave Nodes the transceiver's power down option should be explored.

7.1.2 PC Software

Much functionality could be added to the PC program i.e. Base Station. Like the Slave sensor mote starts transmission only if it gets a certain character as a signal to start the transmission of data. If the software code for slave mote should have written in the Assembly language it would be helpful to reduce the power consumption to some extent. Besides, high quality hand crafted assembly language programs can run much faster and use much less memory and other resources than a similar program written in a high level language. Speed increases of two to 20 times faster are fairly common.

7.1.3 Size

Size, like power consumption is required to be reduced drastically to meet future goals. Reducing size means reducing the size and number of components used and has the added benefit of most likely reducing power consumption. It is recommended that as much as is possible, surface mount components with as few pins as possible be used. An investigation should be conducted into the effects of removing certain functional blocks of the circuitry, to determine whether any unnecessary components/functional blocks are in use. If so, these should be removed. (Like LM317)

7.1.4 Wireless Transmission

A real time application such as temperature monitoring in an office environment is implemented using the XBee module whose range is 30m indoors and 100m outdoor. In the interests of producing an improved quality WSM signal at far distant place, some other transceivers should be analyzed for long range according to applications requirement. An application such as wild life monitoring requires a radio with long range.

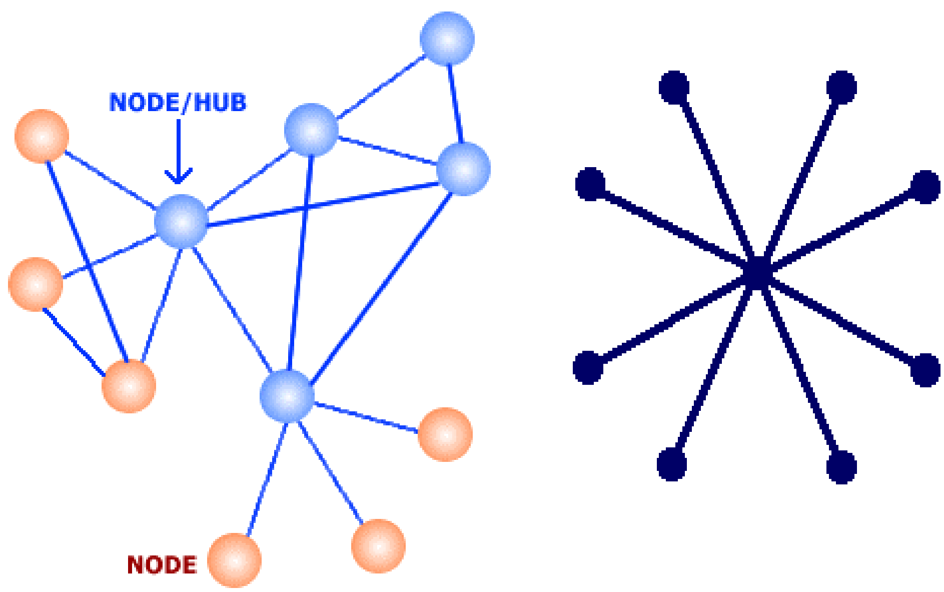
7.1.5 TinyOS

Present work is not implemented on TinyOS architecture, which has been designed particularly for sensor motes. It is suggested that with the use of TinyOS the motes should be implemented and compared with the present work in terms of Hardware and Software architecture, power dissipation etc.

7.2 Applications

After discussing the details of system improvements the applications, which can be possibly implemented using the present proof of concept model should be discussed.

7.2.1 Networking



(a) (b)

Figure 7.1: Mesh and Star Topology

XBee module supports Mesh and Star topology (Figure 7.1). Similar such motes as implemented in the present work can be implemented and can be arranged in the mesh or star topology. These networks can further be analyzed in terms of sensor networks.

7.2.2 Environmental control in office buildings

The temperature inside an office can vary by few degrees. The airflow of the room is not evenly distributed. So to control the airflow and temperature, a distributed sensor network can be used. Some of the topologies like mesh, star, tree, which are Zigbee compliant, can be used since we have used Xbee transceiver which is Zigbee compliant.

