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DESIGN AND IMPLEMENTATION OF WIRELESS MODULES FOR FARM MONITORING

Master's thesis for the degree of Master of Science in Technology submitted for inspection, Vaasa, 10 November, 2014.

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LIST OF ABBREVIATIONS

ACK	Acknowledgement
ADC	Analog to Digital Converter
AM	Amplitude Modulation
APL	Application Layer
ARM	Advanced RISC Machines
ASCII	American Standard Code for Information Interchange
ASK	Amplitude Shift Keying
BER	Bit Error Ratio
CB	Citizens Band
CDMA	Code Division Multiple Access
CEPT	Conference of European Posts and Telecommunications Administrations
CPU	Central Processing Unit
ETSI	European Telecommunications Standard Institute

FDD	Frequency Division Duplexing
FDMA	Frequency Division Multiple Access
FFD	Full Function Device
FH	Frequency Hopping
FM	Frequency Modulation
FSK	Frequency Shift Keying
FTDI	Future Technology Devices International
HF	High Frequency
IC	Integrated Circuit
IDE	Integrated Development Environment
IEEE	Institute of Electrical and Electronics Engineers
IPv4	Internet Protocol Version Four
IPv6	Internet Protocol Version Six
ISM	Industrial, Scientific and Medical Band
ISP	In-System Programming

ITU	International Telecommunications Union
ITU R	International Telecommunications Union-Radiocommunications Sector
LCD	Liquid Crystal Display
LED	Light Emitting Diode
LOS	Line-Of-Sight
MAC	Medium Access Control Layer
MCU	Microcontroller Unit
MIPS	Million Instructions Per Second
NWK	Network Layer
OOK	On Off Keying
OS	Operating System
OSI	Open System Interconnection
PDIP	Dual in-Line Package
PHY	Physical Layer
PTP	Point-to-Point

PM	Phase Modulation
PMP	Point-to-Multipoint
QAM	Quadrature Amplitude Modulation
RF	Radio Frequency
RFD	Reduced Function Device
RSL	Received Signal Level
RSSI	Received Signal Strength Indicator
RXD	Receiver
SD	Secure Digital
SDHC	Secure Digital High-Capacity
SMART	Self-Monitoring, Analysis and Reporting Technology
SPI	Serial Peripheral Interface
SSH	Secure Shell
TCP	Transport Control Protocol
TDD	Time Division Duplexing

TDMA	Time Division Multiple Access
TTL	Transistor-Transistor Logic
TXD	Transmitter
UART	Universal Asynchronous Receiver/Transmitter
USART	Universal Synchronous Asynchronous Receiver/Transmitter
USB	Universal Serial Bus
WSN	Wireless Sensor Network
ZC	ZigBee Coordinator
ZED	ZigBee End-Device
ZR	ZigBee Router

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ABSTRACT

Since the last quarter of the 20th century, technological advancement in the industry has grown exponentially, likewise the agricultural sector. The extent is as far as the use of drones and automated robots on farms. Today wireless automation has become very popular in homes and industries alike since they are considered more efficient, safe and financially viable. Microcontroller applications in the area of wireless automation is very advanced considering the cheap cost compared to PLCs and the general cheap cost of electronic components has driven more funds into researching and further industrializing microcontroller technology.

The aim of this Master's Thesis "Design and Implementation of Wireless Modules for Farm Monitoring" was to plan, design, construct and implement wireless modules to be used to automate, control and monitor a farm. The modules consists of two nodes, each equipped with RF modules to enable communication between the nodes wirelessly. One of the nodes is also connected to a computer (the raspberry pi), enabling access to the modules remotely via internet. This Master's Thesis describes the software and hardware tasks necessary for the total operation of the modules such as the control of IOs, communication between the wireless nodes and the control of the nodes via internet. Range measurement results and throughput measurements were also discussed.

KEYWORDS: IEEE 802.15.4, Wireless Node, Radio Frequency, Wireless Automation.

1. INTRODUCTION

Improvements on farm mechanization and automation has been gradual from the 1920's till now, but the changes has been significant. For example, 2.59 Square kilometers of fields in the year 1920 could be tended by eight teams of horses but over the decades, tractors and their countless trailer attachments has been the turn around, making the work much easier. Although these improvements are highly significant, more could be done. (Dobbs 2013.)

Addition of more computational power, automation and information technology has proven to be very relevant, squeezing the best possible harvest out of each square kilometer. Tractors and agricultural machines have moved from manned to sophisticated and more accurate unmanned machines, generating even better yields and maximized returns considering limited investment and labor factors. A look into the future technological applications on farms, indicates that, though the self-driving tractors make for a fantastic show, precision agriculture is still in its early days. (Dobbs 2013; Qiu, Xiao & Zhou 2013: 522–525.)

