MAY, 2018

M.Sc. in Electronics and Computer Engineering

BATUR ALP AKGÜL

HASAN KALYONCU UNIVERSITY

GRADUATE SCHOOL OF

NATURAL & APPLIED SCIENCES

LOW-POWER PIC-BASED SENSOR NODE DEVICE DESIGN AND THEORETICAL ANALYSIS OF ENERGY CONSUMPTION IN WIRELESS SENSOR NETWORKS

M. Sc. THESIS

IN

ELECTRONICS AND COMPUTER ENGINEERING

BY

BATUR ALP AKGÜL

MAY 2018

“Low-Power PIC-Based Sensor Node Device Design and Theoretical Analysis of Energy Consumption in Wireless Sensor Networks”

M.Sc. Thesis

in

Electronics and Computer Engineering

Hasan Kalyoncu University

Supervisor

Assoc. Prof. Dr. Muhammet Fatih HASOĞLU

by

Batur Alp AKGÜL

May 2018

REPUBLIC OF TURKEY
HASAN KALYONCU UNIVERSITY
GRADUATE SCHOOL OF NATURAL & APPLIED SCIENCES
NAME OF THE DEPARTMENT

Name of the thesis: Low-Power PIC-Based Sensor Node Device Design and Theoretical Analysis of Energy Consumption in Wireless Sensor Networks.

Name of the student: Batur Alp AKGÜL

Exam date: May 10, 2018

Approval of the Graduate School of Natural and Applied Sciences.

Prof. Dr. Mehmet KARPUZCU
Director

I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science.

Dr. Öğr. Üyesi Bülent HAZNEDAR
Head of Department

This is to certify that we have read this thesis and that in our consensus/majority opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

Doç. Dr. M. Fatih HASOĞLU
Supervisor

Examining Committee Members	Signature
Prof. Dr. İbrahim Taner OKUMUŞ	....
Doç. Dr. M. Fatih HASOĞLU	....
Dr. Öğr. Üyesi Bülent HAZNEDAR	....

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Batur Alp AKGÜL

ABSTRACT

LOW-POWER PIC-BASED SENSOR NODE DEVICE DESIGN AND THEORETICAL ANALYSIS OF ENERGY CONSUMPTION IN WIRELESS SENSOR NETWORKS.

AKGÜL, BATUR ALP
M.Sc. in Electronics and Computer Engineering.
Supervisor: Assoc. Prof. Dr. Muhammet Fatih HASOĞLU
May 2018
124 pages

Advancing technology has enabled the production of smaller more energy efficient and cheaper electronic components. Therefore, previously existing many computer and electronics science-engineering ideas have become feasible. One of them is the technology of wireless sensor networks. Wireless sensor networks have become the realization of the necessary technical requirements applicable today with low energy consumption. Moreover, other scientific studies have become made mandatory in the design of sensor networks such as communication algorithms, energy harvesting protocols and renewable energy technologies.

In this thesis, I have studied the concept of sensor networks which has been made viable by the convergence of microelectronic systems technology, wireless communications, and digital electronics. First, the sensing tasks and the potential sensor networks applications have explored and a review of factors influencing the design of sensor networks have been provided. Then, the communication architecture for sensor network has been outlined. Besides, new hardware architecture has designed to make it possible for a single node to communicate with WLAN renewable energy resources have used in the nodes.

I have been examined WSN in terms of the analytical and applied sciences. Theoretical analyzes have been supported by scientific applications. Studies have been conducted on wireless sensor networks based on the realization of low energy and maximum safety principle. After designed the wireless sensor network system; Energy consumption and network location behavior of wireless sensor nodes have ben tested and analyzed. The relationship between low energy consumption and sensor nodes are evaluated in detail.

PIC-Based microcontrollers have used in the design of the sensor nodes. The design of the sensor nodes are supported with ultra-low power nano-watt technology for very low-cost design. Processing, memory, and wireless communication units have been integrated onto the sensor nodes. The designed sensor node's operating system has written with the PIC C language and PIC operating system has allowed different features such as measuring humidity, smoke, temperature and light sensitive. A computer software has developed with C# programming language so that data can be recorded and monitored from a central location.

Decision-making unit has been created through the software algorithm and hardware modules for the implementation of decisions taken by the developed sensor nodes. Developed PIC-Based sensor nodes have supported a unique external PIC-Controlled voltage unit with renewable energy sources such as solar panel, rechargeable battery, and a supercapacitor for energy production and energy-saving. Developed wireless sensor network system can be used in industrial applications and daily life applications such as smart factories and smart homes. WSNs can be designed to be used in a wide range of applications. The results of this study are expected to be helpful for the development of WSN especially with renewable energy sources.

Key Words: Wireless, Sensor, Energy, Consumption, PIC, Node, Develop, Design

ÖZET

KABLOSUZ SENSÖR AĞLARI İÇİN PIC TABANLI VE DÜŞÜK GÜÇ TÜKETİMLİ SENSÖR DÜĞÜMÜ TASARIMLARI VE ENERJİ TÜKETİMLERİNİN TEORİKSEL ANALİZİ.

AKGÜL, BATUR ALP
Yüksek Lisans Tezi, Elektronik Bilgisayar Müh. Bölümü
Tez Yöneticisi: Doç. Dr. Muhammet Fatih HASOĞLU
Mayıs 2018
124 sayfa

Teknolojinin ilerlemesi, daha enerji verimli ve daha ucuz elektronik bileşenlerinin daha küçük üretilmesini sağlamıştır. Bu nedenle, daha önce mevcut birçok bilgisayar ve elektronik bilim-mühendislik fikirleri uygulanabilir hale gelmiştir. Bunlardan birisi de kablosuz sensör ağları teknolojisidir. Kablosuz algılayıcı ağlar, düşük enerji tüketimi ve gerekli teknik gereksinimlerin gerçekleşmesi ile uygulanabilir hale gelmiştir. Ayrıca, Kablosuz algılayıcı ağlarının tasarımında iletişim algoritmaları, enerji tasarruf protokolleri ve yenilenebilir enerji teknolojileri gibi diğer bilimsel çalışmalar zorunlu hale gelmiştir.

Bu tez, mikroelektronik sistemler, kablosuz iletişim ve dijital elektronik teknolojisinin ilerlemesiyle uygulanabilir hale gelmiş sensör ağları teknolojisini kapsamaktadır. Birincisi, algılama görevleri ve potansiyel algılayıcı ağ uygulamaları araştırılmış ve algılayıcı ağlarının tasarımını etkileyen faktörlerin gözden geçirilmesi sağlanmıştır. Ardından sensör ağları için iletişim mimarisi ana hatlarıyla belirtilmiştir. Ayrıca, tek bir düğümün WLAN ile iletişim kurabilmesi için yeni donanım mimarisi tasarlanmış ve düğümlerde yenilenebilir enerji kaynakları kullanılmıştır.

Bu tezde WSN, analitik bilim ve uygulamalı bilim açısından incelenmiştir. Düşük enerji tüketimi ve iletişim protokolleri arasındaki ilişki değerlendirilmiş ve bilimsel sonuçlara varılmıştır. Teorik analizler bilimsel uygulamalarla desteklenmiştir. Çalışmalar, düşük enerji ve maksimum verimlilik prensibinin gerçekleştirilmesine dayalı kablosuz sensör ağları üzerinde gerçekleştirilmiştir. Kablosuz sensör ağlari sistemi tasarlandıktan sonra; sensör düğümlerinin enerji tüketimi ve kablosuz ağdaki davranışları test ve analiz edilmiştir. Düşük enerji tüketimi ile sensör düğümleri arasındaki ilişki detaylı olarak değerlendirilmiştir.

PIC Tabanlı mikro denetleyiciler sensör düğümlerinin tasarımında kullanılmış ve çok düşük maliyetli tasarım için ultra düşük güçte, nanoWatt teknolojisi ile desteklenen sensör düğümleri tasarlanmıştır. İşleme birimi, bellek birimi ve kablosuz iletişim birimi sensör

düğümlerine entegre edilmiştir. Tasarlanan sensör düğümünün işletim sistemi PIC C dili ile yazılmıştır ve PIC işletim sistemi nem, sıcaklık, ışığa duyarlılık ve duman sensörü gibi farklı özelliklerin ölçülmesine izin vermiştir. Sensörlerden gelen verilerin merkezi bir konumdan kaydedilmesi ve izlenebilmesi için, C# programlama dili ile bilgisayar yazılımı geliştirilmiştir.

Gelişmiş algılayıcı düğümler tarafından alınan kararların uygulanması için yazılım algoritması ve donanım modüllerini içeren karar verme sistemi tasarlanmıştır. Gelişmiş PIC Tabanlı sensör düğümleri, enerji üretimi ve enerji tasarrufu için, güneş enerjisi paneli, şarj edilebilir pil ve süper kapasitör gibi yenilenebilir enerji kaynakları ile benzersiz bir PIC Kontrollü voltaj birimi ile desteklenmiştir. Geliştirilmiş kablosuz sensör ağları sistemi, endüstri uygulamaları, akıllı fabrikalar ve akıllı evler gibi günlük hayat uygulamaları için de kullanılabilecektir. Kablosuz algılayıcı ağlar geniş bir aralıkta kullanılmak üzere tasarlanmıştır. Tezin sonuçları, özellikle yenilenebilir enerji kaynakları ile WSN'nin geliştirilmesine yardımcı olmayı amaçlamaktadır.

Anahtar Kelimeler: Kablosuz, Sensör, Enerji, Tüketim, PIC, Düğüm, Geliştirme, Tasarım.

ACKNOWLEDGEMENTS

I would like to thanks to Assoc. Prof. Dr. Muhammet Fatih Hasoğlu for his constant support at all academic and research levels. All were priceless factors that helped me to achieve more than I thought possible. I want to also thank him for providing lab stations available for use and the equipment required to complete the project. He suggested me some software tools to use as a base for my own development and provided to allow me to quickly learn the basics of microcontroller programming so that I was able to easily develop my own material.

I would also like to thanks to the Electronics & Computer Engineering department staffs for their continuous encouragement, excellent guidance, invaluable suggestions, and support at all the stages of my research work. Their interest and confidence in me was the reason for all the success I have made. I have been fortunate to have them as my guides as they have been a great influence on me, both as a person and as a professional.

TABLE OF CONTENTS

CHAPTER IV - RESULTS AND DISCUSSIONS

CHAPTER V - CONCLUSIONS

CHAPTER VI - APPENDICES

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ADC	Analog to Digital Converters
API	Application Program Interface
BMAC	Berkley Media Access Control
CDMA	Code Division Multiple Access
CSMA	Carrier Sense Multiple Access
DAC	Digital to Analog Converter
EYES	Energy Efficient Sensor Networks
FDMA	Frequency Division Multiple Access
GEAR	Geographic and Energy Aware Routing
ICSP	In-Circuit Serial Programming
IEEE	Institute of Electrical and Electronics Engineers
LDR	Light Dependent Resistor
MAC	Media Access Control
MEMS	Micro Electro Mechanical Systems
MIMO	Multiple Input Multiple Output
NTC	Negative Temperature Coefficient
OSI	Open System Interconnection
PHY	Physical Layer
PIC	Peripheral Interface Controller
RAM	Random Access Memory
RFID	Radio Frequency Identification
SCI	Serial Communication Interface
SPI	Serial Peripheral Interface
SRAM	Static Random-Access Memory
TMAC	Timeout MAC
TCP	Transmission Control Protocol
TDMA	Time Division Multiple Access
TRAMA	Traffic-Adaptive Medium Access Protocol
UART	Universal Asynchronous Receiver Transmitter
WSN	Wireless Sensor Networks

CHAPTER I

INTRODUCTION

Introduction chapter is organised as Problem Definition, Goal of this Thesis, Organisation and Outline of Thesis and an introduction to wireless sensor networks. This chapter presents a general overview of the wireless sensor networks and therefore this chapter focuses on outlining the general ideas behind of the wireless sensor networks, provides a background of the wireless sensor network, explains the purpose of the thesis, and also presents the problem definition.

WSNs continue to undergo rapid improvement with recent technological advances. WSNs can be found everywhere in the worldwide. Examples may include object tracking, habitat monitoring, patient monitoring, fire detection, traffic control, industrial applications, brilliant home applications, etc. WSNs are infrastructures containing sensing unit, computing unit and a communication unit. The units provide the ability to measure, collect and response to events in the monitored environment.

Introduction part presents an overview of the WSNs. This first section, I aim to provide a general overview of the WSN components, reporting an overview of WSNs technologies, main applications and standards, features in WSNs design, and evolutions. This chapter provides a background of the wireless sensor network. At the beginning, an architectural of a sensor node, networking standards, protocol stack, communication protocol architecture, the performance modeling of WSN are overviewed.

1.1. Problem Definition and Goal

In recent years, development of sensor nodes can be smaller, lower cost and lower power devices than before. A sensor node is able to observe conditions of a certain area like temperature, vibration, pressure, sound, humidity, motion, pollutants, and so on. Measured values are recorded in a database for further processing. In the past, WSNs were made up of small numbers of sensor nodes which were wired to the database. But nowadays, researchers focus on wireless sensing nodes which transfer data without being dependent on wires. Moreover, it is easier to replace nodes which have to be observed. In the future, WSNs are expected to be produced in large numbers and will be become cheaper.

The objective of this thesis is to explore all aspects of WSNs under different modules including these as well in a systematic flow: Sensor nodes, existing hardware, sensor node's operating systems, PIC-Based control, node deployment options, topologies used for WSN, architectures, WSN lifecycle, resource constraint nature, applications, routing challenges and protocol design issues, existing protocols, protocol classifications, power-energy consumption issues, developing software, etc.

Disadvantages of WSNs exist due to limitations in processing power, routing problems, bandwidth, storage, energy constraints and supply. Therefore, the goal of this thesis is to find the most suitable hardware and software sensor node design for low power consumption, a faster routing process, renewable energy sources consumption, a long network lifespan.

One of the goals of this thesis is to develop a PIC-Based sensor node platform with renewable energy and ultra-low power consumption. Prototyping and software development is more constrained and is about developing a prototype working sensor node and related software. Once prototype design has been made, it is implemented in a schematic diagram then can be printed onto a circuit board. Later, the circuit has been made and the last thing to do is testing and verification.

Another goal of this thesis is to understand in depth and analyze the problem of energy constraint in WSNs. The energy of the nodes is the primary metric that dominates WSNs due to its profound impact on features such as network operational lifetime connectivity and routing protocols. So renewable energy sources are very important to extend lifespans such as solar power and rechargeable battery using the unique PIC-Based power circuit.

Another goal of this thesis is to develop a software for recording and monitoring data from a central location. I have developed a decision-making unit in the software algorithm and hardware modules for the implementation of decisions made by the developed sensor nodes.

In summary, there are three goals need to be realized in this system, including:

1) Develop PIC-Based wireless sensor nodes with ultra-low power consumption

2) Develop a unique PIC-Controlled power module along with integrated renewable energy.

3) Develop a software for monitoring system and recording data to the database.

4) Develop a decision-making in software and hardware for the implementation of decisions taken by the developed sensor nodes.

1.2. Organization and Outline

The thesis is organized into 5 chapters. Chapter 1 presents a general overview and provides a background of the wireless sensor network. Chapter 2 presents a literature review in the scientific researches, academic theses and scientific articles are studied. Meterials and methods are given in the Chapter 3 such as components of microcontrollers, sensors used in WSNs, routing protocols, power consumption, applications, applications, renewable energy and software management. Chapter 4 gives results and discussion obtained in this thesis. Finally, Chapter 5 presents detailed conclusions of the thesis.

1.3. Overview of the Wireless Sensor Networks

In recent years, WSNs have become a very emerging field in computer science due to its multifarious applicability including military applications, industrial applications, home applications, monitoring temperature, humidity, vehicular movement, etc. [1]. WSNs mostly uses so many microcontrollers from different companies such as Microchip, Atmel, etc. WSNs are composed of a large number of sensor nodes. In general, WSN architecture has four key important features:

- It is self-organized,
- It can take the decision locally,
- It supports wireless communication,
- Its traffic flow is almost unidirectional towards the destination or sinks.

Microprocessor units are essential and important part of the wireless sensor nodes. Microcontrollers process all algorithms and protocols. They are responsible for switching between different operating processes. The transceiver is used for the communication between the sensor nodes. The transceiver is responsible for transmitting, receive, sleep and idle functions. Sensors are responsible for measuring environmental conditions such as humidity, temperature, pressure, etc. Sensor nodes are not connected to power supply unit for energy, instead batteries (rechargeable or rechargeable) are used to meet energy requirements. An example of the block diagram of the sensor node is given in the Figure 1.1.

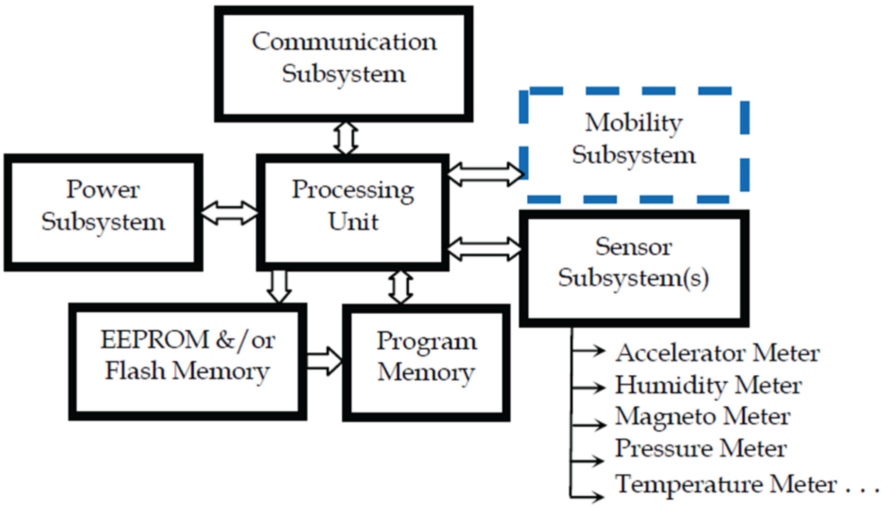


Figure 1.1: Block diagram of wireless sensor node, drawn by A.K. Dwivedi and O.P. Vyas 2012, [2].

Sensor nodes, which may be small on a mobile phone or other devices that can communicate themselves or wirelessly with a base station. Sensor node detection, data processing, wireless communications, data storage and the ability to work together that they have led to the emergence of the idea of WSNs. WSNs show differences compared to other networks. The most distinct features in present; time while there is a one-sided communication in other networks, whether sending or receiving data, in WSNs there is a mutual communication. Illustration of wireless sensor network is given in the Figure 1.2.

1.3.1. Sensors

Sensors are electronic devices to detect and respond some types of input from the physical environmental areas. Specific inputs can be motion or light sensitivity, heat-temperature measuring, pressure level or any one of the other environmental phenomena. Most of the time, outputs are signals that are converted to human-readable display at the sensor location or that are transmitted electronically over the network for reading or processing. For example, a thermocouple can sense heat energy at one of its junction and produce an equivalent output voltage which can be measured by a voltmeter. More the temperature rise, higher voltage read by a voltmeter.

Sensors are classified based on the nature of quantity. Further classification can be done based on the principle of operation and nature of output signal (analog or digital). Followings are example types of the most common sensors. Acoustic and sound sensors, automotive sensors, chemical sensors, electric and magnetic sensors, environmental sensors, optical sensors, mechanical sensors, proximity and presences sensors, radiation sensors, digital sensors, analog sensors, passive sensors, and active sensors.

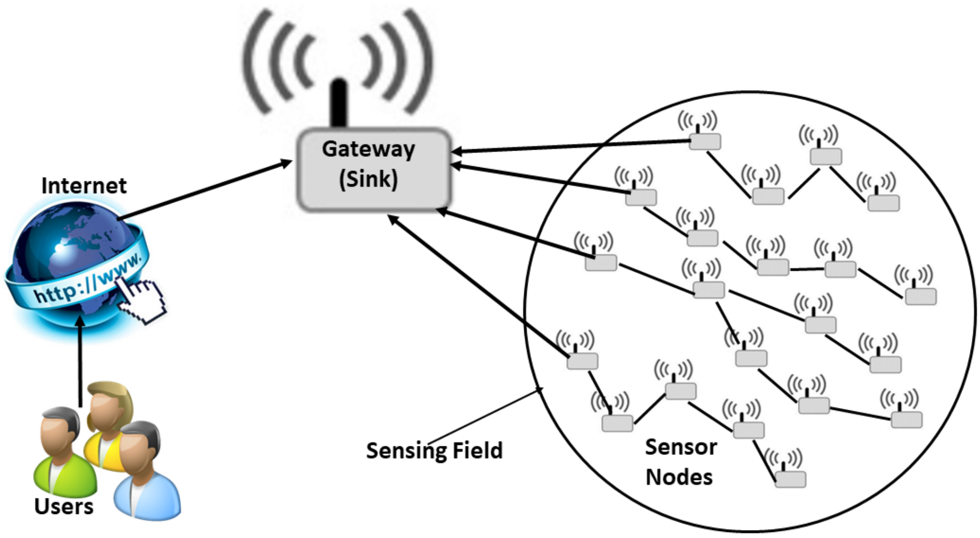


Figure 1.2: Illustration of wireless sensor networks, this study 2018.

1.3.2. Microcontrollers and Features

The microcontroller is a self-contained system with peripherals, memory and a processor that can be used in the embedded systems. Most programmable microcontrollers used nowadays are embedded in other consumer products or machinery including phones, peripherals, automobiles and household appliances for systems. Some embedded systems are more developed and sophisticated, while others have minimal requirements for memory and programming length and a low software complexity. Input and output devices include solenoids, LCD displays, relays, switches, and sensors for data like humidity, temperature etc.

1.3.3. Wireless Communication Technologies Used in WSN

Wireless is a term used to describe telecommunications in which electromagnetic waves carry the signal over part or all of the communication pathways. Some monitoring devices, such as intrusion alarms, employ acoustic waves at frequencies above the range of human hearing; these are also sometimes designed as wireless. Common examples of wireless equipment in use today include; mobile phones, laptop computers, tablets, home entertainment systems, and satellite television. A wireless system comprises interconnected active and passive elements. Functioning of processes on the transmitter side is as follows. The obtained basic input signal at a given frequency coupled with the carrier signal from a local oscillator. Than amplified with the help of the amplifier and transmitted to the antenna. Signal, that reaching receiver is raised against weakened [3]. An example of the digital receiver and transmitter block diagrams for the wireless sensor networks are given in the Figure 1.3.

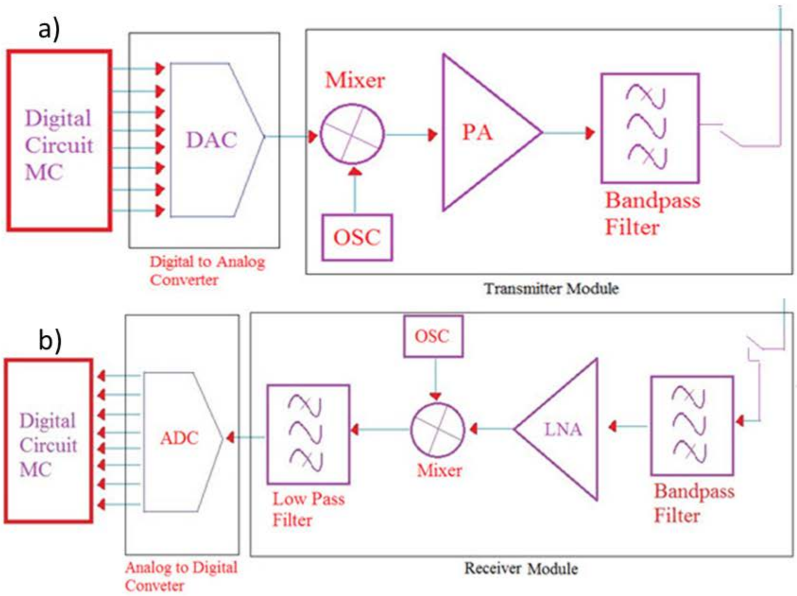


Figure 1.3: a) Wireless transmitter module, **b)** Wireless receiver module, drawn by T. Agarwal 2014, [4].

1.3.4. Wireless Communication Standards Used in WSN

Recent advances in standard-based WSN protocols for industrial control applications have come a long way to solve many of the challenges facing practical WSN deployments. This explains a comparison of present WSN standards that are available for sensor network applications. Several standards are currently ratified for WSNs.

Sensor network protocol stacks are almost same the traditional protocol stack, with the layers: application layer, transport layer, network layer, data link layer, and physical layer. Physical layer responsible for signal detection, modulation and data encryption, frequency selection, and carrying frequency generation. Data link layer is responsible for medium access and error control, multiplexing of data streams, data frame detection. These layers ensure point to point or point to multipoint connections in a communication network. Network layer responsible for routing the data supplied by the transport layer. Network layer design in WSNs has to consider such as power efficiency, data aggregation, data-centric communication etc. Transportation layer assists and manages data flow, so it can be important if WSNs are planned to be accessed through the internet or other external networks. According to the sensing tasks, different types of application software can be developed and can be used on the application layer.

WSNs have to be aware of the following management planes in order to function and manage efficiently: these are power, mobility and task management plane. Among them, functions of task, mobility, and power management planes must be elaborated. Power management plane is responsible for minimizing power consumption and if necessary it can close functionality in order to preserve energy. Mobility management plane is responsible for detecting and registering movement of nodes so that a data route to sink is always provided. Figure 1.4 shows wireless communication standards diagram with network layers.

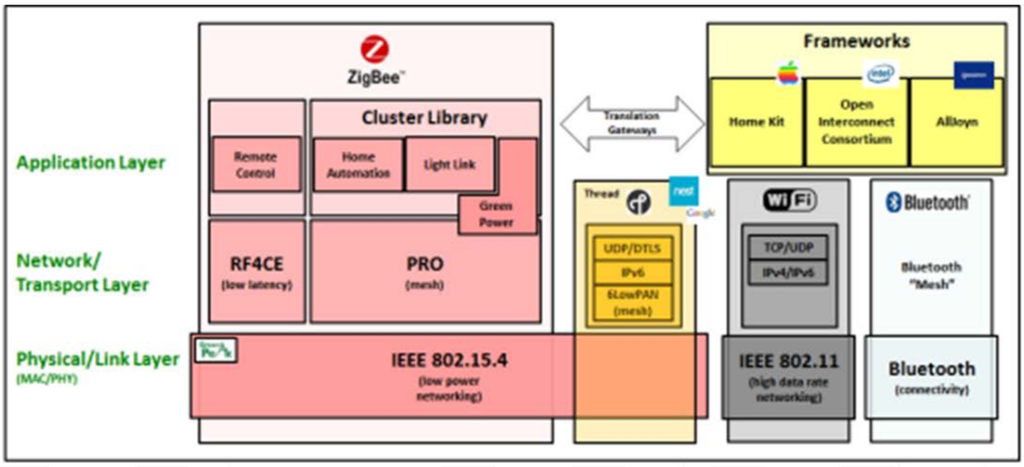


Figure 1.4: Wireless communication standards, drawn by GreenPeak Technologies, 2015, [5].

Task management panel is responsible for balancing, scheduling and sensing tasks assigned to sensing field and therefore only necessary nodes are assigned with sensing tasks and the remainder are able to focus on routing and data aggregation. In WSNs, QoS management system is very important if there is a real-time requirement with regard to data services. QoS management is responsible for error control, fault tolerance and performance optimization. Security management is the process of managing, monitoring, and controlling the security-related behavior of a network. The primary function of security management is in controlling access points to critical or sensitive data [6].

1.3.5. Routing Protocols

In WSNs, routing protocols are responsible for managing and maintaining the routing process in a wireless network. Protocols have to ensure reliable and uninterrupted communication under these conditions. Routing protocols are in charge of discovering and maintaining routes in the network. Sensor nodes have some important restrictions, these are limited energy, limited bandwidth, and limited computing power. Despite these limitations, the lifespan of WSNs wanted to be as long as possible in application. There are many routing protocols developed for this purpose. WSN protocol stack is given in the Figure 1.5, also WSN simple rooting process is given in the Figure 1.6.

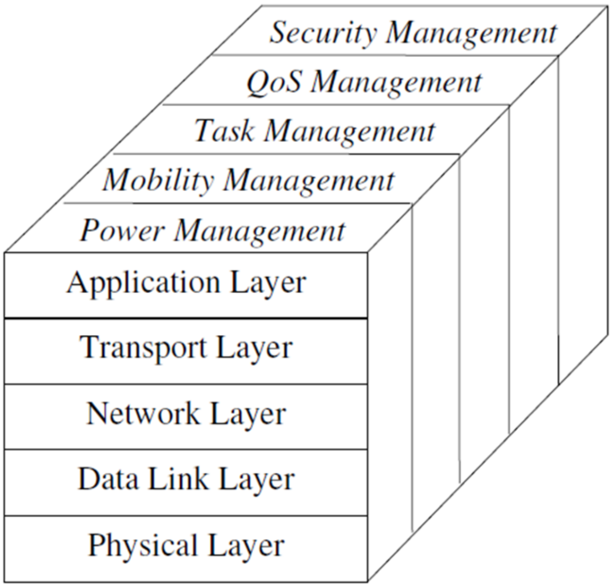


Figure 1.5: Protocol Stack in WSN, drawn by F. Akyildiz and V. C. Vuran 2010, [7].

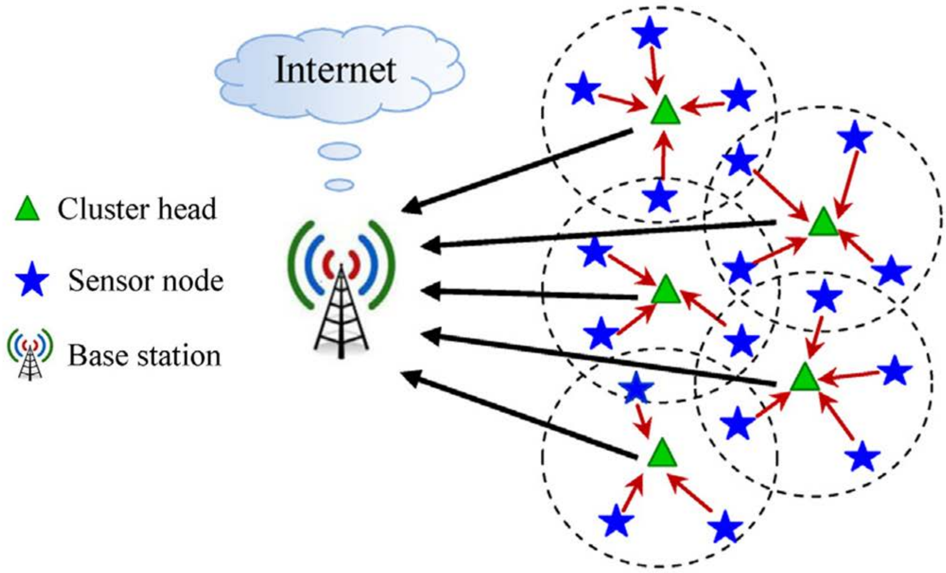


Figure 1.6: Wireless sensor networks in a simple routing, drawn by P. Kuila and P. K. Jana 2014, [8]

1.3.6. Network Topologies Used in WSN

In WSNs, a few protocols can be used as the media access protocol on WSN structure. So, some special media access protocols are developed for only WSNs. Protocols are necessary for the low power consumption for the sensor nodes. Classic access protocols consume much more energy and they cause unnecessary packet access density. These protocols are time division, frequency division, code division or based on the rule may be the type of access to media. Figure 1.7 shows diagrams of the three kinds of WSN topologies.

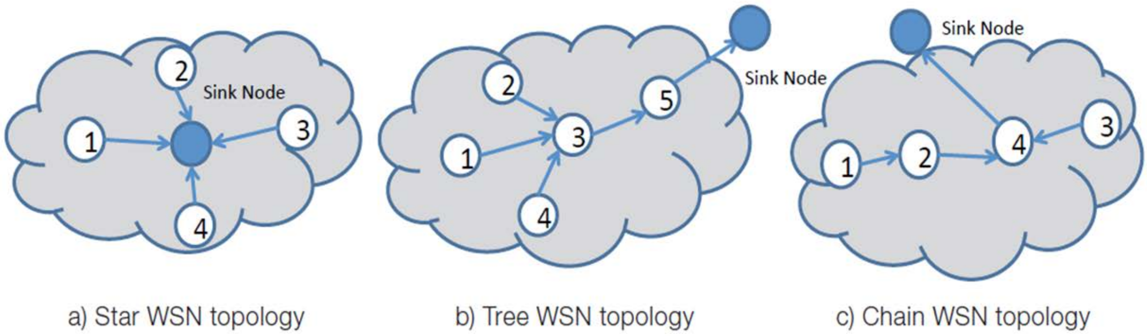


Figure 1.7: Three kinds of WSN topologies, drawn by Courtesy of Shenyang Institute of Automation 2014, [9].

WSNs have to be possessed self-organizing abilities. The right choice of the topology bound up with available resources used transmission frequency and transmission distance [10]. Star topology has two major drawbacks: Transmission distance is limited, because nodes have to be in the range of the base station, and every node has just one link to the base station. If this link breaks down, possibly by an obstacle which is put between sensor and base station, there is no possibility to transfer measured data and the sensor node will be isolated. Nevertheless, star topology provides lowest overall power consumption abilities, because the sensors do not have to forward data from other nodes. In contrary to a star topology, the mesh topology is a multi-hop system sensor node are also connected to each other and thus communication through the base station is avoided. Design and implementation of such a decentralized system are complex, but its advantage is the high fault tolerance because every node has multiple paths to the base station and to other nodes. Despite this, topology shows highest overall power consumption, every sensor node would have to listen for a possible communication all time.

1.3.7. Power Requirements and Configuring Power Supply and Energy Issues

The most studied subject in WSNs, which is the sensor node power problems. The power supply of WSNs are key constraints that have a direct impact on devices autonomy and performance. Some applications with a very low-power-consumption can have enough autonomy with a non-rechargeable, small battery while other applications with higher power demand will require a rechargeable large battery. Due to the lack of adequate non-rechargeable batteries, rechargeable batteries are used as well as fulfilling its function as sensor nodes and trying to charge the battery. The most preferred of these methods is to take advantage of solar energy [11]. Engineers are working improving the WSNs power supply with solar energy. The subject of this thesis is the design of solar energy in WSNs. Engineers are also working in areas other than solar energy, for example, one another methods, there are researchers going to road vibration generator to produce electricity for the sensor nodes in a mobile environment. Parallel and serial battery configurations are given in the Figure 1.8.

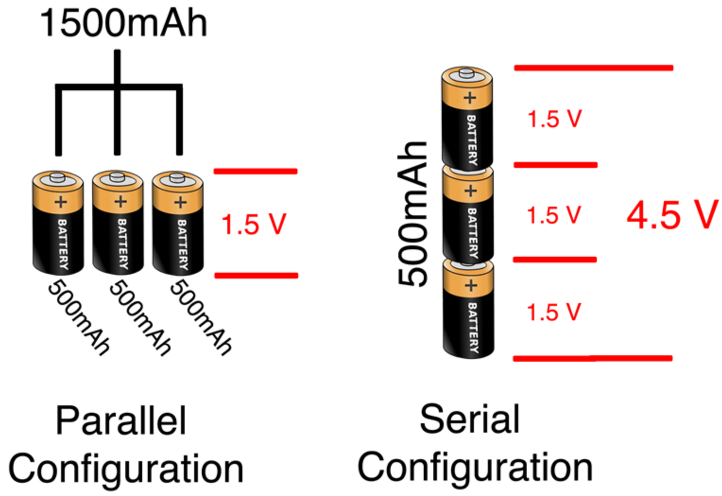


Figure 1.8: Parallel and Serial Battery Configurations, drawn by I. Galarraga, 2013, [12].

1.3.8. Applications of WSNs

Variety of possible applications of WSNs to the real world is practically unlimited from environmental monitoring, health care, positioning and tracking [13], logistic, localization and so on. Military applications, home, and healthcare applications assisted living and environmental science applications are major application areas for WSNs. Advances in the field of MEMS and communication technology have enabled development of a new and modern technology that has already been implemented in a wide variety of scenarios, and its applications are growing every day [14]. WSNs are an important new technology with great potential for improving so many applications in military, agriculture, medicine, transportation and industrial process control as well as creating new revolutionary systems in areas such as smart buildings, environmental monitoring, medical care and precision agriculture, etc.

1.4. Sensor Node Architecture, Functions, Design & Hardware Constraints in WSNs

In this section, some important WSN subjects are explained shortly. For instance, sensor node architecture with integrated units (processing unit, a communication unit, a sensing unit, and power unit), sensor node functions (communication, processing, sampling, monitoring), design and hardware constraints such as energy and memory.

1.4.1. Sensor Node Functions

A sensor network is a term referring, in general, to a collection of networked embedded systems. Each of the systems constituting the network is called a sensor node [15]. Each sensor nodes have the following basic functions.

- **Data Sampling**, gather data from the environment.
- **Data Processing**, Process the data using the node's processing capabilities.

- **Data Communication**, Relay data to other nodes through the network.

Diagrams of the organization and transmission processes for WSNs are given in the Figure 1.9.

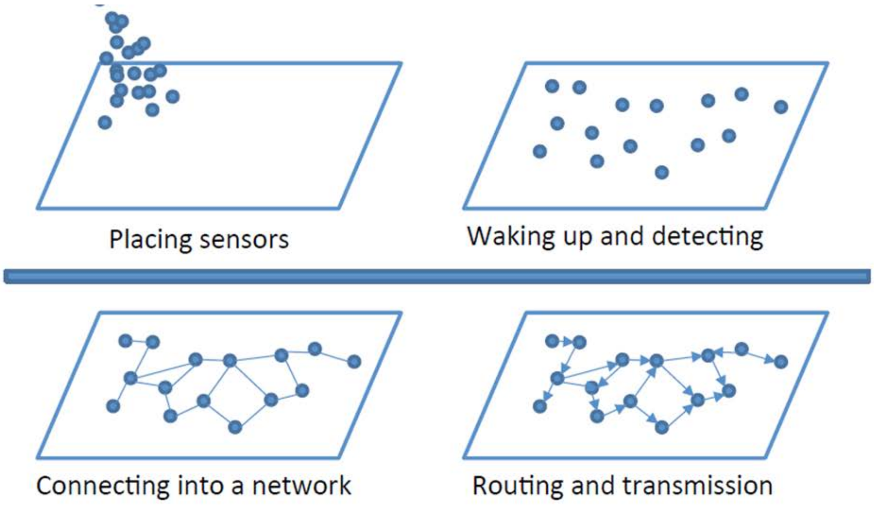


Figure 1.9: Organization and transmission process of WSNs, drawn by C. Uimer 2000, [16].

1.4.2. Sensor Node Architecture

A sensor is a transducer which measures a physical quantity such as light, temperature, pressure, and humidity. The sensor converts physical quantities into an electrical signal which can be used by a human or by an instrument to take necessary decisions. They self-organize and collaboratively coordinate the sensing process depending on the phenomenon. Sensors are typically small, battery powered, low-cost devices with wireless communication capability. Sensor nodes are capable of performing processing, gathering information and communicating with other connected nodes in a sensor network. Basically, a typical sensor node made up of following four basic components: a processing unit, a communication unit, sensing unit and power unit. In addition to these components, a sensor node may also contain some application specific components: mobilizer, location finding system, and power generator. System architecture of WSN is given in the Figure 1.10.

In sensor nodes, the functionality of processing unit is converting the electrical signals received from the sensor into an intelligible message format, schedule tasks, process data received, execute the algorithms for data forwarding and control the functionality of other hardware components in the sensor node. Processing unit is made up of the embedded processor.

Communication unit has both a transmitter and a receiver for establishing wireless communication between sensor nodes. A communication unit which combines both transmitting and receiving tasks are called transceiver. The essential task of the transceiver is to convert the digital bit stream coming from the microcontroller into radio waves and vice versa. The RF-based wireless communication suits most of WSN applications. Transmit, Receive, Idle and Sleep are the operational states of the transceiver.

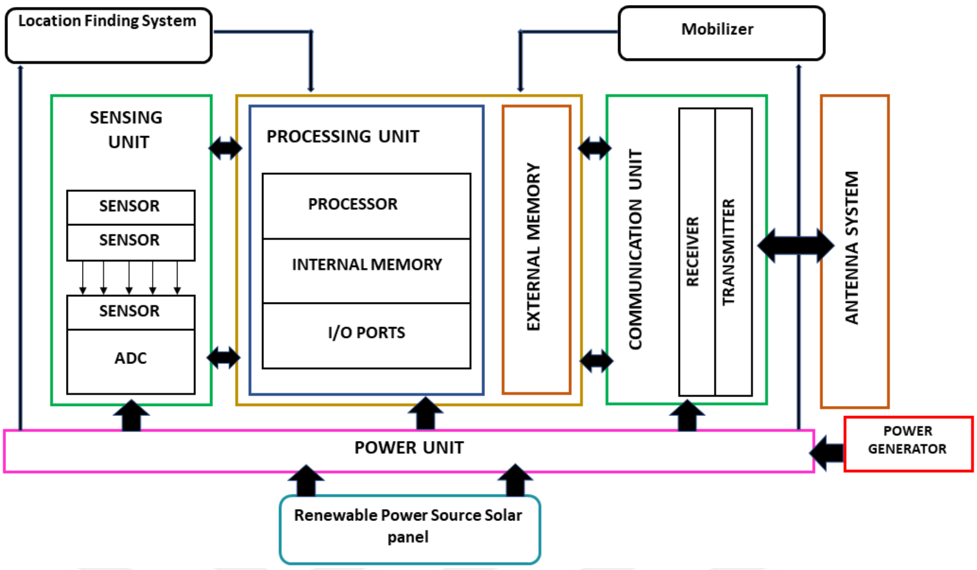


Figure 1.10: System Architecture of WSNs, this study 2018.

Sensing unit consists of two subunits, these are sensors and ADC converters. The sensor is a transducer to produce a measurable electrical signal to a change in physical phenomena such as chemical level, light intensity, sound, temperature, magnetic fields, image, etc. Sensors can be classified as either analog sensors or digital sensors. The sensors produce continuous analog signals, converted into digital signals by ADC and then fed to the processor.

1.4.3. Constraints in Wireless Sensor Networks

WSNs consist of so much spatially distributed sensor nodes and naturally their resources are constrained. WSN nodes have very low data storage capacity, limited computational capability and low communication bandwidth. These limitations are due to physical size of the sensor nodes and very limited energy sources. Because of these constraints, it is difficult to directly design and use the conventional routing protocols in wireless sensor networks.

Sensor nodes are usually battery powered devices. WSNs are deployed to operate and collect data in remote environments. Therefore, it is very difficult to replace or recharge batteries in such environment. Energy is one of the biggest constraints for a WSN. Communication between sensor nodes consumes most of the available power, much more than that of the sensing processes and computation processes.

The processing unit in a sensor node performs computational tasks related to locally sensed information and information communicated by other sensors. In order to meet large-scale deployment of sensor nodes and also due to economical constraints, low cost embedded processors such as microcontrollers are often selected when designing sensor nodes. These embedded processors significantly limited in terms of computational power. Because of the limitations of such processors, devices typically run specialized component-based embedded operating systems.

