# CHAPTER 1

# INTRODUCTION

## 1.1 BACKGROUND

In recent years, a new wave of network labeled Wireless Sensor Networks (WSNs) have attracted a lot of attention from researchers in both academic and industrial communities. WSNs consist of tiny, energy efficient sensor nodes communicating via wireless channels, performing distributed sensing and collaborative tasks for a variety of monitoring applications. They include temperature, humidity, vibrations, seismic events and pollution detection to feature extractions.

An energy source of sensor node supplies the energy needed by the device to achieve the programmed assignment. This energy source often consists of a battery with a limited energy plan. In addition, it could be infeasible or difficult to recharge the battery, because nodes may be deployed in a hostile or impractical environment. On the other hand, the sensor network should have a life span long enough to fulfill the application requirements. Therefore, the crucial issue is to prolong the network lifetime.

In some cases, it is likely to scavenge energy from the external environment (e. g. by using solar cells as energy source). However, external energy sources regularly exhibit a non-continuous performance such that an energy buffer (a battery) is needed as well. In any case, Energy is a very significant resource and must be used very scarcely. Therefore, one of the main issues in Wireless Sensor Networks is how to prolong the network lifetime of WSNs with certain energy source and also how to maintain the coverage and connectivity. Optimizing the energy consumption in WSN has recently become the most important requirement. Hence, energy management is a key issue in wireless sensor networks.

## 1.2 WIRELESS SENSOR NETWORKS

### 1.2.1 Introduction

A Wireless Sensor Network consists of spatially distributed autonomous sensor nodes to monitor physical or environmental conditions such as temperature, sound, pressure, etc. and to cooperatively pass their data through the network to a main location as shown in Figure 1.1. In typical deployment scenarios, a few neighboring nodes lie within the communication radius of each node. Each sensor node performs the functions such as

- Sensing the physical parameters of its environment
- Processing the raw data locally to extract the feature of interest
- Transmitting the information to its neighbors through a wireless link.

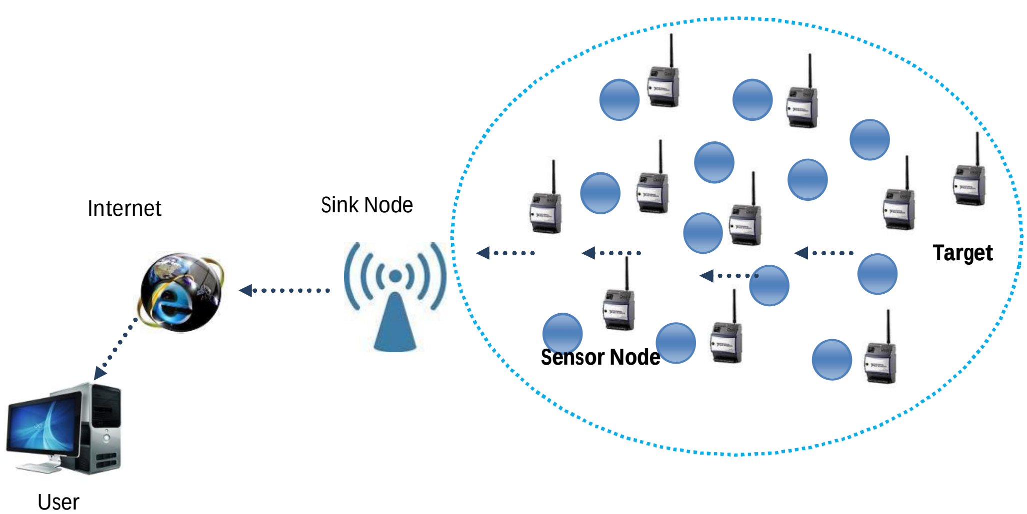


**Figure 1.1 Wireless Sensor Network**

Unlike Cellular Networks or Wireless Local Area Network (WLAN), there are no distributed base stations or access points in WSN. Hence, each node operates as a relay point to implement a multi hop communication link by receiving data from one of its neighbors, and then processing it before routing it to the next neighbor in the direction of destination. In some cases, additional functions such as data compression and encryption are also incorporated as discussed by Akyildiz et al (2002).

### 1.2.2 Sensor Node Architecture

A sensor node, also known as a mote, is a node in a wireless sensor network that is capable of performing some processing, gathering sensory information and communicating with other connected nodes in the network. A sensor node is a tiny device that includes four basic components: a sensing subsystem for data acquisition from the physical surrounding environment, a processing subsystem for local data processing and storage, a wireless communication subsystem for data transmission and a power supply subsystem consisting of a battery with a limited energy budget.