It is envisioned that, the near future, of say, a decade, specialty tractors and massive farm machines that have made large scale farming possible over the years might be replaced by multiple and small unmanned robots. The vision being that, each of these small machines will work restrictedly on a single row of crops at a time with path differences of just few inches between rows. Robots that use vision systems for crop-tending, laser sensors, instruments employing satellite positioning among other technologies to measure parameters such as humidity and temperature can build up a database of information about each plant, this will give the possibility to detect the onset of diseases. Automated harvesters will then employ these databases to identify and gather individual produce upon their readiness. (Dobbs 2013; Technology Quarterly 2009.)

Drones of relatively smaller sizes will fly from one plant to the other dropping precise amount of manure or spraying pesticides at right quantity. In fact, drones are already in use in countries like Japan, in areas where the conventional large tractors cannot reach. (Dobbs 2013.)

The acronym SMART, has within a period of two decades, become very significant in engineering technology. It is evident in applications such as SMART homes, SMART phones, SMART cars and SMART TV. The list of SMART applications ranges from domestic to industrial. (ITP.net Staff Writer 2011.)

SMART means Self-Monitoring, Analysis and Reporting Technology. It is basically the equipping of systems with technology, making the systems intelligent. To further explain, *SMARTness* of a system is the ability of the system to monitor its environment for information, analyze the information and react to the analyzed information without the assistance of humans.

SMART farmers, from the comfort of their home, could keep an eye on cattle in the fields or even locate where there are green pastures for their cattle to eat. SMART technologies can increase crop and pasture yields by targeting the use of water and fertilizers. Also livestock production via better rotation of animals and pastures is possible. Impact on the environment, ensuring resources are used efficiently to reduce water and carbon footprint, are aided by these technologies. (Australian Center for Broadband Innovation 2013.)

This research aims to provide a basic practical module, intended to facilitate the SMART applications on farms. In this practical module, a microcontroller based technology, employing Universal Asynchronous Receiver/Transmitter (UART) for serial communication between the microcontroller and its peripherals, such as the XBEE, a radio module based on Institute of Electrical and Electronics Engineers (IEEE) 802.15.4 protocol

(Digi International Incorporated 2011) and RASPBERRY PI, a single-board computer produced by the Raspberry Pi Foundation, is realized.

In this research, there are two wireless sensor nodes, one in the farm controlling some equipments in the farm such as water pumps, lighting and heaters. The other node is stationed in the farmhouse and connected to the internet via the Raspberry Pi, it controls some switches in the farmhouse as well as controlling the farm node via wireless connection. In general, the module serves as a SMART system for wireless automation. The sketch below (see **Figure 1**) gives a general overlook of the module.

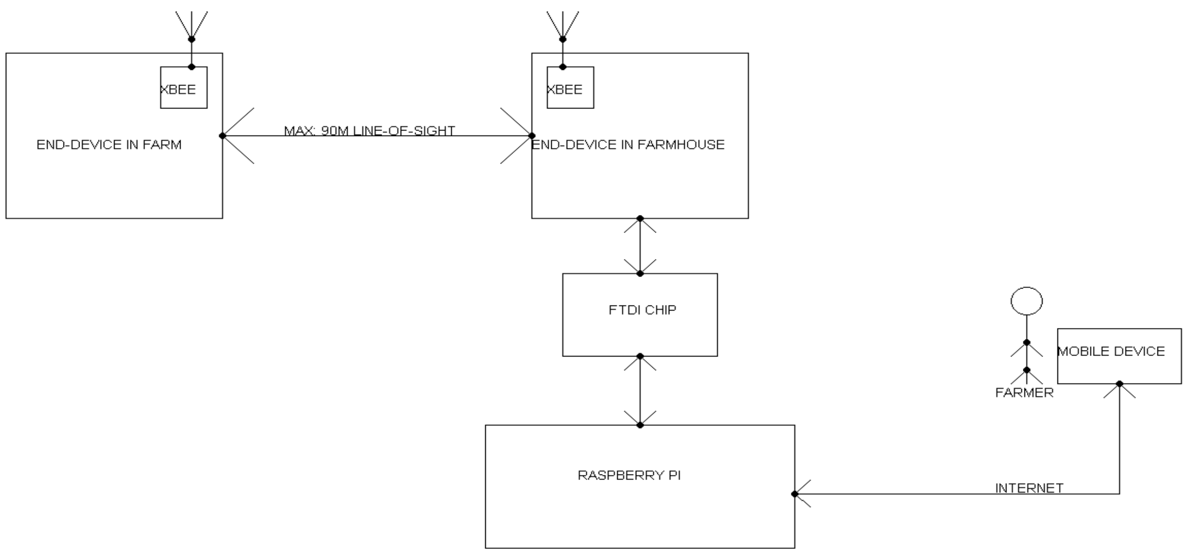


Figure 1. A block diagram of the module.