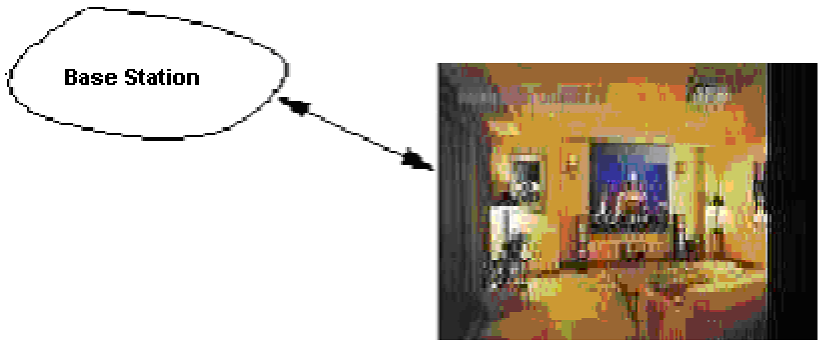


Figure 7.2: Environmental control in Office Building

7.2.3 Monitoring Nuclear Reactor

The application discussed here is for controlling chain reaction in nuclear reactors. The sensors monitor the reaction by observing parameters like radiation and temperature. The observer uses data from sensors and maintains the nuclear reactor in a stable state. In nuclear reactors, different sensors are used for sensing radiation and temperature. The sensor node senses information and sends to the control node. The control node aggregates the data and sends to the observer and also checks abnormal conditions like drastic changes in radiation or temperature. If abnormal condition occurs, then control node sends information to the observer and as well as to an alarm (actuator).