Majority of the sensor nodes are made up of the microcontroller as a processing unit. These have a small amount of storage in the form of random access and read-only memory include both program memory and data memory. There is generally not enough memory space running complex algorithms after loading the operating system and application code. Wireless sensor node includes a low data rate and short range wireless radio transceivers. In spite of limited capability, these RFs are improving in sophistication including improvements in cost, immunity to noise, tunability, spectral efficiency, fading, and interference. Radio communication devices are often the most power-intensive operation in a WSN device, therefore, radio has to incorporate energy efficient sleep and wake up modes to extend the node lifetime.

WSNs are different from traditional wired and wireless networks in terms of service provided by them. It is not possible to have global addressing as like in wired networks. Since the WSNs have relatively too many of nodes, this increases overhead of ID maintenance. WSNs are data-centric, which means that messages are not sent to individual nodes but to geographical locations or regions based on the data content

WSN nodes must be low cost with small physical size and battery powered. Therefore, sensor nodes are tightly constrained in computation, communication, storage capacity, and energy resources. Also, they require efficient energy management techniques to prolong the network lifetime.

1.4.4. Design Challenges and Hurdles

WSN networks offer numerous challenges mainly the stringent energy constraints, limited computing power, communication range, and storage space of sensor nodes. Primary design propose of WSNs is to implement and realize data communication while trying to extend the lifetime of the sensor network and also to prevent connectivity corruption by employing aggressive energy efficient techniques.

Design of routing protocols in WSNs are affected by several challenging factors. These factors must be properly dealt with efficient communication can be achieved in WSNs. In the followings, I will be descring some of challenges, limitations and technical design subjects that affect in WSN Systems. Challenges and limitations of wireless sensor networks include following issues.

WSNs are typically deployed to measure a certain physical phenomenon that ranges from fractions of a second to a few months or even year. A typical alkaline battery provides about 50 watt-hours of energy can last less than a month of continuous monitoring the environment. In a large network and deployment in the possibly hazardous environment, replacing batteries is not feasible.

Developments in battery design and energy harvesting techniques can offer only partial solutions. This is the reason that most protocols are designed with energy efficiency as the primary purpose. Extending network lifetime can be achieved by forcing the nodes to with periodic switching between sleep and wake-up modes. Synchronization of sleep and wakeup schedules is challenging itself, long time sleep periods can decrease responsiveness and effectiveness of sensors.

WSNs give rise to the final key challenge of ensuring both privacy and security. Need for security and privacy is evident in certain applications such as health care and military applications. Data reporting in WSNs are dependent on application and time criticality of data. Data reporting can be either event-driven, time driven, query driven. Data reporting greatly influences network lifetime in terms of route cost and energy consumption.

1.4.5. Components of a Sensor Node

WSNs include hardware and software components. In this section, I focuse on the hardware and software requirements. WSNs are a typical example of the Electronic and Computer Engineering Science because of the includes hardware and software components. I will explain shortly this component in this section. Because of the economic reasons, embedded processors are fundamentally limited in terms of the power consumption. Therefore, sensor nodes usually work specialized component-based embedded operating systems. WSN devices consist of advanced low power design techniques, such as sleep and idle modes and dynamic voltage scaling to reduce power consumption [17].

In storage, program memory and data memory are important. Size of the memory is usually very restricted because of the economic reasons. With falling prices, quantities of storage and memory used on sensor nodes increase. WSN devices include a low rate and short-range radio due to power constraints. These radios are to improve in sophistication over time including improvements in cost, immunity to noise, fading, spectral efficiency, tunability, and interference. Radio communication is the most power-intensive operation in sensor devices and thus radio must incorporate energy efficient sleep and wake-up modes.

Sensor devices generally support low data and short-range sensing due to the limitations of power and bandwidth. In many applications, multimodal sensing is necessary that every device could have multiple sensors implemented. Analog to digital converter unit translates analog signals to digital signals and it can be provided by sensors. Digital signals that can be processed by the processor unit.

Analyzing measured data is very important to know in which location data was monitored in sensor networks. Some applications of WSNs allow designers to preconfigure location of sensor nodes. Especially for randomly deployed WSNs, which are used, for instance, for outdoor operations, location finding systems, normally based on satellite GPS, have to be implemented. Usually, on WSN devices, the power source is a small battery. Limited battery power is likely to be a big problem in most of WSN applications.

According to previous researches [18], software applications of sensor nodes can usually be separated into five subsystems, this is examined in the following section. Operating System Microcode represents code that is used by high-level software modules to support a variety of functions. It also covers software from machine level functionality of microprocessor. A famous example of a commonly used operating system for sensor networks is TinyOS. In this project, the operating system is written in PIC-C language.

Sensor drivers are software modules that manage basic functions of sensor transceivers. Communication processors manage communication functions, including routing, topology maintenance, medium access control, packet buffering and forwarding, and encryption. These software modules operate details of radio channel transmission link, including synchronization, and clocking, bit recovery, bit counting, signal encoding, signal levels and modulation. Basic applications signal-value storage, data processing, manipulations, etc. These are supported at sensor node level for in-network processing.

CHAPTER II

LITERATURE REVIEW

In this chapter, I present in-depth and detailed academic literature search and provide information about academic and scientific research conducted in the recent years. Some major academic studies will be described and will be presented. In the past years, the wireless sensor networks were widely studied and applied in different areas, also different implements were developed for various applications. And also, WSN history review will be conducted. Especially in scientific articles, journals, books, previous projects and works will be explored as sources of literature reviews. Some major academic studies will be described and will be presented.

Sensors to detect physical phenomena such as light, heat, temperature, gas, humidity, pressure, etc. Today sensors are everywhere. Sensors are one of the most important components of networks. In sensor section, I am going to describe the main concepts and components of sensors. I am going to give a basic understanding of the concepts behind wireless sensor networks, which is important as a prerequisite to a discussion of sensor considerations that is the core subject for the rest of this thesis. In sensor section, I am going to explore the sensor mechanisms for wireless sensor networks developed in recent years. My goal is to explain and help to understand the current sensor mechanisms for wireless sensor networks and remark and focus open issues that can be subject to further research.

2.1. Literature Survey of WSNs

Development of WSN requires technologies from three different research areas, these are sensing, communication and computing. Therefore, combined and separate advancements in each of these areas have driven research in WSNs. The first examples of WSNs include radar networks used in air traffic control. National power grid, with its many sensors, can be viewed as one large sensor network. These systems were developed with specialized computers and communication capabilities and before term, WSNs came into vogue. In the past decade, wireless sensor networks have received tremendous attention from academia and industry in the world. A large amount of academical research activities have been carried out to explore and solve various design and application issues and significant advances have been made in the deployment of WSNs. Some of them are explained in the following sections.

In the past years, PC microcontroller communication was done through the RS232 serial port or parallel port Adil Fatih Kiremitci [19] in his MSc Thesis study, carried out its USB serial port and analog data is transferred to the PC from the microcontroller. Nowadays, USB port is the most commonly used port for this process. In the design, 18F4550 microchip is used, which produced by Microchip Company has used the USB supported microcontroller and the lower level of the USB communication protocol process has done by the microcontroller. USB-PC communication 18F4550 basic circuit is given in the Figure 2.1.

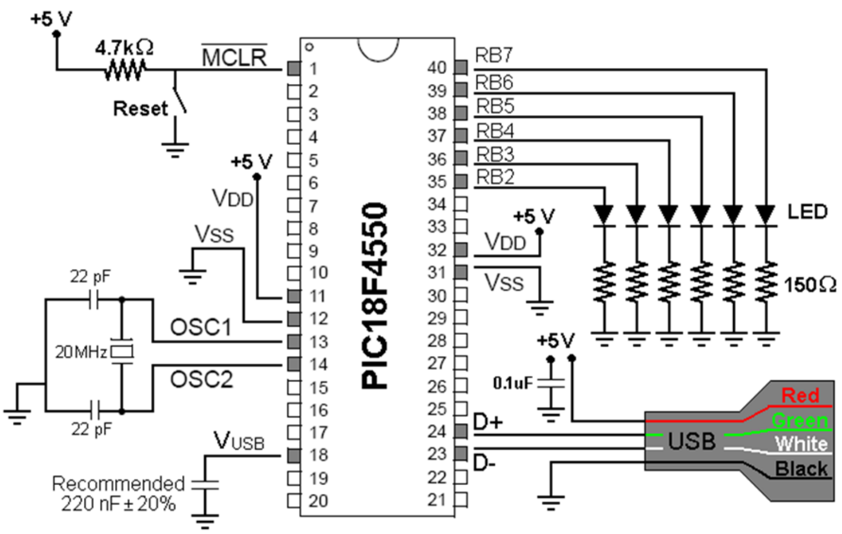


Figure 2.1: USB-PC communication 18F4550 basic circuit, developed by A. F. Kiremitci, 2007, [19]

B. Ovalı and T. Uzun [20] have designed a wireless narrowband modem in addition to computer hardware for wireless communication between computers. This wireless modem is a device running serial RS232 standard. This device receives data from the serial port and transmits to another PC in the same port. They are realized by connecting an external transceiver unit to UART port with a microcontroller.

B. Lo and G. Z. Yang [21] also have designed sensor nodes for WSNs. They have used the MSP430 microcontrollers of Texas Instrument Company. MSP430, which has 12-bit ADC, 2 KB RAM, a 60 KB flash memory, it is a 16-bit microcontroller that 15µw energy is spent in sleep mode. As the wireless transceiver unit, CC2420 transceiver unit is preferred that belongs to Chipcon of the company. It has 802.15.4. standard and a bandwidth of 250 kbps. In addition to the circuit, 512 KB memory unit is connected to meet the needs of memory.

B.B. Suyabatmaz in the study [22], he designed a transceivers card to develop for wireless data communication. While designing the system that has benefited from two main components, namely the microcontroller and transceiver. The 16F876 microcontroller is used as the microcontroller of Microchip Company. As the wireless transceiver unit, CC1000 by the Chipcon company transceiver unit is used. Both components are suitable for targeting narrowband (76.8 kbaud) wireless communication.

J. S. Lee and Y. C. Huang [23] have designed a wireless sensor node using the ZigBee/IEEE 802.15.4 wireless communication standard and they have given the name “ITRI ZBnode” to their design. They used 10-bit ADC with 32-bit ARM-720T in the microcontroller design. As the wireless transceiver unit, Chipcon company's CC2420 transceivers have used the transmitter unit. Figure 2.2 shows diagram of the developed Zbnode.

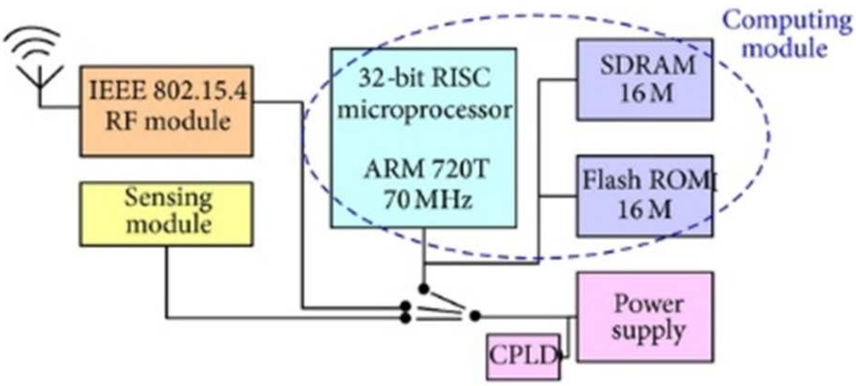


Figure 2.2: ITRI Zbnode, drawn by J. S. Lee and Y.C. Huang 2006, [23].

Y. Cetin, in Inonu University, “ATO and ATC Systems for Railways” in 2008 [24], he designed moving blocks and communication-based train protection system for railways and he has tried to work on a real train line. Designed system’s diagram of the train protection is given in the Figure 2.3.

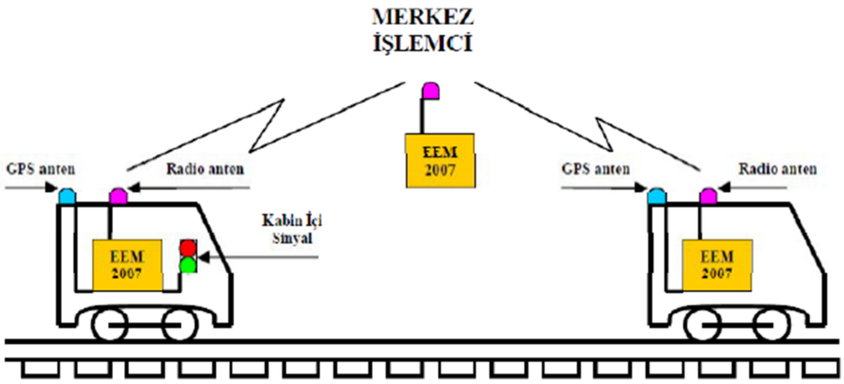


Figure 2.3: Train protection system, developed by Y. Cetin 2008, [24].

S. S. Aslan, in Cukurova University "Computer Controlled Robot Car" named work [25], his model is shown in the Figure 2.4, tool has remote control via the computer and the images were taken on a computer from the camera is placed on the vehicle. In the design, Microchip Company's 16F876 microcontroller is used.

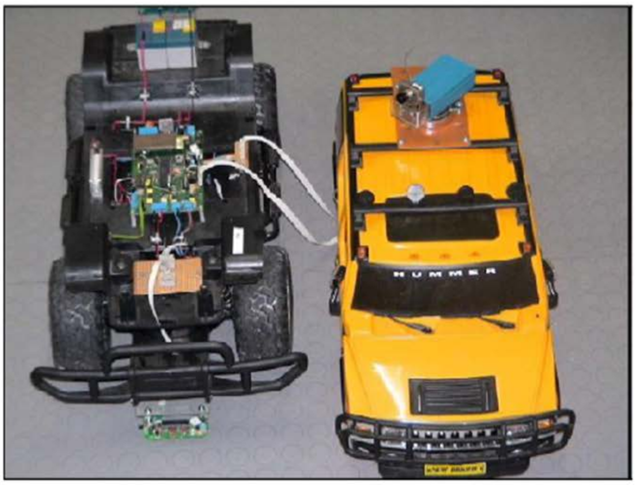


Figure 2.4: Computer Controlled Robot Car, developed by S. S. Aslan 2006, [25].

K. Hovasapian and N. Agarwal [26] have developed a low power modular WSN for real-time monitoring such as temperature, humidity, pressure, and location through a GPS unit. The project put together three nodes and a PDA four output display, these are; one master node, and two slave nodes, a Piconet. Master node consisted of a power, communications, and a data and control module. Slave nodes consisted of same modules in addition to sensor modules. Communication module was a Bluetooth module a wireless transmitter unit with an antenna. Data and control unit consisted of a PIC microcontroller 16f877. Power module consists of a 6V camera battery, two sharp voltage regulators, and an RS232 unit. Prototypes of the developed WSNs are given in the Figure 2.5.

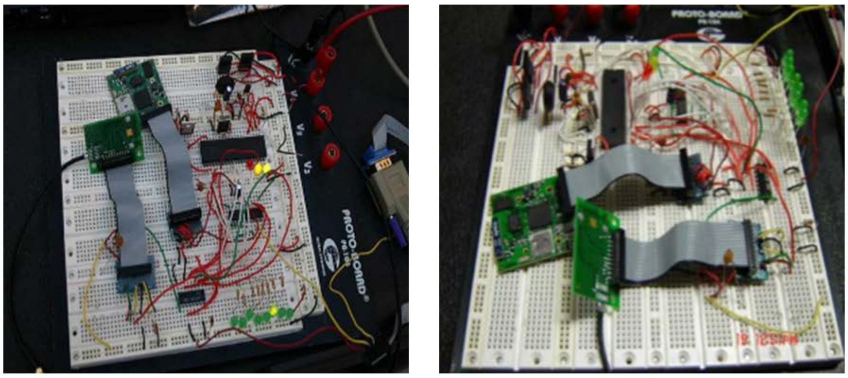


Figure 2.5: Low power Bluetooth WSN prototypes developed by K. Hovasapi and N. Agarwal, 2004, [26]

C. Lynch and F. O'Reilly in the work [27], they have designed a wireless sensor node with Microchip PIC16F877-based platform. Design architecture is shown in the Figure 2.6. As the transceiver unit, they have used Nordic company's RF903 transceiver unit that running at 868 MHz and 76.8 Kbps bandwidth.

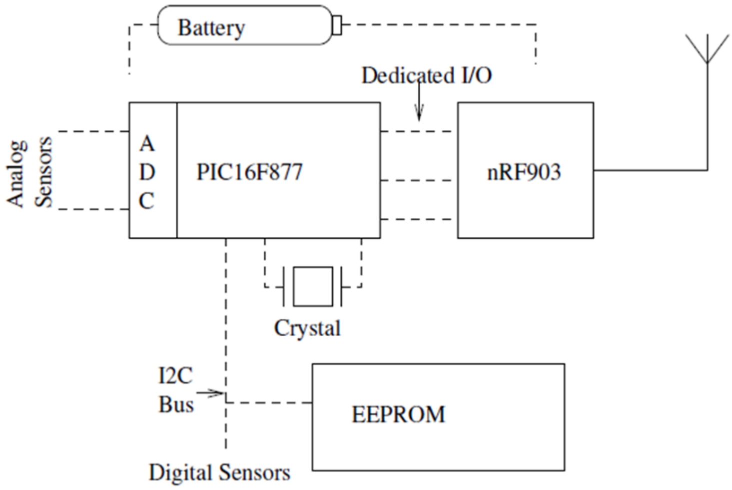


Figure 2.6: Diagram of the Wireless Sensor Node, drawn by C. Lynch and F. O'Reilly 2004, [27].

T. Voigt, H. Ritter and J. Schiller in their studies in 20016 [28], they are utilized solar power in wireless sensor networks. They have presented two protocols for solar aware routing. Solar-aware routing preferably routes traffic via nodes powered by solar energy. Their simulations of two solar-aware protocols show that they could provide significant energy savings in many scenarios. Results suggest that utilizing solar power in wireless sensor networks is efficient and feasible. The design has named "Utilizing Solar Power in WSNs". Figure 2.7 shows an image of the utilized solar panel of the WSN.

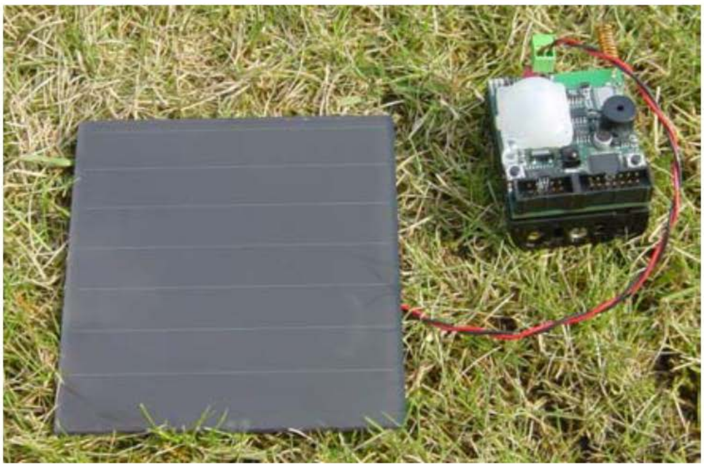


Figure 2.7: Utilizing solar power in WSN by T. Voigt, H. Ritter and J. Schiller 2006, [28].

T. Soylu in his studies in Trakya University [29], he has conducted research on wireless sensor network applications and he has designed a sensor node that has been designed with the sensor node for temperature measurements in the medical field. He called his study “Wireless Sensor Networks Applications and Design of Sensor Node”. Images of the developed sensor nodes are given in the Figure 2.8.

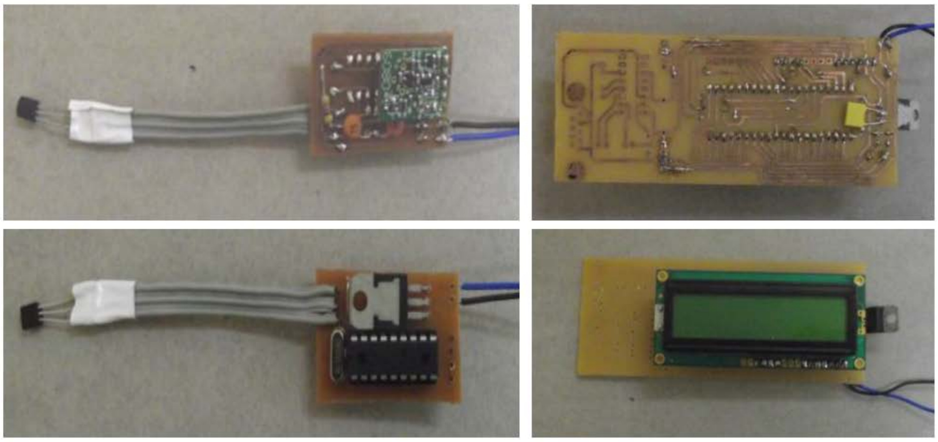


Figure 2.8: Design of the wireless Sensor nodes, developed by T. Soylu 2012, [29].

O. Ozcan in 2011 [30], he has conducted research on wireless sensor network applications and he has designed a sensor node. The designed system to allow the various software applications and to allow different types of sensors. Although internal light on the system LDR sensor and temperature LM35 sensor, 9-pin system has been integrated into an expansion slot, sensor nodes have the very simple circuit structure. Developed sensor node is shown in the Figure 2.9.

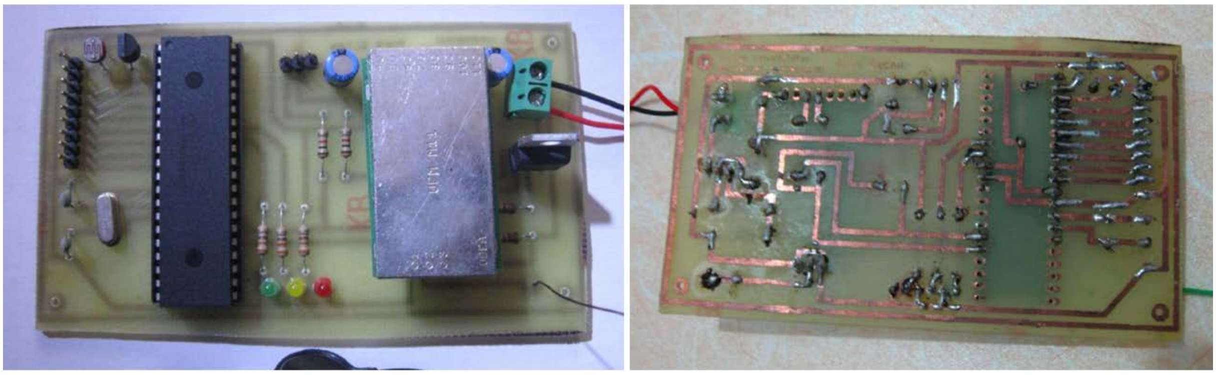


Figure 2.9: Wireless sensor node, developed by O. Ozcan 2011, [30].

L.Ma, J. Yan, S. Yan, B. Wang, K. Liao and J. Wang have developed a study of agricultural meteorological monitoring system based on WSN, in order to development of agricultural industry, the WSN project purpose is monitoring four basic essential element changes, which are carbon dioxide, temperature, light intensity, humidity and applying the corresponding solution is really necessary. ZigBee wireless technology is designed. In their system [31], they have used DHT11 to collect temperature and humidity information and ON9658F collect light intensity information. CC2430 is used as processor module and the communication module of nodes and provides power that system needs through the battery.

R. Pitarma, G. Marques, and F. Caetano [32] have developed Monitoring Indoor Air Quality to Improve Occupational Health based on WSN, in order to monitor indoor air quality to improve occupational health. The IAQ system was an automatic indoor air quality monitoring system that allowed the user, such as the building manager, to know, in real time, a variety of environmental parameters as air temperature, relative humidity, carbon monoxide, carbon dioxide and luminosity. Wireless communication was implemented using the XBee module what implements the IEEE 802.15.4 radio and ZigBee networking protocol. Developed IAQ sensor hardware shown in the Figure 2.10.

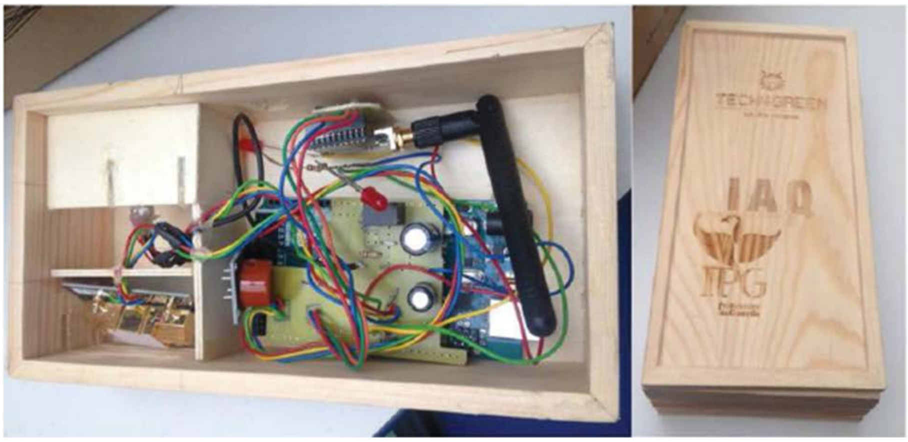


Figure 2.10: IAQ sensor hardware, developed by R. Pitarma, G. Marques, and F. Caetano 2016, [32].

In the thesis study [33], Y. Y. Kardas has developed a smart home automation system which communicates with Smart Phones over 3G network. Two electronic circuits were designed to control electrical devices. These were central unit and environment units Sensors on environment RF modules collect information. Motion, temperature, and fire sensors were used in this study. Any electrical device was being controlled over relays. Relays were on environment RF modules card. This unit transmits information to the central unit via radio frequency. He was used PIC based PIC18F4550 microcontroller unit and PIC based PIC16F88 microcontroller unit. Figure 2.11 show images of the developed RF module and center unit.

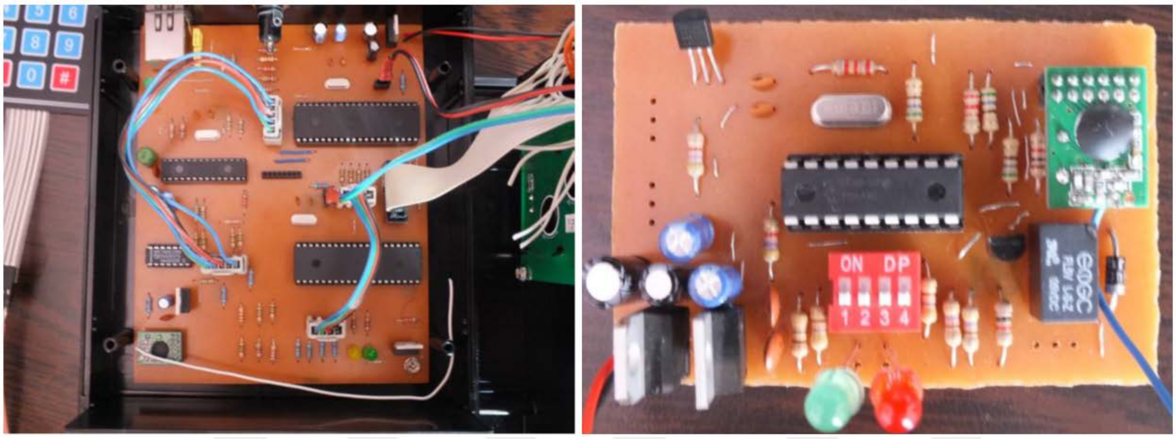


Figure 2.11: RF Module and Center Unit, developed by Y. Y. Kardas 2014, [33].

M. Shaker and A. Imran [34] have developed a WSN based microclimate monitoring system for greenhouse plants with a new irrigation system. System deployment includes multi WSN each one was responsible to monitor and control one plant's row inside the greenhouse. The system mainly consisted of two node types; sensing node and control node. Sensing nodes are deployed inside the greenhouse among plants to measure climate parameters. Each sensing node transceiver module was configured to work as ZigBee end device. On the other hand, Control node was fixed near to the solenoid valve. It was responsible to drive actuators, start a network, and manage network data traffic. Greenhouse microclimate monitoring WSN devices are given in the Figure 2.12.

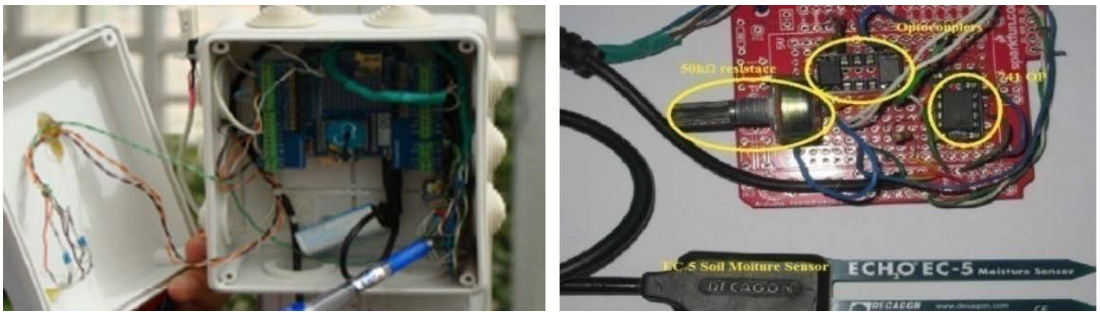


Figure 2.12: Greenhouse microclimate monitoring devices, developed by M. Shaker and A. Imran 2013, [34].

B. P. Ladgaonkar and A. M. Pawar [35] have developed a sensor node for monitor humidity of High-Tech poly house environment which based on an embedded technology and the RF module Zigbee a wireless sensor node is designed about highly promising AVR ATmega8L microcontroller and implemented for WSN development one of the wireless sensor nodes, and the other is base station and Humidity Sensor SY-HS-220. Employing embedded technology, based on AVR ATmega 8L microcontroller and RF module Zigbee operated at 2.4GHz ISM band.

S. A. Agarkar, K. D. Kulat and R. V. Kshirsagar [36] have developed a wireless sensor network based on Low Cost and Low Power EPM Design and Field Micro Climate Analysis using Embedded Controllers. They have used a PIC16LC74A microcontroller which provides very low-cost environment monitoring. Image of the developed WSN-EPM sensor node is shown in the Figure 2.13.

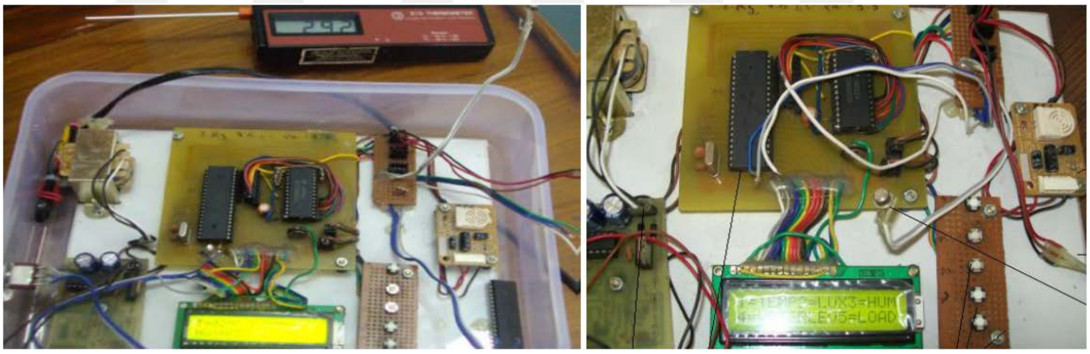


Figure 2.13: WSN-EPM sensor node, developed by S. A. Agarkar, K. D. Kulat and R.V.Kshirsagar 2010, [36].

Q. A. Haija, H. Qadeeb and A. Lwaimi [37] have developed a WSN sensor node for Monitoring of AIR quality in King Faisal University using a microcontroller. Their sensor node design has Included this major hardware component: Arduino Microcontroller, MQ-2 GAS Senor, Breakout Board, ADC, Light Emitting Diodes and Plastic Cabinet: to hold the connected components of the design as one package. Their proposed design was used to measure the air quality in several places inside the King Faisal University and included different gases levels but focused mainly on measuring tow main gases: Carbone Monoxide CO and Liquid Petroleum Gas LPG. The hardware design schematic diagram is given in the Figure 2.14.

A. Ghobakhlou, T.A.S.A. Perera, P. Sallis, O. Diegel and S. Zandi have developed a WSN based environmental monitoring sensor node system [38]. WSN hardware was divided into two main components namely, coordinator node and router node. For both node types, one wireless plugin module was used. Plugin board was based on CC2431 wireless microcontroller.

Microcontroller had an on-chip 2.4GH wireless radio, 128KB in-system programmable flash and hardware-based location awareness.

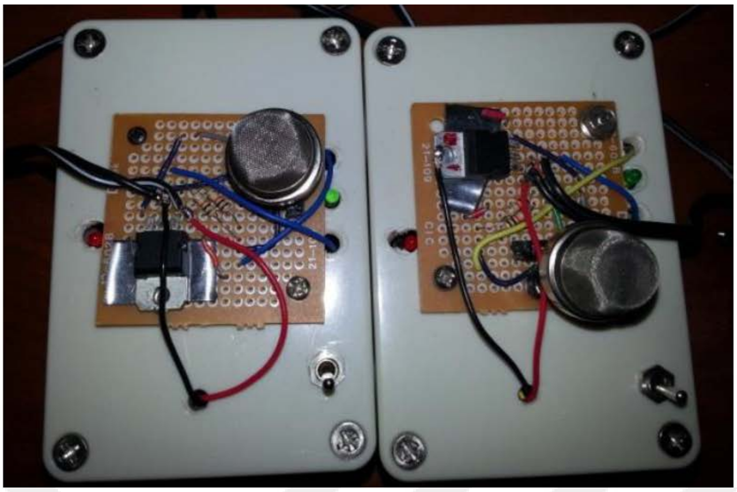


Figure 2.14: Hardware design schematic diagram, Q. A. Haija, H. Qadeeb and Lwaimi 2013, [37].

N. R. Mohanty and C. Y. Patil have developed a WSNs Design for Greenhouse Automation. The hardware of the system consisted of this equipment: MICAz, IEEE802.15.4, CC2420 802.15.4 RF-transceiver, CC1100 RF-transceiver, CC2430 RF transceiver, Tmote Sky module, nRF24L01 were used for enabling low power wireless sensor networks. In this project, CC2510 RF transceiver was used as a wireless communication module. WSN [39] consisted of a sensor module, a processor module, a wireless communication module and power supply. Sensor module used temperature, humidity and light sensors. Images of the developed hardware design is given in the Figure 2.15.

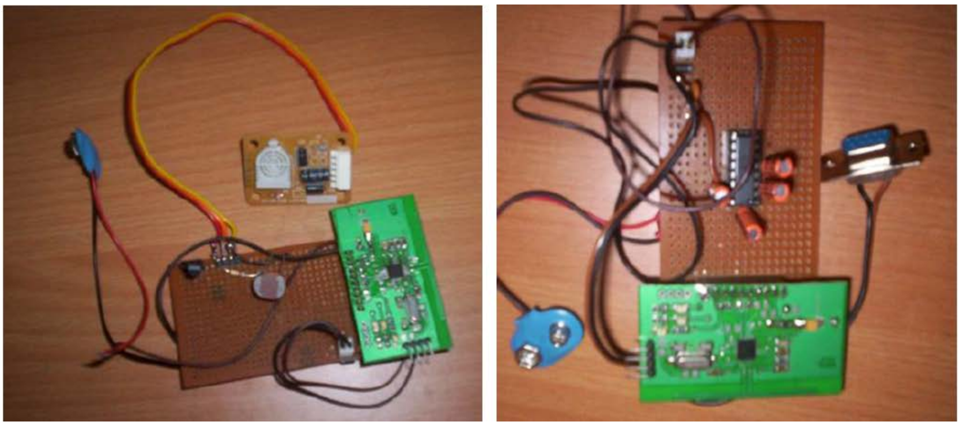


Figure 2.15: Sensor node and sink node, developed by N. R. Mohanty and C. Y. Patil 2013, [39].

A. Lambebo and S. Haghani [40] have developed "A Wireless Sensor Network for Environmental Monitoring of Greenhouse Gases". Gases and temperature were built and successfully tested in real time where data was successfully captured and displayed on a website. Each transmitting node consists of one off-the-shelf XBee wireless module, greenhouse gas sensors, temperature sensor, and a GPS module. Developed transmitter node and receiver node are given in the Figure2.16.

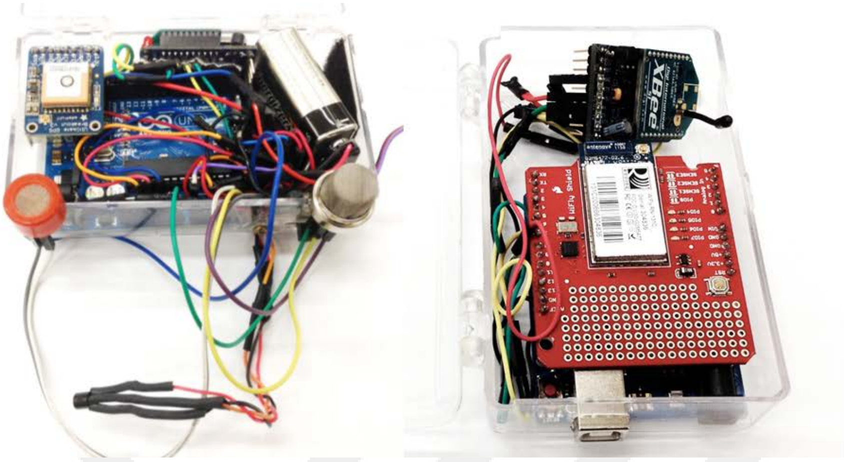


Figure 2.16: Transmitter node and Receiver Node, developed by A. Lambebo and S. Haghani 2014, [40].

W. S. Mohan and R. J. Devi [41] have developed a Monitoring of Geological CO2 based on WSNs project. Geological CO2 leakage monitoring equipment based on WSN was composed of the air environment sensors array including CO2, temperature, humidity and light sensor. Microcontroller as a central processing unit, SD card data storage module, LCD display module and GPRS wireless transmission module are used. ARM LPC2148 microcontroller was managed the operation of each module. COZIR CO2 sensor represented a breakthrough in low power gas detection and humidity sensor SY-HS-220 was used to sense humidity. Transmission of Realtime collected data was accomplished via GPRS wireless module SIM900A. Figure 2.17 shows images of the developed sensor nodes.

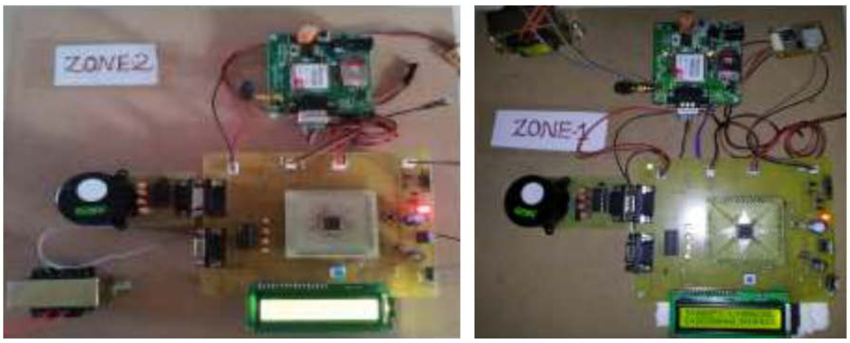


Figure 2.17: System circuit boards for zone 1 and zone 2, developed by S. Mohan and R. J. Devi 2014, [41].

P. V. Raju, R. V. R .S. Aravind and B. S. Kumar [42] have developed a Pollution Monitoring System using WSN. The proposed pollution node was designed by integrating sensor associated circuitry, Atmege 328p low power microcontroller and Xbee communication module. An array of sensors consisted of three sensors, used to detect carbon monoxide, carbon dioxide, and sulfur dioxide concentration in air.

S.B. Tayade, D. S. Chandak and P. S. Choudhari [43] have developed a Real-Time Monitoring of Geological CO2 Storage and Leakage Using WSN. Geological CO2 leakage monitoring equipment based on WSN were mobile devices used by humans. Equipment was composed of the air environment sensors array, GSM module, central processing unit, memory for data storage. Microcontroller LPC2148 Chip was based on 32-bit ARM7TDMI-S CPU with real-time emulation and embedded trace support combine microcontroller with embedded highspeed flash memory ranging from 32KB to 512KB. LDR was used as light intensity sensor. SIM900A was used as transmission of Real-time collected data was via GPRS. Circuit boards of the developed WSN monitoring are given in the Figure 2.18.

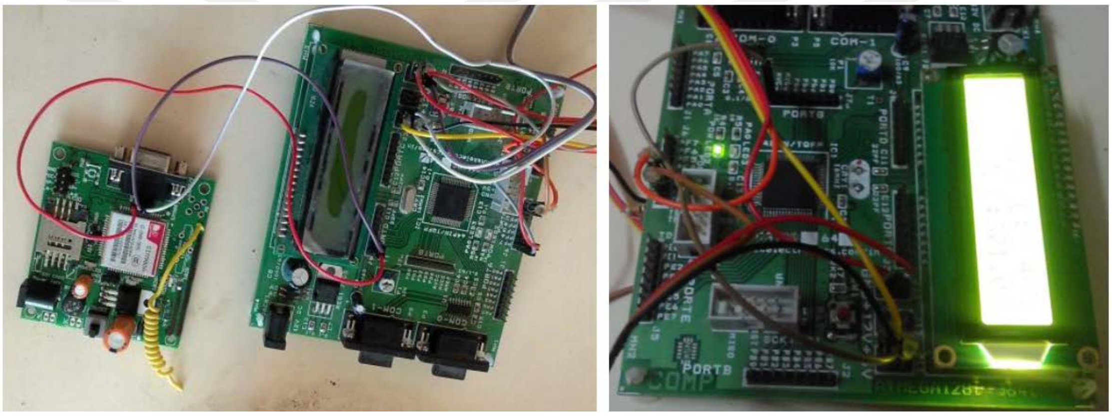


Figure 2.18: WSN of CO_2 monitoring, developed by S.B. Tayade, D. S. Chandak and P. S. Choudhari 2015, [43].

G. Panic, O. Stecklina and Z. Stamenkovic [44] have developed an Embedded Sensor Node Microcontroller with Crypto-Processors. Design of a sensor node was based on the IPMS430 processor core, which was fully compatible with the Texas Instruments MSP430 processor architecture. IPMS430 was an asynchronous processor addressing up to 1 MB of memory space. TNODE5 included the on-chip peripherals such as standard serial interfaces, a 16-bit and a 32-bit timer, digital IO ports, communication and crypto accelerators as well as controllers for the integrated ADC and Flash memory.

M. Martino and J. Varley [45] have developed a Wireless Sensor Node Powered by a PV/SuperCapacitor/Battery Trio. Compınenets of the WSN were; BQ25504 - Ultra Low Power Boost Converter with Battery Management for Energy Harvester Application, TPS62203 - High Efficiency, SOT23 Step-Down, DC-DC Converters, TPS62202 - High Efficiency, SOT23 Step-Down, DC-DC Converters, SN74LVC1T45 - Single-Bit Dual-Supply Bus Transceiver. Images of the implemented WSN devices are shown in the Figure 2.19.