Adding to the influx of technological advancements in agriculture, farming on a SMART level with this module could enhance the ease of mobility to farmers, providing the capability of working on the farm remotely via the internet. This means, the days of restricted movement of farmers on farms could be over and farmer-poultry relationship, which has proven unhealthy over the years, could be significantly reduced.

2. WIRELESS COMMUNICATION PRINCIPLES

The main principles governing wireless communications is discussed in this chapter. Section 2.1. discusses the radio communication with focus on the communications spectrum, the ways of radio communications and bandwidth. The section 2.2 describes the wireless systems in use while the subsequent sections highlights the modulation techniques in radio communication and the multiple access techniques applied in wireless communications.

2.1. Radio Communication

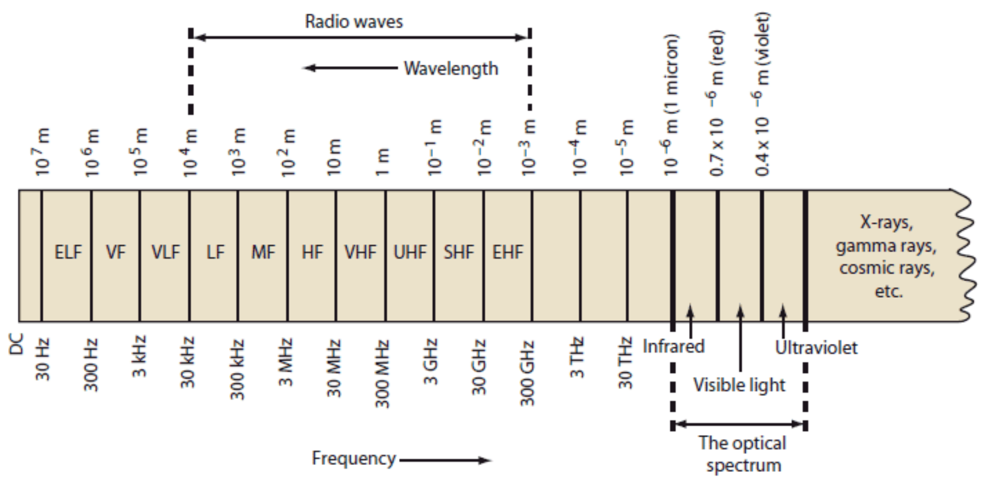
At high frequencies, application of sufficient power to electromagnetic waves, enables its propagation through good conducting materials and poorer conducting material alike. Propagation at frequencies above 100kHz enables electromagnetic waves to penetrate air and this is what is termed radio. Radio communication is basically the transporting of information through the air from a sender (transmitter) to an intended recipient (receiver) via electromagnetic waves. (Clark 2000: 23.)

2.1.1. The Communications Spectrum

Time-varying quantities such as voltage and current are usually the electrical communication signals. These signals exist in the time domain but they can also be represented in the frequency domain. The frequency domain description of a signal is known as the spectrum, where the signal is viewed as consisting of sinusoidal components at various frequencies. (Carlson, Crilly & Rutledge 2002: 18.)

Electromagnetic waves propagate via different frequencies. The set of frequencies of electromagnetic waves, basically used for the purpose of communication among others such as radar is termed frequency spectrum or communication spectrum. (Reardon 2012; NTIA 2014.)

The frequency spectrum usage and designation within a country is controlled by the government of the country through governmental regulatory bodies. " According to Clark (2000: 24), the International Telecommunications Union-Radiocommunications Sector (ITU-R) a subdivision of International Telecommunications Union (ITU) is the organization responsible for radio frequency spectrum usage internationally". Without these control bodies, the frequency spectrum will be used anyhow and radio communication will be impossible with a clustering of interfering radio signals in the atmosphere.



1. The electromagnetic frequency spectrum ranges from dc to light. The lower radio frequencies are designated mainly by frequency. The optical ranges are referred to by wavelength.

Figure 2. The electromagnetic frequency spectrum, indicating the radio frequency range. (Ken 2013).