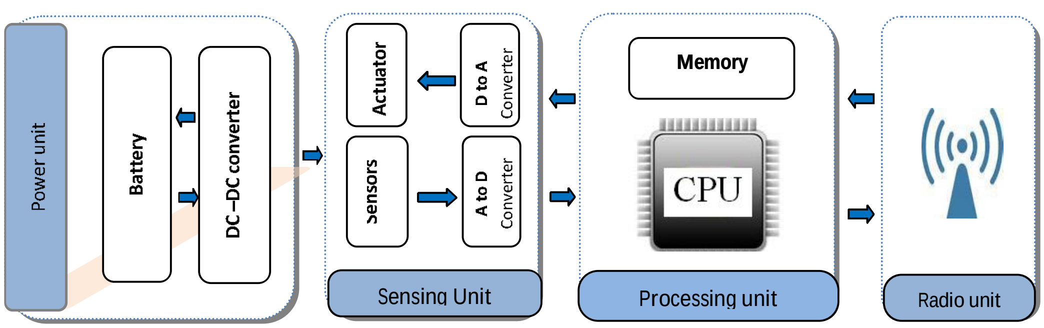


**Figure 1.2 Architecture of a Sensor Node**

The general hardware architecture of a sensor node and typical functional subsystems within a wireless sensor node is depicted in Figure 1.2. Moreover, additional components can also be integrated into the sensor node depending on the application. These components include a power generator, a mobilizer and a location finding system.

**Sensing Subsystem**

Sensing Subsystem includes several sensing units, which provide information gathering capabilities from the physical world. Each sensor unit is responsible for gathering information of certain type, such as temperature, humidity, or light and is usually composed of two sub units: a sensor and an Analog-to-Digital Converter (ADC). The analog signals produced by the sensor are converted to digital signals by the ADC and fed into the processing unit.

**Processing Unit**

The processing unit is the main controller of the wireless sensor node, through which every other component is managed. The processing unit may consist of an on-board memory or may be associated with a small storage unit integrated into the embedded board. The processing unit manages the procedures that enable the sensor node to perform sensing operations, run associated algorithms, and collaborate with other nodes through wireless communication.

**Radio Unit**

Communication between any two nodes is performed by radio (transceiver) units. A communication unit implements the necessary procedures to convert bits to be transmitted into radio signal (RF) and recovers them at the other end. The MICA2 node includes a 433/868/916 MHz transceiver at 40 kbps. MICAz and IRIS nodes are equipped with IEEE 802.15.4 compliant radio and operate at 2.4 GHz with a data rate of 250 kbps.

**Power Unit**

One of the most important components of a wireless sensor node is the power unit. Usually battery power is used, but other energy sources are also possible. Each component in the wireless sensor node is powered through the power unit and the limited capacity of this unit requires energy-efficient operation of the tasks performed by each component.

### 1.2.3 Applications of WSNs

WSNs find useful applications in various fields ranging from environmental monitoring to monitoring the parameters of vital signs of patients in hospitals. WSNs can be deployed on a global scale for the applications of military surveillance and reconnaissance in battle field, search and rescue operations in case of emergency, infrastructure health monitoring in buildings**,** environmental applications in the forests and fields, or even within human bodies for monitoring the conditions of patients.

Wireless Sensor Networks may consist of many different types of sensors such as seismic, magnetic, thermal, visual, infrared, acoustic and radar. They are able to monitor a wide variety of ambient conditions that include temperature, humidity, vehicular movement, lightning condition, pressure, soil makeup, noise levels, the presence or absence of certain kinds of objects, mechanical stress levels on attached objects and the existing characteristics such as speed, direction and size of an object.

**Military applications**

The rapid deployment, self-organization and fault tolerance characteristics of sensor networks make them a very promising sensing technique for military command, control, communications, computing, intelligence, surveillance, reconnaissance and targeting (C4ISRT) systems as discussed by Akyildiz et al (2002). Military sensor networks could be used to detect and gain as much information as possible about enemy movements, explosions and other phenomena of interest such as battlefield surveillance, nuclear, biological and chemical attack detection and reconnaissance.

**Environmental applications**

WSNs have been deployed for environmental monitoring, which involves tracking the movements of small animals and monitoring environmental conditions that affect crops and livestock. In these applications, WSNs collect readings over time across a space large enough to exhibit significant internal variation. Other applications of WSNs are chemical and biological detection, precision agriculture, biological, forest fire detection, volcanic monitoring, meteorological or geophysical research, flood detection and pollution study.