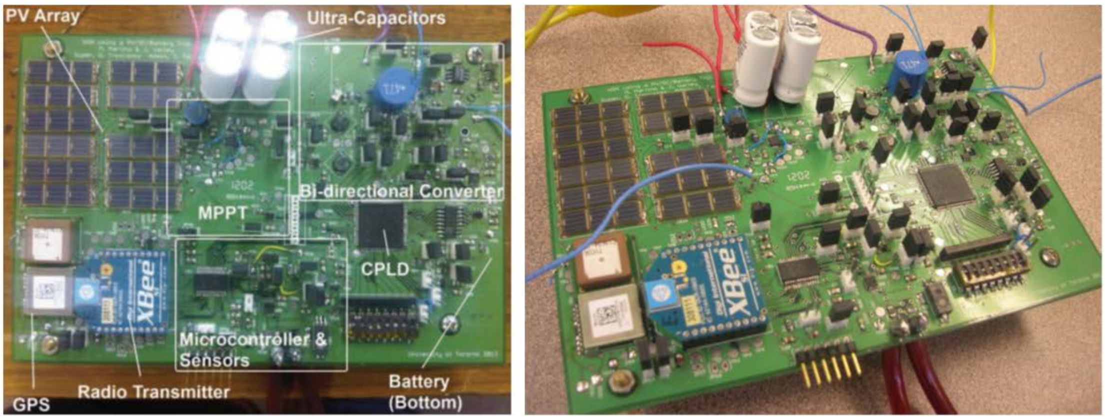


Figure 2.19: Low powe implemented WSN, developed by M. Martino and J. Varley 2012, [45].

S. E. Jero, A. B. Ganesh and T. K. Radhakrishnan [46] have developed a project that called an Implementation of WSN Node for Detection of Gaseous Substances Leakage. In this study, a customizable sensor node was indigenously constructed and various sensing modalities such as carbon dioxide, oxygen, temperature, and humidity were integrated. The system used a low power PIC18LF4620 microcontroller and MRF24J40MA Zigbee module. Zigbee wireless module was practiced using MRF24J40MA, operated at 2.4 GHz which used IEEE standard 802.15.4 complaint RF transceiver. Figure 2.20 shows an image of the developed sensor node.

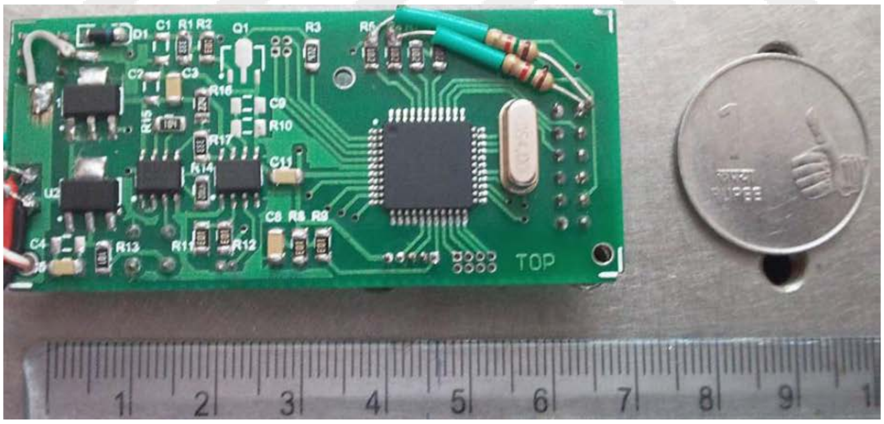


Figure 2.20: Designed sensor node device, developed by Jero,A. B. Ganesh and T.K. Radhakrishnan 2011, [46].

P. V. Mane-Deshmukh, B. P. Ladgaonkar, S. C. Pathan and S. S. Shaikh [47] have developed a Microcontroller Pic 18f4550 Based Wireless Sensor Node to Monitor Industrial Environmental Parameters. The sensor node was wired to the microcontroller 18F4550, from PIC family. Based on AVR atmega8L. This microcontroller was having smart on-chip resources. LM35 was a precision integrated circuit temperature sensor. Sensitive material of MQ-3 gas sensor was SnO2. MQ-3 were deployed. Zigbee is a wireless communication module launched by Digi Corporation and it is built to support 802.15.4 standard.

H. Ghayvat, S. Mukhopadhyay, X. Gui and N. Suryadevara [48] have developed a project that called WSN and IoT-Based Smart Homes and Their Extension to Smart Buildings. In this study, flexible force sensor was a Piezoresistive sensor A301 used to calculate the amount of pressure given to any object. To design temperature sensing unit the LM35 IC was connected to conditioning circuit for ambient temperature monitoring on any object. PIR movement monitoring unit was designed to detect the motion within the coverage range of the sensing system. These were binary mode sensors, and they were interfaced with RF XBee modules. Figure 2.21 show images of the developed sensor node.

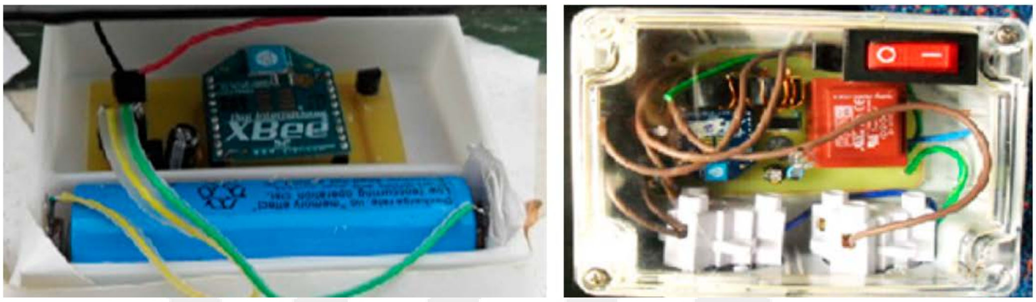


Figure 2.21: Designed sensor node, H. Ghayvat, S. Mukhopadhyay, X. Gui and N. Suryadevara 2015, [48].

A. H. Isilak has developed [49] a brilliant project that called Smart Home Applications for Disabled People by Using Wireless Sensor Network (2010). The focus of this project was on the integration WSN in smart homes and applications of this system. In this engineering project, Tmote Sky had a radio chip called Chipcon CC2420, in order to send and receive messages using radio frequency. This radio chip supports communication with IEEE 802.15.4 ZigBee standard. With sensitivity exceeding the IEEE 802.15.4 specification and low power operation, the CC2420 provided reliable wireless communication. Images of the developed WSN system is given in the Figure 2.22.

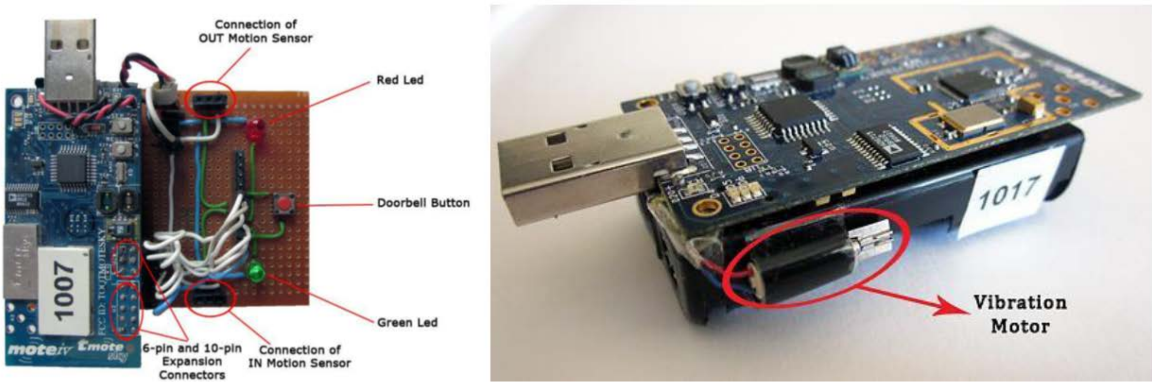


Figure 2.22: Door control node and Human node, developed by A. H. Isilak 2010, [49].

Rohit Vaish has developed a project that called Application of WSN for Environmental Monitoring and Development of an Energy-Efficient Cluster based Routing [50]. In this thesis study, measurement of temperature & light by the used of Crossbow sensor kit in which there were different nodes/motes placed at different locations. These nodes were having different node identification and they will sense the temperature and light of there surrounding location and send it to the base station node which was connected through USB port to the computer by the used of MoteView and MoteConfig environment. An image of the implemented sensor node is given in the Figure2.23.

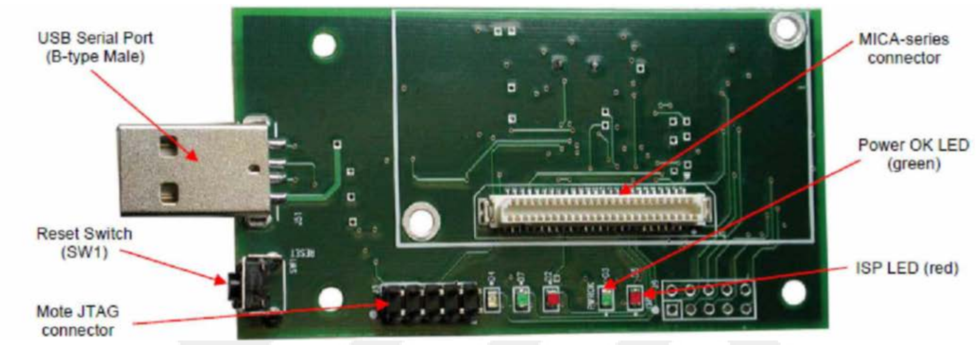


Figure 2.23: Photo of top view of sensor node, implemented by R. Vish 2009, [50].

M. Toledano-Ayala, G. Herrera-Ruiz, G. M. Soto-Zarazúa, E. A. Rivas-Araiza, R. D. B. Trujillo and R. E. Porrás-Trejo have developed a project that called Long-Range Wireless Mesh Network for Weather Monitoring in Unfriendly Geographic Conditions [51]. In this study, a long-range wireless mesh network system was presented. It consisted of three main parts: RTUs, BTUs and a CS. The RTUs shared a wireless network transmitting in industrial, scientific and medical applications ISM band, which reached up to 64 Km in a single point-to-point communication. A BTU controlled the traffic within the network and has as its main task interconnecting it to a Ku-band satellite link used an embedded microcontroller-based gateway. Embedded HTTP Server of base terminal unit is given in the Figure 2.24.

J. Lozano, J. I. Suárez, P. Arroyo, J. M. Ordiales and F. Álvarez have developed a project that called WSN for Indoor Air Quality Monitoring [52]. The network consisted of a base station and a few sensor nodes equipped with different sensors to measure temperature, light, air quality and humidity. Communication between nodes and host was based on standard IEEE 802.15.4 Zig-Bee protocol using Xbee and communication between host and PC was performed through a USB interface. Implemented wireless sensor nodes and developed control software are shown in the Figure 2.25.

Figure 2.24: Embedded HTTP Server, implemented by M. Toledano-Ayala and others 2011, [51].

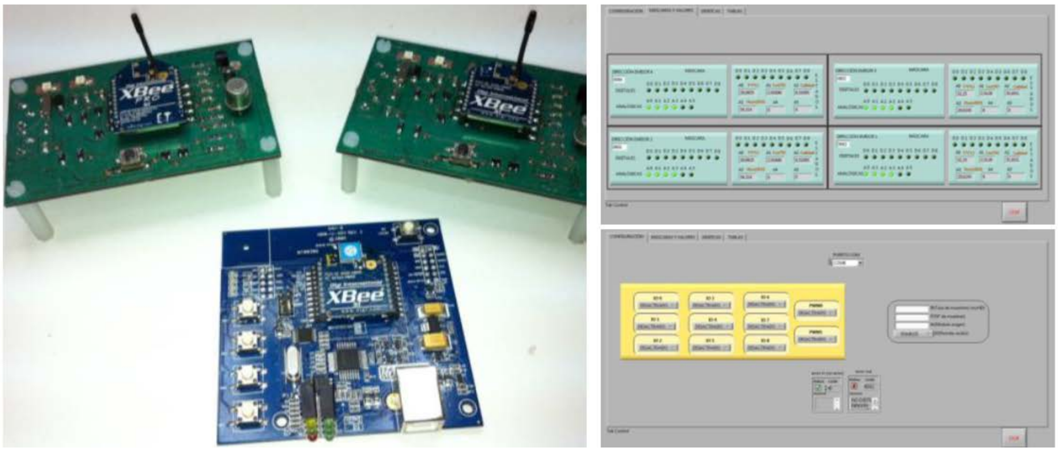


Figure 2.25: Nodes and control program, developed by j. Lozano and others 2012, [52].

N. Gahlot, V. Gundkal, S. Kothimbire and A. Thite have developed a project that called a Zigbee Based Weather Monitoring System [53]. The proposed hardware of this system includes LPC2148, Temperature, humidity, wind direction, wind flow, raindrop and Sun intensity measurement sensors, LCD. LPC2148 microcontrollers are based on a 16-bit/32-bit ARM7TDMI-S CPU with real-time emulation and embedded trace support. XBee RF Modules are designed to operate within the ZigBee protocol and support the unique needs of low-cost. LM35 is an integrated circuit sensor that can be used to measure temperature with an electrical output proportional to the temperature. Developed WSN system shown in the Figure 2.26.

M. Varchola and M. Drutarovsky have developed a project that called Zigbee Based Home Automation WSN [54]. As a wireless communication, ZigBee Alliance selected the IEEE 802.15.4 standard. A Freescale MC13203 chip was chosen for data retransmitting due to its availability in time of consideration and the original RF board with the compatible chip was also available. A Phillips LPC2138 and an Analog Devices ADuC836 were chosen as the MCU platform.

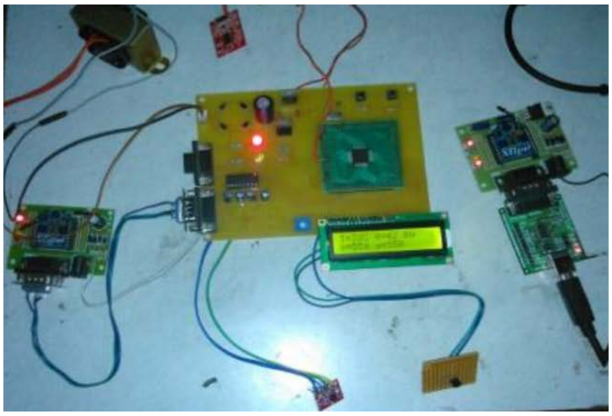


Figure 2.26: WSN system developed by N. Gahlot, V. Gundkal, S. Kothimbire and A. Thite 2015, [53].

J. Maloco has developed a WSN system project [55] that called Design of a WSN for Housing Community in his thesis. WSN node was provided by a Microchip PIC microcontroller. These were the microcontroller unit (PIC12F675 MCU), radio transmitter (PIC12F675), the sensor/sensor interface, and power source. Figure 2.27 show images of the developed sensor nodes.

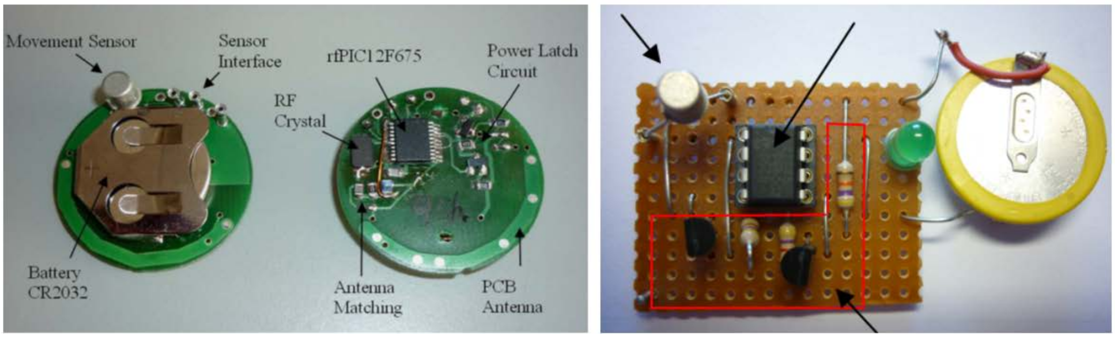


Figure 2.27: Photo of wireless sensor node 1 and node 2, developed by J. Maloco 2010, [55].

Z. Hailin has developed a WSN system project [56] that called Design and Implement of WSNs Data Publishing System in his thesis. The thesis introduced how to publish data without a sink node. LowPAN technology was used here to solve the communication problem between IEEE802.15.4 and IP-based networks. X-CTU is a Windows-based application provided by Digi. This program was designed to interact with the firmware files found on Digi's RF products and to provide a simple-to-use graphical user interface to them.

M. Raghuvanshi has developed a WSN project [57] in his master thesis that was called Implementation of WSN by him. The three components that dominated power dissipation for slave sensor node were the microcontroller, the radio and the buffers. This current was comparable to Mica Mote. Zigbee wireless standard was chosen as a communication protocol. Slave node is responsible for collecting and processing the data. It consists of this component: Microcontroller, temperature sensor, transceiver, power supply. Atmega16 microcontroller is low power CMOS 8-bit RISC microcontroller. To get the temperature reading they use the Dallas DS1620 integrated. Images of the designed sensor nodes are given in the Figure 2.28.

Figure 2.28: Designed slave node and master node, developed by M. Raghuvanshi 2006, [57].

P. Sausen, A. Sausen, F. Salvadori, R. E. Júnior and M. Campos have developed and implemented [58] a project that called Development and Implemented of WSN Network for the Electricity Substation Monitoring. PLC system installed in the central area of Porto Alegre city, in low voltage cabling, underground sensor network, consisted of a pair of transmitter and receiver, developed from a PLC MODEM PL-3120 manufacturing ECHELON. TRF-2.4GTM transceiver modulewas used for radio communication. TMS320F2812 DSP uses Harvard architecture. Images of the Developed intelligent sensor module SSM are shown in Figure 2.29.

Figure 2.29: Intelligent sensor module SSM, developed by P. Sausen and others 2012, [58].

S. P. Nayse and M. Atique [59] have developed a project that called Design of Application Based Wireless Sensor Node. Proposed WSN node was a highly flexible and PSoC architecture along with integrated RF radio chip which integrates with the CPU core with a choice of M8C 8051. Data acquisition components like programmable gain amplifier ADC, multiplexer, programs routine and protocol stack could transmit data. Figure 2.30 shows an image of the proposed sensor node.

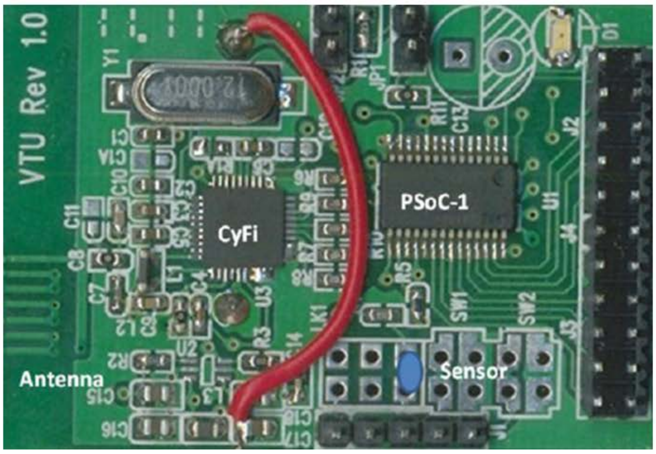


Figure 2.30: Proposed sensor node, implemented by S. P. Nayse and M. Atique 2014, [59].

The Ph.D. thesis [60], A. E. Tumer has designed a wireless CH4 monitoring system which was presented energy-efficient routing protocol based on LEACH protocol. Implemented WSN system has three units, these are; CH4 detection circuit unit, detection sensor node and MIB510 Interface Unit. Implemented WSN system images are shown in the Figure 2.31.

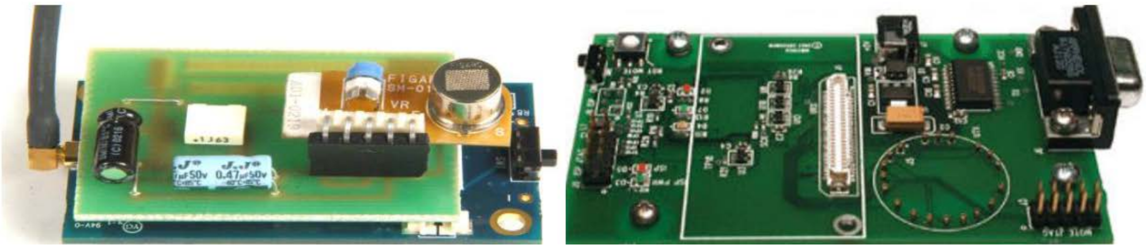


Figure 2.31: CH4 monitoring system, implemented by A. E. Tumer 2011, [60].

CHAPTER III

MATERIALS AND METHODS

Microcontroller devices are used in controlled some products and some devices, for example; remote controls, automobile control systems, appliances, power tools, medical systems, office machines, appliances, power tools and other embedded systems. Microcontrollers which are the best choices for embedded control systems. Due to their elasticity connect to other devices and easily programmable, cheap, less power consumption, etc. Also, microcontroller devices can go to sleep and idle state while part of the controller can be active. Additionally, microcontrollers with integrated Flash program memory provide increased system flexibility by enabling field programmability, data storage, and remote upgrades. This offers new oppurtunities to the designers using self-programming memory based microcontrollers.

Microcontrollers section present an overview of the microcontrollers and purpose at reporting an overview of microcontroller technologies and features. Microcontroller section provides a background for microcontrollers. I am going to explore this aspect of hardware design by focusing on a node's microcontroller. I am going to survey various commonly used microcontrollers and the characteristics of the typical microcontrollers.

Sensors are devices to detect physical phenomena such as light, heat, temperature, gas, humidity, pressure, etc. Sensors are one of the most important components of networks. In sensors section of this chapter, I am going to describe the main concepts and components of sensors. I am going to give a basic understanding of the concepts behind wireless sensor networks. I am going to explore the sensor mechanisms for wireless sensor networks developed in recent years. Thhhis will help me to understand the current sensor mechanisms for wireless sensor networks and remark and focus open issues that can be subject to further research.

In order to meet the needs of this wireless communication, IEEE has begun to form new working groups and to look beyond short distance WLAN standards to define the future. Communication Standards section provides an overview of technical aspects of the WSN standards along with on their information. WSN standards are largely based on the same technologies and all offer support for features such as adaptive modulation and coding and various enhanced transmission systems.

Communication Standards section presents and discusses different wireless communication standards and proprietary solutions for WSN environments within different standards and features suitable for a WSN system. WSNs are progressively adopted industrial world due to their advantages. Additionally, to reduce cabling costs, WSNs are widened the field of environments feasible for monitoring. Therefore, to add sensing and acting capabilities to objects in the environmental world and allow for communication with objects and services in future WSNs.

Due to the limitation and WSNs providing electrical power is very difficult. Hence, sensor devices need to be powered by batteries and alternative renewable energy sources such as solar energy and rechargeable battery. Because battery energy is limited, using different techniques for energy saving is one of the essential tasks in WSNs. In energy consumption section, I present a survey of power saving and energy optimization techniques for WSNs. Many efforts have been taken to reduce the energy consumption of the hardware, software, communication protocols, and applications. Therefore, in energy consumption section presents an approach for evaluating the power consumption of WSN applications with a set of tools to automate the proposed approach.

In this section, I also present the different techniques proposed by recent studies used to deal with these challenges. Fast data transmissions are constantly improved but the most notable and pressing problem involving wireless sensor networks is power consumption. Battery power efficiency is a critical factor in wireless sensor networks since sensor nodes are typically powered by nonrenewable batteries. It is a critical factor in discerning the lifespan of WSNs. Therefore, this power issues section proposes control sensor networks lifespan. So, it is important to monitor and control energy consumption of each sensor node.

WSNs have been widely used in many areas especially for surveillance and monitoring in agriculture and habitat monitoring. Environment monitoring applications have become an important field of control and protection, providing a real-time system and control communication with the physical world. Military surveillance, home health care or assisted living, and environmental science are three major application areas for wireless sensor networks. In this section, Applications and usage areas will be shown on WSNs for environmental and industrial monitoring applications will be presented and reviewed in order to implement a good monitoring system and designed good wireless sensor nodes.

3.1. Microcontrollers

One of the main components of sensor nodes is microcontrollers. Actually, microcontrollers are small computer systems which have on a single integrated circuit containing a processor, small memory, and programmable I/O peripherals. Generally, microcontrollers are designed for embedded applications. In contrast to the microprocessors, microcontrollers are used in general purpose applications consisting of various discrete chips [61]. Microcontrollers perform the main task in the sensor nodes i.e. processing data and controlling functions of the other components. These are some of the controllers most of the time using as field programmable array and environmental monitoring applications. So, microcontrollers are more suitable for WSNs. WSN mostly uses microcontrollers. Figure 3.1 shows basic layout of the microcontroller.

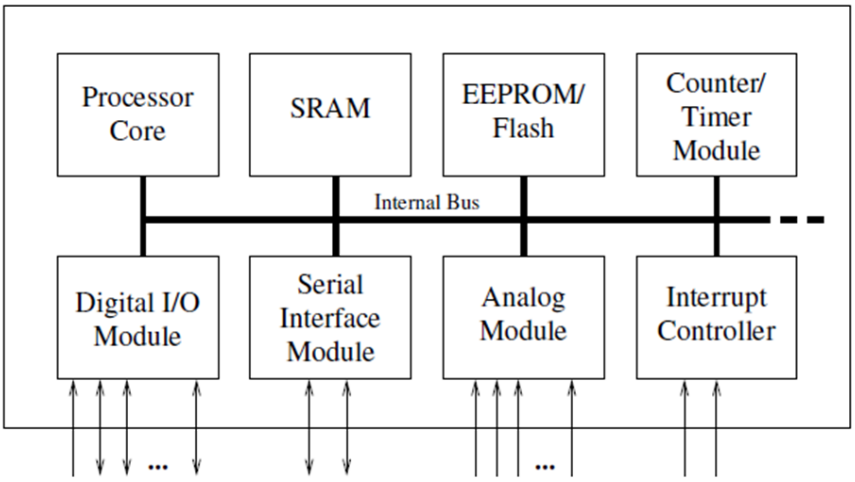


Figure 3.1: Basic layout of the microcontroller, drawn by G. Gridling and B. Weiss 2007, [62].

Main internal designs of microcontrollers are quite similar components. In microcontroller designs, all components are connected via an internal bus and these are all integrated on one chip. Some modules are connected to the outside world via input/output pins. The following section contains usually integrated microcontroller modules and this component is described below in detail. CPU of the microcontroller which contains an arithmetic logic unit, control unit, and register units. The processor core is the main part of every microcontroller and it is often taken from an existing processor. The processor consists of a data path which executes coming instructions and controls unit which basically tells selecting data path what to do. Figure 3.2 shows architecture of the basic CPU.

Most of the current WSN devices are designed around microcontrollers. The devices have all the basic features needed to manage WSN devices. The microcontroller in WSN node is the key component which controls all the work of peripherals and radio communication. The brain of each WSN nodes is the microcontroller which processes readings from its own sensors. PIC microcontrollers are made by microchip technologies are limited. These are mainly used in industrial development due to their low cost and it has serial programming capability. They are widely used in embedded systems today.

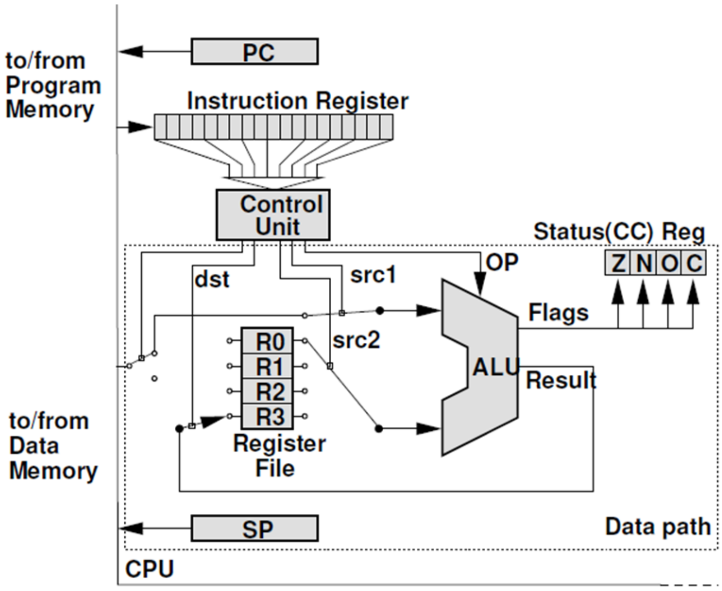


Figure 3.2: Basic CPU architecture, drawn by G. Gridling and B. Weiss 2007, [62].

The microcontroller has a number of register files which works as general-purpose ram some of special purpose control registers for on-chip researchers. In this memory is divided into banks. Addressability of memory depending on the device, and all microcontrollers have some banking mechanism to extend addressing to additional memory. Later series of devices feature move instructions which can cover whole addressable space, independent of selected bank.

In microcontrollers, memory is very limited due to the cost. But recently MCUs often are used for simple tasks. Therefore, applications don't need excessive amounts of memory. This way, total system cost is decreased considerably. MCUs usually provide different amounts of memory according to the needs. So particular MCU can be chosen which offers the appropriate memory space.

Most controllers have Timer/Counters can be used to timestamp events, measure intervals, or count events, also most of the controllers contain PWM outputs can be used to drive motors or safe breaking. Moreover, PWM output can provide an external filter be used to realize digital/analog converter. Timer module absolutely speaks a counter module which is an important part of every microcontroller. Timers which are used for a variety of tasks ranging from simple delays over measurement of periods.

Digital Input/Output to the ability to directly monitor and control hardware, this is the main characteristic of microcontrollers. As a result, usually, microcontrollers have digital Input/Output pins can be directly connected to hardware. Digital input functionality is used monitor signal should be interpreted digitally changing between two states high and low. Most of the microcontrollers have integrated ADC. In some cases, microcontrollers can include digital/analog converters. Microcontrollers equipped with analog inputs that are multiplexed and go to a single internal ADC. ADCs allow to set up next channel while current conversion is in progress and take over new settings as soon as the current conversion is finished.

Microcontrollers have serial interface can be used to download program and for communication with PC. Most of the microcontrollers also contain integrated bus controllers for the most common busses. Microcontrollers can also contain PCI, USB, or Ethernet interfaces and contain several communication interfaces such as UART modules. The basic goal of the interface is to allow the microcontroller to communicate with other units, other microcontrollers, peripherals, or a PC. UART module utilizes a transmit line and a receiving line for full-duplex or half-duplex communication. UART is not communication protocol but this is a module can be used for asynchronous serial communication [62].

In microcontroller systems, it is important to guard against errors in the program and the hardware. So, watchdog timer unit and debugging unit are very important. Watchdog is used to reset controller in case of software crashes. It is also used to monitor software execution.

BUS is used to transfer and receive the data from one peripheral to another. It is classified into two types such as data bus and address**.** Data Bus is used for only transfer or receives the data. The address bus is used to transmit the memory address from the peripherals to the CPU. I/O pins are used to interface external peripherals; UART-USART is a serial communication protocols are used for interfacing serial devices like GSM, GPS, IR, etc.

Oscillators are used for timing generation. PIC microcontroller consists of external oscillators like RC oscillators or crystal oscillators. Where the crystal oscillator is connected between the two oscillator pins. Value of the capacitor is connected to every pin that decides the mode of the operation of the oscillator. Modes are the crystal mode, high-speed mode and the low-power mode.

3.1.1. Features of Microcontrollers on the Embedded Systems

The microcontroller can be organized a self-contained system with a processor, memory, and peripherals and it can be used as an embedded system. Most of the microcontrollers in use are embedded systems for example appliances, telephones, automobiles and computer systems. Majority of the embedded systems are advanced with minimal requirements for memory and program length and no operating system and low software complexity. Typical input and output devices include switches, LEDs, solenoids, relays, sensors, displays, radio frequency devices. Embedded systems usually have no keyboard, disks, screen or other recognizable I/O devices.

Microcontrollers are usually deployed as mobile devices which run on batteries. Therefore, low power consumption is essential for a microcontroller. In order to reduce energy consumption, the microcontroller has several techniques are possible, these are; Voltage Reduction, Clocking Frequency Reduction, Optimized Design, and Shutdown of Unused Modules. Many microcontrollers have a sleep mode which was placed on the processor core.

Microcontroller programs have to fit in available on-chip memory, because of cost to provide an external or expandable memory. Programmers are used to converting high level and assembly language codes into a microcontroller for storage in microcontroller's memory. Depending on the device, program memory can be a permanent or read-only memory, and can only be programmed at the factory, can be field alterable flash or erasable read only memory. Microcontrollers usually included EPROM version program memory can be erased by ultraviolet light, ready for reprogramming after a programming and test cycle.

In the past, microcontrollers were only programmable with assembly language, but nowadays various high-level programming languages, such as Python, JavaScript, C++, etc. are commonly used to target microcontrollers and embedded systems [63]. These languages are designed especially for the purpose or versions of general purpose. Compilers for general purpose languages will have some restrictions and enhancements to better support unique characteristics of microcontrollers and embedded systems.

3.2. Sensors

A sensor device detects and responds to some type of inputs from real-physical environments. Specific inputs can be light, pressure, temperature, motion, moisture or any one of a large number of other environmental signals. Sensors which gives an output by detecting the changes in quantities or events can be defined as a sensor.

Sensors produce an electrical signal or optical output signal corresponding to the changes in the inputs. Most of the sensors in use today are actually going to be able to communicate with an electronic device that is going to be doing the measuring and recording.

3.2.1. Classification of the Sensors

Sensor devices are classified based on the nature of quantity they measure. Further classification can be done based on the principle of operation and nature of output signal (analog or digital). But, there are a few types of sensors such as temperature sensors, IR sensors, ultrasonic sensors, pressure sensors, proximity sensors, and touch sensors are frequently used in most of the electronics applications. According to scientists the most frequently used different types of sensors are classified based on the quantities such as Electric current or Potential or Magnetic or Radio sensors, Humidity sensor, Fluid velocity or Flow sensors, Pressure sensors, Thermal or Heat or Temperature sensors, Proximity sensors, Optical sensors, Position sensors, Chemical sensor, Environment sensor, Magnetic Switch sensor, etc.

There are different types of sensor that produce a continuous analog output signal and these sensors are considered as analog sensors. This continuous output signal produced by the analog sensors is proportional to the measurement. There are various types of analog sensors; practical examples of various types of analog sensors are as follows: accelerometers, pressure sensors, light sensors, sound sensors, temperature sensors, and so on.

A digital sensor is electronic or electrochemical, where data conversion and data transmission are done digitally. Digital sensors produce discrete signals. Information received from digital sensors, it has the rising value of certain steps. Digital sensors produce discrete digital pulses for a change in its environment. A push button switch is a good example of a digital sensor. The output of this sensor can be either "ON" or "OFF", it can be either 1 or 0. Analog output graphic and diagram are shown in the Figure 3.3.

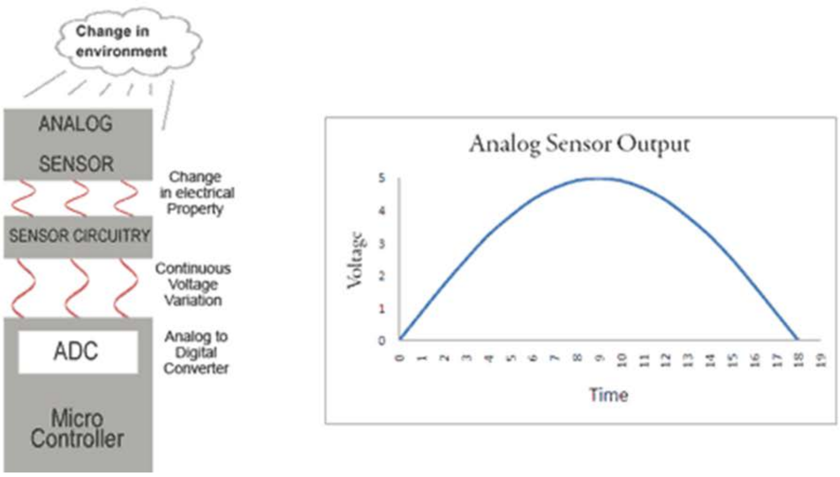


Figure 3.3: Analog sensor output, www.robotplatform.com 2018, [64].

Analog Sensors output a change in the electrical property to signify a change in its environment. Change can be a variation in Voltage, Current, Resistance, Charge, and

Capacitance. Sensor circuits are designed to monitor these changes and provide a voltage difference. All modern microcontrollers have an analog to digital converter circuitry built-in. Analog output graphic and diagram are shown in the Figure 3.4.

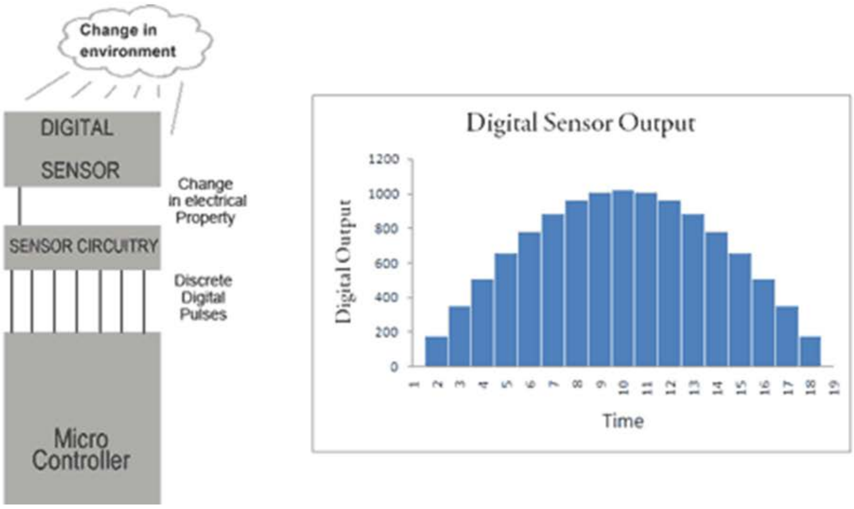


Figure 3.4: Analog sensor output, www.robotplatform.com 2018, [64].

Passive sensors are microwave instruments designed to receive and to measure natural emissions produced by constituents of the Earth's surface and its atmosphere. Power measured by passive sensors is a function of the surface composition, physical temperature, surface roughness, and other physical characteristics of the earth.

An active sensor is a radar instrument used for measuring signals transmitted by the sensor that was reflected, refracted or scattered by the Earth's surface or its atmosphere. Spaceborne active sensors have a variety of applications related to meteorology and observation of the Earth's surface and atmosphere.

3.3. Wireless Communication Standards

Communication systems contain nodes within the software for communication is organized according to a layered structure that is called protocol stacks. Protocols are set of rules that communicating parties and protocols usually belongs to one layer in the protocol stack. There is a universally reference protocol stack that called OSI model [65]. OSI model has seven layers, these are application layer, presentation layer, session layer, transport layer, network layer, data link layer and physical layer. The application layer is to user interface whereas physical layer is to communication channel involving actual hardware. Layers deal with its specific part of communication task and each layer provide services to the layer above.

TCP/IP protocol stack consists of five layers, in TCP/IP network model, top three layers of the OSI model: application layer, presentation layer, and session layer have merged into one application layer. A layered approach is adapted to break down complex task of building a communication system, this approach is a divide and conquers fashion. Each layer can be optimized individually and also every layer can be contained more than one protocol. TCP/IP stack consists of two protocols in transport layer: UDP protocol and TCP protocol. Diagrams of the OSI model and TCP model are shown in the Figure 3.5.

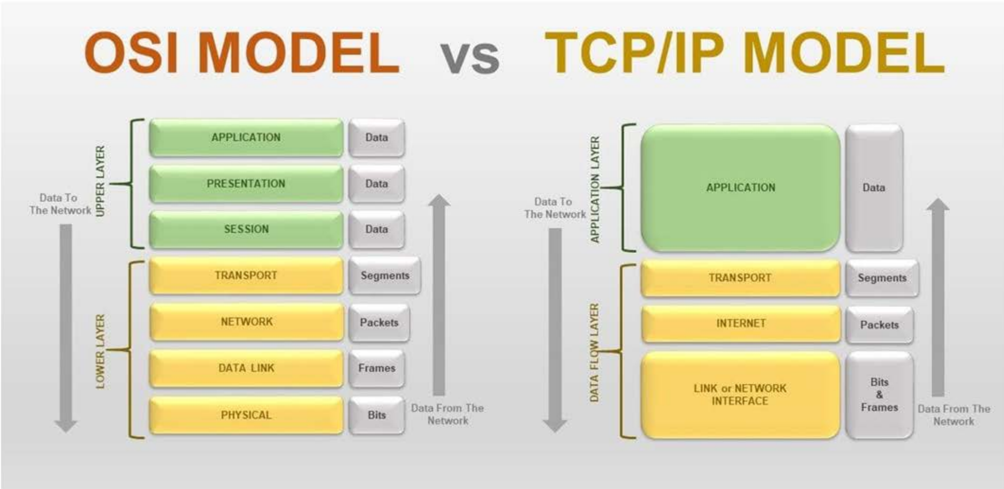


Figure 3.5: OSI model VS TCP model drawn by R Kumar 2017, [66]

3.4. Routing Systems in WSN

Routing in a wireless sensor network is very challenging task due to the natural characteristics and the relatively large number of sensor nodes. It is impossible to build a global addressing scheme for deployment a large number of sensor nodes. Therefore, traditional IP based protocols absolutely cannot be applied to WSNs. Because of the differences, many new algorithms have been proposed for the routing problems in WSNs. These routing mechanisms have taken into consideration inherent features of WSN applications and architecture requirements.

3.4.1. Routing Challenges and Routing Issues in WSNs

WSNs have several restrictions such as limited computing power, limited energy supply and limited bandwidth of the wireless links connecting sensor nodes. One of the main design goals of the wireless sensor network is to carry out data communication while trying to prolong the lifetime. WSNs affected negatively by limitations of several network resources such as central processing unit, storage, bandwidth and energy [67]. Routing protocols designed for WSNs should consider application area and architecture of the network. Design of routing protocols in WSNs are influenced by many challenging factors. These factors must be overcome before efficient communication can be achieved in the WSNs.

In WSNs, communicating nodes are linked by a wireless medium. Traditional problems associated with a wireless channel can affect the operation of the sensor network. Usually, required bandwidth of sensor data will be low. Related to transmission media is the design of MAC. MAC design for WSN is to use TDMA based protocols that conserve more energy compared to contention-based protocols like CSMA. In WSNs, sensor nodes are expected to be highly connected. Connectivity depends on the possibly random distribution of nodes. In wireless sensor nodes, each sensor node obtains a certain view of the environment. A given sensors view of the environment is limited in range and inaccuracy; it can cover a limited physical area of the environment. Thus, area coverage is also one of the important design parameters in WSNs.