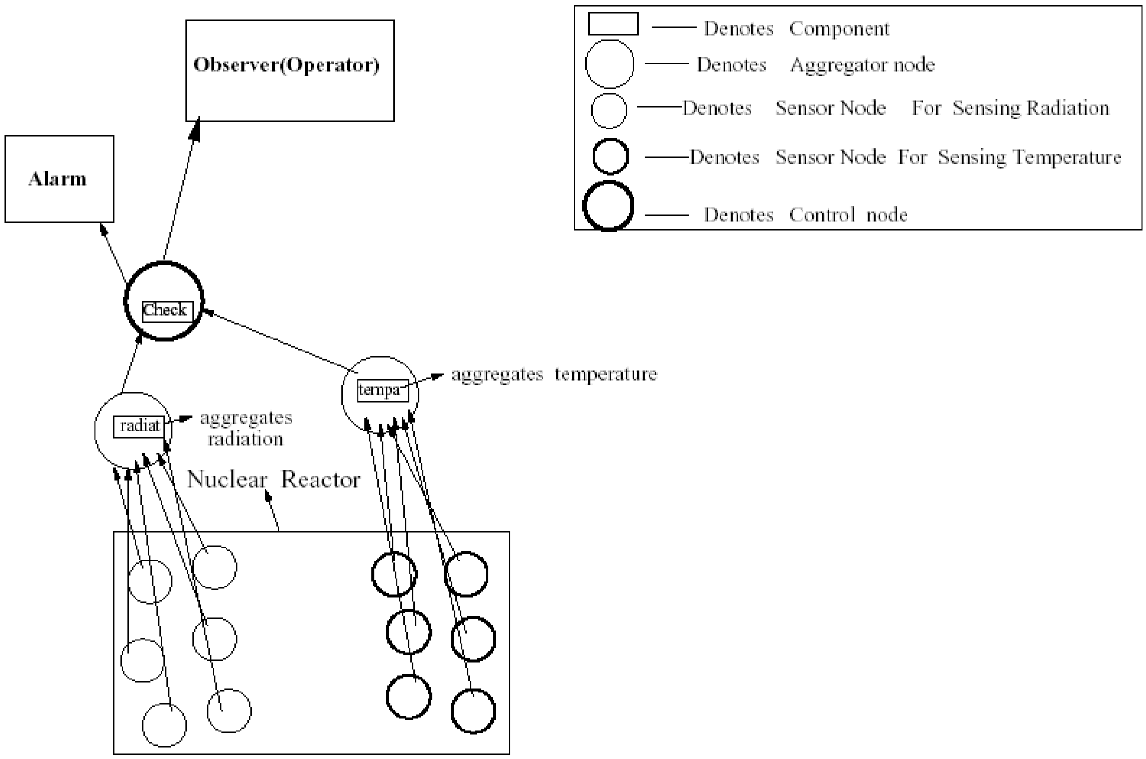


Figure 7.3: Monitoring Nuclear Reactor

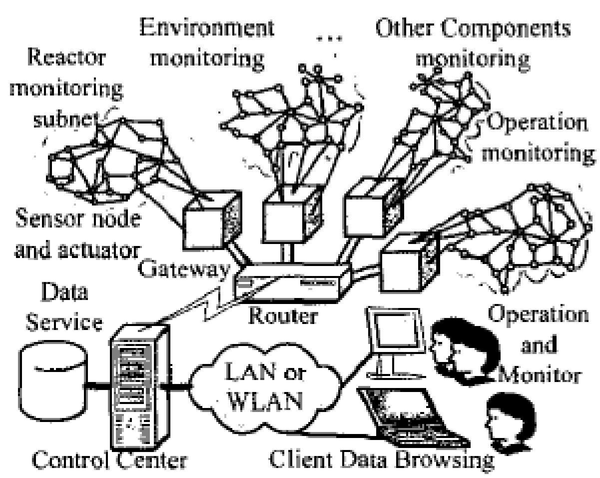


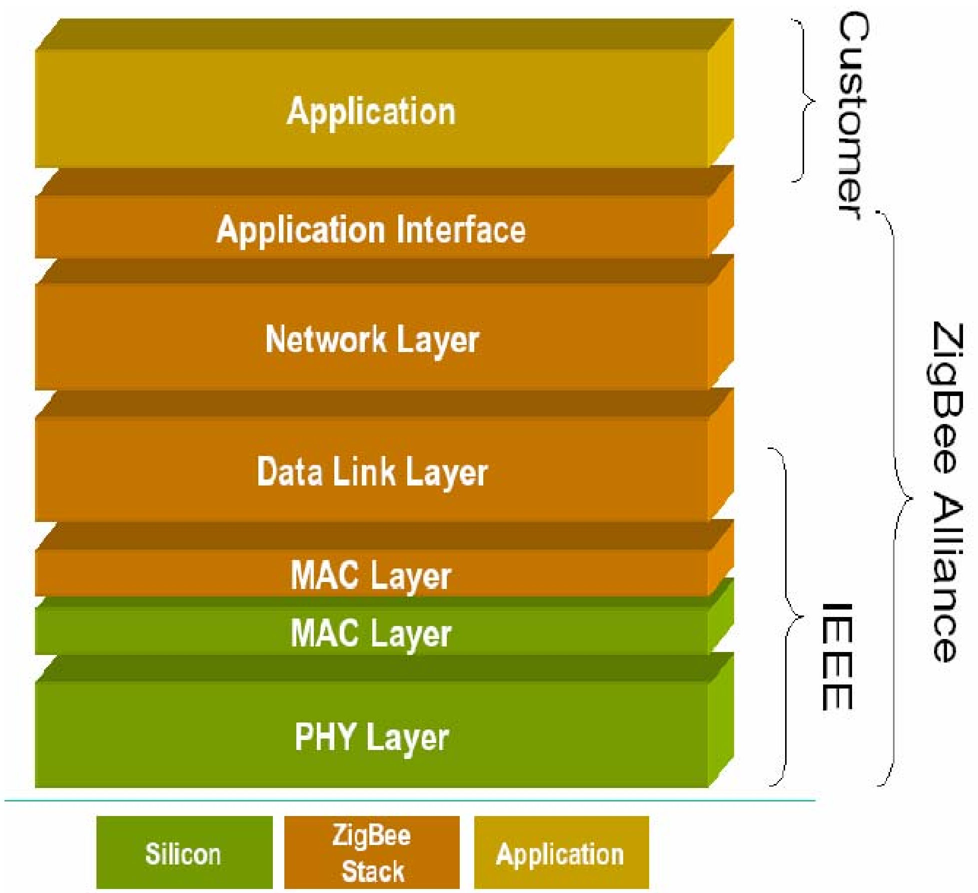
Figure 7.4: Architecture for real time monitoring of Nuclear power plant

A possible application is to find out Maximum Temperature in a given region, which consist of thousands of sensor nodes, which monitor the temperature. A possible topology is shown in the figure 7.3. Initially for implementing such a system, the research can be continued to obtain a design of complete system for monitoring the Nuclear power plant as suggested by Ruizhong Lin and et all [51]. Figure 7.4 shows the architecture for real time monitoring of nuclear power plant (RTMNPP).