Monitoring applications include indoor/outdoor environmental monitoring, health and wellness monitoring, power monitoring, inventory location monitoring, factory and process automation, seismic and structural monitoring. WSNs can also be used to track objects, animals, humans, and vehicles. It can be deployed in environment, health, home and other commercial areas. It is possible to expand this classification with more categories such as space exploration, chemical processing and disaster relief.

One of the renowned case is the Great Duck Island experiment as discussed by Mainwaring et al (2002) which collected information about a special seabird named petrel living on the island. The petrel had been a very difficult subject for zoologists to study due to the bad climatic conditions on the island and abnormal lifestyle. With the help of WSNs, detailed study of such rare wildlife species can be provided.

Vasilescu et al(2005) developed an underwater monitoring platform for underwater sensor networks to be used for long term monitoring of coral reefs and fisheries. The nodes communicate via point-to-point links using high speed optical communications. Nodes broadcast using an acoustic protocol integrated in the TinyOS protocol stack. They have a variety of sensing devices, including temperature, pressure sensing devices and cameras. Similarly, Zebra Net system is a mobile Wireless Sensor Network used to track animal migrations as stated by Zhang et al (2004).

**Healthcare applications**

WSN based technologies such as Ambient Assisted Living and Body Sensor Networks provide dozens of solutions to healthcare's biggest challenges such as aging population and rising healthcare costs. Body sensor networks can be used to monitor physiological data of patients. It can monitor and detect elderly people's behavior, e.g., when a patient has fallen. These small sensor nodes allow patients a greater freedom of movement and allow doctors to identify pre-defined symptoms earlier on. The small installed sensor can also enable tracking and monitoring of doctors and patients inside a hospital. Each patient has small and lightweight sensor nodes attached to them, which may be used to detect the heart rate and blood pressure. Doctors may also carry a sensor node, which allows other doctors to locate them within the hospital.

Welsh et al(2007) proposed Mote Track, a patient tracking system developed by Harvard University which tracks the location of individual patient’s indoors and outdoors, using radio signal information from the sensor attached to the patients. Heart@Home is a wireless blood pressure monitor and tracking system. Heart@Home uses a SHIMMER mote located inside a wrist cuff which is connected to a pressure sensor. A user’s blood pressure and heart rate is computed using the oscillometric method. The SHIMMER mote records the reading and sends it to the T-mote connected to the user's computer. A software application processes the data and provides a graph of the user's blood pressure and heart rate over time.

**Home applications**

With the advancement in technology, the tiny sensor nodes can be embedded into furniture and appliances, such as vacuum cleaners, microwave ovens and refrigerators. They are able to communicate with each other and the room server to learn about the services they offer, e.g., printing, scanning and faxing. These room servers and sensor nodes can be integrated with existing embedded devices to become self-organizing, self-regulated and adaptive systems to form a smart environment. Automated homes with Personal Area Networks using protocols such as ZigBee can provide the ability to monitor and control mechanisms like light switches, HVAC (heating, ventilating, air conditioning) thermostats, computers, TVs and other electronic devices, smoke detectors, alarm panels, motion sensors and other security devices such as electricity, water and gas meters.

Traffic conditions can be easily monitored and controlled at peak times by WSNs. Temporary situations such as road works and accidents can also be monitored. Further, the integration of monitoring and management operations such as sign post control is facilitated by a common WSN infrastructure.

## 1.3 CHALLENGES AND RESEARCH ISSUES IN WSNs

WSNs have unique characteristics which are different from traditional wired or wireless networks. First, there is no fixed infrastructure and sensors self organize via collaboration. Second, sensors are constrained to limited resources such as energy, bandwidth, processing and memory. Third, sensors may malfunction due to reasons like energy drainage, interference, movement or obstacles. Therefore, the network topology can change quickly and dynamically. Due to the unique characteristics above, WSNs have the following open challenges and research issues as mentioned by Gowrishankar et al (2008).

### 1.3.1 Energy Conservation

Depending on the specific application, WSNs may have a lifetime of at least several months to years. Due to the fact that most sensors are powered by limited batteries, prolonging the network lifetime is the primary challenge. There are several key factors which can affect the energy consumption in WSNs. Since the sensor nodes are composed of sensing, communication and processing units, the energy consumption can also be divided into three parts correspondingly. First, some low power hardware components can be installed on the sensor board to reduce energy consumed during sensing phase. Second the selection of different protocols on various layers can influence the energy consumption greatly.