3.4.2. Routing Techniques and Protocols in WSN

Routing in WSNs can be divided into four categories, these are location-based routing, flat based routing and hierarchical based routing and depending on the network structure. All nodes are typically assigned equal roles or functionality in the flat based routing. Nodes play different roles in the network in the hierarchical based routing. Figure 3.6 shows routing protocols in the wireless sensor networks.

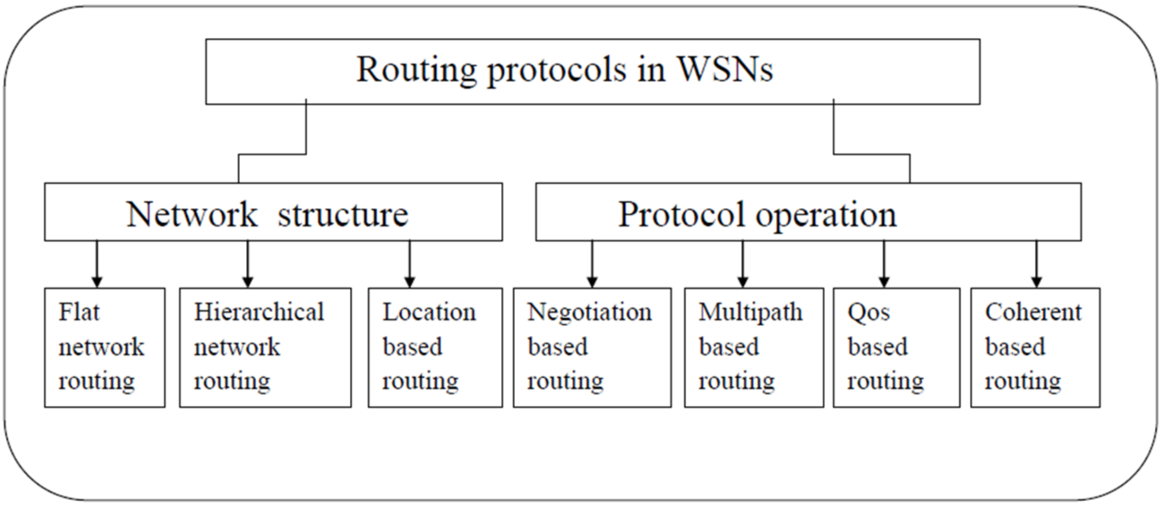


Figure 3.6: Routing Protocols in WSN, drawn by J. N. Al-Karaki and A. E. Kamal 2006, [68].

In location-based routing, sensor nodes positions are exploited to route data in the network. Moreover, these protocols can be classified into five categories, these are multipath based, QoS based, query-based, negotiation based and coherent based routing techniques depending on the protocol operation. In addition, routing protocols can be classified into three categories, these are proactive, reactive, and hybrid protocols depending on how source finds a route to the destination. All routes are computed before they are needed in the proactive protocols. While in the reactive protocols, routes are computed on demand. Hybrid protocols use a combination of these two protocol types. Another class type of routing protocols is called cooperative routing protocols Sensor nodes send data to a central node where data can be aggregated and can be subject to further processing in the cooperative routing, so reducing route cost in terms of energy use. Many other protocols can be classified rely on timing and position.

MAC protocol is one of the important techniques that enable successful operation of the network. MAC protocol is to avoid collisions so that two interfering nodes do not transmit at the same time. There are many MAC protocols are developed for wireless communication networks. Typical examples include time division multiple access, contention-based protocols, and code division multiple access [69]. To design a good WSN MAC protocol WSNs can be considered this attribute. The first feature is energy efficiency. The second feature is prolonging network lifetime for nodes is a critical issue. Third protocol is scalability to change in network size, node density, and topology.

3.5. Energy Consumption in Wireless Sensor Networks

Nowadays advanced technology of WSNs are used in many applications like health, environment, education, industry, battlefield etc. Sensor nodes are powered by sources with limited energy supply such as batteries. So, sensor nodes equipped with limited power sources. Thus, efficiently utilizing sensor nodes energy can maintain a prolonged network lifetime. One of the important issues in wireless sensor networks is developing an energy consumption to improve the lifetime of the networks. Many energy efficient systems have been proposed by the community, spanning architectures [70], operating systems [71], sensor usage [72], algorithm and protocol design [73]. Researchers in the low power compilation community has developed a number of techniques [74] that can optimize the compilation process for energy consumption when targeting specific systems design.

3.5.1. Power Constraints in WSN and Design Issues of Energy Constrained in WSN

The main drawback of WSNs are limited energy resource. There are many types of research are not sufficient to improve the lifetime of WSNs. To make the WSNs more efficient to extend the lifetime of WSN it is required that battery life of every participating sensor should be improved and the total energy of the WSN should be optimized. To achieve this node must activate only when they have to transmit or receive any signal from other nodes. Every node has a radio transceiver that has four modes of operation:

Transmission: It consumes the maximum power in WSN.

Receiving: Information received b/w sensor nodes. It consumes the medium power.
Stand-by: Sensor node is currently inactive and turned on & ready for data transmission.
Sleep: Sensor node is in OFF state.

The wireless sensor node is made up four basic components; Sensing unit (Sensors, ADC), Processing unit (Processor, Storage), Transceiver unit and Power unit. Sensing units have two subunits, these are sensors and ADC. Sensors convert physical phenomena into electrical signals. Sensors can be classified as analog or digital devices. Analog signals produced by sensors are converted to digital signals by analog to digital converter unit and then fed into processing unit.

The processing unit has a microprocessor which is responsible for control of sensors, signal processing algorithms, execution of communication protocols and gathering data from sensors. There are four main processor states can be identified in the processor unit. These are; off, idle, sleep and active. CPU and most internal peripherals are turned on in the sleep mode and it can only be activated by an external interrupt. In idle mode, CPU is still inactive, others are active. RF unit responsible for the wireless communication with neighboring nodes and the outside world. There are several factors that affect power consumption characteristics of transceiver unit. These are operational duty cycle, data rate and transmit power. These power consumption characteristics must be adopted in the communication schema. Transceivers can operate in Transmit and Receive, Idle and Sleep modes. The sleep mode is a very important energy saving feature for WSNs due to energy conserving methods.

Energy from power techniques can be stored in rechargeable batteries and this can be a useful combination of wireless sensor node environments. Because maintenance operations like battery changing are impractical and sometimes difficult. Saving energy in a power unit can additionally support power conservation techniques are developed such as dynamic voltage scaling unique voltage design that can help conserve the energy. So, energy consumption to be the essential factor in determining sensor node lifetime.

3.5.2. Operational Energy Costs in Wireless Sensor Networks

In wireless sensor applications, energy used by a sensor node and it consists of energy consumed some processing, these are; computing, receiving, transmitting, listening for messages on RF channel, sampling data and sleeping. Switching of state, RF can also cause significant energy consumption. Calculation of these operational energy costs in a sensor node can be considered MAC protocol, as it has a significant impact on energy consumption. Its parameters related to energy costs calculation can be summarized as the followings:

Sampling period (S) = 360 s, Neighborhood size (nb) = 5, Preamble (bytes) = 3,144.
Channel check interval (CCI) = 0.1 s, Check time (Tch) = 0.000128

Power consumption for passive sensors is negligible in comparison to other devices on a wireless sensor node such as passive light or temperature sensors. Power consumption For active sensors can be significant such as sonar, soil and gas sensors, Each sensor node can be included several sensors, and each of these sensors has its own energy consumption characteristics such as own sampling frequency.

The following formulas [75] are utilized when calculating the operational energy costs of the designed sensor nodes in the discussions and result section of this study. Sensing energy consumption(E_{sm}) formula is given in the Formula 3.1.

$$E_{sm} = V_{dc} * I_i * T_i \tag{3.1}$$

Where (T_i) is the time required for obtaining a single sample from sensor (i) and (I_i) is the current draw of sensor (i). (T_i) depends on the start-up (T_s) response (T_r) and measurement (T_m) times of the sensors. As (T_m) is small in comparison to (T_s) and (T_r) for most sensors, I consider only (T_s) and (T_r) in calculating (T_i).

Computational energy cost (E_{comp}) of sensor nodes is essential and important of the operational energy costs in WSNs. Computational energy cost includes active mode and other modes such as standby mode, idle mode, sleep mode energy consumption of the microprocessor. It is significant compared to communication energy, response time, sensor startup time. Computational energy consumption formula is given in the Formula 3.2, the cost can be approximately expressed with the following formula;

$$E_{comp} = V_{dc} * I_{mcu-act} * T_{mcu-act} + V_{dc} * I_{mcu-slp} + T_{mcu-slp} \tag{3.2}$$

Where ($I_{mcu-act}$) and ($I_{mcu-slp}$) are the MCU active and sleep mode current, respectively. ($T_{mcu-act}$) and ($T_{mcu-slp}$) are the MCU active and sleep modes durations, respectively.

Communication energy cost (E_{comm}) is the most important and essential element of the operational costs in WSNs. Components of the communication energy cost are including listening mode, transmission mode, reception mode, sleeping mode and switching energy mode.

Transmission energy cost presents and explains to energy consumed during transmission of the data packets. Transmission energy cost (E_{tr}) formula is given in the Formula 3.3, the cost can be approximately expressed as;

$$E_{tr} = V_{dc} * I_{tr} * P_b * T_b \quad (3.3)$$

Where (I_{tx}) is the current consumption in the transmission mode of the radio. (P_b) is the bit length of the packet to be transmitted along with the preamble for the MAC. Based on the MAC packet format for a two-byte payload, ($L_{preamble}$+$L_{trpacket} = (3125 * 8 + 19 * 8)bits$)) and ($T_b$) is the transmission time of a single bit.

Reception energy (E_{rx}) component of the (E_{comm}) refers to the energy consumed when receiving packets. Reception energy formula is given in the Formula 3.4.

$$E_{rx} = V_{dc} * I_{tr} * P_{br} * T_b \quad (3.4)$$

Where (I_{tx}) is the current consumption in reception mode and (P_{br}) is the bit length of the packet to be received along with the preamble for MAC, which can vary from (P_{br}) to (P_{Pb}) so, a node can receive more than one packet during one period.

Listening energy (E_{listen}) is radio energy consumption when RF is active, but this is not receiving or sending packets. This listening is to check for messages on the RF channel, if possible, it can be duty cycles and low power listening. Low power listening cost formula is given in the Formula 3.5, the listen cost can be approximately calculated as:

$$E_{listen} = V_{dc} * I_{listen} * T_{listen} \quad (3.5)$$

Where (I_{listen}) is the current draw of the radio in listen mode and (T_{listen}) is the time in each period that the radio stays in listen mode, which depends on the MAC protocol. For the MAC. ($T_{listen} = \frac{S}{CCI} * T_{tch}$) where (S) is the period (CCI) is the channel check interval and (T_{tch}) is the time during which the node is awake in every (CCI) and values used for these variables were presented earlier.

Switching states in the radios are regular occurrences in WSNs. So, cost of switching RF is not negligible. For the RF, following equation determines energy consumed for the switching state formula is given in the Formula 3.6, the Switching (E_{sw}) cost approximately calculated as follows:

$$E_{sw} = \frac{(I_{stj} - I_{sti}) * T_{stij} * V_{dc}}{2} \quad (3.6)$$

Where (I_{stj}) is the current draw of the radio in the state switched, (I_{sti}) is the current draw of the radio in current state and (T_{stij}) is the time required for the radio to go from state (i) to (j).

When an RF switches on from sleep mode to transmission or receives mode, it uses wakeup time. Sleep time (E_{sleep}) is simply time remaining that is not consumed by other operations, estimated slep time formula is given in the Formula 3.7.

$$E_{sleep} = V_{dc} * I_{sleep} * T_{sleep} \quad (3.7)$$

Where Islp is the current draw of the radio in sleep mode, ($T_{sleep} = S - (P_b * T_b + P_{br} * T_b + T_{listen} + T_d + T_{stij}/2)$) where ($T_d = T_i + T_{mcu-actv}$). Radio needs to switch between sleep and listening mode (S=CCI = 360=0:1 = 300) 3,600 times during the period (360 s).

3.5.3. Energy – Power Optimization Methods

Energy savings methods can be classified into two categories. These are Device-Level Methods and Network Level Methods. In Device-Level Methods, hardware component and hardware configuration to achieve low energy consumption in WSN. In network level methods, communication methods and protocols to minimize energy consumption. In a sensor node system, there are four important units, these are processing unit, sensing unit, power unit, and a transceiver unit. The processing unit is a part of microcontroller unit can read sensor data and can perform computations and prepare a data packet ready to transfer to RF channel. Power consumption of WSN in the Various States are given in the Figure 3.7.

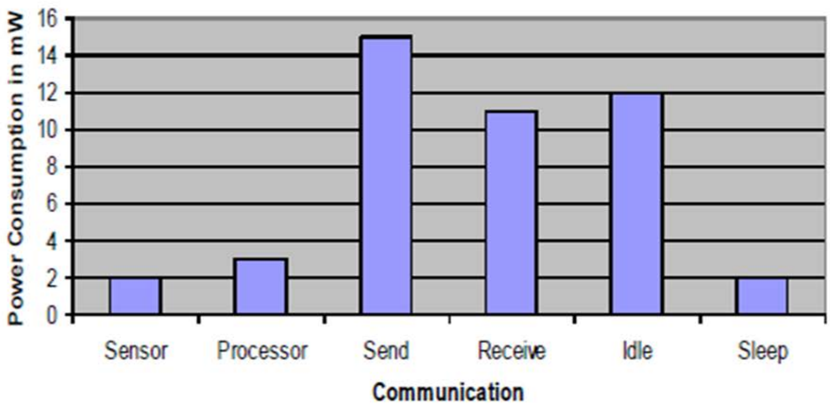


Figure 3.7: Power consumption of WSN in the Various States, drawed by V. K. Sachan et al. 2012, [76].

3.5.3.1. Node Architecture

The architecture of node can be designed based on processing, radio, sensing and power unit conditions. Component selection can be selected based on energy saving and minimum energy consumption. Environmental energy harvesting technology from external source is important to extend network lifetime. The power consumption of processor depends on processor operating unit tasks such as sleep and idle mode and connection with the operation of the node. The power consumption of nodes depends on operating voltage, duty cycle internal logic and above all on efficient manufacturing hardware technology. Figure 3.8 shows an image of three subsystem, power management, control and communication.

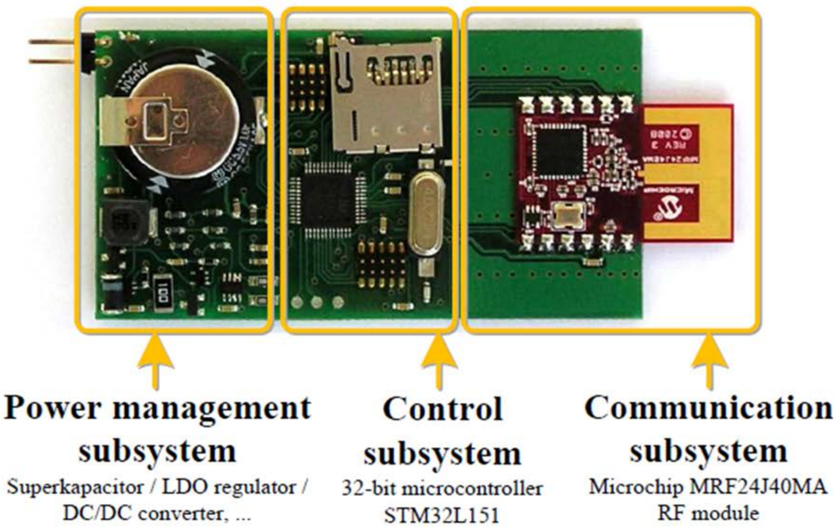


Figure 3.8: RF Power management, control and communication subsystems, J. Micek and M. Kochlan 2014, [77].

Radio transmission and reception are mainly energy consumer in a wireless sensor network. Most of the sensor network, for energy conservation, two methods are used to minimize communication cost [78]. One of the first methods is configuring MAC protocol and network layer for which multihop communication nodes switch off their radios when they are not in use. The second method is the data reduction and data aggregation where exploitation of the correlation in data is achieved to decrease the size of data and also communication cost. RF needs to be more active for long period in communication when nodes send data to one or other base stations. The transceiver can be described as a combination of receiver and transmitter. Transceiver unit consists of receiver and transmitter. Communication between node within network and transfer of data between base stations to the node require a combination of transmitter and receiver. Power consumption of the wireless interfaces are given in the Chapter 4, see Table 4.1 for comparison of the communication power cost.

The sensor unit is one of the essential units of the wireless sensor node, sensing unit sense and detect physical state of the environment and sends a data package to the processor. The processor manipulates data and decides to transmit data package to the base station. The sensor converts energy from analog form to digital form. Wireless sensor node can be designed with the different type of sensor and they consume a different amount of energies. Some of the sensors require a significantly large amount of energy than others such as active sensors, an example is radar sensors. Some of the sensors consume little energy such as passive sensors, examples are humidity and temperature. Power cost comparison of some popular sensors are given in the Table 3.1, also Figure 3.9 shows sensor subsystem module.

Sensor Type	Power Consumption
Gas sensor	500mW-800mW
Image sensor	150mW
Pressure sensor	10mW-15mW
Acceleration sensor	3mW
Temperature sensor	0.5mW-5mW

Table 3.1: Power cost comparison of some popular sensors, created by V. K. Sachan et al. 2012, [76].

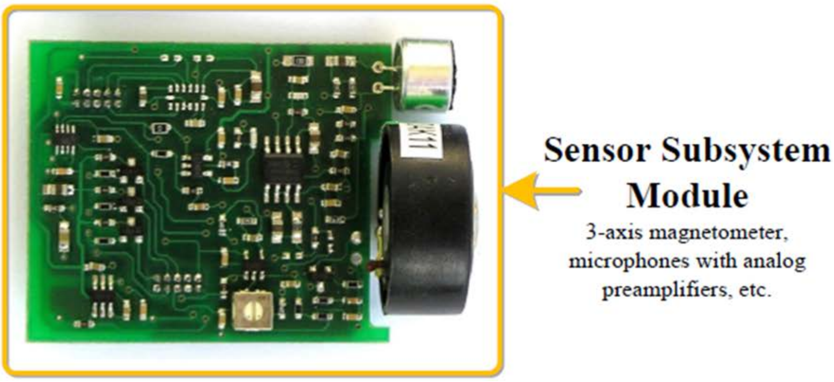


Figure 3.9: Sensor subsystem module, J. Micek and M. Kochlan 2014, [77].

Usually, wireless sensor nodes are designed with non-rechargeable AA batteries and battery replacement is difficult and laborious in the WSNs. So, it is very important to know and approximate power consumption needs of the sensor node. Appropriate selection in the design phase of transceiver and microcontroller are very important in terms of the energy consumption. Hardware platform have to make sure on which sensor node is power conscious and this can be useful in managing the power of the system.

3.5.3.2. Communication Architecture

Communication architecture [79] is the most major design issue for energy constrained and WSN introduces various challenges. The main goal of a communication architecture for energy constrained WSNs are to achieve rates close to primary capacity limits of the channel while overcoming channel impairments using relatively little energy.

In WSN, because of the limited power and difficulty in recharging most of the sensor nodes, energy efficiency and maximizing network lifetime are the most important design goals for the sensor network. Channel fading and radio interference pose a major challenge at the design of energy efficient communication protocols for Wireless sensor networks. Reducing the fading effects in the wireless channel, MIMO scheme is utilized for the wireless sensor network. MIMO systems can be increased significantly channel capacity and reduce transmission energy in wireless fading channels. To apply multiple antenna techniques directly to wireless sensor network is impractical due to the limited size of a sensor node. So generally, it supports a single antenna. Cooperative transmission and reception of antennas in a group of sensor nodes can be used to construct a system equivalent to a MIMO system for WSN [80].

3.5.4. Energy Harvesting Technologies and Energy Storage Solutions

In WSN energy harvesting design, some of current renewable energy sources technology is available such as kinetic, thermal and solar systems. See Figure 3.10. Power needs of the application need to be taken into account in order to select right hardware for the job and for the maximum energy efficiency in wireless sensor networks, designers must carefully consider the hardware and software partitioning and the trade-offs required to optimize ultra-low power operation.

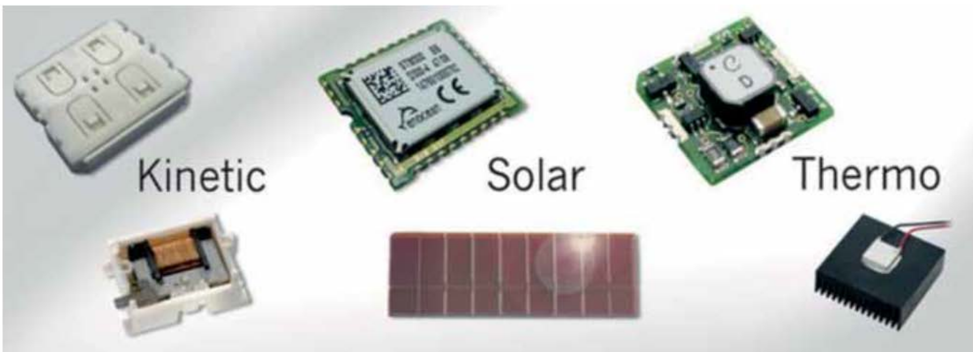


Figure 3.10: Sensor nodes configured with ambient energy harvesting devices, white paper 2014, [81].

Energy harvesting not only is realized by conventional optical cell power generation, but also through miniature piezoelectric crystals, micro-oscillators, thermoelectric power generation elements or electromagnetic wave reception devices. Advanced energy storage solutions, such as renewable energy sources, solar panel, supercapacitors and thin film batteries, have started and combined to apply for new applications with wireless sensor networks. Existing battery-operated systems are benefiting from the application of energy harvesting technology of extending sensor node lifetime. Primary energy harvesting systems consist of some components, these are memory and communications circuitry, transducer, sensor, power conversion, computing, and energy storage. Energy harvesting block diagram is given in the the Figure 3.11.

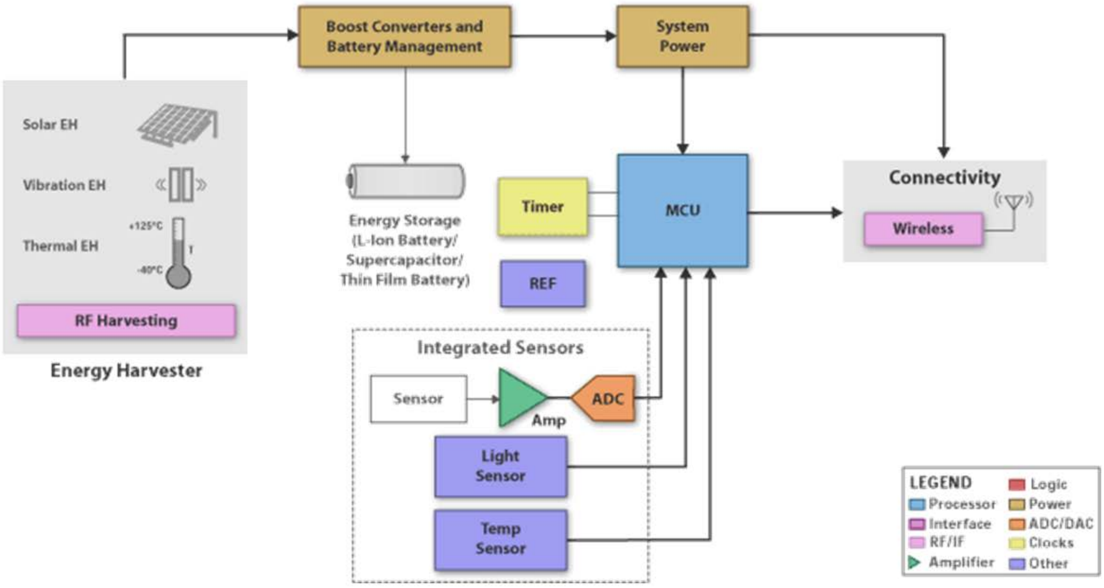


Figure 3.11: Energy harvesting block diagram, Texas Instruments Company 2014, [82].

3.6. Applications of WSNs

In the past few years, WSNs have been widely used most of the applications in daily life. WSNs are important with great potential for improving many applications in medicine, industrial process control, agriculture, transportation, military and creating new revolutionary systems in areas such as global scale environmental monitoring, home, assisted living medical care, smart buildings, precision agriculture, cities and numerous future military applications. This section discusses implemented wireless sensor network systems and covers important application areas of WSNs.

Recently, WSNs have been widely utilized in a variety of application fields related to water monitoring, industrial monitoring, forest monitoring, agriculture monitoring, battlefield surveillance, intelligent transportation, animal behavior monitoring, smart homes and disaster prevention. This technology can certainly be applied to monitoring of marine environments.

Applications of WSNs technology have categorized into a few groups and additional applications [83]. Each of these groups is explained in following sections.

3.6.1. Environmental WSNs System Applications

Environmental monitoring has grown rapidly in agricultural monitoring, habitat monitoring, indoor monitoring, greenhouse monitoring, climate monitoring and forest monitoring. It is a good effort and brings advantage because the community has realized the importance of the WSN technologies in daily life applications. Environment and habitat monitoring is a natural candidate to apply wireless sensor networks as variables to be monitored, e.g., temperature, are usually distributed over a large region. WSNs can greatly contribute to the development of hazard response systems, natural disaster detection systems, energy-monitoring systems and many more examples can be given.

Agricultural monitoring always focuses mostly on the farming area. Gravity feed water systems can be monitored water tank levels, pumps can be controlled using wireless sensor devices and water use can be measured and wirelessly transmitted back to a central control center for billing. Irrigation automation enables more efficient water use and reduces waste. Application of the watersense in the agricalture is shown in the Figure 3.12.

Figure 3.12: WSN agriculture monitoring by WaterSense Co. 2018, http://www.projectwatersense.nl/ [84].

Most of the animal monitoring sensor systems have been developed in the past few years. More recent applications have the goal of monitoring specific health or nutritional parameters to allow quick intervention and to reduce the labor requirements necessary to manage large herds. One of the WSN animal sensing systems LynxNet is mobile sensing and sparse radio connectivity network. The architecture offers an animal-centric paradigm for sensing at the edge of the Internet using an opportunistic sensor networking approach. Application of the animal monitoring is shown in the Fgure 3.13.

WSN technologies in living monitoring have become one of the main options for people for the safe indoor environment. People normally spend most of their time in indoor environments. Thus, their health depends heavily on the indoor environment in which they live. Hence, meticulous attention should be given to make sure the indoor environment is safe and comfortable.

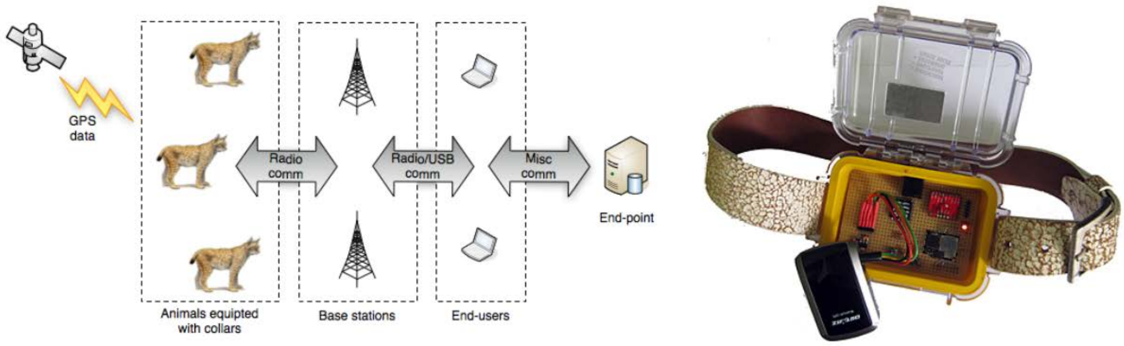


Figure 3.13: LynxNet system architecture and collar device, implemented by R. Zviedris et al. 2009, [85].

Habitat monitoring is essential to make sure their species autonomies and prevent any ecological disturbance for animals and plants.WSN solutions for habitat monitoring show enormous potential benefits for the industrial and scientific communities, and society as a whole, because of their long-term data collection ability at scales and resolutions that are difficult to obtain and their easy interaction with other external networks. Example of the WSN habitat monitoring application is shown in the Figure 3.14.

Figure 3.14: WSN habitat monitoring application implemented by A. Mainwaring et al. 2004, [86].

Greenhouse monitoring is an essential one for variable climate changes. The greenhouse effect occurs when solar radiation which is sun heat, is trapped by gases in the earth atmosphere and reflected back from earth. Therefore, it will heat the surface of the earth and leads to global warming. This is essential to ensure stabilization of the environment.

Forests are essential sources for biodiversity and ecological balance. Several studies have highlighted forest monitoring system [87]. In order to ensure long-term forest autonomy, it is essential to implement a monitoring system that is responsible providing effective monitoring of forest environment. Example of the WSN Forest fire detection system's infrastructure is shown in the Figure 3.15.

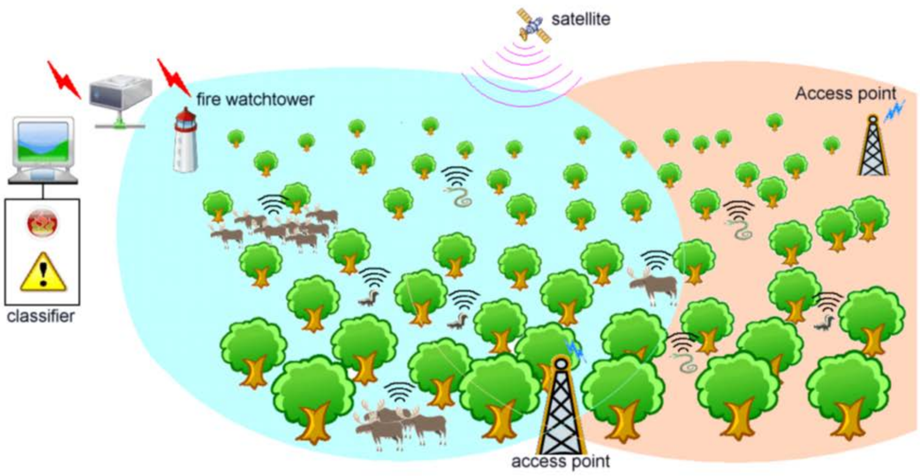


Figure 3.15: Forest fire detection system's infrastructure, drawn by Y. G. Sahin 2007, [88].

3.6.2. Military or Border Applications

WSNs was originally used for military applications. Examples of military WSNs range from large-scale acoustic surveillance systems for ocean surveillance to small networks of unattended ground sensors for ground target detection. WSNs are becoming an integral part of the military command, intelligence systems, control and communication.

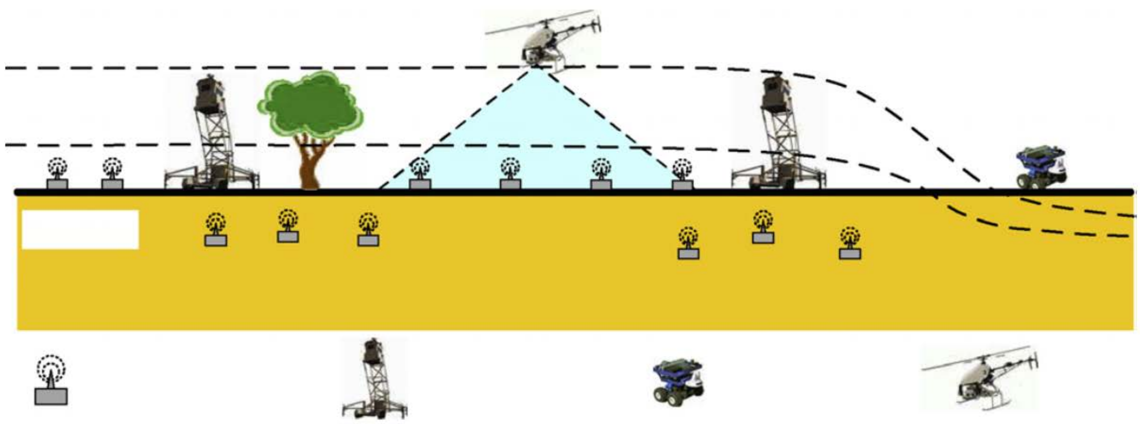


Figure 3.16: Architecture of WSN border patrol, developed by Z. Sun et al. 2011, [89].

Sensors can be deployed on a battlefield to monitor the presence of forces and vehicles, and track their movements, enabling close surveillance of opposing forces [90]. Border patrol systems have recently gained interest to address the concerns about national security. The major challenge in protecting long stretches of borders is the need for intensive human involvement in patrolling the premises. Figure 3.16 shows Architecture of WSN border patrol.

3.6.3. Nuclear, Biological, Chemical, Meteorological and Geological Applications

In chemical and biological warfare, it is required to carry out reconnaissance without exposing anyone to nuclear radiation. These sensors act as a biological or chemical warning system, which provides the forces with critical reaction time, which drops casualties drastically. In this section, I will be explained this kind of WNS applications.

Sensing the winds and weather has been important over the centuries. WSNs can be used to collect a large amount of information about rainfall, wind speed and direction, air temperature, barometric pressure, relative humidity and solar radiation. These data can be stored in databases and it becomes useful to forecast the weather and also to predict more accurately or detect harsh natural phenomena.

Air pollution emerged in many parts of the world as a result of explosive industrial growth. Road transport is also one of the major contributors to air pollution, which contribute to climate change that has perilous domestic and global consequences. Air pollution monitoring is considered as a very complex task but nevertheless, it is very important. WSNs can make air pollution monitoring less complex readings can be obtained [91].

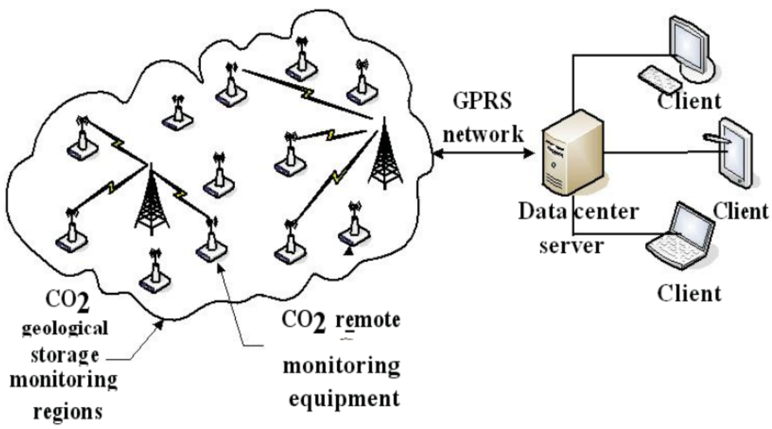


Figure 3.17: System structure of geological monitoring drawn by A. Anusha and B. Jeyaraman 2012, [92].

Geological monitoring refers to the control, supervision, and study of several geological magnitudes. Changes in these magnitudes help in understanding the earth’s state. Geological disasters such as earthquakes, tsunamis, volcanic eruptions, and landslides, which are related to an underground event can be more accurately predicted by using these features. System structure of geological monitoring system is shown in the Figure 3.17.

Production and consumption of energy resources are very important to the global economy. The advantage of using wireless tech as measuring temperature or human presence in a room and taking the necessary steps, such as switching off a light or turning down the heat for useenergy sources economically.

3.6.4. Health Care Applications

Advances in WSNs have opened up new opportunities in healthcare systems. Sensor-based technology has invaded medical devices to replace thousands of wires connected to these devices found in hospitals. So WSNs can be used to monitor and track elders and patients for health care purposes, which can dramatically relieve the severe shortage of healthcare personnel and reduce health care expenditures in current healthcare systems.

WSNs are mainly used to monitor and track patients in hospitals to avoid the spread of some infectious diseases. Remote patient’s blood pressure, electrocardiograph (ECG) and body temperature can be measured by special kinds of sensors which can be knitted into clothes to provide remote nursing, especially for elderly people. In disability assistance applications, smart sensors are implanted to operate within the human body to counteract organ weaknesses or to monitor important physiological parameters or particular organ viability.

In cardiology, the value of the implantable cardioverter-defibrillator has increasingly been recognized for the effective prevention of sudden cardiac death. Sensors are much useful in drug administration in hospitals. If sensor nodes are attached to medications, the chance of getting and prescribing wrong medication to patients can be minimized. Computerized systems as described in have shown that they can help to minimize adverse drug events. Figure 3.18 shows diagram of the wireless body area network.

Currently, one of the most important issues on medical grounds is preventing medical accidents caused by human error. Many deaths occur in hospitals because of medical accidents caused by human errors [93]. WSNs can notify the nurses in case of the occurrence of the same accident, thus many medical accidents can be reduced that can save many human lives.

Life-cycle monitoring of civil infrastructures is critical to the long-term operational cost and safety of aging structures. In this context, WSNs are gaining special attention and attempts are made in this direction to minimize cost and maximize the utility of the system by performing the real-time monitoring. Real-time structural monitoring of civil infrastructure with WSNs issues early warning about hazardous structures and impending collapses.

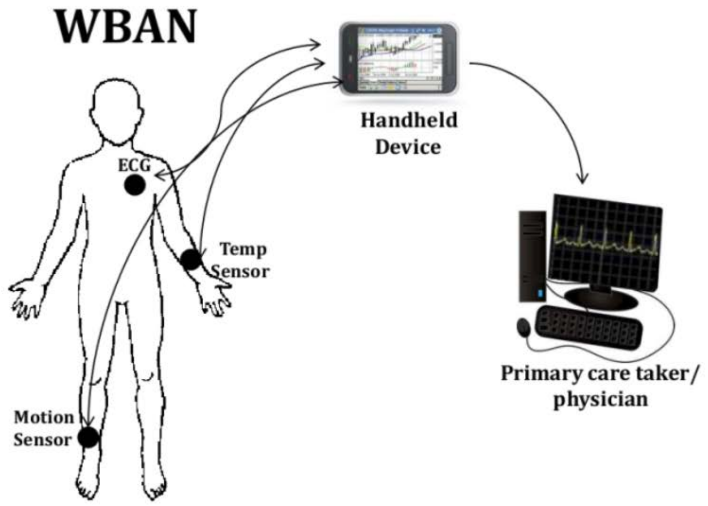


Figure 3.18: Wireless body area network, drawn by G. Ramamurthy and S. Nanda 2013, [94].

3.7. PIC-Based Sensor Node Platform

This section summarizes and highlights the intent, design, testing and success regarding the development of a wireless sensor node. It first outlines my objective to create a device that uses renewable energy efficiently to prolong its operating time. It then lists the requirements for such a device to achieve that goal and describes. At the end I will explain the design that implements those requirements. What follows is a presentation of the degree to which the requirements are fulfilled through my Wireless Sensor Node. The section concludes with comments on my accomplishments.

3.7.1. Background, Motivation, and Goal of Sensor Node Design

The focus of my project is on WSNs, which are small devices that collect and transmit data about the environment, such as ambient temperatures, humidity, smoke detection or light conditions. These devices rely on ambient energy sources, including solar energy [95]. My motivation for this project lies in the exciting opportunity to create a device that relies solely on renewable solar energy and to develop a strategy for managing that energy to extend the lifetime of the WSNs, and a rechargeable battery, which has a high energy capacity. This section goal is to create wireless sensor nodes that use a unique power management scheme to coordinate power storage and delivery between a small solar array and rechargeable batteries with a supercapacitor, ensuring long-time operation.

3.7.2. Requirements of the PIC-Based Sensor Node Platform

WSN will perform the following functions: Collect environmental data including humidity, temperature, light intensity, and smoke density. Collect on-board electrical data including solar panel open-circuit voltage, super capacitor voltage, battery voltage and current.

Transmit the collected data wirelessly to a nearby computer over a distance of 60m. The microcontroller program is used for testing and final operation. Allow the onboard microcontroller to communicate with each other. Implement a DC/DC Converter to regulate the output voltage of the solar array as dictated. Recharge the rechargeable devices with supercapacitor and surplus solar energy. Control power management program is used to maximize the operational lifetime.

Wireless sensor node must adhere to the following constraints: Recharge the rechargeable devices with surplus solar energy, use a rechargeable battery as an energy storage device, operate outdoors during the day under varying lighting conditions and during the night and operate autonomously once deployed.

3.7.3. System General Summary

My designed system which can be examined in four sections in general terms. Sensor node hardware that will be met the requirements (transmitter sensor nodes and one receiver sensor node). RS232 interface that will be provided the connection between the sensor nodes and the PC. PIC codding software and IDE that will be managed and flushed PIC microcontrollers. PC software will be developed to monitor the wireless sensor network system and recording data that delivered from sensor nodes.

3.7.4. Implementing of Sensor Node Designing Platform

The proposed system is composed of a PIC microcontroller, wireless transceiver (receiver and transmitter) modules, LED indicators and a power regulator. In the sensor node system, a DHT11 humidity sensor and a temperature sensor are connected to the system and the system evaluation procedure was carried out. Sensor nodes can connect LCD screen panel and therefore, software and hardware structures of system support other types of sensors.

3.7.5. Hardware Platform of Sensor Node

WSN platform uses a PIC microcontroller which is Microchip PIC16F886. This microcontroller has 28 Pin Flash-Based, 8-Bit CMOS Microcontroller with nanoWatt Technology. The PIC has an external oscillator, 4K EEPROM, ADC, timers, PWM pulse-width modulation, 1 EUSART. In order to reduce power consumption, no external memory unit was used. FS1000A module was used as wireless transmitter unit, and XY-MK module was used as a wireless receiver. FS1000A and XY-MK modules work in 433 Mhz band and can run on 10 different channels. In order to read data on the sensor node without a computer program, 1602A LCD panel was integrated. For collecting data to the computer database, RS232 connection port and RS232 transceiver (MAX232) is integrated. In order to increase wireless communication signal, antennas were integrated to the sensor node system in two side receiver and transmitter. JQC-3FC/T73 model relays are designed to sensor nod receiver system for electrically activated switch purposes. Figure 19 and Figure 20 show designed WSN hardware platform.

Figure 3.19: Overview of the designed WSN system, this study 2018.

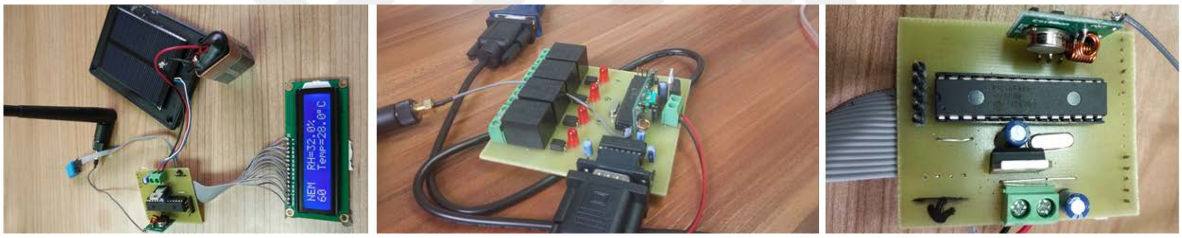


Figure 3.20: Designed platform transmitter node and receiving node, this study 2018.