The relationship between frequency (f) and wavelength (λ) as observed in **Figure 2** is given below (see **equation 1**), where v is the velocity of light given as 3×10^8 m/s.

$$v = f\lambda \qquad (1)$$

2.1.2 Radio Communication Ways

A given radio band is allocated in provision of a spectrum for a specific application by a national regulatory body as earlier mentioned. In terms of quantity, spectrum requirement is dependent on application, hence different bandwidth allocation for different applications. Three types of communications exist and they are the full-duplex, half duplex and the simplex as shown in **Figure 3**.

In the simplex type communication, information can only be sent in one direction within a communication channel. Application of simplex communication is rather great though not obvious. When two distinct channels are used for communication such that one channel is for transmission from transceiver A to transceiver B and the other channel is for transmission the other way around, simplex communication is observed. This is quite common in communication involving fiber optics, (TCP/IP Guide 2005). In recent times, simplex communication is mostly used for broadcast applications in radio communication. Simplex communication is the most efficient in the use of radio spectrum, (Clark 2000: 29–41).

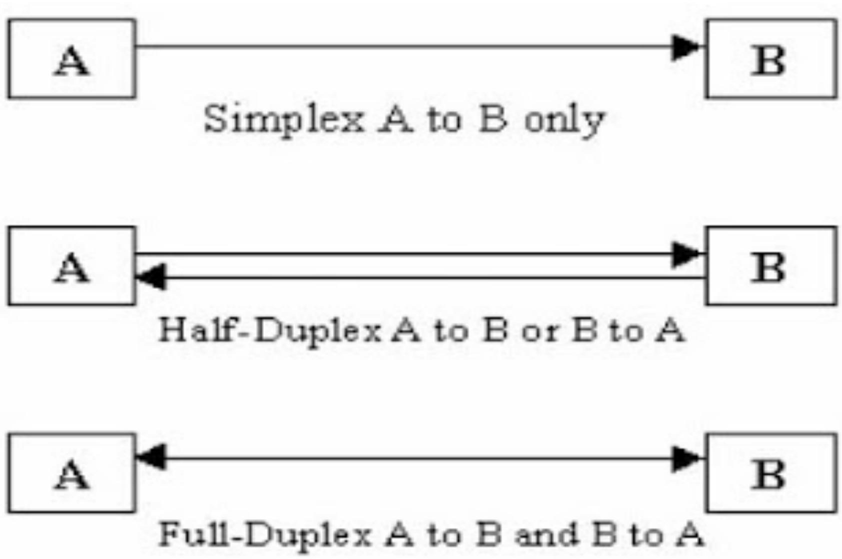


Figure 3. The three communication ways.

Half-duplex type communication is an upgrade on the simplex communication. In this type communication, the transceiver A and transceiver B can both transmit to each other within the same communication channel but not simultaneously. When one transceiver transmits, the other can only receive. This can be utilized in Time Division Duplexing (TDD). Challenge of half-duplex communication is that, the received signal of half duplex node is erased during the nodes own transmission period. Application area of half-duplex is Citizens Band (CB) radio. (Guo & Zhang 2010.)

Full-duplex type communication is quite common and the most used communication type. In this type, transmission and receiving is possible between transceiver A and transceiver B simultaneously. In this communication way, frequency Division Duplexing (FDD) is realized. The total radio bandwidth required in full duplex system doubles that needed in simplex system. (Tech Terms 2012; Clark 2000: 30–31.)

2.1.3. Bandwidth

As mentioned in the introduction of this subsection 2.1.2., the radio spectrum is structured into subdivisions called bands and these bands are sold out to communications service providers. The service providers also in-turn sell out or lease parts of these bands (channel) to end users. Each channel for a specific application. (Clark 2000: 33.)

Each channel has a bandwidth, suppose to satisfy the application for which it is intended. Bandwidth, " according to the Editors of Encyclopaedia Britannica, is the range of frequencies occupied by a modulated radio-frequency signal". Maximum data transfer of a network or the measure of quantity of data to be transferred over a communication link is described by the bandwidth, (Tech Terms 2012).

Apart from noise and interference, bandwidth is one of the major challenges in wireless communications. Bandwidth is a very limited radio resource. More of it is being used but more of it cannot be made. A survey by Credit Suisse conducted in 2011 reveals a 80% capacity of use of the mobile networks in North America with 36% of their base stations facing constraints while the base station capacity utilization globally is at 65%. (Baldwin 2012). The United States bandwidth allocation for example is very much exhausted, (see **Figure 4**).