For example, the node sleeping and wakeup mechanism as quoted by Wang et al (2006) can be introduced in the MAC layer to reduce energy consumption. Advanced signal processing techniques as stated by Dong et al (1997) can be adopted to improve the processing efficiency of different kinds of data message. By adopting power control and power management, not only the energy efficiency but also the network capacity and interference performance can be improved.

### 1.3.2 Deployment

Deployment means setting up an operational sensor network in a real world environment as stated by Ringwald & Romer (2007). Deployment of sensor network is a labor intensive and cumbersome activity and no influence can be made over the quality of wireless communication and the real world parameters puts strains on sensor nodes by interfering during communications. Sensor nodes can be deployed either by placing one after another in a sensor field or by dropping it from a plane.

Research issues include improving the range and visibility of the radio antennas when deployed in various physical phenomenon, detecting wrong sensor readings at the earliest in order to reduce latency and congestion.

### 1.3.3 Topology Design

The topology design and network coverage of WSNs is critical to network reliability, connectivity as well as energy consumption as discussed by Yu et al (2004). The sensor nodes can be deployed either beforehand with specific pattern (like disk or grid) or promptly in a random distribution (e.g. dropped from airplane). The energy workload balancing with the aid of topology design is a practical challenge to the successful implementation of WSNs.

### 1.3.4 Architecture Design

The WSNs must deal with modules like energy, processing and memory which are dynamic. The system should operate autonomously, changing its configurations as required by each application. Hence the node's internal architecture needs to be carefully designed based on hardware platform as mentioned by Razavilar et al (1999). Also, the consideration of interconnection between WSNs and other networks has been discussed by Finn (1987). Other function modules like localization, synchronization, signal processing and the storage and retrieval of data information under the whole architecture need to be considered.

### 1.3.5 Clock Synchronization

Clock synchronization is an important service in sensor networks. Time Synchronization in a sensor network aims to provide a common timescale for local clock of nodes in the network. A global clock in a sensor system will help to process and analyze the data correctly and predict future system behavior. Some applications that require global clock synchronization are environment monitoring, navigation guidance, vehicle tracking, etc. A clock synchronization service for a sensor network has to meet challenges that are substantially different from those in infrastructure based networks as discussed by Sivrikaya & Yener (2004).

Various research issues include building analytical model for multi-hop synchronization, improving the radio communication in the existing synchronization protocols like RBS (Reference Broadcast Synchronization) and LTS (Light Weight Tree Based Synchronization).

### 1.3.6 Sensor Localization

Sensor localization is a fundamental and crucial issue for network management and operation. In many of the real world scenarios, the sensors are deployed without knowing their positions in advance and also there is no supporting infrastructure available to locate and manage them once they are deployed as discussed by Pandy et al(2005).

Determining the physical location of the sensors after they have been deployed is known as the problem of localization. The research on mobile nodes localization and motion analysis in real time continue to grow as sensor networks are deployed in large numbers and as applications become varied. Scientists in numerous disciplines are interested in methods for tracking the movements and population counts of animals in their habitat i.e. passive habitat monitoring. Another important application is to design a system to track the location of valuable assets in an indoor environment. It is necessary to improve the maximum likelihood estimation in a distributed environment like sensor networks. Developing mobile assisted localization is another important research area.

### 1.3.7 Data Aggregation and Data Dissemination

Data gathering is the main objective of sensor nodes. The nodes processes and transmits the data to the base station or sink. The frequency of reporting the data and the number of sensors which report the data depends on the particular application. Data gathering involves systematically collecting the sensed data from multiple sensors and transmitting the data to the base station for further processing. But the data generated from sensors is often redundant and also the amount of data generated may be very huge for the base station to process it. Hence a method is required for combining the sensed data into high quality information and this is accomplished through Data Aggregation as discussed by Rajagopalan & Varshney (2006). Data Aggregation is defined as the process of aggregating the data from multiple sensors to eliminate redundant transmission and estimating the desired answer about the sensed environment and providing fused information to the base station.

Main research focus in data aggregation is geared towards conserving energy. Other research issues include improving security in data transmission and aggregation, handling tradeoffs in data aggregation i.e. tradeoffs between different objectives such as energy consumption, latency and data accuracy, improving quality of service of the data aggregation protocols in terms of bandwidth and end to end delay.