3.7.5.1. Microcontroller Used in Design

WSNs, are not only data received, are not a working wireless device transmits a particular center, but also sensor nodes at same time calculations are devices with capabilities such as perceptual data collection and communication with other sensor nodes [96]. Said ability to fulfill these, sensor nodes must have a microcontroller on these devices. What is the use of a microcontroller is a question without a definitive answer? This can be change varies according to needs and requirements. Many WSNs designed with different microcontrollers were developed. The reason of this, I will be considered factors that are not linked to the microcontroller and that are linked to the microcontroller. These factors are described below.

In this study, PIC16F886 microcontroller is used Microchip Company. PIC16F886 is 24 pins Flash-based members of the versatile PIC16F886 family of low cost, high performance, CMOS, fully static, 8-bit microcontrollers. This operates at advanced RISC architecture. PIC16F886 have enhanced core features, an eight-level deep stack and multiple internal and external interrupt sources.

PIC16F886 devices have integrated features to reduce external components, therefore for reducing system cost, enhancing system reliability and reducing power consumption. PIC16F886 fits in applications ranging from battery chargers to low power remote sensors. Flash technology makes customizing application programs fast and convenient. Small footprint packages make microcontroller ideal for all applications. Low cost, high performance, low power and Input/Output flexibility make PIC16F886 very much versatile.

Low-Power is a very important issue in this study. Because one of the purposes is low power consumption for produced wireless sensor nodes. Reduced energy consumption of the components used in wireless sensor networks is important. So which of the microcontroller to be used, it should consume as little energy. PIC16F886 has 8 oscillator configurations. This oscillator provides a low-cost solution and minimizes power consumption. Power characteristics are as follows. The sensor nodes they spend most of the time in sleep mode in wireless networks. if power characteristics examined the power values of the microcontroller can be seen that quite well for sensor nodes in wireless networks. It spends much less energy. At the same time, it can work much wider voltage range. When PIC16F886 in idle mode it consumes the current 1.0µA and when it in sleep mode it consumes the current 50nA. These values are excellent for WSNs. PIC16F886 microcontroller's features are given in Table 3.2.

Device	Program Memory	Data Memory		I/O	10-bit A/D (ch)	ECCP/ CCP	EUSART	MSSP	Comparators	Timers 8/16-bit
	Flash (words)	SRAM (bytes)	EEPROM (bytes)							
PIC16F882	2048	128	128	24	11	1/1	1	1	2	2/1
PIC16F883	4096	256	256	24	11	1/1	1	1	2	2/1
PIC16F884	4096	256	256	35	14	1/1	1	1	2	2/1
PIC16F886	8192	368	256	24	11	1/1	1	1	2	2/1
PIC16F887	8192	368	256	35	14	1/1	1	1	2	2/1

Table 3.2: PIC16F6886 microcontroller properties, Microchip Technology Inc. 2009, [97].

WSN applications require low power cost and long-time battery power. New sensor network applications have to consume little power while running from a single battery. To enable applications like these, products with Microchip's nanoWatt Technology presents industry's lowest currents for run and sleep. NanoWatt Technology is industry's lowest power, widest operating voltage range, and most flexible power-managed technology available for embedded systems today. NanoWatt technology is a new microcontroller low-power technology for power consumption. The PIC16F886 was developed with nanoWatt technology by the Microchip Company.

Connecting to sensor devices is simple if sensor devices are inherently digital themselves. Switches, relays and encoders are easily interfaced with gate circuits because of the on/off nature of their signals. However, when analog devices are involved in the system, interfacing becomes much more complex. What is needed is a way to electronically translate analog signals into the digital quantities, and vice versa is the same problem. An analog to digital converter that called simply ADC, performs a former task while a digital to analog converter that called simply DAC, performs latter. An ADC inputs an analog electrical signal such as voltage or current and outputs a binary number. Microcontroller to be used in the study, the PIC16F886 has analog comparator module for processing analog signals. This module consists of two analog comparators, one of the 16-bit Capture/Compare and other 10-bit PWM.

Two types of data memory are provided on PIC16F886 microcontroller devices. Nonvolatile EEPROM data memory is produced for long-term storage of data, such as calibration values, look up table data, and any other data which may require periodic updating in the field. Nonvolatile EEPROM data memory is not lost when power is removed. Another data memory produced is regular RAM data memory. It is provided for temporary storage of data during the normal operation. Data is lost when power is removed.

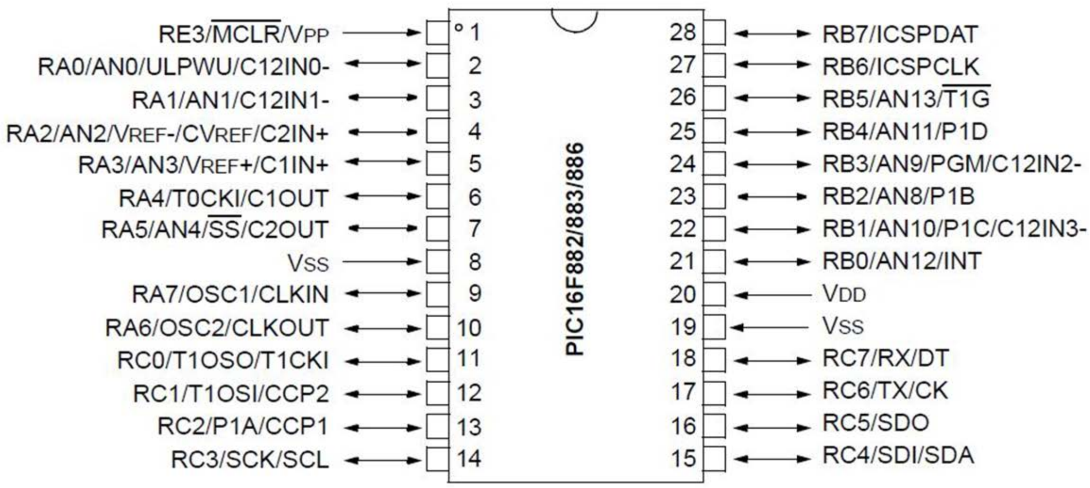


Figure 3.21: Input-Output and pin structure, Microchip Technology Inc. 2009, [97].

PIC16F886 microcontroller has two ports, PORTA and PORTB. Some pins for these Input/Output ports are multiplexed with alternate functions for peripheral features on the device. Usually, when a peripheral is enabled, the pin can not be used as a general-purpose Input/Output pin. In WSNs, timers are an indispensable element of the sensor nodes. Sensor nodes have an important place sleep-wake times and packet timing. The PIC16F886, which has tree timer modules. These are Timer0, Timer1, and Timer2. Timer0 is an 8-bit timer/counter with 8-bit programmable prescaler. Timer1 is a 16-bit timer/counter with external crystal/clock capability. Timer2 is an 8-bit timer/counter with the 8-bit period register, prescaler, and post scale. This timer can be used for various purposes such as watchdog timer with an independent oscillator for reliable operation and powerup timer and oscillator startup timer [97]. Figure 3.21 shows PIN diagram of the PIC16F882 microcontroller.

3.7.5.2. Sensors Used in the Node Design

In WSN, sensors are one of two essential elements of the WSN. On each sensor node, there are a few sensors depending upon applications and according to the mission and goals. In my sensor node design, DHT11 and LDR temperature and humidity sensor, the MQ-2 gas sensor and LM35 precision centigrade temperature sensors are used. Sensor specifications and integrity of sensor node design, it is described in detail in the following sections.

Designed sensor node integrates DHT11 sensor. The DHT11 sensor features complex with a calibrated digital signal output. By using exclusive digital signal acquisition technique and temperature and humidity sensing technology, it ensures high reliability and excellent long-term stability. This sensor includes a resistive type humidity measurement component and an NTC temperature measurement component, and connects to a high-performance 8-bit microcontroller, offering excellent quality, anti-interference ability and fast response. The power supply of DHT11 is 3-5.5V DC and the single wire serial interface makes system integration quick and easy. Its small size, low power consumption and up to 20-meter signal transmission making it the best choice for various applications [98].

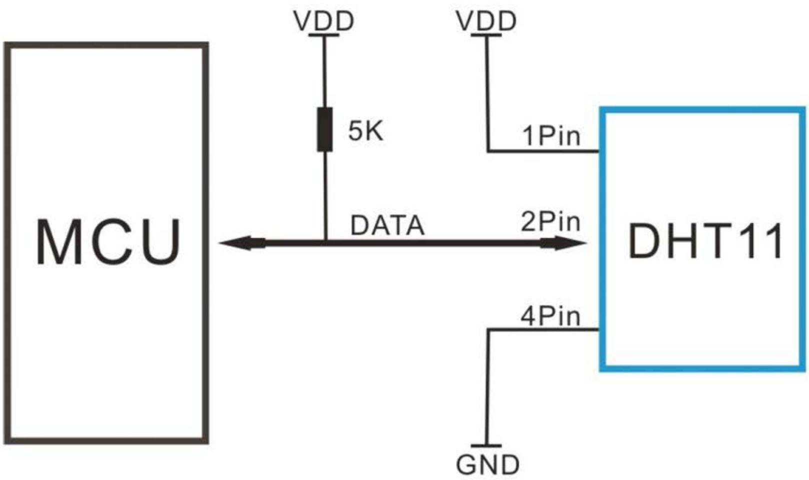


Figure 3.22: DHT11 Sensor application diagram, D-Robotic 2010, [98].

LM35 series are precision integrated circuit temperature devices with an output voltage linearly proportional to centigrade temperature. Lower cost is assured by trimming and calibration at the wafer level. The low-output impedance, linear output, and precise inherent calibration of the LM35 device make interfacing to readout or control circuitry especially easy.

The device is used with single power supplies or with plus and minus supplies [99]. DHT 11 Sensor application diagram is shown in the Figure 3.22.

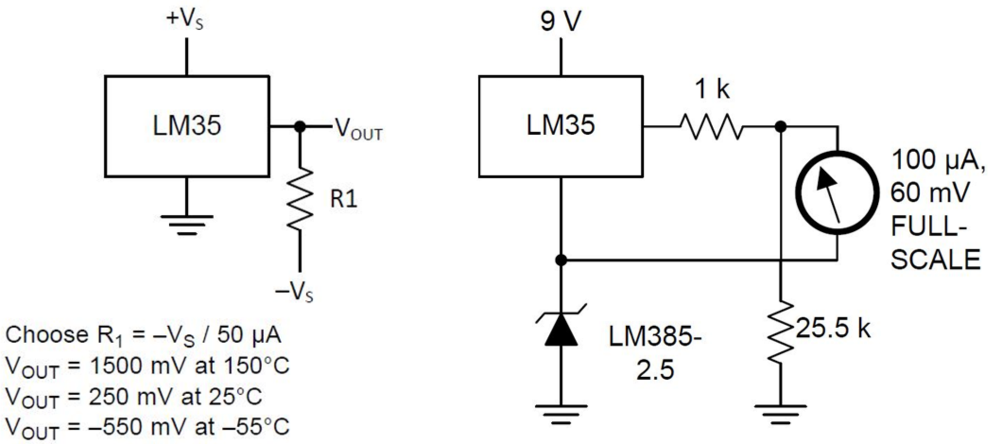


Figure 3.23: Circuit diagrams of the LM35 sensor, Texas Instruments 2016, [99].

Gas Sensor (MQ2) sensor device is useful for gas leakage detecting (in home and industry). It can detect H2, LPG, CH4, CO, Alcohol, Smoke, Propane. Based on its fast response time. Measurements can be taken as soon as possible. Sensitive material of MQ2 gas sensor is SnO2, which with lower conductivity in clean air. Circuit diagrams of the LM35 sensor are shown in the Figure 3.23.

When target combustible gas exists, the sensor's conductivity is higher along with gas concentration rising. The MQ2 gas sensor has high sensitivity to Methane, also to Propane and Butane. The sensor could be used to detect different combustible gas, especially Methane, it is with low cost and suitable for different application [100]. Circuit diagrams of the MQ2 gas sensor is shown in the Figure 3.24.

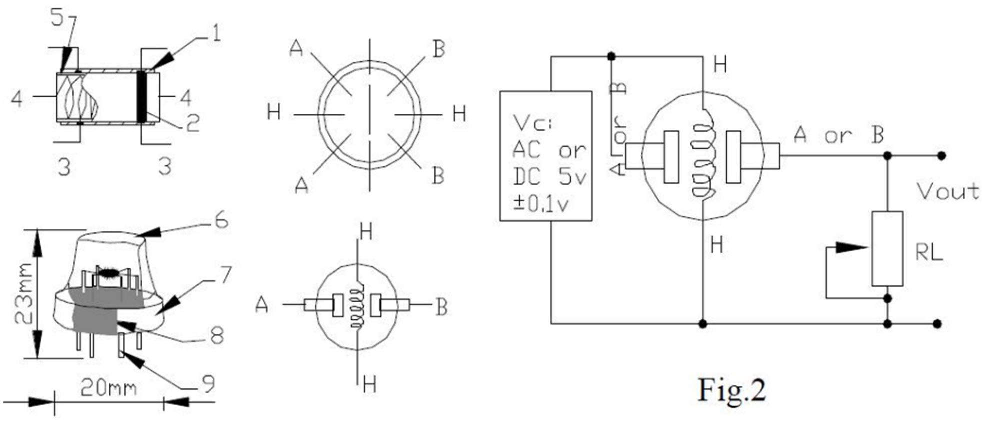


Figure 3.24: DHT11 Sensor application diagram, Hanwei Electronics Co. 2011, [100].

Two cadmium sulfide (CDs) photoconductive cells with spectral responses similar to that of the human eye. Cell resistance falls with increasing light intensity. Applications include smoke detection, batch counting, automatic lighting control and burglar alarm systems [101]. A typical structure for an LDR uses an active semiconductor layer that is deposited on an insulating substrate. A semiconductor is normally lightly doped to enable it to have the required level of conductivity. Contacts have then placed either side of the exposed area. Light-dependent resistors have a particular property in that they remember the lighting conditions in which they have been stored. This memory effect can be minimized by storing the LDRs in light prior to use. Light storage reduces equilibrium time to reach steady resistance values. LDR sensor circuit diagrams are shown in the Figure 3.25.

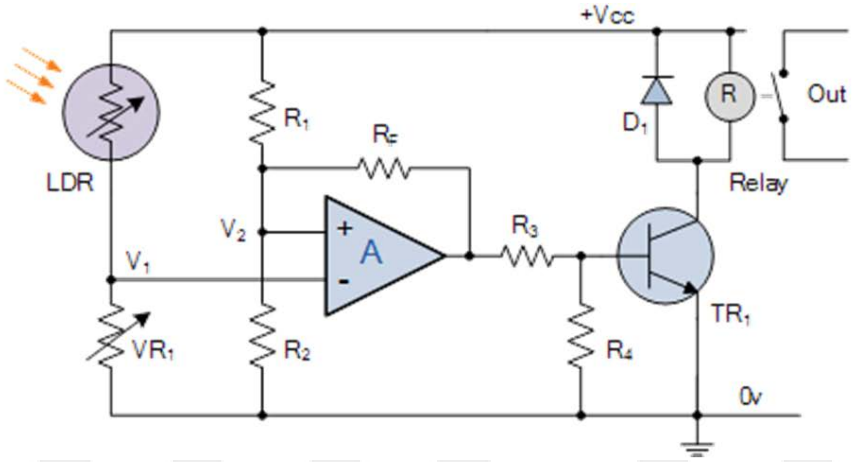


Figure 3.25: LDR sensor circuit diagrams, RS Components 1997, [101].

3.7.5.3. Implementation of Wireless Communication Technology Used in Design

One of two essential elements of WSN is wireless communication. Each sensor node networks must have wireless communication. This may be on the microcontroller or external wireless receiver-transmitter units may be. Wireless communication units are selected in accordance with a number of criteria such other elements. Thus, samples of different wireless communication units are present in many sensor nodes. According to some criteria, the wireless communication unit is selected such as application requirements, power consumption, dimensions, location, coverage, bandwidth, operating frequency range and cost.

XY-MK-5V receiver for short-distance remote control application is an ideal solution because of its low price and energy consumption. Module; except antenna is designed according to the PCB assembly without any RF component requirements. Using a simple wire antenna can be connected. This operation is preferred because of its low power consumption. Important features of the data receiver are given in the preceeding paragraph.

The receiver has 4 pins Vcc, DATA, GND. There are 2 DATA pins, and any of them can be used to read the output of the module. When looking from the front side, there is a small hole in the bottom left corner of the module, which is where an external antenna can be connected if needed. Data to be sent over long distances without the antenna is not possible. Images of the XY-MK-5V data receiver and FS1000A transmitter are shown in the Figure 3.26.

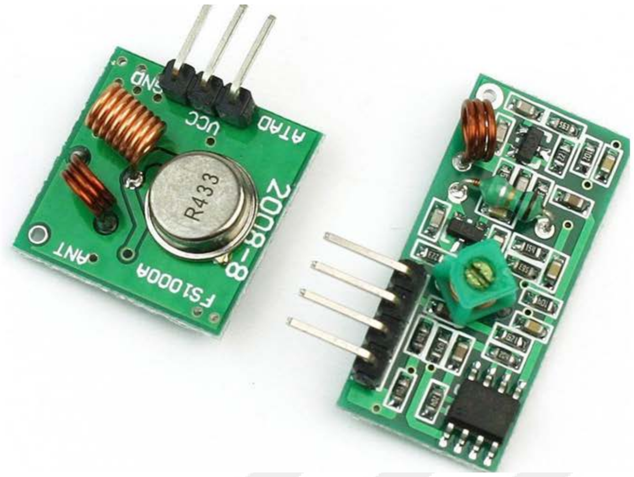


Figure 3.26: XY-MK-5V data receiver and FS1000A transmitter, RF Wireless Techn. 2011, [102, 103].

Two most important points required for efficient data transmission and reception is selecting a good antenna and RF grounding right. The module has a simple antenna connector pins. A suitable UHF antenna connected directly to the pin. XY-MK-5V can be connected to the module is soldered to a simple antenna cable to the antenna input 17cm in length. Antenna, if the necessary connection to a remote area of the module, a 50-ohm coaxial antenna cable must be used. The grounding of antenna cable must be made from a place close to the antenna.

FS1000A module is designed to be integrated into the developer's system, therefore it is an ideal solution for my design. FS1000A is a UHF ASK transmitter module. FS1000A is an ideal solution because of low prices for short-distance remote control applications. The module does not need any RF components except the antenna. It is designed to PCB the installation. Using a simple wire antenna can be connected. It is preferred because of its low power consumption. Important features are the followings. For FS1000A Data Transmitter, antenna implementation method is exactly same as XY-MK-5V data receiver. Antenna application management is described in detail above.

3.7.5.4. Implementation of Screen Panel Used in Sensor Node Design

In order to read data on the sensor node without a computer program, 1602A LCD panel was integrated into my designed sensor node. 16×2 Character LCD is a very basic and low-cost LCD module which is commonly used in electronic products and projects [104]. The interface between this LCD and Microcontroller can be 8-bit and the difference between them is in how the data or commands are sent to LCD. 8-bit data and commands are sent through the data lines

DB0 – DB7 and data strobe is given through E input of the LCD. 1602A LCD panel block diagram is given in the Figure 3.27.

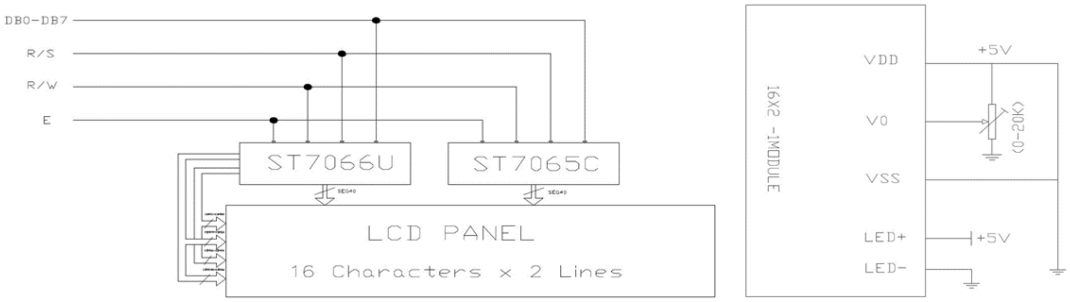


Figure 3.27: 1602A LCD panel block diagram, Shenzhen Eone Electronics 2009, [104].

3.7.5.5. Implementation of Decision-Making Algorithms with RELAY Device

A relay is quite simply an electrically operated switch. It consists of a coil internally which will create a magnetic field that attracts a movable lever and then changes switch contacts when a current is flowing through it. I integrated JQC-3FC/T73 to my sensor node design in order to run decision-making algorithms in the receiver node's PIC chip. For example, the air conditioner will work when the temperature rises or the weather dies lamps will be opened automatically. Wiring diagram of the delay is given in the Figure 3.28.

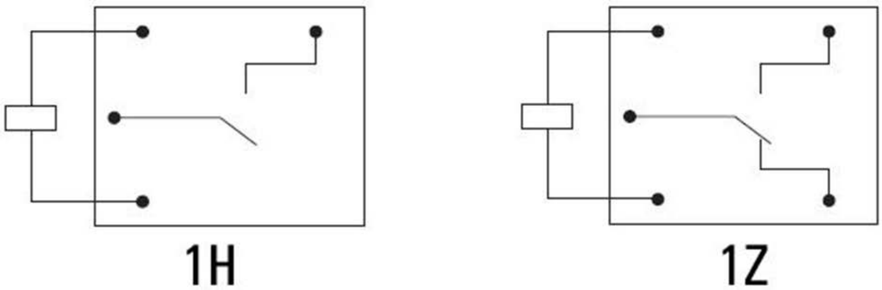


Figure 3.28: JQC-3FC/T73 wiring diagram, Yueqing Hengwei Electronics 2007, [105].

3.7.5.6. Implementation of RS-232 Transceiver and Communication Port

MAX232 transceiver and RS232 communication port are integrated to designed sensor node in order to collect data from all the transmitter PIC nodes. The MAX232 is a hardware layer protocol converter IC manufactured by the Maxim Corporation. Commonly known as an RS-232 Transceiver, it consists of a pair of drivers and a pair of receivers. At a very basic level, the driver converts TTL and CMOS voltage levels to TIA/EIA-232-E levels, which are compatible with serial port communications. The receiver performs the reverse conversion. Circuit diagram of the MAX232 and RS232 is given in the Figure 3.29.

Used in embedded microcontroller systems, and computers, this IC has been one of the most popular components in production for well over two decades. If you have a microcontroller circuit that requires communication through a serial port, then this is the chip to use. RS-232 is a serial communication protocol defined by the EIA/TIA-232-E. This protocol requires a voltage between -3 V to -15 V to represent binary 1, and a voltage between +3 V to +15 V to represent binary 0. For CMOS and TTL communication, this is incompatible since TTL uses 5 V to represent binary 1 and 0 V to represent binary 0. This chip, therefore, performs the necessary protocol conversion of the electrical voltage levels in both directions.

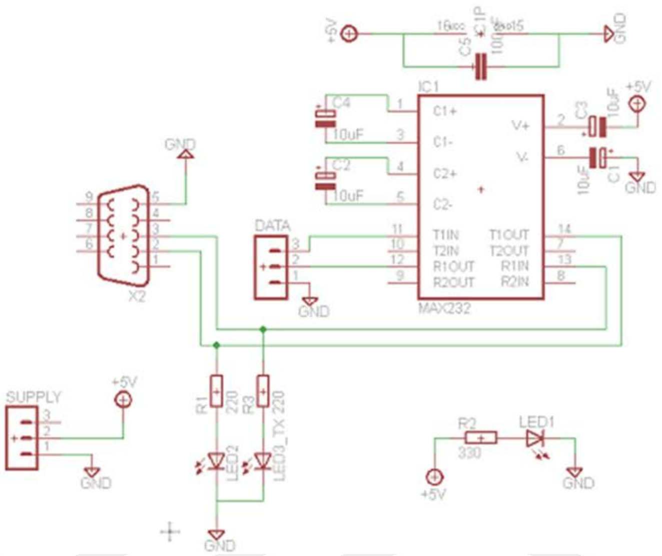


Figure 3.29: MAX and RS circuit, http://www.robotizando.com.br/artigo_conversor_ttl_pg1.php 2018, [106].

3.7.5.7. Implementation of Voltage Regulator

In this study, LM317 voltage regulator is implemented for the power unit. This voltage regulator series of fixed voltage integrated circuit voltage regulators are designed for a wide range of applications. Power unit provides power to the sensor node is shown in the Figure 3.30.

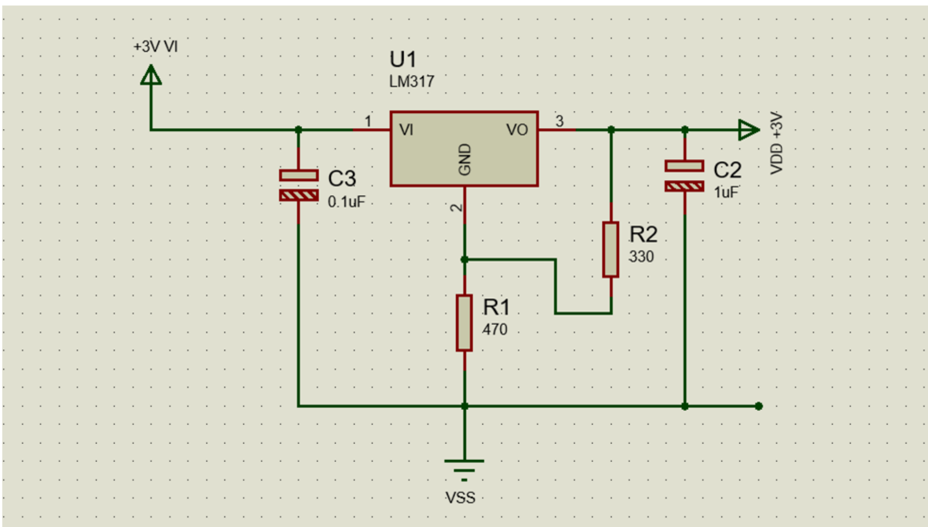


Figure 3.30: Power Regulator circuit drawing of the Designed WSN Platform, this study 2018.

The LM317 voltage regulator was implemented on the power unit which includes on-card regulation for elimination of noise and distribution problems. Regulators can deliver up to 1.5A of output current and Output Voltage Range Adjustable from 1.25V to 37V [107]. PIC16F886 microcontroller can operate within the range of 2.0V - 5.5V. FS1000A and XY-MK modules can also operate within the range 3.5V – 12V. Therefore, the system works on 3.5V because PIC microcontroller and wireless communication modules support this voltage. Low-power routing algorithms and low power media access (MAC) protocols can decrease energy consumption and increase battery life.

3.7.5.8. Implementation of Energy Efficient and Routing Protocols

In this study, Timeout MAC protocol was implemented for power saving. When sensor node wakes up, the sensor doesn't start to send data, it just waits until discharging of the medium. So, sensor node can adapt itself to traffic and it could also be possible to sleep sometimes then wake another time. In this way, power saving was decreased.

In TMAC protocol there is no regular sleep-wake cycle. Sleeping operation takes place when sensor node is unable to obtain data at a certain time. Waking can start with the start of sending data or when sleeping time expires. Sensor nodes have a certain time limit for sleeping. Each sensor reading period in the design is ~ 8 s. Reading the sensor does not mean sending the data due to TRAMA protocol. If there is no data in the environment, the sensor node sends data. If there is no data in the environment, the sensor node goes to sleep after ~ 160 seconds. After ~ 160 seconds, the sensor wakes up again.

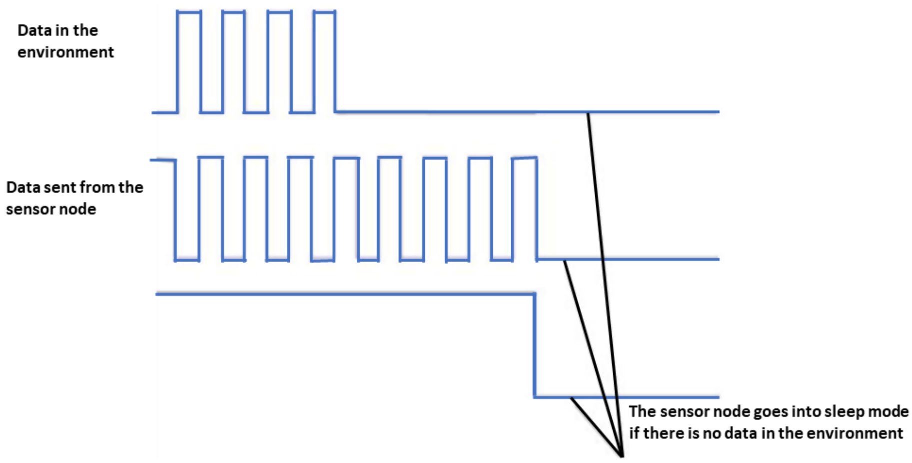


Figure 3.31: Diagrams of the Timeout and TRAMA MAC Hybrid working systems, this study 2018.

A routing algorithm determines the way the data will go through. Routing algorithms in WSNs are completely managed by software. Point to point routing schema is used as routing protocol. In WSN, MAC protocols are determined by both hardware and software. During communication, MAC determines interaction with devices. MAC protocol for WSNs has a special significance.

Power consumption can be reduced due to MAC protocol and thus sensor nodes with limited storage facilities can use their memories better. Wireless transceiver unit does not allow code division multiple access. Therefore, frequency division or time division algorithms must be used. TRAMA, a time-divisional MAC is used in the design. Sensors become synchronized by waiting for each other with TRAMA protocol when media is empty, sensors have access to the environment. Diagrams of the Timeout and TRAMA MAC Hybrid working systems are shown in the Figure 3.31.

3.7.6. Sensor Node Pictures and Circuit Drawings of the WSN System

All of the circuits and layouts are drawn with Proteus Design Suit software. Detailed circuit drawing of equipment (receiver and transmitter nodes) and the links in the designed system are shown in Figure 6.1 and Figure 6.2. PCB layouts of sensor nodes are shown in Figure 6.3 and Figure 6.4. The designed sensor node pictures (bottom view and top view) are shown in between Figure 6.5 and Figure 6.8. Please see Apendix E in the Chapter 6.

3.8. PIC-Controlled Voltage Module Design

Designed voltage module platform uses a unique power management scheme to coordinate power storage and delivery between a small solar array, and rechargeable batteries with a supercapacitor, ensuring long network life operations. Energy consumption data was measured while the system is running and reflects the maximum amount of consumption. When operating at maximum power, power consumption could be high and sensor node’s battery life could be shorter. However, with help of low power routing algorithms and MAC protocols, consumption could decrease and sensor node’s battery life could be longer. Therefore, efficiently utilizing sensor nodes energy can maintain a prolonged network lifetime.

One of the major issues in sensor networks is developing an energy consumption to improve the lifetime of the networks. This section summarizes and design, testing, development of a solar panel power unit with a supercapacitor, and a battery. It first outlines my aim to create a device that uses renewable energy efficiently to extend its network and sensors lifetime.

3.8.1. Requirements of the PIC-Based Voltage Module Design

In this section, requirements of the PIC-Controlled voltage module design with integrated renewable energy for wireless sensor networks are described in detail. Voltage module platform will be performed in the following functions and PIC based voltage module platform must be adhered to the following constraints:

- Collect solar panel voltage, super capacitor voltage, battery voltage.
- Implement a DC/DC Converter to regulate the output voltage of the solar array as dictated,
- Recharge the rechargeable devices with a supercapacitor and solar energy,
- Control power management program to maximize the operational lifetime of the WSN,
- Manage renewable energy between the rechargeable battery and solar panel energy.
- Recharge the rechargeable devices with surplus solar energy,
- Use a rechargeable battery as an energy storage device,
- Operate outdoors during the day under varying lighting conditions and during the night.

3.8.2. PIC-Controlled Eergy Harvesting Module Design General Summary

In this study, the designed energy harvesting module which can be examined in some general terms. These; designed energy harvesting module that will be met the renewable energy requirements (solar energy, supercapacitor, and battery). The integrated PIC of the designed energy harvesting module will be managed and collected renewable energy.

Voltage circuit will be supported two energy input these are solar panel input and rechargeable battery input, and also voltage circuit will be supported one voltage output to connect WSN sensor nodes. Figure 3.32 shows the developed PIC based energy harvesting module platform with sensor node and renewable energy devices.

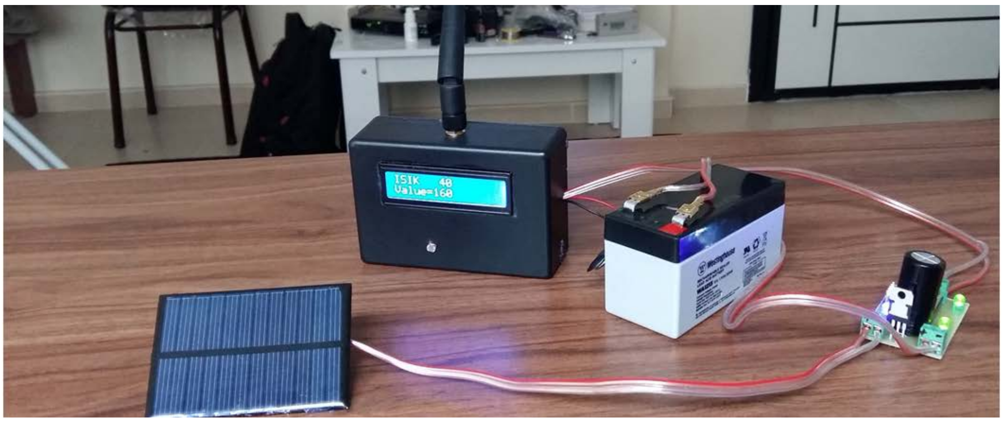


Figure 3.32: Designed PIC-Based voltage module for WSNs, this study 2018.

3.8.3. Integrated the Super Capacitor to the Power Unit

Designed DC converter provides an interface to connect to a solar panel, a rechargeable battery and a supercapacitor that provides efficiency across all operating conditions. Designed DC Converter uses less than 470 µA of current and power unit has ability to harvest available solar energy by using the solar array of panels to support all required components. The obtained energy is stored in a 5F supercapacitor and a 350 mAh lithium-ion battery. Volumetric energy density of capasitor and battery are shown in the Figure 3.33.

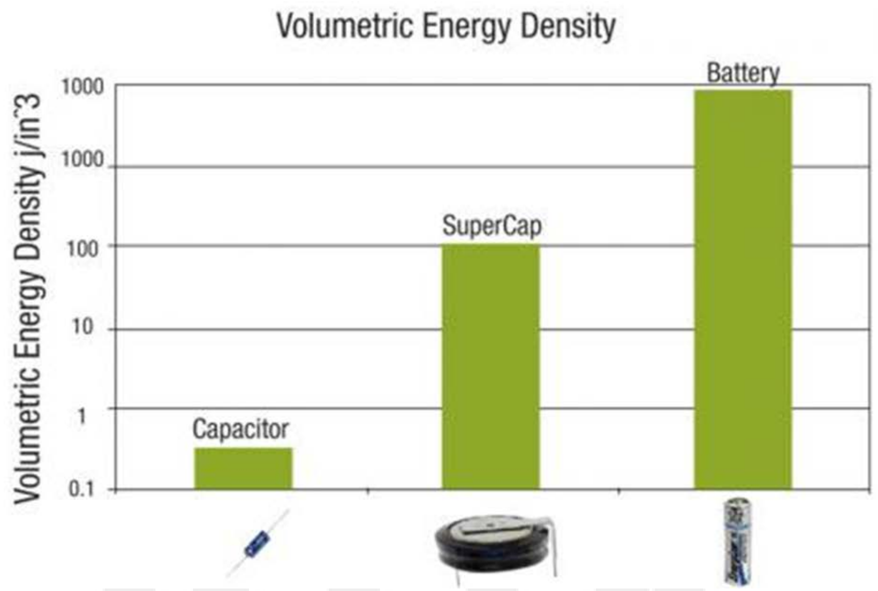


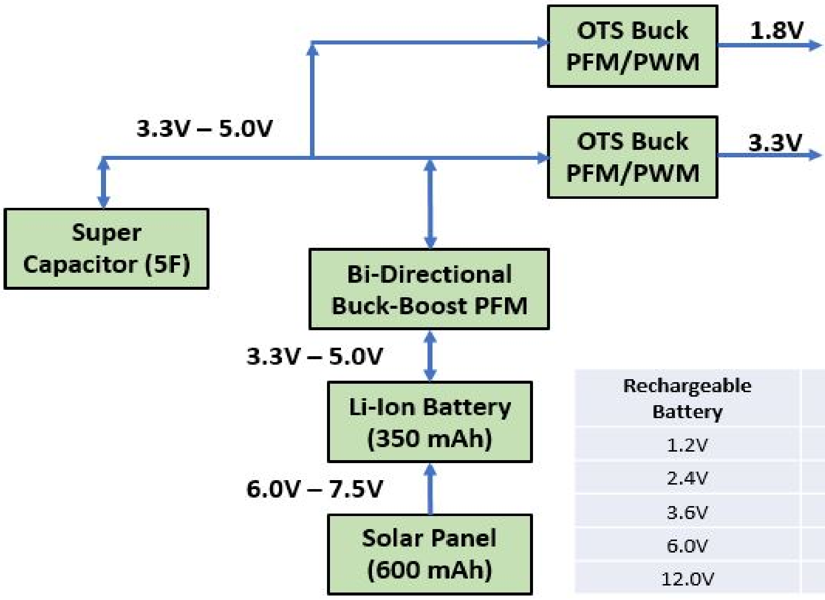
Figure: 3.33: Volumetric energy density of capasitor and battery, drawn by M. R. Johnson et al. (2010), [108].

3.8.4. Integrated the Chargeable Battery System to the Power Unit

I have used a rechargeable battery as an energy storage device for all sensor nodes. Wireless sensor network features the ability to solar energy from the outdoor environment and delivers this energy to the supercapacitor and battery storage devices. Figure 3.34 contains solar panel DC table and block diagram of the energy storage delivery module which consists of the 5 Farad supercapacitor, 350mAh rechargeable lithium-ion battery and one classic bidirectional converter method are used.

3.8.5. Integrated the Solar Panel Energy System to the Power Unit

A solar panel is used as the primary energy source, with secondary energy storage devices being a rechargeable battery and supercapacitor for all the sensor nodes. Solar panel prices are rising according to the power and characteristics of the solar panel. Designed renewable panel power unit uses a unique power management scheme to coordinate power storage and delivery between a small solar array and rechargeable batteries with a supercapacitor, ensuring long network life operations.



Rechargeable Battery	Solar Panel
1.2V	2.0V - 2.5V
2.4V	3.5V - 4.0V
3.6V	5.0V - 6.0V
6.0V	7.5V - 9.0V
12.0V	15.0V - 18.0V

Figure 3.34: Energy module and Solar panel DC reference table, this study 2018.

3.8.6. Microcontroller Used in Voltage Circuit Design

In this study, Microchip PIC16F716 microcontroller is used. The PIC16F716 is 18-pin Flash-based members of the versatile PIC16F716 family of low cost, high-performance, CMOS, fully static, 8-bit microcontrollers. Which is work an advanced RISC architecture. PIC16F716 have enhanced core features, an eight-level deep stack, and multiple internal and external interrupt sources.

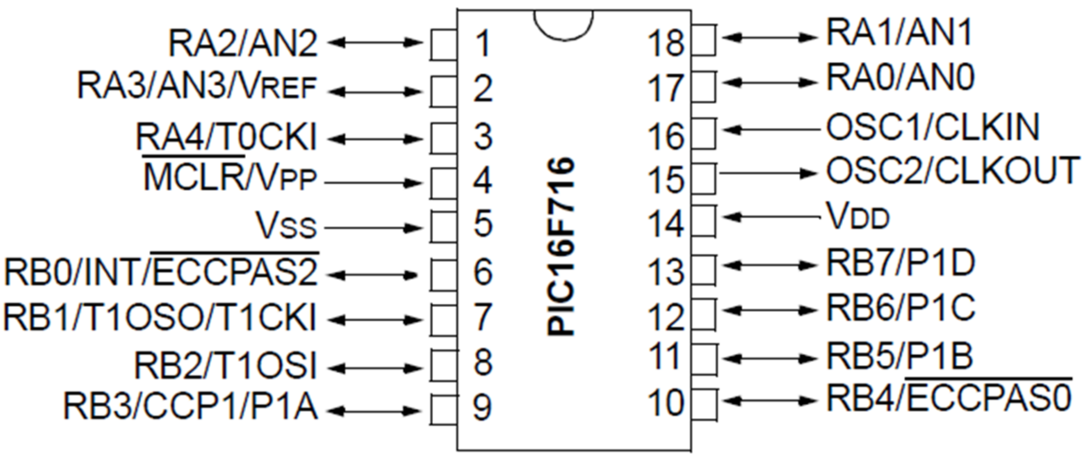


Figure 3.35: PIN diagram of the PIC16F716, Microchip Technology Inc 2007, [109].

PIC16F716 devices have integrated features to reduce external components, therefore reducing system cost, reducing power consumption and enhancing system reliability. Low-power is a very important issue in this study. Reduced energy consumption of the components used in wireless sensor networks is important. So, choice of the microcontroller to be used, it should consume as little energy.

PIC16F716 fits in applications ranging from battery chargers to low power remote sensors. Low cost, high performance, low power and ease of use and Input/Output flexibility make PIC16F886 versatile. PIC16F716 microcontroller properties are shown in the Table 3.3, also PIN diagram of the PIC16F716 is given in the Figure 3.35.

Device	Memory		I/O	8-bit A/D (ch)	Timers 8/16	PWM (outputs)	VDD Range
	Flash	Data					
PIC16F716	2048 x 14	128 x 8	13	4	2/1	1/2/4	2.0V-5.5V

Table 3.3: PIC16F716 microcontroller properties, Microchip Technology Inc 2007, [109].

3.8.7. Power Regulator Used in Voltage Circuit Design

In the voltage module, LM317 voltage regulator is implemented for the power unit. This voltage regulator series of fixed voltage integrated circuit voltage regulators are designed for a wide range of applications (see Figure 3.30). These applications include on-card regulation for elimination of noise and distribution problems associated with single point regulation. Each of these can deliver up to 1.5 A of output current. Internal current limiting and thermal shutdown features of these regulators essentially make them immune to overload.

3.8.8. Circuit Drawings and Pictures of the Designed PIC-Based Voltage Module

Detailed circuit drawing of equipment and links in the designed energy harvesting module platform is given in the Figure 6.9. The designed energy harvesting module pictures (bottom view and top view) are shown in the Figure 6.10 and 6.11. PCB layout of the designed voltage module platform given in the Figure 6.12. See Appendix F in the Chapter 6.

3.9. Software Development

In the wireless sensor networks, software issues can be grouped under two headings. One of this; computer software that will monitor the PIC sensor nodes and collect and record the data from sensor nodes. The other; small embedded PIC operating system (software) that control and manage sensor nodes. These issues are going to be explained under this section.

3.9.1. Microcontroller Software (Operating System)

All operations of sensor nodes are managed by operating system. The operating system has been developed using PIC-C language. The developed PIC16F886 sensor node operating system is responsible to determine routing algorithm and MAC protocol, sending data retrieval, data processing, reading data from analog and digital sensors and memory management, communications between sensor nodes etc.

The developed PIC16F716 energy harvesting controller operating system is responsible for managing, collecting and controlling voltage. I explained all information in the previous sections in details. Figure 3.36 shows the microcontroller CCS company programmer software and Figure 3.37 shows the PIC programmer device US-BURN BRENNER 8 of the Microchip.