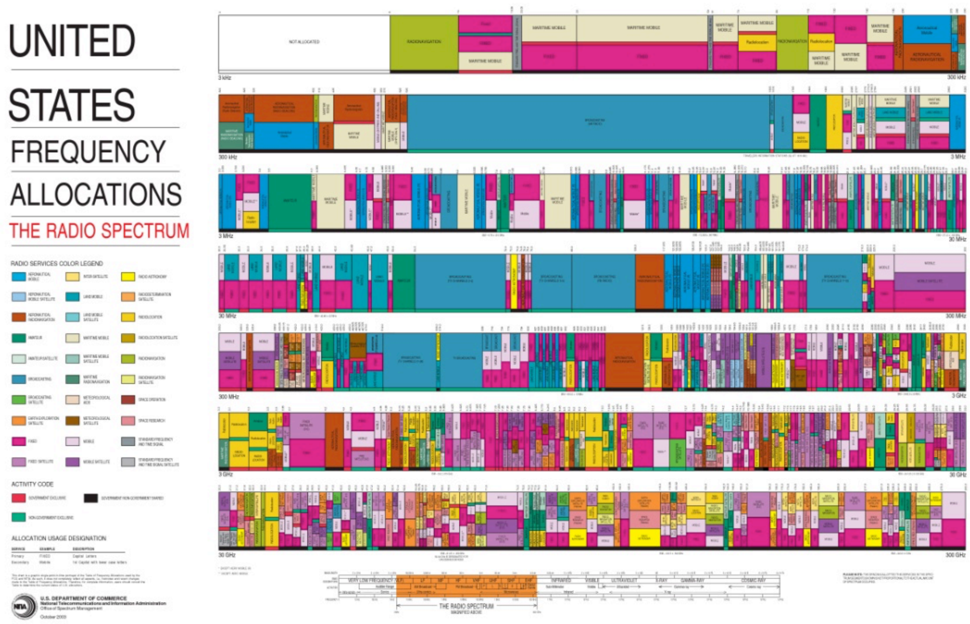


Figure 4. The United States Bandwidth Allocations, 2011.

2.2. Wireless Systems Characteristics

Wireless systems are designed for specific applications and it is this applications which gives the character of a system. Differences between wireless systems are usually in the modulation techniques applied in coding of the radio signal. The terms Point-To-Point (PTP), Any-To-Any and Point-To-Multipoint (PMP) helps in defining a radio system. (Clark 2000: 41–42 .)

2.2.1. Point-to Point Radio Systems

As mentioned earlier, full-duplex radio, allows for two-way communication between two end points such as that between two mobile phone users. When communication between two end points which are fixed, takes place frequently or permanently, the establishment of a permanent point-to-point radio link tends to make meaning.

So it is clear that PTP systems are intended to provide a link between two fixed end-points. It is common for PTP radio systems to have a fixed bandwidth or bit rate while optimization of the system for transmission along its single link differentiates it from broadcast radio. Line Of Sight (LOS) is often necessary between the two end-point antennas because frequency bands allocated to PTP systems find it difficult to diffract around or propagate through obstacles. Furthermore, an inconvenient LOS check during installation of High Frequency (HF) PTP link, makes the system more expensive. The advantage though, is that the LOS check during installation, gives the possibility of a high bandwidth PTP link using high frequency radio band which is unsuited for broadcast. (Clark 2000:42–43.)

2.2.2. Any-to-Any Radio Systems

When the condition of frequent or permanent communication between two endpoints is lifted, hence communication between two endpoints is not so frequent, then the establishment of temporal links between endpoints amongst a pool of endpoints as and when needed makes for an efficient use of the radio spectrum.

The set back in Any-to-Any radio systems is that, omnidirectional antennas has to be used in contrast to the directional PTP antennas, and this is because the direction of radio transmission is unknown. Omnidirectional antennas have lower gain compared to the directional ones hence a reduced quality and reliability in Any-to-Any systems compared to

PTP systems. Furthermore, omnidirectional antennas leads to a more potential radio interference and also gives room for interception and overhearing of signals by third party. (Clark 2000: 43–44.)

2.2.3. Point-to-Multipoint Radio Systems

In this system, a number of endpoints share the facilities provided by a single base station (uplink) or a base station broadcast (downstream) same signal to a number of remote stations. In PMP systems, uplink and downlink must be always considered separately. An omnidirectional antenna is mostly used in the downstream for an equal compass resulting in a circular area of coverage called a cell. (Clark 2000: 44–45.)