### 1.3.8 Security

Security is a nontrivial problem for WSN. It includes research issues like security infrastructure, key management, authentication, robustness to Denial of Service (DoS) attacks, secure routing, privacy, etc. as discussed by Perrig et al (2000). To achieve a secure system, security must be integrated into every component module rather than each separate module since components designed without security can become a point of attack in WSN. Sensor networks also have thrust privacy concerns. The most obvious risk is that ubiquitous sensor technology might allow ill-intentioned individuals to deploy secret surveillance networks for spying on others. Employers might spy on their employees; shop owners might spy on customers; neighbors might spy on each other etc. As the sensor devices are advancing, this trend might become worse if there is no law enforcement.

The security issues posed by sensor networks are a rich field for research problems like designing routing protocols with built in security features, a symmetric key cryptography for sensor networks, designing secure data aggregation protocols, designing intrusion detection systems and security systems for multimedia sensors.

### 1.3.9 Quality of Service

Quality of service is the level of service provided by the sensor networks to its users. The authors Iyer & Kleinrock (2003) define Quality of Service (QoS) for sensor networks as the optimum number of sensors sending information towards information-collecting sinks or a base station. Since sensor networks are implemented in more and more number of applications which includes mission critical applications such as military applications and nuclear plant monitoring applications, QoS is being given considerable review as the events occurring in these situations are of utmost importance.

The performance of the most wired routing algorithms relies on the availability of the precise state information while the dynamic nature of sensor networks make the availability of precise state information next to impossible. Nodes in the sensor network may join, leave and rejoin and links may be broken at any time. Hence maintaining and re-establishing the paths dynamically which is a problem in WSN is not a big issue in wired networks.

## 1.4 NEED FOR ENERGY MINIMIZATION IN WSN

In WSN, the nodes are mostly operated using batteries. The output capability of a battery over a period of time is referred to as its capacity. It is measured in Ampere-hours and is mostly proportional to the voltage. Over a period of time, the capacity of a battery can be established as a function of a continuous discharging process. As the current drawn increases, the corresponding voltage, remaining capacity, available energy and expected lifetime of the battery decreases.

Detail of estimates of the power consumption requirements of major subsystems of sensor node as shown in Figure 1.3. As Figure 1.3 shows, in most modern wireless sensor applications a majority of the energy consumption is attributable to communication.

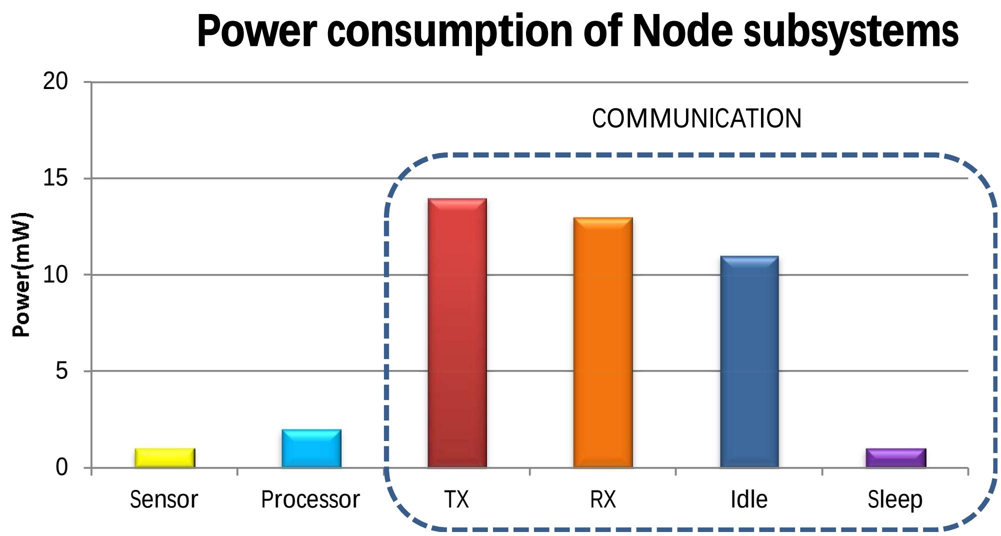


**Figure 1.3 Power Consumption of Sensor Node Subsystems**

It is well known that the energy consumed for transferring one bit of data can be used to perform a large number of arithmetic operations in a sensor processor (power consumed for transferring one bit of data to a receiver 100m away is equal to that needed to execute 3,000 instructions). This necessitates the development of energy aware mechanisms that minimize the number of radio related activities, thereby reducing the energy consumption in the node and network. This research work focuses on the minimization of energy usage in the radio module using three domains namely clustering, routing and data aggregation.