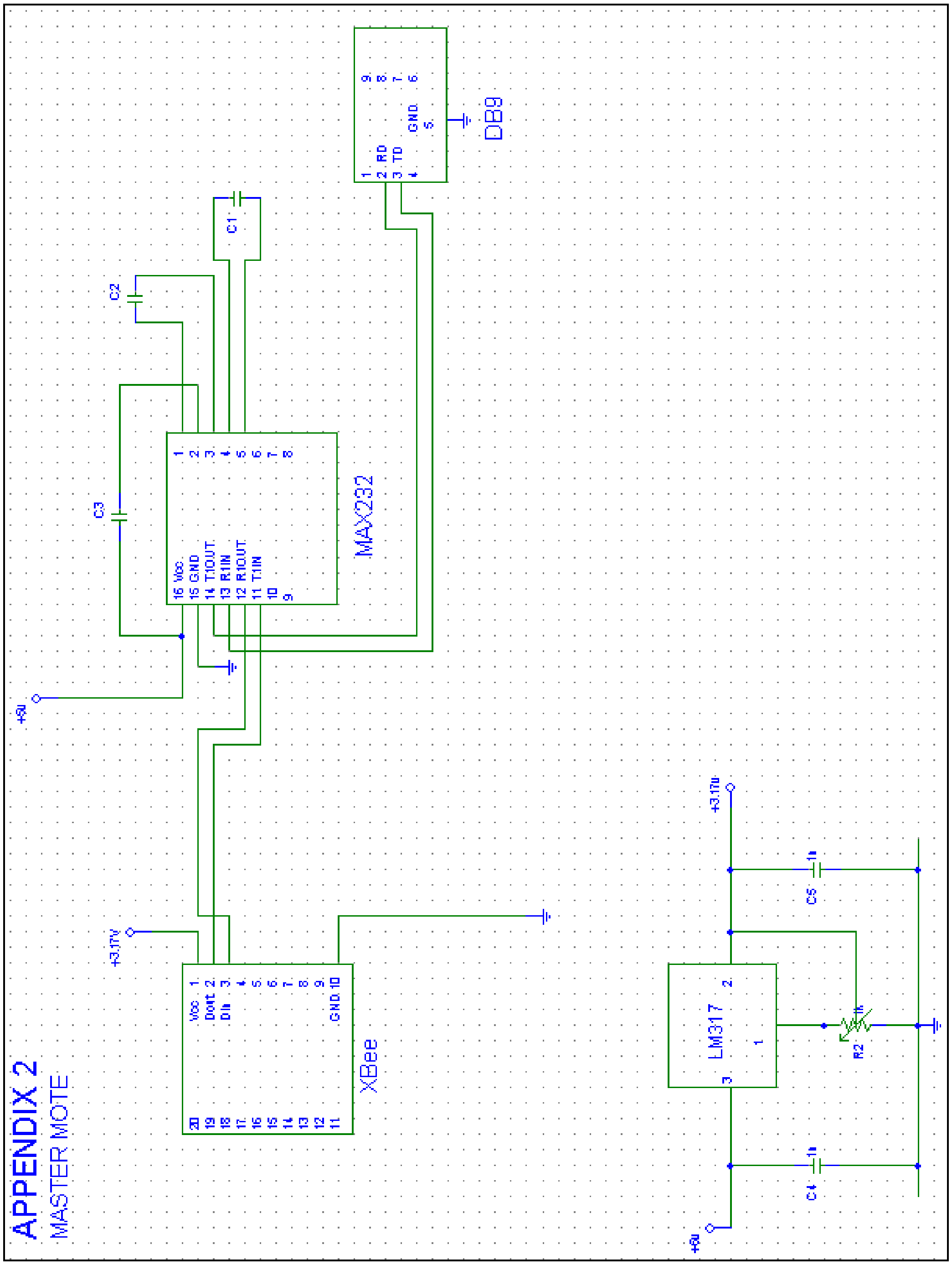
In summary, the vast potential of wireless sensor networks proves to be challenging and still be an emerging technology for research and new applications, in coming years.