For the system to ensure that only the desired recipients receive signal from the base station, preventing interference to and from other base stations and endpoints, radio modulation and multiple access schemes must be designed in that favor, (Clark 2000: 44-45.)

For the upstream, directional antennas helps reduce interference and multiple access schemes must also be employed to allow the available radio spectrum to be shared by the endpoints. (Clark 2000: 44–45.)

2.3. Radio Modulation

A radio wave travels at the speed of light (3×10^8 m/s) through the atmosphere. Upon striking a receiving antenna, a high frequency current which is a replica of the current flowing in the transmitting antenna is induced making the transfer of high frequency electrical energy from a point to another without wires possible, (Schuler 1994: 268).

A wireless signal travel over the air via a radio frequency known as the carrier frequency. TV and radio broadcast, GPS and wireless phones all use airwaves and their signal and data are carried through the airwaves via their carrier frequencies. The concept of modulation is that, a pure sinusoidal wave with the right frequency and amplitude is used as a carrier of the information signal. (Reardon 2012.)

Modulation could be defined as the modification of an information (speech, video, data packet, etc.) before transmission through a communication channel which in this case is air. There are at least two reasons for this modification: first the modified signal is optimized for the characteristics of the channel for efficient transmission, second the modification makes for possible simultaneous multi-use of the channel.

Modification done to the information must be possible to remove upon reception by the intended recipient, that is, it must be an invertible process and this is the main condition for modification. (Tomasi 2004: 13.)

There are three types of modulation, they are Amplitude Modulation (AM), Phase Modulation (PM) and Frequency Modulation (FM).

2.3.1. Amplitude Modulation

In this modulation type, the information signal is carried in the amplitude of the carrier. In this modulation system, the information signal is used to control the amplitude of the Radio Frequency (RF) signal. (Shuler 1994: 269.)

As indicated by Couch (1989: 285–286), **equation 2** is a mathematical representation of a modulated signal, where g(t) is the complex envelope of an AM signal.

$$s(t) = Re\{g(t)e^{jwct}\} \qquad (2)$$

$$g(t) = A_c[1 + m(t)] \tag{3}$$

the constant A_c in the complex envelop is an inclusion to specify the power level and m(t) is the modulating signal (analog or digital). From the two equations, s(t) representing the AM signal can be written as

$$s(t) = A_c[1 + m(t)]cos\, w_c t \tag{4}$$

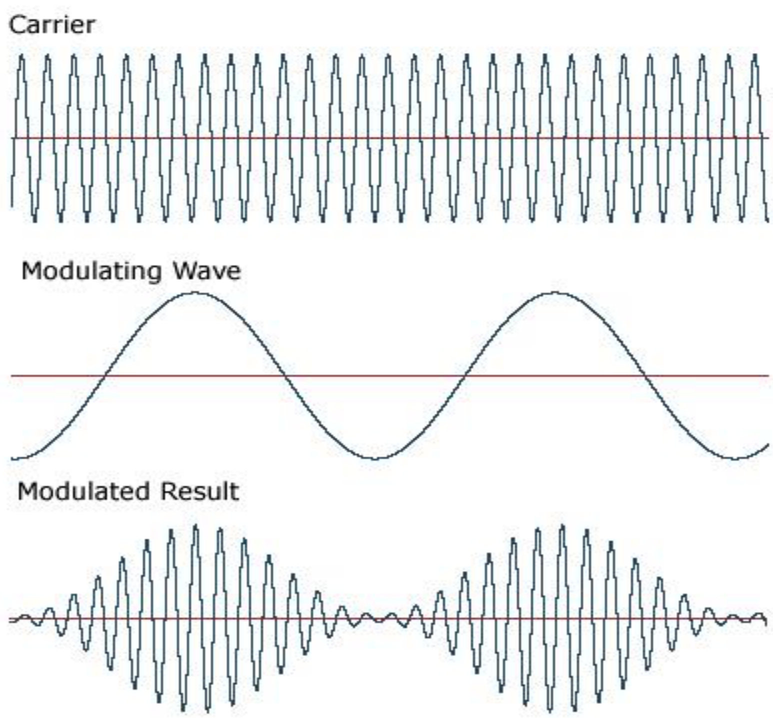


Figure 5. AM signal as an output of a modulating sine wave on a carrier, (Telecom-Phone 2012).

So far, the AM described (see **Figure 5**) is for analog systems. The digital version of AM is called, On-Off Keying (OOK) or Amplitude Shift Keying (ASK). In this digital version of AM (see **Figure 6**), the amplitude of the carrier frequency is varied between a set amplitude and zero or two set amplitudes with one of them representing zero. The set amplitude corresponds to On with binary value of '1' and the zero amplitude or the set amplitude representing zero, corresponds to Off with binary value of '0'. An example of this technique is the Morse code radio transmission. (Clark 2000: 59–60; Couch 1989: 332.)