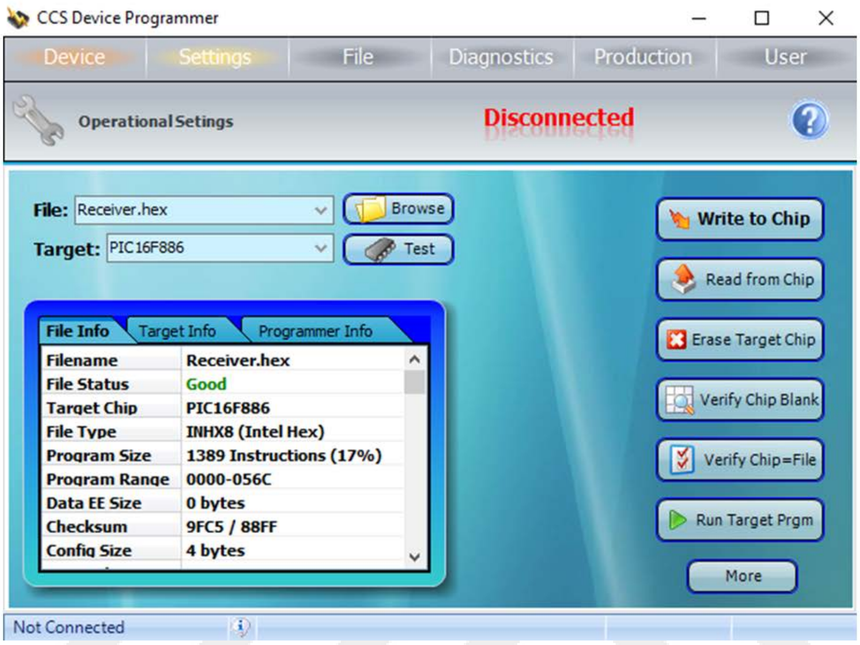


Figure 3.36: CCS device programmer, CCS Company Inc. 2018, [110].

Figure 3.37: Microchip PIC programmer, Microchip company 2006, [111].

3.9.2. Operating System Data flow and Memory Organization of the Microcontroller

For wireless communication microcontroller software uses a packet structure of 1 Byte. The data stream is in bytes. Microcontroller’s memory has the capacity to store 1000 packets. Memory capacity goals that if the network gets busy, data should wait in microcontroller’s memory for a while. In the system, data from the sensor and all the data from the other sensors are collected in a single queue.

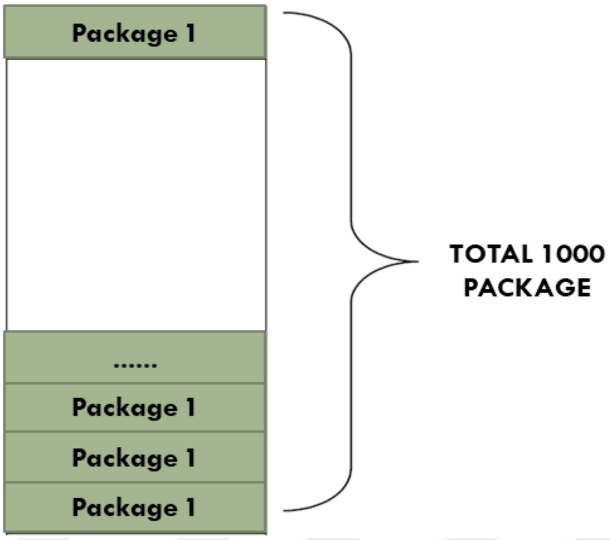


Figure 3.38: Data queue structure of the operating software, this study 2018.

Each piece of data from the sensors is transferred to the queue as 1 byte. The data reading time of the sensors is made using timers in the software. The data is transferred to the queen by reading the sensors at specific time intervals. Diagram of transferring data from sensors to the queue is shown in the Figure 3.38 and diagram of data delivery system to other sensors or base station is shown in the Figure 3.39. Microcontroller's memory organization, size, capacity, structure and features easily explained in the previous hardware section. USART interface is used to receiving data. Data flows are controlled by cutting. The incoming data is transmitted to the queue for transmission via the cutting process.

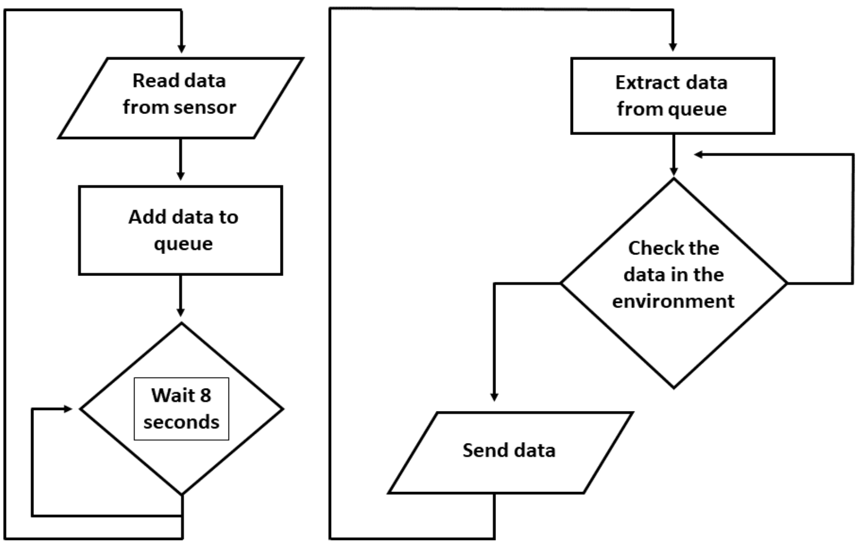


Figure 3.39: Data transfer and data delivery diagrams of the operating software, this study 2018.

3.9.3. MAC Protocol, Forwarding Protocol and RoutingAlgorithm Used in Software

TRAMA (Traffic-adaptive medium access protocol) is used as the environment access protocol. Sensors that start communicating with this protocol together or at different times they synchronize by waiting for each other's media accesses. Sensors access the environment when the media is empty without any restrictions. Point to point schema is used as routing protocol.

Figure 3.40 shows point to point routing system of the designed WSN. According to this algorithm, data coming out of a sensor node will reach directly receiver sensor node. Each transmitter sensor nodes can send its own data to receiver sensor node in many times. Forwarding protocols and MAC protocols were explained detail in the previous sections.

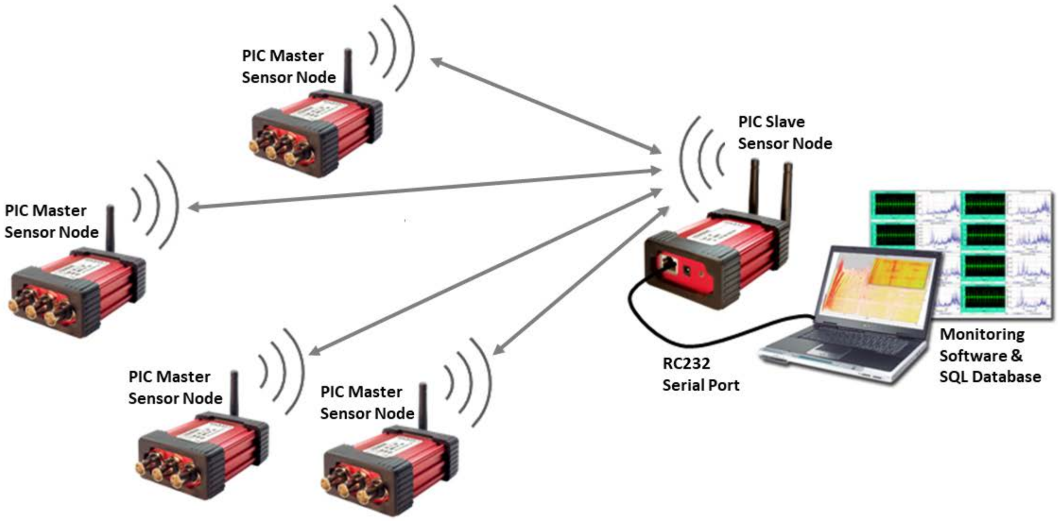


Figure 3.40: Point to point routing system of the designed WSN, this study 2018.

3.9.4. Monitoring Software

WSNs do not have any monitoring screen unit on the sensor nodes in many applications due to high cost and energy consumption. (In the current designed sensor nodes, I have used LCD panles for testing purposes). But all of the applications, the data needs to be displayed and recorded in the database and also obtained data could be observed and processed.

In this work, I have developed an application on the Microsoft Visual Studio and C # language to monitor and save the data in the database. So, data could be observed and stored. The interface of the developed application and monitoring process are shown in the Figure 3.41 with developed software, also the Figure 3.42 shows data value histories.

Communication between computer observation software and wireless sensor nodes is carried out through RS232 to USB interface. Data collected from the network is stored for processing and displaying later. Data from sensors can be recorded and displayed in Microsoft SQL database. Figure 3.43 demonstrates that database with tables and stored data. The data from the sensors are saved in the database instantly and the data saved in the database can be seen from the histories menu of the develoed software.

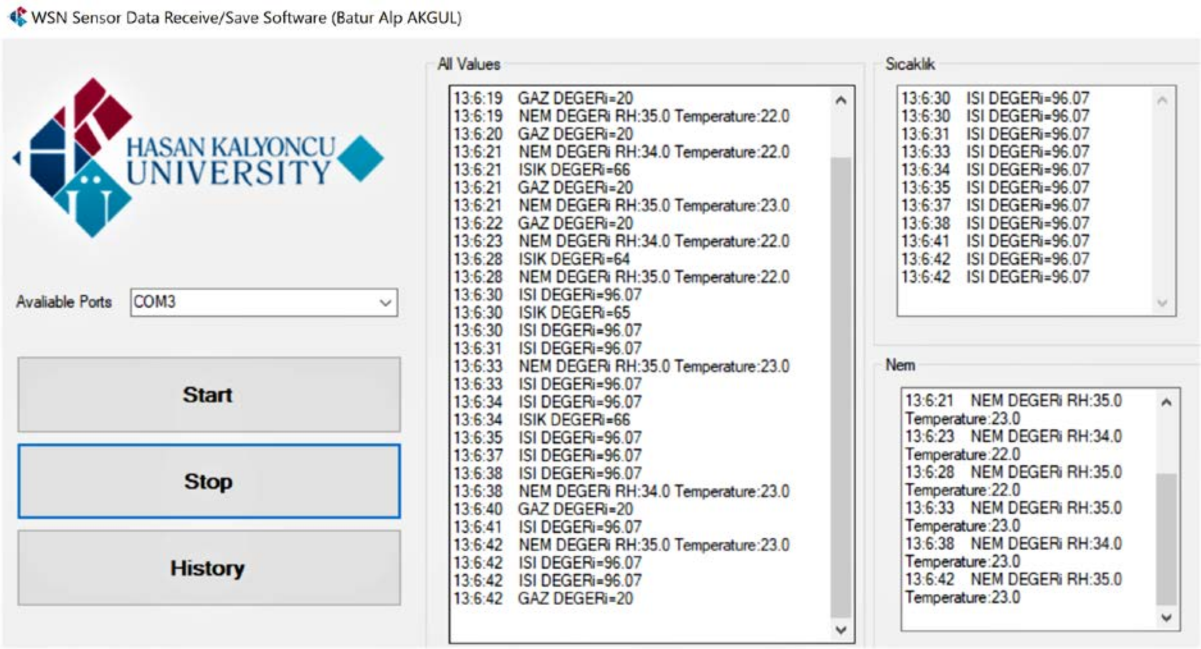


Figure 3.41: Interface of developed application and monitoring process, this study 2018.

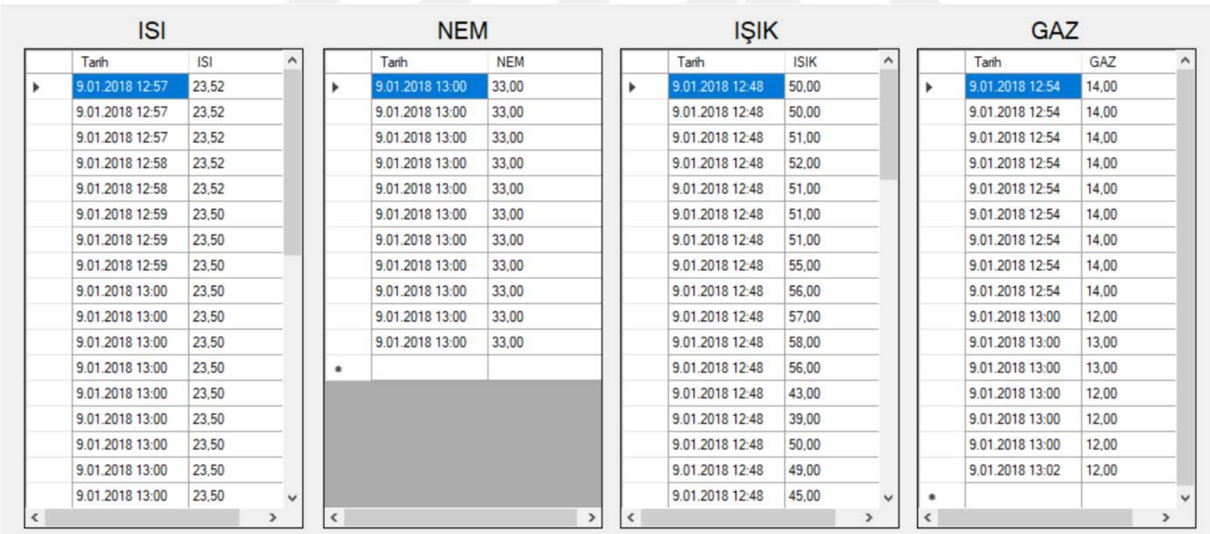


Figure 3.42: Data value histories on the developed software, this study 2018.

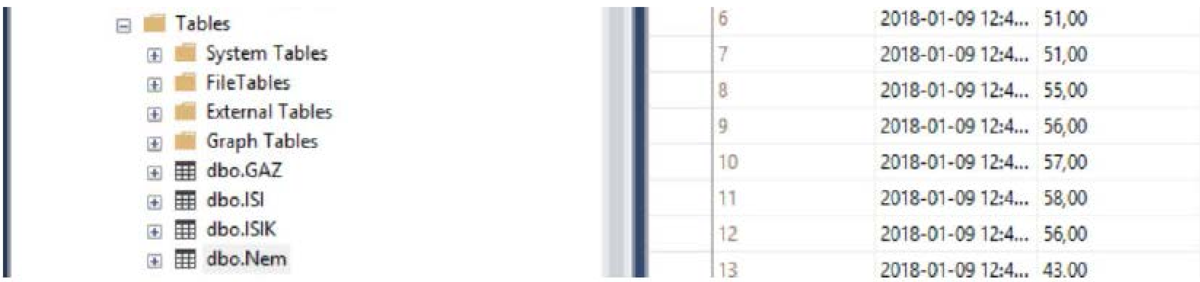


Figure 3.43: SQL Database with tables and stored data, this study 2018.

CHAPTER IV

RESULTS AND DISCUSSIONS

In this chapter, the results and discussions of the thesis is presented in details. Designed PIC-Based wireless sensor nodes, designed external PIC-Based voltage module and designed monitoring and recording data software results are explained. Relevant discussions and some future works are explained and designed devices are shown in the Table 4.1. The results of studies on renewable energy sources are explained and evaluated in terms of the solar panel used and rechargeable battery used aspower supply and planned future works. Safety algorithms and the cryptology that can be used in the wireless sensor networks are examined and discussed. Obtained results are presented with comparison tables after analyzing. Power consumption results and discussions of the designed sensor nodes are presented. Some important energy consumption parameters are calculated, analyzed and compared with each other. The resulting energy consumption costs are shown in a table and the results are interpreted. Results in terms of the renewable energy sources and designed external PIC-based voltage module are discussed. Results from this work are compared with the work done in the past years and the results are presented in tabular forms. Results and discussions for the monitoring and data recording software issues are presented in this chapter.

4.1. Results of the Designed Wireless Sensor Nodes

In this study, my motivation is to create a device that relies solely on renewable solar energy and to develop a strategy for managing that energy to extend the lifetime of the wireless sensor networks with solar panel and rechargeable batteries with a high energy density. My primary goal is to create wireless sensor nodes that use a unique power management scheme to manage power storage and delivery between a small solar array and rechargeable batteries with a supercapacitor, ensuring long-time operation. Therefore, four transmitter nodes designed to monitor and examine the conditions of the environment. A receiver sensor node designed that collect data and send to computer program via the RS232 port with relay unit. The communication module is an RF 433 module a wireless transmitter unit with an antenna. Data and control unit includes a PIC microcontroller 16F886.

Designed wireless sensor nodes have been tested in a real environment with normal battery and also with a rechargeable battery. Renewable voltage support module (external) has been used and tested with all the transmitter wireless sensor nodes. The data obtained from the environment were observed both on the sensor node's LCD screen and on the computer software and data has stored on the computer. The result shows that the system is stable and works without any errors. Table 4.1 shows that the designed wireless sensor node's information.

As future studies, some works can be done on integrating more than one sensor into a single sensor node because of the prevent energy cost and economical cost. More than one task is assigned to a single PIC and the results will be examined. For example; 4 sensor nodes will be designed with 8 sensors. Impact of the multi-sensor design on energy consumption and network system performance will be investigated in wireless sensor networks.

DESIGNED WIRELESS SENSOR NODES						
Designed Sensor Node Type	Used Sensor	Used PIC	Voltage Regulator	Used LCD Panel	Rechargeable Battery & SC	Solar Panel
Receiver Node	✗	PIC16F886	LM7805	✗	✓	✓
Transmitter Node	DHT11	PIC16F886	LM7805	1602A LCD	✓	✓
Transmitter Node	LM35	PIC16F886	LM7805	1602A LCD	✓	✓
Transmitter Node	MQ2	PIC16F886	LM7805	1602A LCD	✓	✓
Transmitter Node	LDR	PIC16F886	LM7805	1602A LCD	✓	✓

Table 4.1: Designed sensor node types and features, this study 2018.

WSN platform uses a PIC microcontroller of model number PIC16F886. This microcontroller has 28 Pin Flash-Based, 8-Bit CMOS Microcontroller with NanoWatt Technology. The PIC has an external oscillator, 4K EEPROM, ADC, timers, PWM pulse-width modulation, 1 EUSART. In order to keep power consumption laws, no external memory unit was used. FS1000A module was used as wireless transmitter unit, and XY-MK module was used as a wireless receiver. FS1000A and XY-MK modules work in 433 MHz band and can run on 10 different channels. In order to read data on the sensor node without a computer program, 1602A LCD panel was integrated. In the Table 4.2 the comparison data provided with the designed sensor node and the other sensor nodes are shown.

SENSOR NODES FEATURES						
Mote Platform	Controller	Bus	Clock	RAM	Flash	EPROM
TelosB/Tmote Sky [112]	TI MSP430F1611	16-bit	4 - 8 MHz	10 K	48 K	1 M
IMOTE [113]	ARM7	32-bit	12 MHz	11 K	512 K	None
MicaZ/Mica2 [112]	Atmel Atmega 128L	8-bit	8 MHz	4 K	128 K	512 K
Tmote Sky [113]	MSP430F	16-bit	8 MHz	10 K	48 K	1 M
SHIMMER [112]	TI MSP430F1611	16-bit	4 - 8 MHz	10 K	48 K	None
EZ-RF2480/2500 [113]	TI MSP430F2274	16-bit	16 MHz	1 K	32 K	None
IRIS Atmel [112]	Atmega1281	8-bit	8 MHz	8 K	640 K	4 K
Mica2Dot [113]	Atmega128l	8-bit	4 MHz	4 K	128 K	512 K
Sun SPOT [112]	Atmel AT91RM9200	32-bit	180 MHz	512 K	4 M	None
Our Platform	PIC16F886	8-bit	20 MHZ	368 K	14 K	256 K

Table 4.2: Feature comparison of sensor nodes, this study 2018.

4.2. Power Consumption Results of the Designed Sendor Nodes

Energy issues on the wireless sensor networks are very complex and sophisticated issues and power consumption values generally depend on the hardware and can vary slightly from one type to another. Calculated energy usage is the product of the power draw and duration. The energy consumption can vary significantly dependıng on the architecture of the sensor nodes. It is very important that these sensor node components are selected from components with low energy consumption. In the Section 3.5.2, all the power cost analyzes have been made in terms of the operational energy costs.

In this section, I have analyzed designed sensor nodes in terms of the power consumption details. For this process, all the sensor node components' technical information from the manufacturer are used. In wireless sensor networks, receiving and transmitting power consumption can be changed according to the sensor node design technics and components. In 2016, some scientists have already discussed and calculated receiving and transmitting parameters for the RF433 transceiver [114], so these parameters are used in the power consumption calculation steps.

In our design, four transmitter sensor nodes have been designed and one receiver node has been designed for building the wireless sensor networks. Power consumption of wireless interfaces are given in the Table 4.3.

RF Module	POWER CONSUMPTION (mW)				
	Sleep	Idle	Wake-up	Tx	Rx
RF433	✗	30.14	12	75.57	31.7
ZigBee	0.165	40.56	22	163.74	89.66
Bluetooth	✗	18.08	96.23	199.05	185.32
Wi-Fi	✗	61.02	66.21	67.44	63.91

Table 4.3: Power consumption of wireless interfaces investigated by C. Gray and L. Campbell 2016, [114].

4.2.1. Power Consumed by Receiver Sensor Node

In order to evaluate designed receiver node in terms of the power consumption, some energy calculations have been made by using the technical information of the units such as receiver, voltage regulator, PIC, etc. are used on the designed receiver node. While calculations are being made, the formulas described in the Section 3.5.2 are used. These are below;

XY-MK-5V Receiver : Pavg = 4.3mA(5V) = 21,5mW (working mode)
XY-MK-5V Receiver : Pavg = 31mA (receiving mode, [114])
MAX233 RS Converter : Pavg = 5.2mA(5V) = 26mW
PIC 16F886 : Pavg = ~ negligible (<= 11 uA)
LM7805 Voltage Regulator : Pavg = 5mA(5V) = 25mW
JQC-3FC/T73 Relay : Pavg = 380mW (optional)

Ptot = 21,5mW + 26mW + 25mW + 380mW
Ptot = 452,50mW (working mode and with decision-making unit)
Ptot = 21,5mW + 26mW + 25mW
Ptot = 72,50mW (working mode and without decision-making unit)

Ptot = 21,5mW + 31mW + 26mW + 25mW + 380mW

Ptot = 483,50mW (receiving mode with decision-making unit)

Ptot = 21,5mW + 31mW + 26mW + 25mW

Ptot = 103,50mW (receiving mode without decision-making unit)

(Note that when Microcontroller Sleeps, Power Consumption drops approximately 9 - 10 %)

Calculated power consumption results show that energy consumption at very low levels in totally for receiver node, even microcontroller energy consumption is negligible. RF receiver unit, RS converter unit and voltage regulator unit spend very low energy and power consumption is found to be below acceptable limits.

The receiver has two important functions, one of the function is to receive the data from the sensors instantaneously and transfer this data to the computer. Another function is the to make instant surveillance and inspection in the environment and make decisions. Table 4.4 shows that the calculated energy consumption with two functions of the designed receiver node.

ENERGY CONSUMPTION OF THE RECEIVER (SLAVE) SENSOR NODE		
Modes	With Relay Unit	Without Relay Unit
Receiving Mode	483.50 mW	103.50 mW
Working Mode	452.50 mW	72.50 mW

Table 4.4: Energy consumption with functions of designed receiver node, this study 2018.

The important finding here, the receiver node will only be used as a passive slave node or will make decisions. If the receiver node is only used to transfer data from the sensor on the network to the computer, the data consumption is very low, the estimated cost is 103.50mW. If the data received from sensors is to be evaluated and transformed into a process, if the PIC microcontroller will decide what to do with the environment check, in this case, the relay unit will be used by the PIC microcontroller on the receiver node, and this will increase the power consumption too. Estimated power cost is 483.50mW with relay unit.

Another important point is that receiver node will be connected to a computer with cable connection. RS232 to USB converter will be used for transferring sensor data to the computer. Therefore, the receiver node power supply could be used as an external for example 5V voltage adapter, battery power is not mandatory for receiver node. For this reason, receiver node power consumption can be negligible.

4.2.2. Power Consumed by Transmitter Sensor Nodes

In order to evaluate designed transmitter node in terms of the power consumption, some energy calculations have been made by looking at the technical information of the units such as receiver, voltage regulator, PIC, etc. are used on the designed transmitter nodes. Calculated power consumption values are the followings;

FS1000A Transmitter	: Pavg = 28mA(5V) = 140mW (working mode)
FS1000A Transmitter	: Pavg = 40mW (transmit mode)
FS1000A Transmitter	: Pavg = 30mW (idle mode [114])
PIC 16F886	: Pavg = 5mW
1602A LCD Panel	: Pavg = 1.2mA(5V) = 6mW
LM7805 Voltage Regulator	: Pavg = 5mA(5V) = 25mW
DHT11 Humidity Sensor	: Pavg = 2.5mA(5V) = 12.5mW
LDR Light Sensor	: Pavg = 20mA(5V) = 100 mW
MQ2 Gas-Smoke Sensor	: Pavg = 800mW
LM35 Temperature Sensor	: Pavg = 1mA(5V) = 5mW

4.2.2.1. Power Consumed by DHT11 Sensor Transmitter Node

Ptot = 140mW + 5mW + 12.5mW + 6mW + 25mW

Ptot = 188.50mW (working mode)

Ptot = 30mW + 5mW + 12.5mW + 6mW + 25mW

Ptot = 78.50mW (idle mode)

Ptot = 140mW + 40mW + 5mW + 12.5mW + 6mW + 25mW

Ptot = 228.50mW (transmission mode)

After working on some sleep mode options:

Receiver Node Ptot = 103.50mW

DHT11 Transmitter Node with transmission mode Ptot = 203.50mW

228.50mW / 103.50mW = 221% (Approximately 221% rise in power consumption from receiver node when running transmission mode)

DHT11 Transmitter Node with working mode = Ptot = 188.50mW

188.50mW / 103.50mW = 183% (Approximately 183% rise in power consumption from transmitter mode when running working mode)

DHT11 Idle Node = 78.50mW

DHT11 Transmitter Node with idle mode = Ptot = 78.50mW

78.50mW / 103.50mW = 75% (Approximately 75% drop in power consumption from receiver mode when running idle mode)

4.2.2.2. Power Consumed by LDR Sensor Transmitter Node

Ptot = 140mW + 5mW + 100mW + 6mW + 25mW

Ptot = 276mW (working mode)

Ptot = 30mW + 5mW + 100mW + 6mW + 25mW

Ptot = 166mW (idle mode)

Ptot = 140mW + 40mW + 5mW + 100mW + 6mW + 25mW

Ptot = 316mW (transmission mode)

After working on some sleep mode options:

Receiver Node Ptot = 103.50mW

LDR Transmitter Node transmission mode Ptot= 316mW

316mW / 103.50mW = 306% (Approximately 306% rise in power consumption from receiver node when running transmission mode)

LDR Transmitter Node with working mode = 276mW

276mW / 103.50mW = 266% (Approximately 266% rise in power consumption from transmitter mode when running working mode)

LDR Transmitter Node with idle mode = Ptot = 166mW

166mW / 103.50mW = 161% (Approximately 161% rise in power consumption from receiver mode when running idle mode)

4.2.2.3. Power Consumed by MQ2 Sensor Transmitter Node

Ptot = 140mW + 5mW + 800mW + 6mW + 25mW

Ptot = 976mW (working mode)

Ptot = 30mW + 5mW + 800mW + 6mW + 25mW

Ptot = 866mW (idle mode)

Ptot = 140mW + 40mW + 5mW + 800mW + 6mW + 25mW

Ptot = 1016mW (transmission mode)

After working on some sleep mode options:

Receiver Node Ptot = 103.50mW

MQ2 Transmitter Node transmission mode Ptot= 1016mW

1016mW / 103.50mW = 986% (Approximately 986% (about 10 times) rise in power consumption from receiver node when running transmission mode)

MQ2 Transmitter Node with working mode = 976mW

976mW / 103.50mW = 943% (Approximately 943% (about 10 times) rise in power consumption from transmitter mode when running working mode)

MQ2 Transmitter Node with idle mode = Ptot = 166mW

866mW / 103.50mW = 840% (Approximately 840% rise in power consumption from receiver mode when running idle mode)

4.2.2.4. Power Consumed by LM35 Sensor Transmitter Node

Ptot = 140mW + 5mW + 5mW + 6mW + 25mW

Ptot = 181mW (working mode)

Ptot = 30mW + 5mW + 5mW + 6mW + 25mW

Ptot = 71mW (idle mode)

Ptot = 140mW + 40mW + 5mW + 5mW + 6mW + 25mW

Ptot = 221mW (transmission mode)

After working on some sleep mode options:

Receiver Node Ptot = 103.50mW

LM35 Transmitter Node transmission mode Ptot= 221mW

221mW / 103.50mW = 214% (Approximately 214% (about 10 times) rise in power consumption from receiver node when running transmission mode)

LM35 Transmitter Node with working mode = 181mW

181mW / 103.50mW = 175% (Approximately 175% (about 10 times) rise in power consumption from transmitter mode when running working mode)

LM35 Transmitter Node with idle mode = Ptot = 71mW

71mW / 103.50mW = 68% (Approximately 68% drop is obtained in power consumption from receiver mode when running idle mode)

Energy consumption results show that the least energy-consuming sensor is the LM35 sensor node, and the most energy-consuming sensor is the MQ2 sensor node. When examining these two sensor nodes in terms of the energy consumption;

MQ2 Transmitter Node transmission mode Ptot= 1016mW

LM35 Transmitter Node transmission mode Ptot= 221mW

1016mW / 221mW = 459% (about 5 times more power consumption in MQ2 than LM35)

MQ2 Transmitter Node with working mode = 976mW

LM35 Transmitter Node with working mode = 181mW

976mW / 181mW = 539% (more than 5 times more power consumption)

MQ2 Transmitter Node with idle mode = Ptot = 166mW

LM35 Transmitter Node with idle mode = Ptot = 71mW

166mW / 71mW = 233% (more than 2 times more power consumption)

When looking at the results, renewable energy sources are needed such as rechargeable battery, supercapacitor and solar panel to use the smoke sensor and gas sensor (MQ2) in wireless sensor networks because of the high energy consumption. LM35 Temperature sensor node is usable with non-rechargeable battery due to the least energy consumption. Table 4.5 shows the obtained energy consumption of the designed transmitter sensor nodes.

POWER CONSUMPTIONS OF THE TRANSMITTER (MASTER) SENSOR NODES				
Modes	DHT11 Node	LDR Node	MQ2 Node	LM35 Node
Transmission Mode	228.50 mW	316 mW	1016 mW	221 mW
Working Mode	188.50 mW	276 mW	976 mW	181 mW
Idle Mode	78.50 mW	166 mW	866 mW	71 mW

Table 4.5: Obtained energy consumption of the designed transmitter nodes, this study 2018.

The LCD screen is usually not used in wireless sensor networks design to reduce energy consumption and save energy. The sensor network system is monitored via computer software. However, in this sensor node design, the LCD screen is used to test the system works and to see the data on the screen. Therefore, energy consumption of the LCD panel is ignored.

4.3. Results of the Renewable Energy Sources

Similar works done in the past show that efforts to move towards renewable energy sources in wireless sensors are extremely limited. In this study, most of the wireless sensor networks scientific publications and articles are examined (see Chapter 2), only a few studies have considered renewable energy sources. The use of solar panels in wireless networks, the use of rechargeable batteries and the use of supercapacitors are very important in terms of the extending sensor network’s lifetime. Table 4.6 shows the comparison of the previously designed wireless sensor network works in terms of the use of the renewable energy and use of the energy harvesting voltage regulator controlled by the PIC microcontroller. Comparison of some previous researches since 2013 are given in the Table 4.6.

Comparison of the Some Previous Researches Since 2013				
Researchers	Year	Normal Battery	Renewable Energy	PIC Based Harvesting Module
Mohanty, Patil [39]	2013	✓	×	×
Raju, Aravind, Kumar [42]	2013	✓	×	×
Deshmukh, Pathan, Shaikh [47]	2013	✓	×	×
Ma,Yan,Wang, Liao [31]	2014	✓	×	×
Lambebo, Haghani [40]	2014	✓	×	×
Nayse, Atique [59]	2014	✓	×	×
Mohan, Devi [41]	2014	✓	×	×
Gahlot, Gundkal, Thite [53]	2015	✓	×	×
Ghayvat, Gui, Suryadevara [48]	2015	✓	×	×
Tayade, Chandak, Choudhari [43]	2015	✓	×	×
Pitarma, Marques, Caetano [32]	2016	✓	×	×
Panic, Stecklina, Stamenkovic [44]	2016	✓	×	×
Varchola, Drutarovsky [54]	2017	✓	×	×
Our Platform-Present Work	2018	✓	✓	✓

Table 4.6: Comparison of previous researchers, this study 2018.

Nowadays, one of the major issues in wireless sensor networks are decreasing energy consumption to increase the lifetime of the networks. Therefore, contrary to previous works, serious attention have been given to renewable energy sources in this study. Designed sensor nodes will be managed energy sources such as rechargeable battery, capacitor and solar energy to survive for long periods of time in WSNs which requires management of the collected environmental energy. Designed sensor nodes have tested and worked with a rechargeable battery and solar panel and results show that the renewable energy system can be used as a stable in future terms (see Chapter 3.10).

The use of renewable energy sources can also contribute to the enhancement of data security in wireless sensor networks. Asymmetric cryptology cannot be used in wireless sensor networks because of the high energy consumption. Finding problems with energy consumption makes it easier to use asymmetric algorithms in sensor networks, which increases network and data safety. Table 4.6 shows the results from some studies since the 2013s, wireless sensor network researches have gained speed and also these tables show that works on trends towards to the renewable energy sources is inadequate. To solve the energy consumption problem in wireless sensor networks, there is no other way than using solar panel and rechargeable battery.

On the use of renewable energy sources in the wireless sensor networks, there are mainly two important constraints. One of important constraint is that the physical dimensions of the solar panels are still too large according to the wireless sensor nodes and small size solar cells are not yet able to store enough energy for sensor networks. The other important constraint is that the physical dimensions of the rechargeable batteries are still too large which seriously complicates sensor node design at micro levels.

4.4. Results of the PIC-Based Voltage Module

Voltage module's operating system has developed by using PIC-C language. PIC operating system is responsible for managing, collecting and controlling voltage. As can be noticed from the Chapter 2 and the Table 4.6, no previous work has been done on the voltage circuit design which can be controlled by PIC, no PIC-based voltage-cycling design was found inliterature. Therefore, in this study, I have desidned a voltage circuit that can be controlled by PIC. The main goal of this work is to present an energy harvesting wireless sensor network platform. The goal is to create a PIC-Controlled voltage module that uses a unique power management scheme to coordinate power storage and delivery between a small solar array and rechargeable batteries with a supercapacitor, ensuring long-lasting operation for WSNs.

Designed PIC-Based voltage module which can be examined in some general terms. These; designed voltage module that will be met the renewable energy requirements (solar energy, supercapacitor, and rechargeable battery). Integrated PIC of the designed voltage module will manage and collect renewable energy. Voltage circuit will be supported by two energy input these are solar panel input and rechargeable battery input, and also voltage circuit will support one voltage output to connect WSN sensor nodes. Table 4.7 shows the designed external PIC-Based voltage module for controlling solar panel and rechargeable battery and managing the energy consumption.

	EXTERNAL PIC-BASED ENERGY HARVESTING MODULE					
Designed Device Type	Used Sensor	Used PIC	Voltage Regulator	Used LCD Panel	Rechargeable Battery & SC	Solar Panel
External Harvesting Module	✗	PIC16F716	LM317	✗	✓	✓

Table 4.7: Design of the external PIC-Based voltage module, this study 2018.

In this study, the voltage circuit is designed as a separate module, which can be implemented in a design that can be integrated on the sensor node in the future periods of the operation to prevent cost and to provide integrity with sensor nodes. In feature design, PIC microcontroller on the sensor nodes can also control renewable energy sources or a separate PIC microcontroller can be used on the sensor nodes for energy resources management and control. Future work will be fueled by these issues.

4.5. Comments on the Software Issues

In this study, software issues are examined under two headings. First, computer software that will monitor the PIC sensor nodes and collect and record the data from sensor nodes. Second, small embedded PIC operating system (software) that control and manage wireless sensor nodes.

The operating system has been developed by using PIC-C language for all wireless sensor nodes. The sensor node operating system is responsible to determine routing algorithm and MAC protocol, sending data retrieval, data processing, reading data from analog and digital sensors and memory management, communications between sensor nodes etc.

In this study, a software has been developed on the Microsoft Visual Studio and C # language to monitor and store the data in the database. With developed software, data could be observed and stored. Communication between computer observation software and wireless sensor nodes was carried out through RS232 to USB interface. Data collected from the network was stored for later processing purposes.

Currently developed software is working pretty well. Programmer's software development and PIC coding skills and creativity move the technology in wireless networks forward.

The designed receiver node uses the RS232 port for data transfer. This port is a wired communication port. When transmitter sensor nodes are completely wireless (including voltage requirements), the receiver node makes the data transfer wired. This shows that cable dependency still continues in wireless sensor networks. Due to the receiver node is wired, it can not be deployed away from the computer. Therefore, in the future work, some attention could be given to wireless transfer of data collected at the receiver node to the computer. It must be emphasised that no research has been conducted on the advantages and disadvantages of wireless data transfer. However, transferring wireless data from the receiving node enables the sensor networks to operate completely wirelessly and increases the mobility of the system.

4.6. Comments on the Routing protocols

In WSNs, routing protocols are responsible for routes in the network, however routing in wireless sensor networks are very challenging because of the sensor network's natural characteristics. Using global addressing schema is impossible to build for deployment of a large number of sensor nodes. Therefore, traditional IP based protocols such as TCP/IP protocol cannot be applied to wireless sensor networks and also essential to design effective and energy saving protocol in order to enhance the WSNs lifetime in terms of energy. Many data protocols, routing protocols and power management systems have been designed for WSNs where energy awareness is an essential design issue. When considering energy saving, routing protocols should also be designed with fault tolerance in communications. Therefore, routing protocols designed for WSNs should be energy efficient to prolong the lifetimes of sensors and network.

In the Chapter 6, all of the protocol design issues, challenges and requirements are explained in detail so that understanding routing protocol mechanisms is important. And also recently developed routing protocols are explained with advantages and disadvantages. In 2010, some researchers [115] have worked in the area of the duty cycling protocols. Table 4.8 shows that some of the important duty cycling MAC protocols.

MAC protocol	Synchronization required	Mechanism	Adaptability	Energy efficiency
SMAC	No	CSMA	Yes	Yes
WiseMAC	No	NP-CSMA	Yes	Yes
T-MAC	No	TDMA/CSMA	Yes	Yes
DSMAC	No	CSMA/CA	Yes	Yes
SCP-MAC	Yes	CSMA	Yes	Yes
B-MAC	No	CSMA	Yes	Yes
X-MAC	No	CSMA	Yes	Yes

Table 4.8: Comparison of some Duty Cycling Protocols, investigated by M. A. Ameen et al. 2010, [115].

As can be depicted from the Table 4.8, MAC protocol types and variants can be adapted to wireless sensor networks. Used mechanisms in the MAC protocols are suitable for sensor networks. Another important point is the MAC protocols provide energy efficiently to the sensor networks. When considering energy consumption as an important constraint, MAC protocols can be contributed to the reduction of energy consumption.

Efficient routing algorithms can save a significant amount of energy in a sensor network while routing occurs frequently. Therefore, in the recent years, some protocols are developed by the scientists [115], and also, they have examined some of these protocols. Table 4.9 shows the comparison of some routing protocols used in WSNs.

Protocol	Network type	Energy consumption	Scalability	Mobility	Data aggregation
Flooding	Flat	High	Limited	No	No
SPIN	Data Centric	Low	Limited	Yes	No
Shah & Rabaey	Data Centric	Low	Good	Yes	No
GBR	Data Centric	Low	Limited	Limited	Yes
LEACH	Hierarchical	High	Good	Yes	Yes
PEGASIS	Hierarchical	High	Good	Yes	No
SPEED	Location based	Low	Limited	No	No
GAF	Location based	Low	Good	No	No
GEAR	Location based	Low	Limited	Yes	No

Table 4.9: Comparison of some routing protocols, investigated by M. A. Ameen et al. 2010, [115].

Clustering mechanism is widely used mechanisms in WSNs for energy efficiency and effective data communication. Therefore, clustering mechanism is very important in the routing protocols in terms of the energy consumption and data communication. In 2012, some researchers [116] have worked in the field of the clustering mechanisms in the routing protocols. Table 4.10 shows comparison of the features of different clustering routing protocols used in the wireless sensor networks.

Ptotocol Name	Energy Efficiency	Cluster Stability	Scalability	Delivery Delay	Load Balancing	Algorithm Complexity
LEACH	very low	moderate	very low	very small	moderate	low
HEED	moderate	high	moderate	moderate	moderate	moderate
DWEHC	very high	high	moderate	moderate	very good	moderate
PANEL	moderate	low	low	moderate	good	high
TL-LEACH	low	moderate	moderate	small	bad	low
UCS	very low	high	low	small	bad	moderate
EECS	moderate	high	low	small	moderate	very high
EEUC	high	high	high	moderate	good	high
ACE	moderate	very low	moderate	small	moderate	very high
BCDCP	very low	high	very low	small	good	very high
PEGASIS	low	low	very low	very large	moderate	high
TEEN	very high	high	low	small	good	high
APTEEN	moderate	very low	low	small	moderate	very high
TTDD	very low	very high	low	very large	good	low
CCS	low	low	low	large	very bad	moderate
HGMR	low	high	very high	moderate	bad	low

Table 4.10: Comparison of different clustering routing protocols, investigated by Xu-Xun Lui 2012, [116].

As can be noticed from Table 4.10, some of the protocols still have problems such as load balancing, delivery delay, energy efficiently and cluster stability. Determining protocols to be used and designing new protocols to be developed by considering these criteria. In WSNs, routing mechanisms are highly essential mechanisms in terms of the energy consumption.

4.7. Other Results and Discussions

Once the designed system is considered from the aesthetic point of view; the designed wireless sensor node was realized at micro-level. For commercial purpose, the boxing process can be done in small sizes with a stylish appearance. One other key feature that should be taken into consideration is weatherproofing. The enclosure is plastic but plastic can be damaged at high temperatures. So, boxes can be built against weather conditions such as temperature, raining and snowing.

When we consider the designed system in terms of the sustainability; designed sensor nodes are quite stable. However, some design modifications must be made in order to expand the sustainability and to create a more robust design. For example, solar panel and rechargeable battery must be used to extend sensor node’s lifetime because the designed system supports renewable energy sources as stable. One other reason why the design is sustainable is the use of add-on wireless sensor nodes. Sensor nodes can be easily swapped and changed out in the field if needed. Also in time, the price of these sensor node components are expected to come down with future releases.