## 1.5 MOTIVATION OF RESEARCH WORK

Energy consumption is the most important factor that determines the life of a sensor network as sensor nodes are being mostly driven by batteries. This necessitates energy optimization in the sensor nodes to increase the lifetime of the network. This can be achieved by incorporating energy awareness in every aspect of design and operation that can be adapted to work efficiently in different environments.

Since energy conservation is the primary challenge for WSN, how to utilize the energy efficiently during routing process so as to prolong network lifetime is an important research issue. The objective of energy conservation is not only to reduce energy consumption during routing process but also to balance energy consumption among the sensor nodes.

The vast number of solutions that have driven the research community over the years made WSN phenomenon a reality. However, their proliferation has so far been limited to the research community with just a minimum number of commercial applications. The major challenge for the proliferation of WSN is energy. Extremely energy efficient solutions are required for each aspect of WSN design to deliver the potential advantages of the WSN phenomenon. Therefore, in both existing and future solutions for WSN, energy efficiency is the major challenge.

From that, the problem of energy optimization in Wireless Sensor Networks is important for the modern researchers and is being taken into considerations for all manufacturers and developers of such systems. Whereas, the main issue of this problem from computer systems and information technology side is the clustering of the Wireless Sensors Network.

Clustering is one of the basic approaches for designing energy efficient, robust and highly scalable sensor networks. Clustered organization dramatically reduces the communication overhead, thereby minimizing energy consumption and interference among the sensor nodes. Moreover, by aggregating the sensor's data at a designated node called cluster Head, the total amount of data to the base station can be reduced. Since most of the clustering protocols are based on local properties, clusters generated by these protocols are often not optimal. In this backdrop, the question of how to create load balanced energy efficient cluster assumes greater significance.

Re-clustering the network is often necessary in order to achieve load balancing. However, re-clustering consumes energy as well, thus to maximize the benefit of the clustering algorithm, this energy consumption must be minimized.

Many approaches based on different criteria are suggested by researchers as stated by Abbasi & Younis (2007). Many clustering algorithms require re-clustering after a round of the protocol operation, causing extra energy consumption as stated by Heinzelman et al (2000). It is worth to investigate a way to reduce this extra energy consumption.

Routing protocols for sensor networks should try to minimize energy consumption in order to maximize the network life time. Among the many routing protocols that have been developed for WSNs, the cluster based hierarchical routing protocols claims more energy efficiency compared to other protocols as mentioned by Akkaya & Younis (2005). The most interesting research issue regarding cluster based hierarchical routing protocols is how to form the clusters , how to find the route and how the CH aggregates the data, so that the energy consumption is optimized.

## 1.6 SCOPE AND OBJECTIVES OF RESEARCH

The main objective of the research work is to investigate the energy efficient schemes for cluster based WSNs. Such an energy efficient scheme should aim for one or more aspect of minimizing the total energy spent in the network, minimizing the number of data transmissions, maximizing the number of alive nodes over time or balancing the energy dissipation among the sensor nodes in the network. This research work employs some approaches such as Clustering, Multi hop communication and Data aggregation in order to extend the network life time.

## 1.7 CONTRIBUTIONS AND ORGANIZATION OF THE THESIS

The following are the major contributions of the thesis:

- To propose an Energy Efficient Clustering (E2C) technique for energy efficiency and load balancing enhancement when compared to the existing clustering techniques for Wireless Sensor Networks.
- To analyze the Energy Efficient Clustering technique with Multilevel Hierarchical Routing in WSN.
- To enhance the energy efficiency of Cluster based Multilevel Hierarchical Routing using Compressed Sensing for data aggregation in WSN.
- To develop a service oriented framework for real time monitoring of agricultural parameters using WSNs.

The thesis work is organized in seven chapters. In Chapter 1, Introduction to the research work has been discussed. Chapter 2 is a literature survey on existing energy efficient protocols for wireless sensor networks. In Chapter 3, the proposed Energy Efficient Clustering (E2C) with detailed explanation has been analyzed. Chapter 4 analyzes the energy efficient clustering with multi level cluster based hierarchical routing sensor networks. To enhance the energy efficiency of cluster based multilevel hierarchical routing, compressed sensing based data aggregation has been introduced in Chapter 5. Chapter 6 focuses on the development of a service oriented framework for real time monitoring of agricultural parameters using WSNs. Conclusion of the thesis is brought in chapter 7 including scope for the future research work.