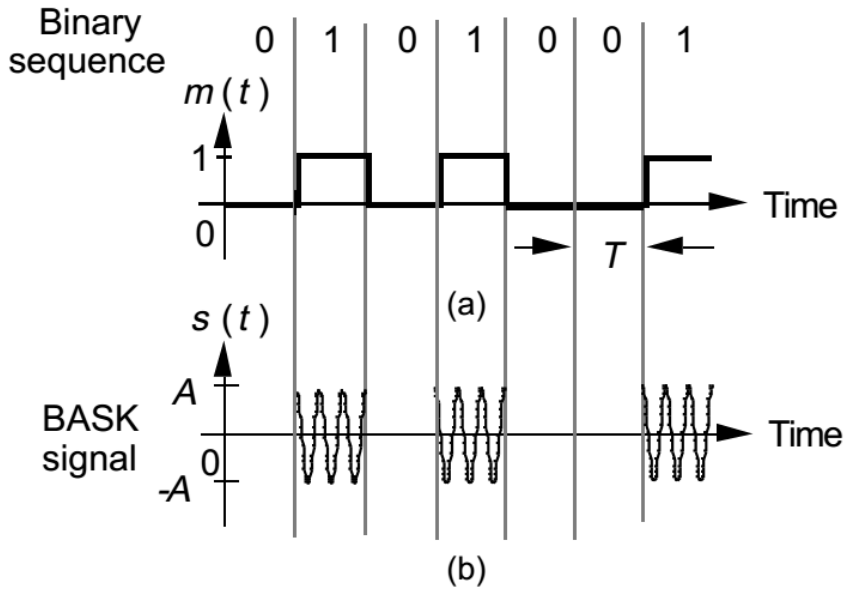


Figure 6. Amplitude Shift Keying (ON-Off Keying), (Setup Solution 2014).

2.3.2. Frequency Modulation

In this type of modulation, the information is carried in the frequency of the carrier. In this modulation system, the modulating bit stream signal content is carried as the carrier signal frequency is altered. (Clark 200: 60.)

FM is an alternative to AM since it has some advantages over AM, making it a choice for applications such as commercial broadcasting and duplex radio work. Challenges of AM which gives FM an edge over applications include sensitivity to noise, radio interferences from lightning and automotive ignition, sparking electric circuits. FM receivers have the capability of being made insensitive to noise making FM more desirable as a noise free alternative but the disadvantage with FM is that it requires more bandwidth which is a rather scarce resource in wireless communication. (Shurler 1994: 278.)

Couch (1989: 298–299) explains that, apart from PM, FM is also a special case of angular modulation. In angular modulation, the angle or phase of a sinusoidal carrier wave are altered to transmit data, making the technique different from the AM where it is the amplitude which is varied to transmit data.

In angle modulation, the complex envelope of the modulated signal is as given in **equation 5**.

$$g(t) = Ace^{j\theta(t)} \tag{5}$$

where the real envelope R(t) = |g(t)| = A_c is a constant and the phase $\theta(t)$ is a linear function of the modulating signal m(t). g(t) though, is a non-linear function of the modulation. So the resulting angle modulation signal from **equation 5** is as given in **equation 6**.

$$s(t) = Ac\, cos[w_c t + \theta(t)] \tag{6}$$

In general, the complex modulation of a complex signal x(t) is as given in the **equation 7**.

$$C(t) = x(t)e^{jwt+\theta} \tag{7}$$

where the transmitted signal y(t) is the real part of the complex modulation. x(t) is the complex envelope and |x(t)| is the absolute real envelope of y(t). (Tomasi 2004: 244–245.)

In FM, the amplitude and phase are unaffected by the modulation process. In the FM process (see **Figure 7**), the information signal is mixed with the carrier, creating an inter-modulated signal with sidebands near to the carrier frequency. So a given frequency (f) of the information signal creates f_c-f and f_c+f as intermodulated products, where f_c is the carrier frequency. (Clark 2000: 60-63).