Once, one to considers the designed system with mass production; the wireless sensor nodes that can be manufactured with profits in mind. Because wireless sensor nodes have so many advantages such as ultra-low power energy consumption, lower costs, external voltage module for renewable energy, using a solar panel and rechargeable battery, micro-level design etc. The sensor node design in this study is a considered as scientifically. The miniature design and system design and component properties can be enhanced for mass production.

CHAPTER V

CONCLUSIONS

WSNs have been identified as one of the most useful technologies in this century and therefore I have focused on outlining the general ideas of wireless sensor networks and on the technologies to implement these ideas wireless sensor networks and strong and weak points of them. Also, the basic parts of WSN components and technologies used with the wireless sensor network have been explained and some of the most relevant issues of WSNs, from the application, design and technology viewpoints are discussed. For designing a WSNs, in fact, we need to define the most suitable technology to be used and the communication protocols to be implemented such as topology, signal processing strategies, etc. These choices depend on different factors, above all the application requirements. The aim is to help designers in the choice of the most suitable technology. Some research information about the network applications, components, congestion control approaches, reliable transport protocols are given. I have provided information concerning the current state of WSNs and I have provided an overview of the hardware, software, and networking protocol design of this important technology in concrete terms. Depending on applications, many other techniques such as synchronization, localization and network processing can be important, which are going to be details discussed in subsequent sections.

The wireless sensor network is a technology that has been used in a vast number of applications and environments with successful results in the past. In the Chapter 2, a deep literature survey has been done. These include many case studies from past to recent research and general understanding towards the theory behind each technology. Especially in scientific articles, journals, books, previous projects, and the internet have served as sources of literature reviews. Major academic case studies are described and it has been found that very little work has been done on renewable resources such as solar energy, supercapacitor, and rechargeable battery. Therefore, renewable energy works and power management issues are considered in this thesis.

The microcontrollers are equipped with a processor, memory, I/O pins, timers and other on-chip peripherals. Therefore, microcontrollers and their features are key factors in embedded systems. Additional advantages of microcontroller integration are easy, higher reliability, upgradability and lower power consumption. These are very important aspects in microcontrollers and embedded systems. These microcontrollers are the central parts of any kind of sensors nodes. It has the ability to self-programming which is a useful feature. The efficient code will be generated with a well-optimized version. Self-programming memory simplifies and cost reduces designs that require software upgrade after the system installation. In order to reduce size and cost of the microcontrollers, I have compared to a design that uses a memory, I/O devices, microcontrollers make it economical to digitally control using more devices and processes.

In recent years an efficient design of a WSNs has become a leading area of research. These sensors are effectively linked and communicate peer to peer with each other via radio frequency waves where they monitor and communicate local status, signals or conditions, such as pressure, temperature, pollutants, motion, vibration, pressure and so forth. Especially these smart sensors can automatically supervise processes and require no manual intervention unless a process fault occurs that cannot be corrected via the action of the smart node or via human commands initiated remotely. Sensors are one of the most important components of networks. In the Section 3.2, I have already described some main concepts and components of sensors. Sensor applications include environmental-habitat monitoring of air, water, soil and structural monitoring for buildings and bridges, industrial machine monitoring, process monitoring, asset tracking and brilliant homes etc.

Over the past ten years, standards published by the IEEE and dominated the wireless networking systems. Leaving the various flavors of 802.11 as the only wireless network access standards for which supporting products are widely usable and available. In fact, industrial companies have been willing to adopt products based on the 802.11 wireless standards despite well-documented security and performance and scalability issues. Lots of industrial companies have been formed to provide small-scale wireless hotspots and, in some cases, to extend the 802.11 standards to provide fixed access broadband wireless communication access in rural areas. These services, work intermittently at best and, by virtue of the 802.11 standards. Recent advances in standards-based WSN protocols for industrial control applications have come a long way to solving many of the challenges facing practical WSN deployments. In the Section 3.3 I have explained a comparison of the current WSN standards are available for applications. Several standards are currently ratified for WSN. In the Section 3.3 I have presented different overview and background of the WSN standards such as 802.11 types, Zigbee, WirelessHART and ISA.lOO, which are recently released industrial wireless network standard. As a result, the standard seems poised to provide a solid alternative to current satellite-based approaches for broadband network access in remote or rural regions.

Routing in WSNs are not new research area, however, it is rapidly growing a set of results. In the Section 3.4, I have surveyed the routing protocols and discussed the protocol design challenges and routing issues in WSNs. Routing in sensor network is an important and essential subject in the recent years and introduced unique challenges compared with traditional data routing in wired networks. One of the main challenges in the design of routing protocols for WSNs is to make it energy efficiency because of the limited energy resources of sensors. Energy consumption of sensor node is dominated by data transmission and reception. So, routing protocols are designed for WSNs should be as energy efficient to prolong the lifetime of sensors, and so network lifetime. In WSNs, transport protocols are an important design issue in providing end to end communication with congestion control. TCP is not able to provide reliable data transport in sensor networks due to limited IP capacity and so much energy consumption. A reliable transport protocol for sensor networks is required to be generic, lightweight, and not dependent upon existing lower layer protocols. Power usage, Data Aggregation, Multipath, Query-based and QoS, since these are an essential consideration for routing protocols in terms of energy saving and traffic optimization in a wireless sensor network. Routing protocols are classified based on their features. All of the classified protocol's common objective is trying to extend the lifetime and conserve energy to the sensor network. Although many of these routing techniques look like promising and routing challenges being solving there will be still many protocol issues that need to be solved in the wireless sensor networks in the future.

Power consumption is a major concern in developing WSN applications. In the chapter 3.5 power related issues in WSNs have been investigated. Power and energy cost of the communication of data are main problems of a WSNs. It is essential to design a network that uses optimal energy resources with its limitations. Some techniques and issues are presented that consider energy efficiency as the essential objective for routing and design of WSNs in order to potentially extend the lifetime of such networks. These techniques provide the suitable flexible structure of WSNs. Also provided a guidance to select suitable scheme according to the application on usage.

The transceiver is an essential constituent of a wireless sensor node that operates at a specific frequency for data communication that is sensitive to several environmental conditions. While designing electronic transceiver circuits, number of powers saving technique should be used. In reducing power consumption first step that should be used is selecting right components and applying appropriate design techniques to each case. Another important goal for routing protocol design is to keep sensors operating for so long as possible to extend network lifetime. Energy consumption of sensors is dominated by data transmission and reception.

Recent advances in embedded systems and wireless sensor networks made it possible to realize low-cost monitoring applications and automation systems for smart grids. Therefore, Section 3.6 has presented WSNs for smart grid applications. Wireless sensor networks and applications aim to provide a reference tool for the increasing number of scientists who depend on reliable sensor networks. Many environmental science applications have been implemented for the wireless sensor networks technology. Most of them have similar requirements such as remote access, storage, reliable data collection and real-time viewing. An intelligent and smart wireless sensor network system can gather and process a large amount of data from the beginning of the monitoring and manage air quality, conditions of traffic, to weather situations. All the industrial monitoring applications were reviewed and explained.

WSNs are small devices that collect and transmit data, and are often placed in remote areas with the capability to extract energy management from ambient sources to last long periods of time with solar panel system and a supercapacitor. Therefore, I have put together four transmitter nodes that monitor and examine the environment and a receiver sensor node that collects data and sends to computer program via the RS232 port. The communication module is an RF module a wireless transmitter unit with an antenna. Data and control unit consists of a PIC microcontroller 16F886. Power module consists of a 9V camera battery, two unique voltage regulators, and an RS232 unit. Sensor module consists of temperature, humidity, pressure and a light unit. Sensor data is collected on transmitter nodes are send over to receiver node via RF. Hardware platforms are developed using to validate a generalized architecture that is technology independent. The general architecture contains a single central controller that performs application and protocol level processing. For flexibility, this controller is directly connected to RF transceiver. For efficiency, the controller is supported by a collection of hardware accelerators that provide basic communication primitives that can be flexibility composed of application-specific protocols.

This study reviews the utilization of renewable (solar) energy to enhance the life of the WSNs in environmental applications. I have showed that design, testing, and successful development of a PIC-Controlled renewable energy unit with a supercapacitor, and a rechargeable battery. I have also presented a new renewable powered model for the rapid prototyping of wireless sensor networks. The platform was developed as a tool for developers of WSN. Solar energy clearly outperforms batteries outdoors and can be an alternative indoors.

For nodes operating continuously, only outdoor solar power can offer a suitable solution whenever small size is required. The goal of collecting energy from the solar panel by using energy storage components for increasing the efficiency is achieved. Designed WSN was implemented using energy collection, energy storage, delivery energy and energy consumption. Energy schema consists of the solar array which extracts as much energy as possible delivers it to the storages such as batteries and supercapacitor. WSN features the ability to harvest available solar energy from the outdoor environment and deliver this energy to the supercapacitor and battery storage devices.

WSN provides a potential technique for monitoring the environment. I have presented a building monitoring system based on Wireless Sensor Networks. In WSNs, the microcontrollers need the operating system to perform the specified tasks, in other words, PIC microcontroller must be coded. The software (operating system) that runs on microcontroller was written in PIC-C language, and it could be adapted for different routing algorithms and sensor types. It is very important that data can be observed instantaneously and recorded to the database on wireless sensor networks. Therefore, I have developed a real-time monitoring software for this purpose. Data obtained from WSNs were stored in certain centers. Through these centers, obtained data could be observed and processed. Observation software had developed for sensor nodes. With developed software, data could be observed and stored.

In order to design WSNs, in fact, the most suitable technology to be used and implemented such as topology, routing and communication protocols, signal processing and power consumption strategies, etc. must be designed. These choices depend on different factors, above all the application requirements. In this thesis, all of the factors are considered for developing the wireless sensor network nodes.

Different wireless communication standards and features suitable for a WSN system. to reduce cabling costs, WSNs are widened the field of environments feasible for monitoring. Therefore, to add sensing and acting capabilities to objects in the environmental world and allow for communication with objects and services in the future WSNs. Recent advances in standards-based WSN protocols for industrial control applications have come a long way to solving many of the challenges facing practical WSN deployments.

Routing in sensor networks have been an essential subject in the recent years and introduced unique challenges compared with traditional data routing in wired networks. In WSNs, transport protocols are an important design issue in providing end to end communication with congestion control. TCP is not able to provide reliable data transport in sensor networks due to limited IP capacity and so much energy consumption. A reliable transport protocol for sensor networks is required to be generic, lightweight, and not dependent upon existing lower layer protocols. Power usage, Data Aggregation, Multipath, Query-based and QoS, since these are an essential consideration for routing protocols in terms of energy saving and traffic optimization in the wireless sensor network.

The power cost of the communication of the data is main problems of a WSNs. It is essential to design a network that uses optimal energy resources with its limitations. Energy consumption of sensors is dominated by data transmission and reception. Therefore, routing protocols designed for wireless sensor networks should be energy efficient to prolong the lifetime of sensors and network lifetime.

According to thesome scientist's experimental reports, asymmetric operations take a lot of execution time which affects the energy consumption of nodes. Asymmetric algorithms are not appropriate for WSNs, because of the necessity of storing two keys and two different algorithms for encryption and decryption. Therefore, symmetric algorithms are obviously for WSNs: It is only necessary to store one single key which is used for encryption and decryption and the algorithm code can be held very small, because of the similarity of the encryption and decryption functions.

Using the renewable energy sources (solar panel, rechargeable battery) can contribute to the enhancement of data security in wireless sensor networks. Asymmetric cryptology cannot be used in wireless sensor networks because of the high energy consumption. Finding problems with energy consumption makes it easier to use asymmetric algorithms in sensor networks, which increases network and data safety.

This thesis presents a building monitoring system based on wireless sensor networks. In WSNs, microcontrollers need the operating system to perform the specified tasks, in other words, PIC microcontroller must be coded accordingly. An operating system runs on microcontroller have been written in PIC-C language, and it could be adapted for different routing algorithms and sensor types. It is very important that data can be observed instantaneously and recorded to the database on wireless sensor networks. Data obtained from WSNs were stored in certain centers. Observation software has developed for wireless sensor nodes. With developed software, data could be observed and stored.

In this thesis, software issues are examined under two headings. One of this computer software that will monitor the PIC sensor nodes and collect and record the data from sensor nodes, the other small embedded PIC operating system (software) that control and manage wireless sensor nodes. The operating system has developed using PIC-C language for all wireless sensor nodes. The sensor node operating system was responsible to determine routing algorithm and MAC protocol, sending data retrieval, data processing, reading data from analog and digital sensors and memory management, communications between sensor nodes etc.

I have developed a software on the Microsoft Visual Studio and C # language to monitor and save the data in the database. With developed software, data could be observed and stored. Communication between computer observation software and wireless sensor nodes was carried out through RS232 to USB interface. Data collected from the network is stored for later processing purposes.

To make a concluding remarks, there are some intended targets are realized and concluded in this thesis, including the followings. First, the sensing tasks and the potential sensor networks applications have explored, and a review of factors influencing the design of sensor networks have provided. Then, the communication architecture for sensor network has outlined. Besides, new hardware architecture has designed to make it possible for a single node to communicate with WLAN. This thesis has introduced a new method of using the power of WSNs. The results of the thesis would be helpful for the development of WSN with, especially renewable energy sources.

In this thesis, WSN has examined in terms of the analytical and applied science. Studies have conducted on wireless sensor networks based on the realization of low energy and maximum safety principle. After completion of the wireless sensor network system; Energy consumption and network location behavior of wireless sensor nodes have tested and analyzed. The relationship between low energy consumption and sensor nodes have evaluated.

Decision-making has created the software algorithm and hardware modules for the implementation of decisions taken by the developed sensor nodes. Developed PIC-Based sensor nodes have supported a unique external PIC-Controlled voltage unit with renewable energy sources such as solar panel, rechargeable battery, and supercapacitor for energy production and energy-saving. Developed wireless sensor network system that can be used in industrial applications and daily life applications such as smart factories and smart homes. WSNs can be designed to be used in a wide range.

In conclusion, the following 4 major goals are achieved in this study;

Developed PIC-Based wireless sensor nodes with ultra-low power consumption

Developed a unique PIC-Controlled power module along with integrated renewable energy.

Developed a software for monitoring system and recording data to the database.

Developed a decision-making in software and hardware for the implementation of decisions taken by the developed sensor nodes.

REFERENCES

[1] I. Banerjee, S Das, H Rahaman, and B. K. Sikdar (2007) “CA Based Sensor Node Management Scheme: An Energy-Efficient Approach. International Conference on Wireless Communications”. Networking and Mobile Computing, WiCom, Taiwan, pp: 2795 - 2798.

[2] A.K. Dwivedi and O.P. Vyas (2011) “Wireless Sensor Network: At a Glance”. DOI: 10.5772/19005 Source: InTech, MATS University, India, pp: 300.

[3] K. Chang (2000) “RF and Microwave Wireless Systems”. Texas A&M University, ISBN: 0-471 35199-7, John Wiley & Sons, Ltd., USA, pp: 149-171.

[4] T. Agarwal (2014) **“**Design and Analysis of Various Wireless Communication Modules”. https://www.efxkits.co.uk/wireless-communication-transmitter-and-receiver-modules/,

[5] GreenPeak Technologies (2015) “Wireless Communication Standards”. 20 March, http://www.epdtonthenet.net/article/91316/Wireless-communication-standards-for-the-IoT.aspx

[6] F. Akyildiz, W. Su, Y. Sankarasubramaniam and E. Cayirci (2009) “A Survey on Sensor Networks”. IEEE Communications Magazine 40(8), USA, pp: 102–114.

[7] F. Akyildiz and V. C. Vuran (2010) “Communication and Networking in Wireless Sensor Networks”. ISBN 978-0-470-03601-3 (H/B), Georgia Institute of Technology, USA, pp: 12.

[8] P. Kuila and P. K. Jana (2014) “A Novel Differential Evolution Based Clustering Algorithm for Wireless Sensor Networks”. Department of Computer Science and Engineering, Indian School of Mines, Dhanbad, India, pp:415, http://dx.doi.org/10.1016/j.asoc.2014.08.064

[9] Courtesy of Shenyang Institute of Automation (2014) “Internet of Things Wireless Sensor Networks”. Shenyang, China, pp: 28.

[10] C. Fötschl and S. Rainer (2006) “Security versus Power Consumption in Wireless Sensor Networks” School of Information Science, Computer, and Electrical Engineering Halmstad University, Master’s Thesis in Computer Engineering, IDE0601, pp: 11-14

[11] T.E. Kalaycı (2009) “Kablosuz Sensör Ağlar ve Uygulamaları”, Harran Üniversitesi, Akademik Bilişim 2009, Şanlıurfa, Türkiye, pp: 197.

[12] I. Galarraga (2013) “Power Supply of WSN, How to Series M2M and IOT”. Now. 22nd, http://www.farsens.com/en/2013/11/22/series-introduction-batteries-wireless-sensor-networks/

[13] J. Hao, J. Brady, B. Guenther, J. Burchett, M. Shankar and S. Feller (2006) “Human Tracking with Wireless Distributed Pyroelectric Sensors”. IEEE Sensors, pp: 1683–1696.

[14] C. Lynch and F. O’ Reilly (2005) “Processor Choice for Sensor Networks. In Workshop on Real World Wireless Sensor Networks”.

[15] E. Egea-Lopez, J. Vales-Alonso, A. S. Martinez-Sala, P. Pavon-Mariño and J. Garcia-Haro (2006) ‘‘Simulation Scalability Issues in Wireless Sensor Networks’’. IEEE Communications, Spain, pp: 64.

[16] C. Uimer (2000) “Wireless Sensor Networks. Georgia Institute of Techn.”. Available: www.craigulmer.com/portfolio/unlocked/000919_sensorsimii/wireless_sensor_networks.ppt

[17] A. E. Kateeb, A. Ramesh and L. Azzawi (2008) “Wireless Sensor Nodes Processor Architecture and Design”. Advanced Information Networking and Applications Workshops, International Conference on, vol. 0, USA, pp: 892–897.

[18] M. A. Taleghan, A. Taherkordi, M. Sharifi and T.H. Kim, (2007) “A Survey of System Software for Wireless Sensor Networks”. Future Generation Communication and Networking, vol. 2, DOI: 10.1109/FGCN.2007.44 · Source: IEEE Xplore, Korea, pp. 402–407.

[19] A. F. Kiremitçi (2007) “USB-PC Data Transfer Interface Implementation with PIC18F4550”. Master Thesis, Ataturk University, Institute of Natural Sciences, Department of Electrical and Electronic Engineering, Erzurum, pp: 3-58.

[20] B. Ovalı and T. Uzun (2005) “Wireless RS232 Communication Through a Radio Modem Study”. 11. Electrical, Electronic and Computer Eng. National Congress, Istanbul, pp: 243.

[21] **B.** Lo and G. Z. Yang (2005) "Architecture Body for Sensor Networks". Conference or workshop paper perspective in pervasive computing, London-England, pp: 23-28.
[22] B. B. Suyabatmaz (2006) "Development Board Transceiver Design for Wireless Data Transmission". Gebze Institute of Tech. and Institute of Eng. and Science, Izmir, pp: 26-39.
[23] J. S. Lee and Y.C. Huang (2006) "ITRI ZBnode: A ZigBee/IEEE 802.15.4 Platform for Wireless Sensor Networks". IEEE Conference on Systems, Man, and Cybernetics October 8-11, Taipei-Taiwan, pp: 15 – 20.
[24] Y. Cetin (2008) "ATO and ATC Systems for Railways". Inonu University, Institute of Science and Technology, Malatya, pp: 37-100.
[25] S. S. Aslan (2006) "Computer Controlled Robot Car". Instıtute Of Natural and Applied Sciences University of Cukurova, Adana, pp: 24-36.
[26] K. Hovasapian and N. Agarwal (2004) "A Low Power Modular Wireless Sensor Network". Department of Electrical and Computer Engineering University of Nevada, Las Vegas-United States of America, pp: 5-39.
[27] C. Lynch and F. O'Reilly (2004) "PIC Based Sensor Operating System". Irish Signals and Systems Sonference, Belfast-Ireland, pp: 237.
[28] T. Voigt, H. Ritter and J. Schiller (2006) "Utilizing Solar Power in Wireless Sensor Networks". Freie Universität, Institut für Informatik, Berlin, Germany, pp: 1-9
[29] T. Soylu (2012) "Wireless Sensor Networks Applications and Design of Sensor Node". Trakya University, Institute of Science, Master thesis, Trakya, Turkey, pp:144.
[30] O. Ozcan (2011) "PIC Based Sensor for Wireless Sensor Network Node Design". Selcuk University, Institute of Science, Master Thesis, Konya, Turkey, pp: 29.
[31] L. Ma, J. Yan, S. Yan, B. Wang, K. Liao, and J. Wang (2014) "A Study of Agricultural Meteorological Monitoring System Based on Wireless Sensor Network". International Journal of Multimedia and Ubiquitous Engineering, Vol.9, No.7, pp:15-26, http://dx.doi.org/10.14257/ijmue
[32] R. Pitarma, G. Marques, and F. Caetano (2016) "Monitoring Indoor Air Quality to Improve Occupational Health". Springer International Publishing, Á. Rocha et al. (eds.), New Advances in Information Systems and Technologies, Advances in Intelligent Systems and Computing 445, DOI 10.1007/978-3-319-31307-8_2.
[33] Y. Y. Kardas (2014) "GSM Based Smart Home Application". Master Thesis, Dicle University, Electric-Electronic Department, Turkey, pp: 20.
[34] M. Shaker, A. Imran, "Greenhouse Micro Climate Monitoring Based on WSN with Smart Irrigation Technique". World Academy of Science, Engineering and Technology International Journal of Electrical, Computer, Energetic, Electronic and Communication Engineering Vol:7, Iraq, pp: 1567, No:12, 2013, scholar.waset.org/1999.5/9996619.
[35] B. P. Ladgaonkar and A. M. Pawar (2011) "Sensor Node for Monitor Humidity of High-Tech Polyhouse Environment". Embedded Technology and Instrumentation Laboratory, International Journal of Advances in Engineering & Technology, ISSN: 2231-1963.
[36] S. A. Agarkar, K. D. Kulat and R. V. Kshirsagar (2010) "WSN based Low Cost and Low Power EPM Design and Field Micro-Climate Analysis using Embedded Controllers", International Journal of Computer Applications (0975 – 8887), Volume 12– No.6.
[37] Q. Haija, H. Qadeeb and A. Lwaimi (2013) "Monitoring of AIR quality in King Faisal University using a microcontroller and WSN". The 4th International Conference on Emerging Ubiquitous Systems and Pervasive Networks, Procedia Computer Science 21, pp: 519.
[38] A. Ghobakhlou, T. A. S. A. Perera, P. Sallis, O. Diegel and S. Zandi (2010) "WSN Based Environmental Monitoring Sensor Node System". Geoinformatics Research Centre, Auckland University of Technology, Auckland, New Zealand.

[39] N. R. Mohanty and C. Y. Patil (2013) "Wireless Sensor Networks Design for Greenhouse Automation". Department of Instrumentation and control, College of Engineering, International Journal of Engineering and Innovative Technology (IJEIT) Volume 3, Issue 2, pp: 259.
[40] A. Lambebo and S. Haghani (2014) "A Wireless Sensor Network for Environmental Monitoring of Greenhouse Gases". ASEE 2014 Zone I Conference, University of Bridgeport, Bridgeport, CT, USA, pp: 2-3.
[41] W. S. Mohan and R. J. Devi (2014) "Monitoring of Geological CO2, based on Wireless Sensor Networks". ISSN: 2277-9655, International Journal of Engineering Sciences & Research, Technology, India, pp: 599, http://www.ijesrt.com/
[42] P. V. Raju, R. V. R. S. Aravind, B. S. Kumar (2013) "Pollution Monitoring System Using Wireless Sensor Network in Visakhapatnam". ISSN: 2231-5381, International Journal of Engineering Trends and Technology (IJETT) - Volume4, Issue4- April, pp:594, http://www.ijettjournal.org
[43] S. B. Tayade, D. S. Chandak and P. S. Choudhari (2015) "Real-Time Monitoring of Geological CO2 Storage and Leakage Using Wireless Sensor Network. Geological CO2 Leakage Monitoring Equipment Based on Wireless Sensors", e-ISSN: 2394 – 3343, p-ISSN: 2394 – 5494, Volume 2, Issue 6, pp: 18-19.
[44] G. Panic, O. Stecklina and Z. Stamenkovic (2016) "An Embedded Sensor Node Microcontroller with Crypto-Processors". Sensors, 16, 607; DOI:10.3390/s16050607, pp: 13, http://www.mdpi.com/journal/sensors
[45] M. Martino and J. Varley (2012) "A Wireless Sensor Node Powered by a PV/SuperCapacitor/Battery Trio". The Edward S. Rogers Sr., Department of Electrical and Computer Engineering, University of Toronto, ECE496Y Design Project Course, Canada, pp:6.
[46] S. E. Jero, A. B. Ganesh and T. K. Radhakrishnan (2011) "An Implementation of WSN Node for Detection of Gaseous Substances Leakage". International Journal on Smart Sensing and Intelligent Systems VOL. 4, NO. 3, 2011, India, pp: 489.
[47] P. V. Mane-Deshmukh, B. P. Ladgaonkar, S. C. Pathan and S. S. Shaikh (2013) "Microcontroller Pic 18f4550 Based Wireless Sensor Node to Monitor Industrial Environmental Parameters". International Journal of Advanced Research in Computer Science and Software Engineering, ISSN: 2277 128X, Volume 3, Issue 10, India, pp: 944-945.
[48] H. Ghayvat, S. Mukhopadhyay, X. Gui, N. Suryadevara (2015) "WSN and IoT-Based Smart Homes and Their Extension to Smart Buildings". Sensors, 15, 10350-10379; DOI:10.3390/s150510350, ISSN 1424-8220, pp: 10357-10358, www.mdpi.com/journal/sensors
[49] A. Haktan (2010) "Smart Home Applications for Disabled People using Wireless Sensor Network". Yeditepe University, Faculty of Engineering and Architecture, Department of Computer Engineering, Turkey, pp: 41.
[50] R. Vaish (2009) "Application of Wireless Sensor Networks for Environmental Monitoring & Development of an Energy-Efficient Hierarchical Cluster-based Routing". Electrical Engineering Department, National Institute of Tech., Rourkela 769008, pp: 39-41.
[51] M. Toledano-Ayala, G. Herrera-Ruiz, G. M. Soto-Zarazúa, E. A. Rivas-Araiza, R. D. B. Trujillo and R. E. Porrás-Trejo (2011) "Long-Range Wireless Mesh Network for Weather Monitoring in Unfriendly Geographic Conditions". Sensors, 11, 7141-7161DOI:10.3390/s110707141, ISSN 1424-8220, pp: 7149 www.mdpi.com/journal/sensors
[52] J. Lozano, J. I. Suárez, P. Arroyo, J. M. Ordiales and F. Alvarez (2012) "Wireless Sensor Network for Indoor Air Quality Monitoring". The Italian Association of Chemical Engineering, Online at: www.aidic.it/cet, AIDIC Servizi S.r.l., ISBN 978-88-95608-21-1; ISSN 1974-9791, VOL. 30, pp: 322-323.
[53] N. Gahlot, V. Gundkal, S. Kothimbire, A. Thite (2015) "Zigbee Based Weather Monitoring System". The International Journal of Engineering and Science (IJES), Volume 4, Issue 4, Pages PP.61-66, ISSN (e): 2319 – 1813 ISSN (p): 2319 – 1805, India, pp: 65.

[54] M. Varchola and M. Drutarovsky (2007) "Zigbee Based Home Automation Wireless Sensor Network". Electronics and Multimedia Communications, Technical University of Košice, Acta Electrotechnica et Informatica No. 4, Vol. 7, Slovak Republic, pp: 1-7.
[55] J. Maloco (2010) "Design of a Wireless Sensor network for Housing Community". National University of Ireland, Department of Electronic Engineering, Faculty of Science and Engineering, Ireland, pp: 91-110.
[56] Z. Hailin (2013) "Design and Implement of Wireless Sensor Network's Data Publishing System". Blaise Pascal University, Harbin Institute of Technology, Dissertation for the Master's Degree in Engineering, pp: 62-74.
[57] M. Raghuvanshi (2006) "Implementation of Wireless Sensor Mote". Indian Institute of Technology, Department of Nuclear Engineering and Technology, India, pp: 57-73.
[58] P. Sausen, A. Sausen, F. Salvadori, R. E. Júnior and M. Campos (2012) "Development and Implemented of WSN Network for the Electricity Substation Monitoring". Regional University of Northwestern Rio Grande do Sul State, Brazil.
[59] S. P. Nayse and M. Atique (2014)" A Design of Application Based Wireless Sensor Node". Position papers of the 2014 Federated Conference on Computer Science and Information Systems, DOI: 10.15439/2014F508, ACSIS, Vol. 3, pp. 177–181.
[60] A. E. Tumer (2011) "Development of Energy Efficient Routing Protocols for Indoor Wireless Sensor Networks". Selcuk University, Turkey, pp:49-61.
[61] I.F. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci (2002)" A Survey on Sensor Networks". IEEE Com. Magazine, Computer Networks 38, USA, pp: 393–422.
[62] G. Gridling, B. Weiss (2007) "Introduction to Microcontrollers". Vienna University of Technology, Institute of Computer Engineering, Austria, pp: 5, 11, 28.
[63] A. S. Berger (2002) "Embedded Systems Design: An Introduction to Processes, Tools, and Techniques". ISBN: 1578200733, CMP Books, pp: 4, 90, 9.
[64] http://www.robotplatform.com/knowledge/sensors/robot_sensors.html, 2018.
[65] IEEE Std. 802.11, Part 11 (1999) "Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications". New York, USA.
[66] R. Kumar (2017) "3 Key Differences between OSI and TCP/IP Model". Technology and Networking, https://www.stemjar.com/osi-vs-tcp-ip-model/
[67] K. Akkaya and M. Younis (2005) "A Survey on Routing Protocols for Wireless Sensor Networks". Ad hoc Networks, vol. 3, no. 3, USA, pp: 325-349, www.elsevier.com/locate/adhoc
[68] J. N. Al-Karaki and A. E. Kamal (2006) "Routing Techniques in Wireless Sensor Networks: A Survey". Electrical and Computer Engineering, Lowa State University, pp: 7.
[69] LAN MAN Standards Committee of the IEEE Computer Society (1997) "Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specification, IEEE, New York, USA, IEEE Std 802.11-1997 edition.
[70] M. Hempstead, N. Tripathi, P. Mauro, Y. Wei and D. Brooks (2005) "An Ultra-Low-Power System Architecture for Sensor Network Applications". Architect News 33(2), USA, pp: 208–219.
[71] J. Hill, R. Szewczyk, A. Woo, S. Hollar, D. Culler and K. Pister (2000) "System Architecture Directions for Networked Sensors". In Architectural Support for Programming Languages and Operating Systems, USA, pp: 93–104.
[72] H. Liu, A. Chandra, and J. Srivastava (2005) "Dense: Data-driven stochastic energy management for wireless sensor platforms". Minnesota, USA, http://www.cs.umn.edu/tech reports upload/tr2005/05-018.pdf
[73] J. Polastre, J. Hill and D. Culler (2004) "Versatile Low Power Media Access for Wireless Sensor Networks". Second ACM Conference on Embedded Networked Sensor Systems, USA.
[74] V. Tiwari, S. Malik, and A. Wolfe (1994) "Compilation techniques for low energy: An Overview". In Proc. of Symp. Low-Power Electronics.

[75] M. A. Razzaque and S. Dobson (2014) "Energy-Efficient Sensing in Wireless Sensor Networks Using Compressed Sensing". Sensors 2014, 14, 2822-2859; doi:10.3390/s140202822, ISSN 1424-8220, Scotland, UK, www.mdpi.com/journal/sensors
[76] V. K. Sachan, S. A. Imam, and M. T. Beg (2012) "Energy-efficient Communication Methods in Wireless Sensor Networks: A Critical Review". International Journal of Computer Applications (0975 – 8887), Volume 39– No.17, India, pp:41-44.
[77] J. Micek and M. Kochlan (2014) "Energy-efficient Communication Systems of Wireless Sensor Networks". Department of Technical Cybernetics, Faculty of Management Science and Informatics, Žilinská univerzita v Žiline Univerzitná 8215/1, 010 26 Žilina, Slovakia, pp: 73.
[78] G. Lu, B. Krishnamachari and S. Raghavendra (2006) "An Adaptive Energy-Efficient and Low-Latency MAC for Data Gathering in Sensor Networks". 0-7695-2132-0/04/$17.00 (C) 2004 IEEE, USA, pp: 1-8.
[79] H. Mandyam and A. Goldsmith (2001) "Capacity of Finite Energy Channels". Proc. Allerton Conf. Commun. Cntl. Comp., Department of Electrical Engineering Stanford University, CA 94305, USA.
[80] Y. Yuan, Z. He and M. Chen (2006) "Virtual MIMO Based Cross-Layer Design for Wireless Sensor Networks". IEEE Transactions on Vehicular Tech., Vol.55, pp: 856-864.
[81] Courtesy of Shenyang Institute of Automation (2014) "Internet of Things: Wireless Sensor Networks, White paper". Shenyang, China, pp: 22.
[82] Energy harvesting block diagram (2014) Texas Instruments Company, http://www.hlxec.com/apply.asp
[83] A. Bayo, D. Antolin, N. Medrano, B. Calvo and S. Celma (2010) "Early Detection and Monitoring of Forest Fire with a Wireless Sensor Network System". Procedia Engineering 5, Austria, pp: 248–251.
[84] WaterSense Company (2018) "WSN in agriculture by WaterSense Company" http://www.projectwatersense.nl/
[85] R. Zviedris, A. Elsts and G. Strazdins (2009) "LynxNet: Wild Animal Monitoring Using Sensor Networks". Nr. 2009/0138/1DP/1.1.2.1.2/09/IPIA/VIAA/004, pp: 1-4.
[86] A. Mainwaring, J. Polastre, R. Szewczyk, D. Culler and J. Anderson (2002) "Wireless Sensor Networks for Habitat Monitoring". ACM 1581135890/02/0009, USA, pp:1-10.
[87] A. Awang and M.H. Suhaimi (2007) "A Forest Monitoring System Using Wireless Sensor Networks". International Conference on Intelligent and Advanced Systems 2007, 1-4244-1355-9/07/$25.00 @2007 IEEE, pp: 1101-1106.
[88] Y. G. Sahin (2007) "Animals as Mobile Biological Sensors for Forest Fire Detection". Sensors 2007, 7, 3084-3099, ISSN 1424-8220, Turkey, pp: 3084-3097.
[89] Z. Sun, P. Wanga, M. C. Vuran, M. A. Al-Rodhaan, A. M. Al-Dhelaan and F. Akyildiz (2011) "BorderSense: Border Patrol through Advanced Wireless Sensor Networks". Ad Hoc Networks 9, pp: 468–477.
[90] S. Prasanna and S. Rao (2012) "An Overview of Wireless Sensor Networks Applications and Security". International Journal of Soft Computing and Engineering, ISSN: 2231-2307, Volume-2, Issue-2, pp: 538-540.
[91] Y. Ma, M. Richards, M. Ghanem, Y. Guo and J. Hassard (2008) "Air Pollution Monitoring and Mining Based on Sensor Grid in London". Sensors, Vol. 8(6), ISSN 1424-8220, London, England, pp: 3601-3623.
[92] Anusha1 and B. Jeyaraman "Online Monitoring of Geological Co2 Storage and Leakage Based on Wireless Sensor Networks". International Journal of Modern Engineering Research (IJMER), International Conference on Advances in Eng. Management (ICAEM), pp: 54-61.
[93] L. T. Kohn, J. M. Corrigan and M. S. Donaldson (2000) "To Err Is Human: Building a Safer Health System", Institute of Medicine, Committee on Quality of Health Care in America, NATIONAL ACADEMY PRESS, Washington, D.C. 1999, pp: 1-35.

[94] G. Ramamurthy and S. Nanda (2013) “Mobile Wireless Sensor Networks: Healthcare in Hospitals”. International Conference on eHealth, Telemedicine, and Social Medicine (eTELEMED 2013), Report No: IIIT/TR/2013/-1, India, pp: 1-6.
[95] C. Park and P. H. Chou (2006) "AmbiMax: Autonomous Energy Harvesting Platform for Multi-Supply Wireless Sensor Nodes". Proc. SECON, vol1. 1, pp: 168-177.
[96] T. E. Kalaycı (2009) “Wireless Sensor Networks and Applications”, Harran Üniversity, Akademik Bilişim, Şubat 2009, Şanlıurfa, Turkey, pp: 37-46.
[97] MICROCHIP Technology Inc. (2009) “PIC16F882/883/884/886/887 Data Sheet, 28/40/44-Pin, Enhanced Flash-Based 8-Bit CMOS Microcontrollers with nanowatt”, page 4.
[98] DHT11 Humidity & Temperature Sensor (2010) “D-Robotics UK, DHT11 Temperature & Humidity Sensor features a temperature & humidity sensor complex with a calibrated digital signal output”. D-Robotics, 7/30/2010, pp: 3. www.droboticsonline.com
[99] Texas Instruments (2016) “LM35 Precision Centigrade Temperature Sensors” SNIS159G –AUGUST 1999–REVISED, pp: 1.
[100] HANWEI Electronics Co. (2017) LTD., MQ-2, http://www.hwsensor.com/, pp: 1.
[101] RS Components (1997) “RS Data Sheet”. NORP12 RS stock number 651-507 NSL19-M51 RS stock number 596-141, PO Box 99, Corby, Northants, NN17 9RS, pp: 1.
[102] RF wireless receiver and transmitter (2011) “433MHZ DC5V (ASK /OOK)”. pp:1.
[103] Electronics-DIY.com (2011) “RF wireless receiver and transmitter” (2011) http://electronics-diy.com/arduino-rf-link-using-433mhz-transmitter-receiver-modules.php
[104] SHENZHEN EONE Electronics Company Ltd. (2009) “1602A-1 LCD Module Specification” Ver1.0, pp: 1-12.
[105] Yueqing Hengwei Electronics (2007) “JQC-3FC/T73 PCB Relay Datasheet”. pp:1, www.chinahwe.net
[106] MAX232 and RS232 Circuit diagram (2018) “TTL to RS232 Converter”. http://www.robotizando.com.br/artigo_conversor_ttl_pg1.php
[107] Semiconductor Components Industries LLC. (2016) Literature Distribution Center for ON Semiconductor, JRev. 14, Publication Order Number: LM317/D, Colorado, USA,
[108] M. R. Johnson, I. You and E. You (2010) “Energy Harvesting and Power Balance in Wireless Sensor Networks”. http://archive.rtcmagazine.com/articles/view/101631
[109] Microchip PIC16F716 (2007) “8-bit Flash-based Microcontroller with A/D Controller and Enhanced Capture/Compare PWM”. DS41206B, pp: 1-2.
[110] CCS Custom Computer Software Inc. (2018) “CCSLOAD - CCS Programmer Control Software”. http://www.ccsinfo.com/content.php?page=ccsloadsw
[111] Microchip Company Inc (2006) “US-BURN BRENNER 8 of the Microchip Company”.
[112] M. Johnson, M. Healy, P. Ven, M. J. Hayes, J. Nelson, T. Newe and E. Lewis (2009) “A Comparative Review of Wireless Sensor Network Mote Technologies”. 2009 IEEE SENSORS, 25-28 October 2009, Christchurch, New Zealand, pp: 1440.
[113] J. Beutel (2006) “Metrics for Sensor Network Platforms. Proceedings of ACM Workshop on Real-World Wireless Sensor Networks” (REALWSN’06), New York, pp: 26-30.
[114] C. Gray and L. Campbell (2016) “Towards an energy-efficient Internet of Things”, 26th International Telecommunication Networks and Applications Conference (ITNAC), University of Melbourne, 978-1-5090-0919-0/16/$31.00 ©2016 IEEE, Australia, pp: 29.
[115] M. A. Ameen, S. M. R. Islam and K. Kwak (2010) “Energy SavingMechanisms for MAC Protocols in Wireless Sensor Networks”. Hindawi Publishing Corporation, International Journal of Distributed Sensor Networks, DOI:10.1155/2010/163413, UWB-ITRC Wireless Communications Research Center, Inha University, Page 6, Republic of Korea, pp: 1-13.
[116] Xu-Xun Lui (2012) “A Survey on Clustering Routing Protocols in Wireless Sensor Networks”. Sensors 2012, 12, doi:10.3390/s120811113, ISSN 1424-8220, pp: 11113-11153.