Appendix 1

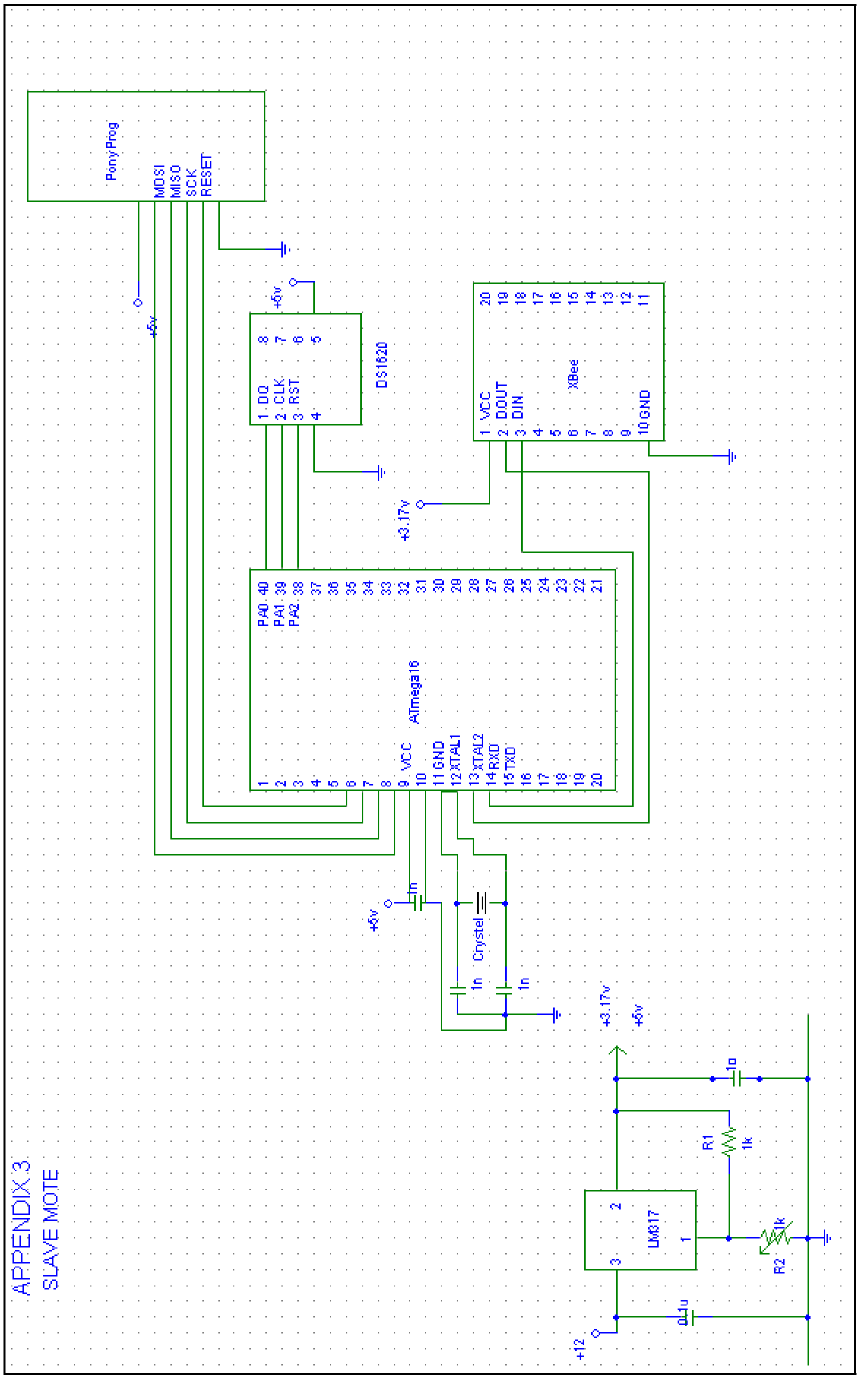
Zigbee Protocol Stack [21]



Appendix 2



Appendix 3


APPENDIX 3
SLAVE MOTE
PonyProg
MOSI
MISO
SCK
RESET
DS1620
XBee
ATmega16
LM317
Crystel

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