Appendix A: Receiver Sensor Node's PIC-C Language Codes

Receiver Sensor Node's operating system has been developed by using PIC-C programming language. The developed PIC16F886 receiver operating system (codes) are presented below as appendix of the thesis.

```
#include <16f886.h>
#fuses HS, NOWDT, NOPUT, MCLR, PROTECT, CPD, NOBROWNOUT, NOIESO,
NOFCMEN, NOLVP, NODEBUG
#use delay (clock=16000000)
#use fast_io(a)
#use fast_io(b)
#use fast_io(c)
#define RX_PIN    PIN_C7
#define LED_PIN    PIN_A2
#define OUT1_PIN    PIN_C0
#define OUT2_PIN    PIN_C1
#define OUT3_PIN    PIN_C2
#define OUT4_PIN    PIN_C3
#use rs232 (baud=9600, xmit=PIN_C6, parity=N, stop=1)//timeout=1)

unsigned int8 data=0;
unsigned int8 id=0;
unsigned int8 ADC1=0; //LDR
short ADC1done=false;
unsigned int8 ADC2=0; //MQ2
short ADC2done=false;
unsigned int8 ADC3=0; //LM35
short ADC3done=false;
float TempADC3=0;
unsigned int8 DHT11rhHIGH=0, DHT11rhLOW=0, DHT11tempHIGH=0,
DHT11tempLOW=0;
short DHT11rhHIGHdone=false, DHT11rhLOWdone=false, DHT11tempHIGHdone=false,
DHT11tempLOWdone=false;
void main()
{

  setup_wdt(WDT_OFF);
  setup_timer_1(T1_DISABLED);
```

```
setup_timer_2(T2_DISABLED,0,1);
setup_CCP1(CCP_OFF);
setup_CCP2(CCP_OFF);
setup_spi(SPI_DISABLED);
setup_comparator(NC_NC_NC_NC);
setup_adc(ADC_OFF);

output_drive(LED_PIN);
output_drive(OUT1_PIN);
output_drive(OUT2_PIN);
output_drive(OUT3_PIN);
output_drive(OUT4_PIN);
output_drive(PIN_C6);
output_low(LED_PIN);
output_low(OUT1_PIN);
output_low(OUT2_PIN);
output_low(OUT3_PIN);
output_low(OUT4_PIN);

printf("MCU CLOCK SPEED %luHz\r\n",getenv("CLOCK"));
printf("RECEIVED DATA\r\n");

  while(TRUE){
      output_high(LED_PIN);

      if(id==5) {ADC1done=true; ADC1=data;}
      else if(id==6) {ADC2done=true; ADC2=data;}
      else if(id==7) {DHT11rhHIGHdone=true; DHT11rhHIGH=data;}
      else if(id==8) {DHT11rhLOWdone=true; DHT11rhLOW=data;}
      else if(id==9) {DHT11tempHIGHdone=true; DHT11tempHIGH=data;}
      else if(id==10) {DHT11tempLOWdone=true; DHT11tempLOW=data;}
      else if(id==11) {ADC3done=true; ADC3=data;}

      if(ADC1done){
        printf("ISIK DEGERi=%u\r\n",ADC1);
        ADC1done=false;
        if(ADC1<50) output_high(OUT1_PIN);
        else output_low(OUT1_PIN);
      }
```

```
      if(ADC2done){
        printf("GAZ DEGERi=%u\r\n",ADC2);
        ADC2done=false;
        if(ADC2>75) output_high(OUT2_PIN);
        else output_low(OUT2_PIN);
      }

      if(ADC3done){
        TempADC3=(float)ADC3*1.960784313725490196;
        printf("ISI DEGERi=%f\r\n",TempADC3);
        ADC3done=false;
        if(TempADC3>35) output_high(OUT3_PIN);
        else output_low(OUT3_PIN);
      }

      if(DHT11rhHIGHdone && DHT11rhLOWdone && DHT11tempHIGHdone &&
DHT11tempLOWdone){
        printf("NEM DEGERi RH:%u.%u Temperature:%u.%u\r\n", DHT11rhHIGH,
DHT11rhLOW, DHT11tempHIGH, DHT11tempLOW);
        DHT11rhHIGHdone = false;
        DHT11rhLOWdone = false;
        DHT11tempHIGHdone = false;
        DHT11tempLOWdone = false;
        if(DHT11rhHIGH>60) output_high(OUT4_PIN);
        else output_low(OUT4_PIN);
      }

      output_low(LED_PIN);
    }

    {
      printf("MANCHESTER RX CRC ERROR\r\n");
    }
  }
```

Appendix B: Transmitter Sensor Node's PIC-C Language Codes

Developed PIC16F886 Transmitter Sensor Node's operating system (codes) are shown in the following lines. Software codes can be changed according to sensor types or various usage purposes if needed.

```
#include <16f886.h>
#device ADC=8
#fuses HS, NOWDT, NOPUT, MCLR, PROTECT, CPD, NOBROWNOUT, NOIESO,
NOFCMEN, NOLVP, NODEBUG

#use delay (clock=16000000)
#use fast_io(a)
#use fast_io(b)
#use fast_io(c)

#define LCD_ENABLE_PIN PIN_C1
#define LCD_RS_PIN PIN_C0
#define LCD_RW_PIN FALSE
#define LCD_DATA4 PIN_C3
#define LCD_DATA5 PIN_C2
#define LCD_DATA6 PIN_C4
#define LCD_DATA7 PIN_C5
#define ADC_PIN PIN_A0
#define TX_PIN PIN_C6
#define LED_PIN PIN_A2
#define XMIT_PIN PIN_A1

#include <LCD_CGRAM_TR.C>
#use rs232 (baud=9600, xmit=XMIT_PIN, parity=N, stop=1)//timeout=1)
unsigned int8 transmit_data=0;
unsigned int16 SENDER_ID=11;
float Temp=0;

void main()
{

  setup_wdt(WDT_OFF);
  setup_timer_1(T1_DISABLED);
```

```
  setup_timer_2(T2_DISABLED,0,1);
  setup_CCP1(CCP_OFF);
  setup_CCP2(CCP_OFF);
  setup_spi(SPI_DISABLED);
  setup_comparator(NC_NC_NC_NC);

  output_drive(XMIT_PIN);
  output_drive(LED_PIN);
  output_drive(TX_PIN);
  output_float(ADC_PIN);
  output_low(LED_PIN);
  output_low(TX_PIN);

  setup_adc(adc_clock_div_32);
  setup_adc_ports(sAN0);
  set_adc_channel(0);
  delay_us(20);

  lcd_init();

  lcd_gotoxy(1,1);
  printf(lcd_putc,"ISI     35%cC",223);

  printf("MCU CLOCK SPEED %luHz\r\n",getenv("CLOCK"));

  while(TRUE){
    delay_ms(266);
    output_high(LED_PIN);
    transmit_data=read_adc();
    printf("SENDER ID=%lu LM35=%u\r\n",SENDER_ID,transmit_data);
    Temp=(float)transmit_data*1.960784313725490196;
    lcd_gotoxy(1,2);
    printf(lcd_putc,"Temp=%f%cC",Temp,223);
    output_low(LED_PIN);
  }
}
```

Appendix C: Developed Monitoring Software C# Language Codes

Developed application on the Microsoft Visual Studio C # language program codes are given in the following lines.

```
using System;
using System.Collections.Generic;
using System.ComponentModel;
using System.Data;
using System.Drawing;
using System.Linq;
using System.Text;
using System.Threading.Tasks;
using System.Windows.Forms;
using System.IO.Ports;
using System.Data.SqlClient;

namespace PICRecordData
{
    public partial class Form1 : Form
    {
        private SerialPort myport;
        private DateTime datetime;
        private string in_data;

        public Form1()
        {
            InitializeComponent();
        }

        #region dbOP

        string ConnStr = "Data Source=.;Initial Catalog=WSNdata;User Id=sa;Password=sasa;";
        public DataTable sc(string c)
        {
            DataTable dt = new DataTable();
            using (SqlConnection conn = new SqlConnection(ConnStr))
            {
                using (SqlDataAdapter adap = new SqlDataAdapter(c, conn))
                {
                    try
                    {
                        conn.Open();
                        adap.Fill(dt);
                    }
                    catch (Exception ex)
                    {
                    }
                }
            }
```

```
    return dt;
}

public int scn(string c)
{
    using (SqlConnection conn = new SqlConnection(ConnStr))
    {
        using (SqlCommand comm = new SqlCommand(c, conn))
        {
            try
            {
                conn.Open();
                return comm.ExecuteNonQuery();
            }
            catch (Exception ex)
            {
                return 0;
            }
        }
    }
}

#endregion

private void Myport_DataReceived(object sender, SerialDataReceivedEventArgs e)
{
    in_data = myport.ReadLine();
    this.Invoke(new EventHandler(displaydata_event));
}
private void displaydata_event(object sender, EventArgs e)
{
    datetime = DateTime.Now;
    string time = datetime.Hour + ":" + datetime.Minute + ":" + datetime.Second;

    if (in_data.Contains("Temperature:"))
    {
        //in_data = in_data.Replace("Temperature:", "").Substring(0, in_data.Length - 2);
    }

    data_tb.AppendText(time + "\t" + in_data + "\n");

    if (in_data.Contains("NEM"))
    {
        txt_Nem.AppendText(time + "\t" + in_data + "\n");
        scn("INSERT INTO Nem (Nem) VALUES ("+in_data.Substring(14,4)+")");
    }
    else if (in_data.Contains("ISI DEGER") )
    {
        txt_Tem.AppendText(time + "\t" + in_data + "\n");
        scn("INSERT INTO ISI (ISI) VALUES (" + in_data.Substring(11, 4) + ")");
```

```
    }
    else if (in_data.Contains("ISIK"))
    {
        txt_Isık.AppendText(time + "\t" + in_data + "\n");
        scn("INSERT INTO ISIK (ISIK) VALUES (" + in_data.Substring(12, 2) + ")");
    }
    else if (in_data.Contains("GAZ DEGER"))
    {
        txt_Gaz.AppendText(time + "\t" + in_data + "\n");
        scn("INSERT INTO GAZ (GAZ) VALUES (" + in_data.Substring(11, 2) + ")");
    }

}

private void start_btn_Click(object sender, EventArgs e)
{
    myport = new SerialPort();
    myport.BaudRate = 9600;
    myport.PortName = comboBox1.Text;
    myport.Parity = Parity.None;
    myport.DataBits = 8;
    myport.StopBits = StopBits.One;
    myport.DataReceived += Myport_DataReceived;

    try
    {
        myport.Open();
        data_tb.Text = "";
    }

    catch (Exception ex)
    {
        MessageBox.Show(ex.Message, "Hata");
    }

}

private void stop_btn_Click(object sender, EventArgs e)
{
    try
    {
        myport.Close();
    }
    catch (Exception ex2)
    {
        MessageBox.Show(ex2.Message, "Hata");
    }
}

private void save_btn_Click(object sender, EventArgs e)
```

```
        {
            try
            {
                string pathfile = @"D:\data\";
                string filename = "sensordata.txt";
                System.IO.File.WriteAllText(pathfile + filename, data_tb.Text);
                MessageBox.Show("Data saved to " + pathfile, "Save File");
            }
            catch (Exception ex3)
            {
                MessageBox.Show(ex3.Message, "Hata");
            }
        }
        private void Form1_Load(object sender, EventArgs e)
        {
            comboBox1.DataSource = SerialPort.GetPortNames();
        }
        private void btn_History_Click(object sender, EventArgs e)
        {
            Form2 frm = new Form2();
            frm.Show();
        }
    }
}
using System;
using System.Collections.Generic;
using System.ComponentModel;
using System.Data;
using System.Data.SqlClient;
using System.Drawing;
using System.Linq;
using System.Text;
using System.Threading.Tasks;
using System.Windows.Forms;

namespace PICRecordData
{
    public partial class Form2 : Form
    {
        public Form2()
        {
            InitializeComponent();
        }
        #region dbOP
        string ConnStr = "Data Source=.;Initial Catalog=WSNdata;User Id=sa;Password=sasa;";
        public DataTable sc(string c)
        {
            DataTable dt = new DataTable();
            using (SqlConnection conn = new SqlConnection(ConnStr))
            {
```

```
                using (SqlDataAdapter adap = new SqlDataAdapter(c, conn))
                {
                    try
                    {
                        conn.Open();
                        adap.Fill(dt);
                    }
                    catch (Exception ex)
                    {
                    }
                }
            }
            return dt;
        }
        public int scn(string c)
        {
            using (SqlConnection conn = new SqlConnection(ConnStr))
            {
                using (SqlCommand comm = new SqlCommand(c, conn))
                {
                    try
                    {
                        conn.Open();
                        return comm.ExecuteNonQuery();
                    }
                    catch (Exception ex)
                    {
                        return 0;
                    }
                }
            }
        }
        #endregion
        private void Form2_Load(object sender, EventArgs e)
        {
            DataTable dt_ISI = sc("SELECT Tarih,ISI FROM ISI");
            grd_ISI.DataSource = dt_ISI;
            DataTable dt_NEM = sc("SELECT Tarih,NEM FROM Nem");
            grd_NEM.DataSource = dt_NEM;

            DataTable dt_ISIK = sc("SELECT Tarih,ISIK FROM ISIK");
            grd_ISIK.DataSource = dt_ISIK;

            DataTable dt_GAZ = sc("SELECT Tarih,GAZ FROM GAZ");
            grd_GAZ.DataSource = dt_GAZ;
        }
    }
}
```

Appendix D: Voltage Module's Operating System PIC C Language Code

Designed Voltage Module's operating system has been developed using PIC-C language. PIC operating system was responsible for managing, collecting and controlling voltage. Developed PIC16F716 voltage controller operating system (C language codes) are shown in the following lines.

```
#include <16f716.h>
#fuses HS, NOWDT, NOPUT, NOBROWNOUT, BORV40, PROTECT
#use delay (clock=20000000)
#use fast_io(b)

unsigned int8 aku1=0,aku2=0,bak=0;

void main()

{

  setup_timer_1(T1_DISABLED);
  setup_timer_2(T2_DISABLED,0,1);
  setup_ccp1(CCP_OFF);
  setup_adc_ports(NO_ANALOGS);

  set_tris_b(0b00000000);
  output_b(0b00001001);

   while(true)
       {
   if( input(PIN_A0) ){output_high(pin_b7);output_high(pin_b4);}
   else{output_low(pin_b7);output_low(pin_b4);}

        }
 }
```

Appendix E: Sennsor Node Pictures and Circuit Drawings of the WSN

Detailed circuit drawing of equipment (receiver and transmitter nodes) and the links in the designed system are shown in Figure 6.1 and Figure 6.2. PCB layouts of sensor nodes are shown in Figure 6.3 and Figure 6.4. The designed sensor node pictures (bottom view and top view) are shown in between Figure 6.5 and Figure 6.8.

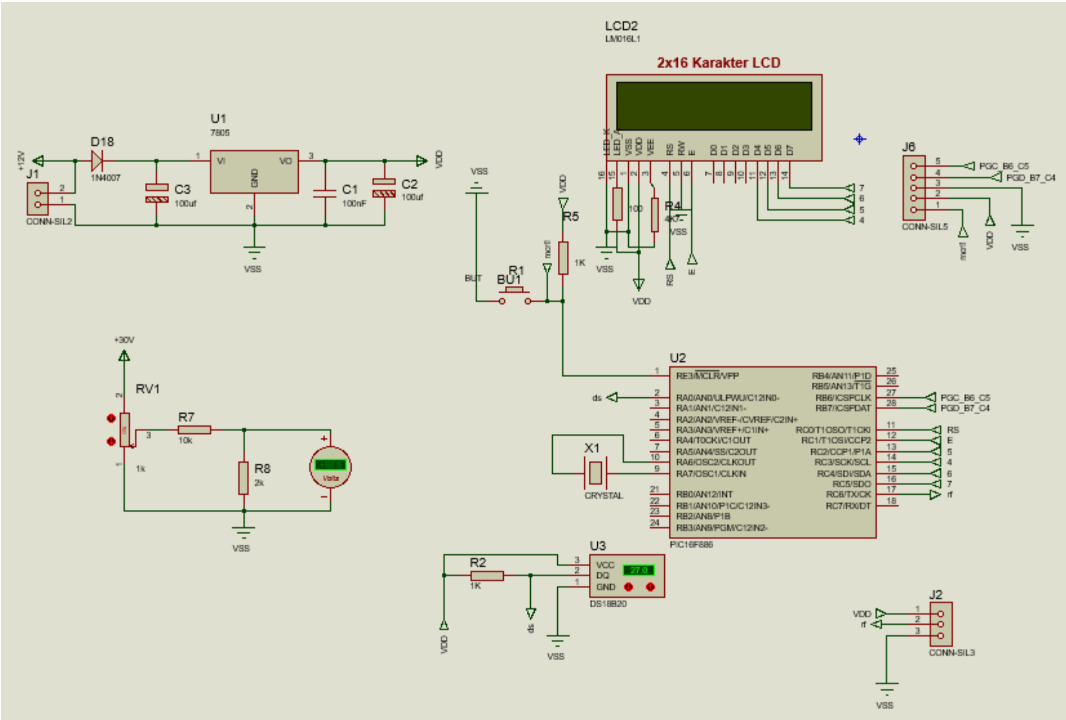


Figure 6.1: Schematic diagram of the designed transmitter (master) sensor node.

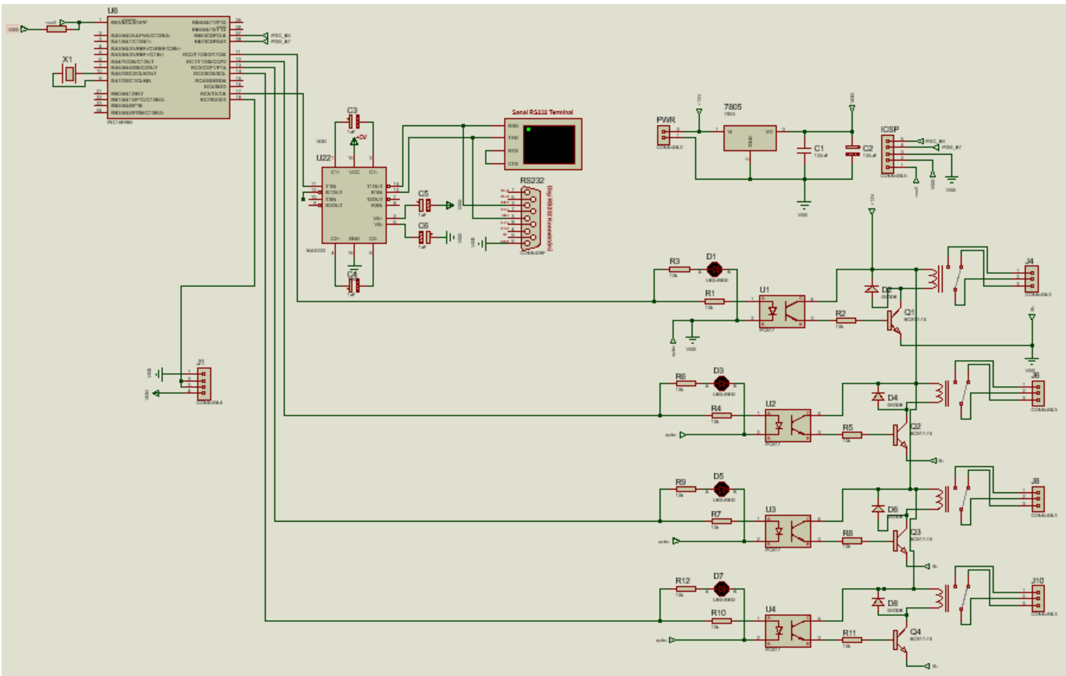


Figure 6.2: Schematic diagram of the designed receiver (slave) sensor node.

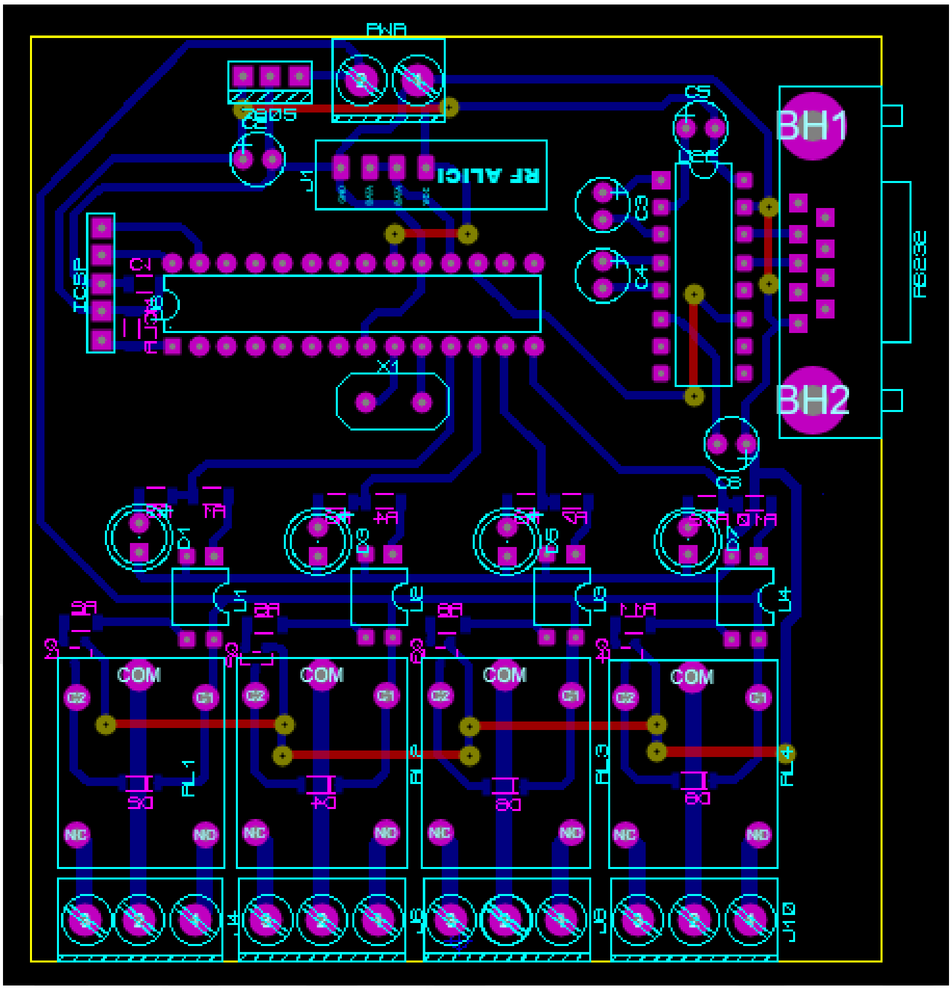


Figure 6.3: PCF Layout of the designed receiver (slave) sensor node.

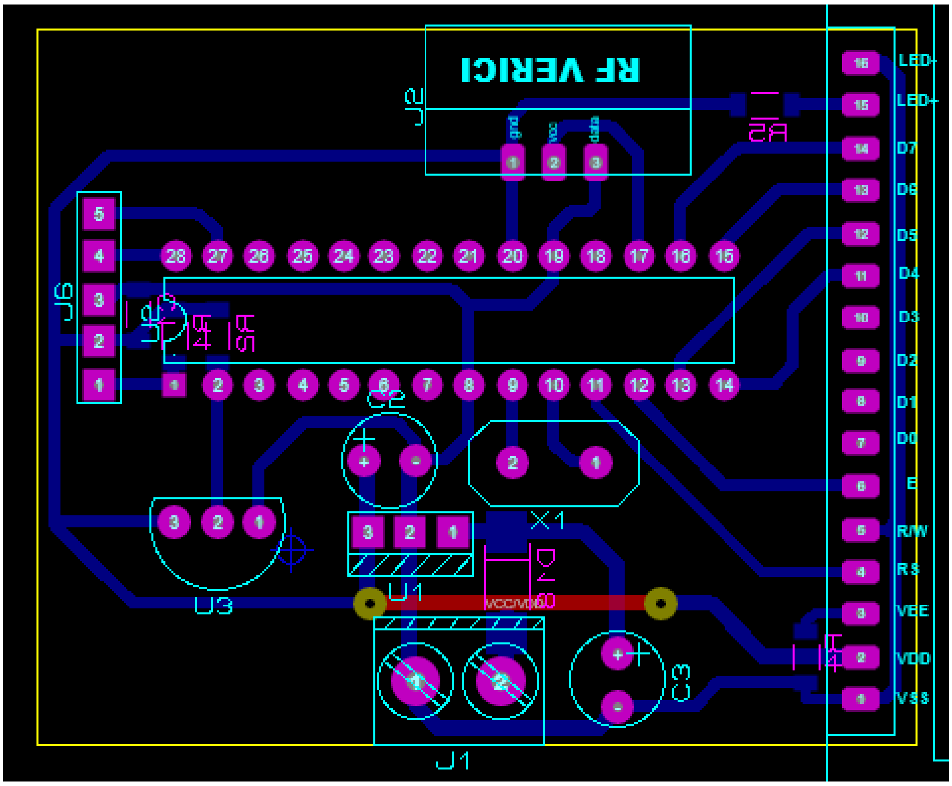


Figure 6.4: PCF Layout of the desgned transmitter (master) sensor node.

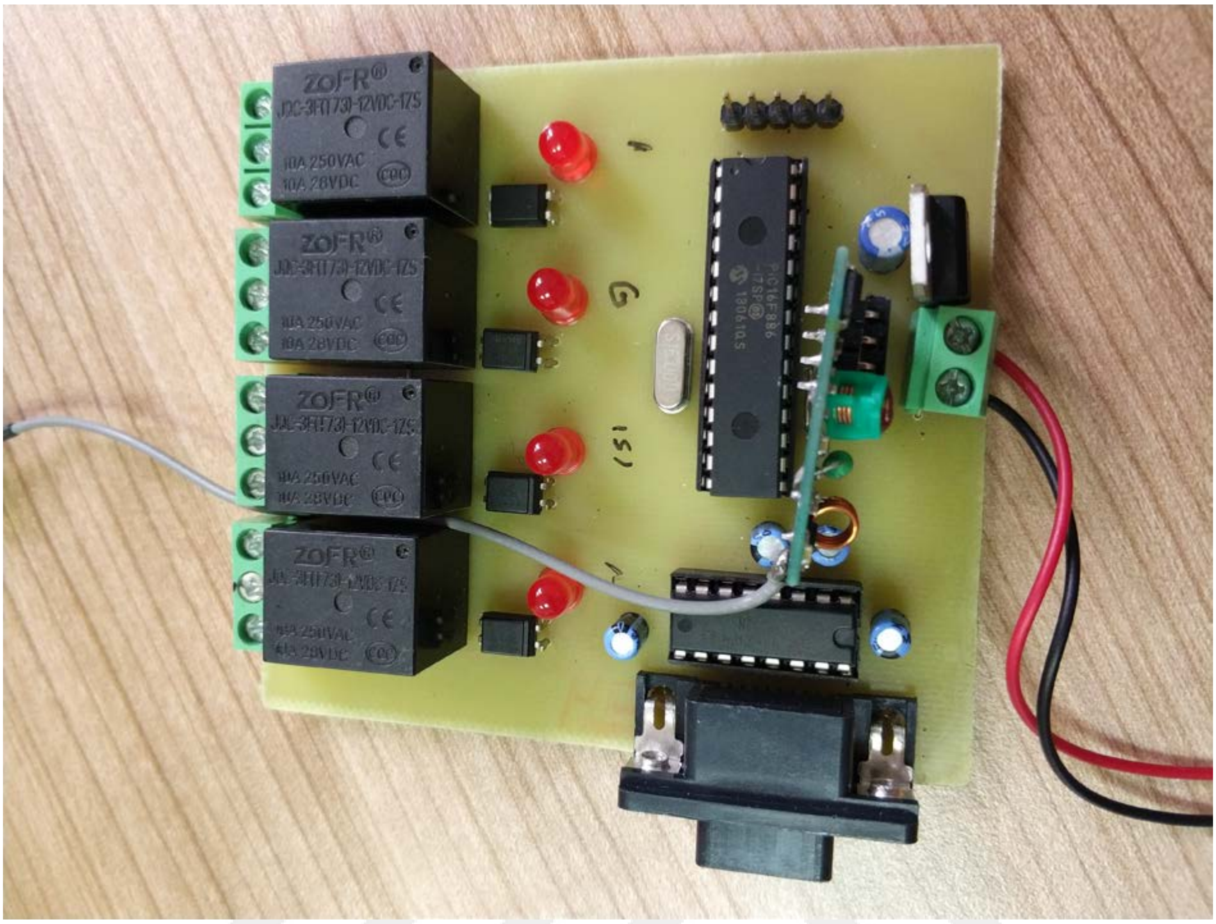


Figure 6.5: Top view of the designed receiver (slave) sensor node.

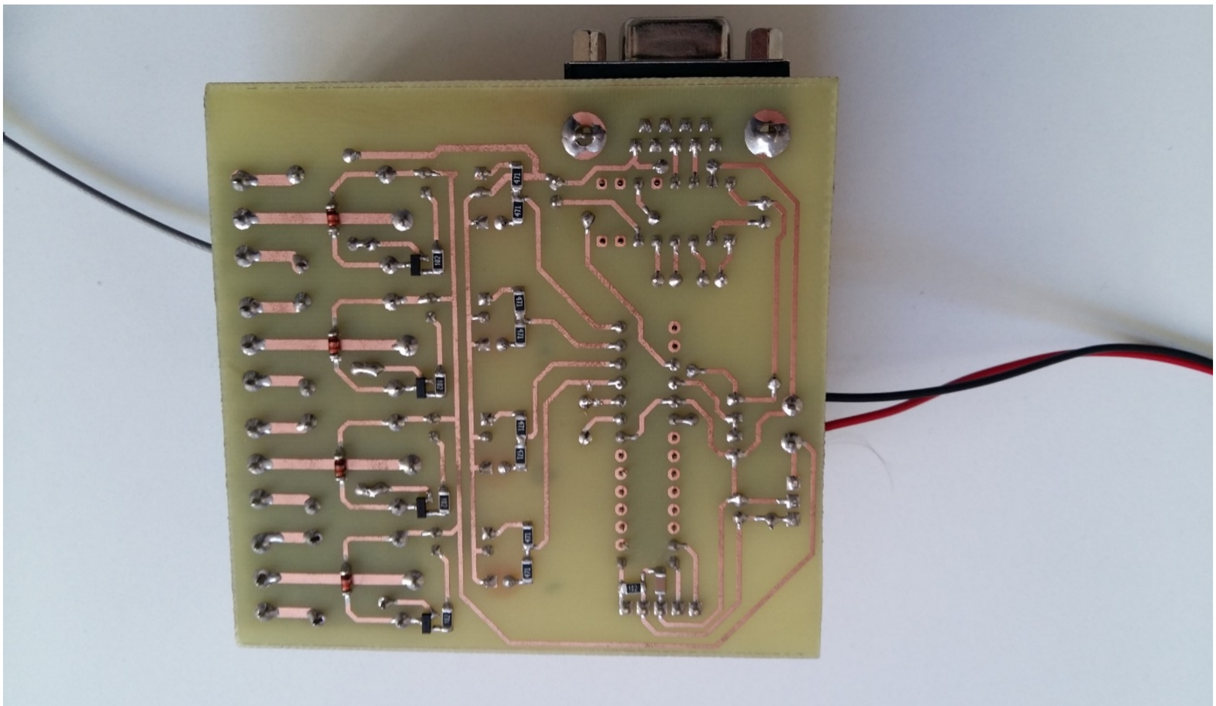


Figure 6.6: Bottom view of the designed receiver (slave) sensor node.

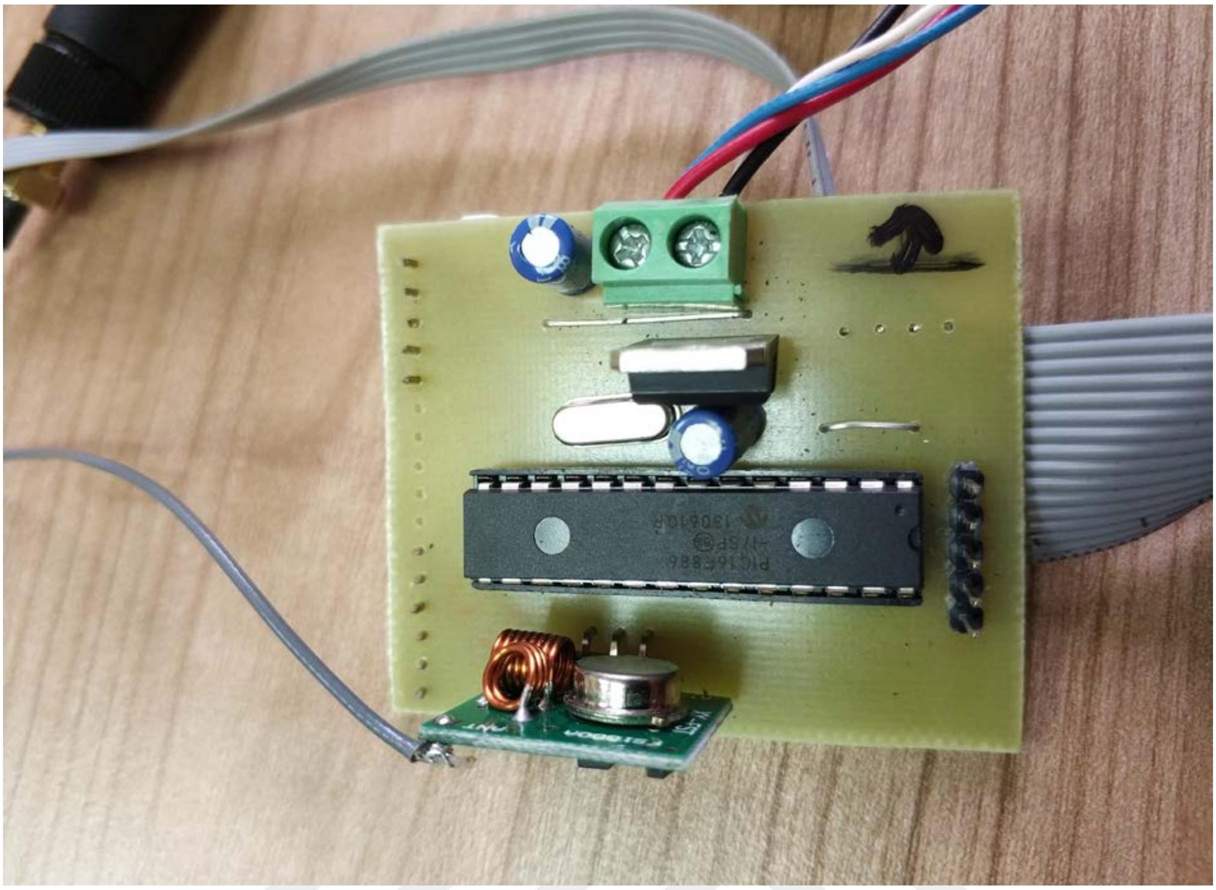


Figure 6.7: Top view of the desgned transmitter (master) sensor node.

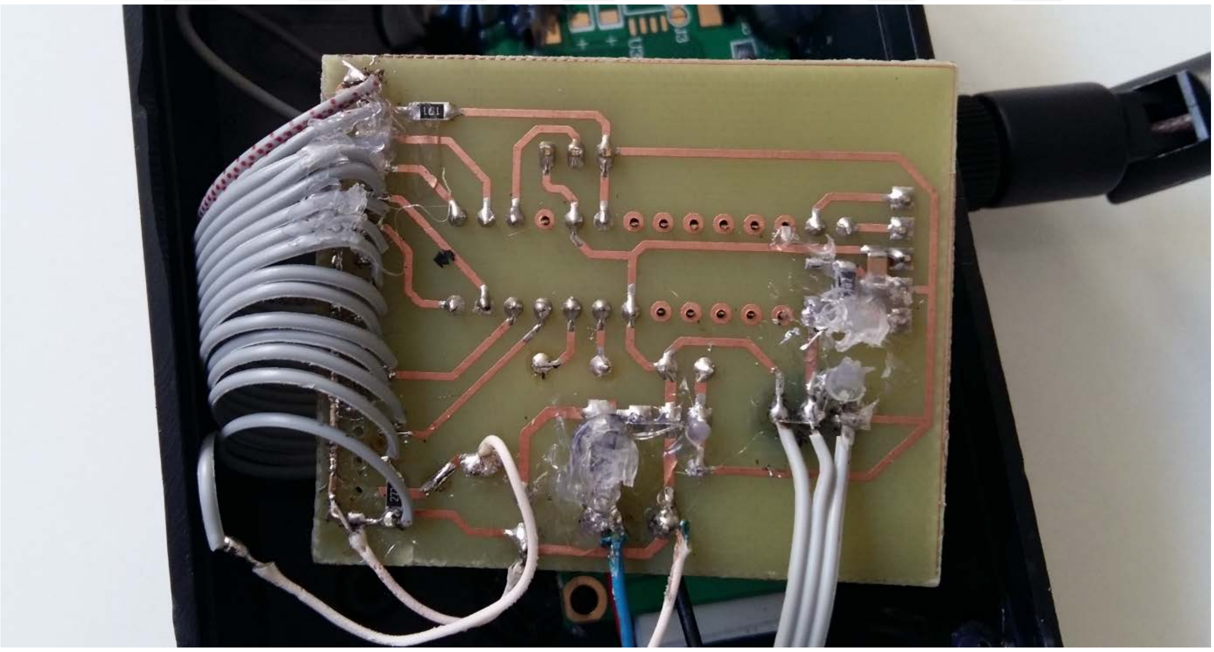


Figure 6.8: Bottom view of the designed transmitter (master) sensor node.

Appendix F: Energy Harvesting Module Circuit Drawings and Images.

Detailed circuit drawing of equipment and links in the designed energy harvesting module platform is given in the Figure 6.9. The designed energy harvesting module pictures (bottom view and top view) are shown in the Figure 6.10 and 6.11. PCB layout of the designed voltage module platform given in the Figure 6.12.

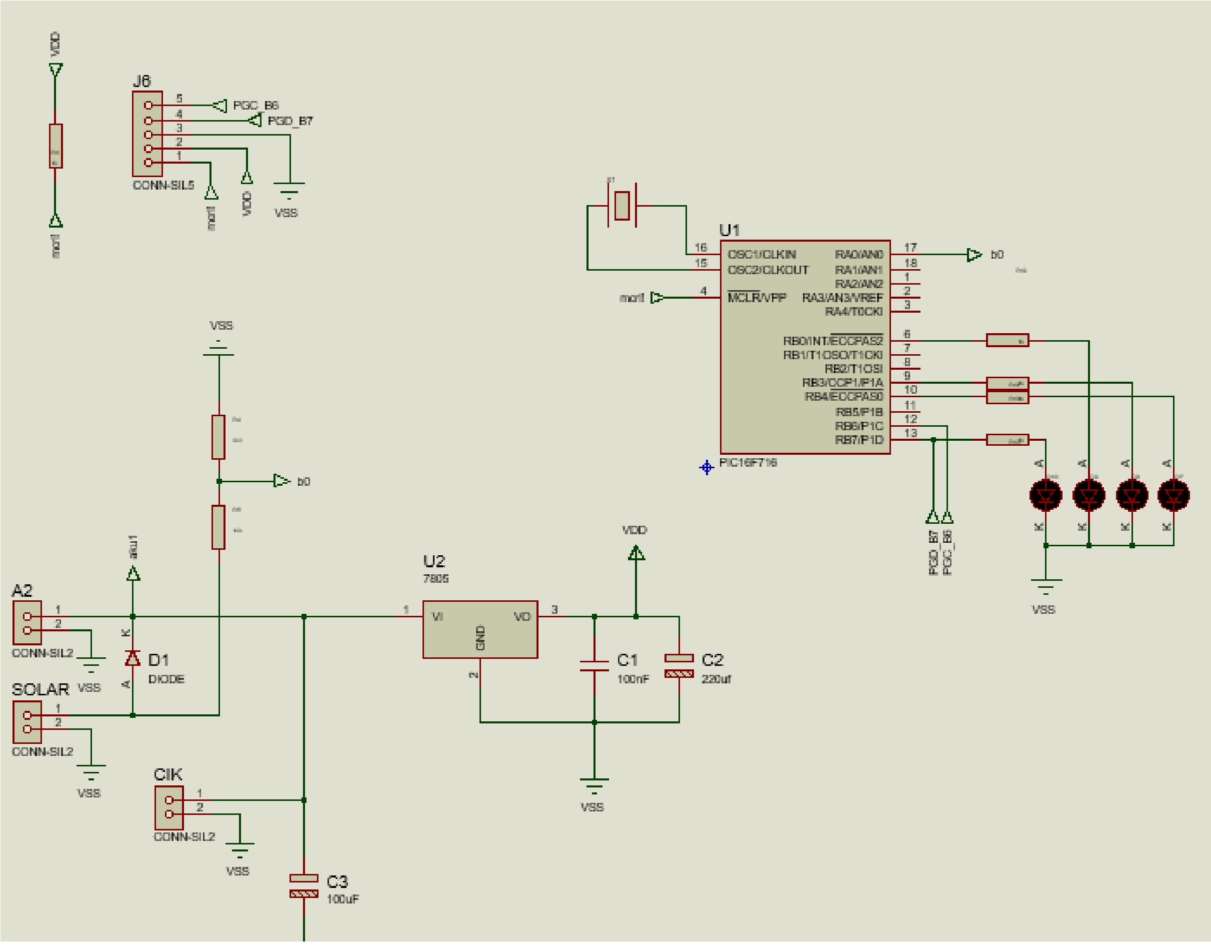


Figure 6.9: Schematic diagram of the designed enrgy harvesting module.

Figure 6.10: An image of the designed energy harvestin module.

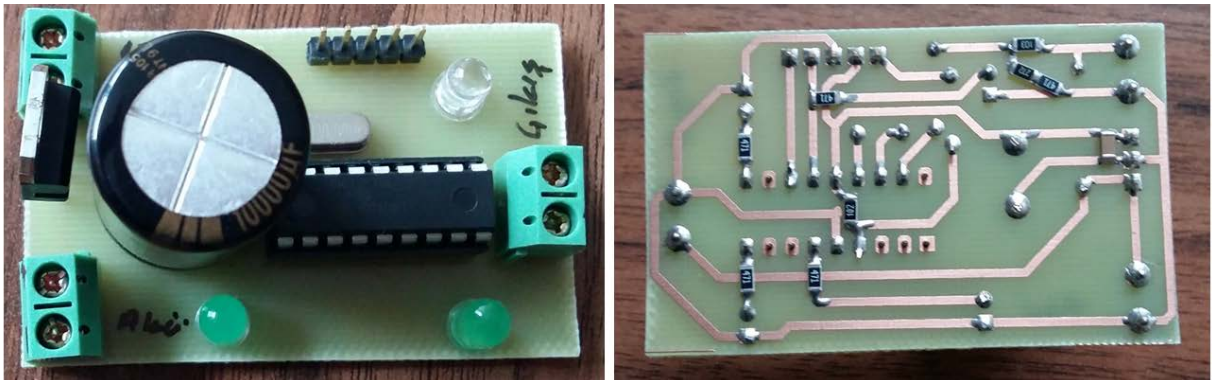


Figure 6.11: Image of the designed energy harvestin module (bottom view and top view).

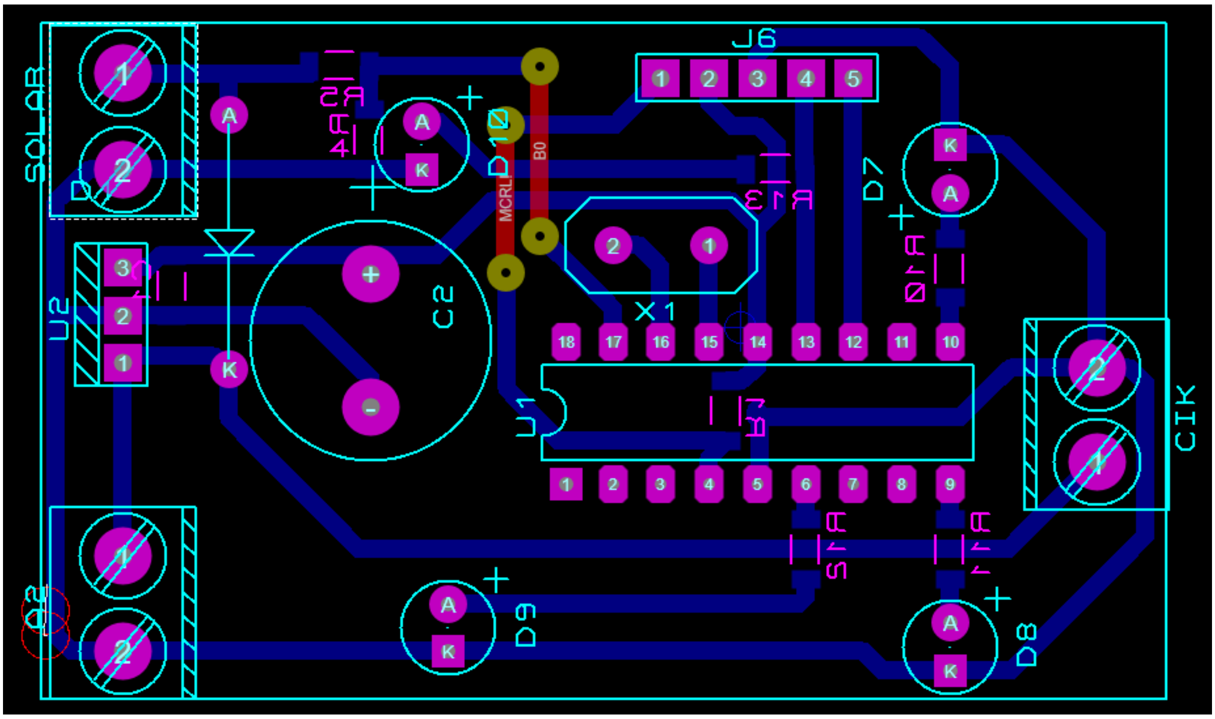


Figure 6.12: PCB layout of the designed energy harvesting module.