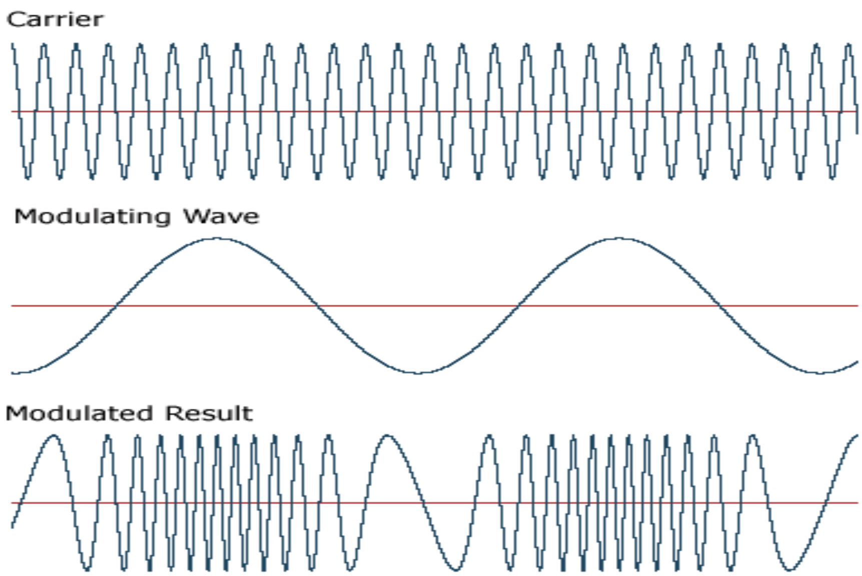


Figure 7. FM signal as a result of a modulating sinusoidal wave on a carrier, (The Free Dictionary 2013).

In digital systems, the FM is refered to as Frequency Shift Keying (FSK), where the frequency of a sinusoidal carrier is shifted from a mark frequency corresponding to sending a binary value of '1' to a space frequency corresponding to sending a binary value of '0' (see **Figure 8**). (Couch 1989: 332.)

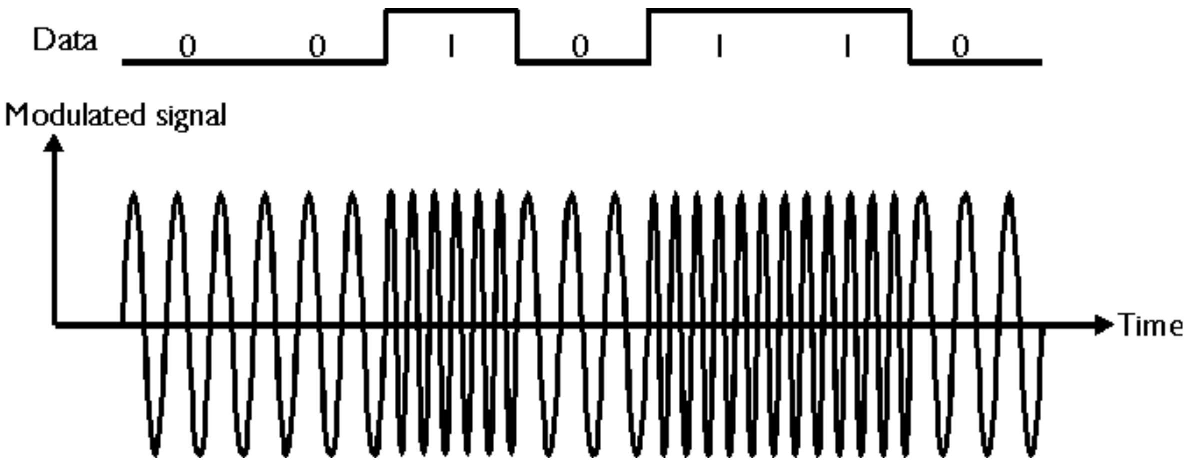


Figure 8. Frequency Shift Keying (FSK), (Modern Technical Details 2003).

2.3.3. Phase Modulation

PM is one of the angle modulations as already mentioned. In this type modulation, information is carried in the phase of the carrier. In PM, the carrier signal, leads or lags in its phase cycle by the modulating signal. For PM, the phase and the modulating signal are directly proportional as shown in **equation 8**.

$$\theta(t) = D_p m(t) \tag{8}$$

The proportionality constant D_p is the phase sensitivity of the phase modulator and it has units of radians per volts when assuming m(t) is a voltage waveform. (Couch 1989: 299.)

Digital PM is known as Phase Shift Keying (PSK) (see **Figure 9**). It consist of the sinusoidal carrier phase shifting between 0 and 180 degrees with a unipolar binary signal. In PSK the carrier signal is allowed to retain its phase or then change its phase at the beginning of each new bit, so a switch from bit 0 to 1 for example could represent a change of phase from 0 to 180 degrees.

Advantage of PM over AM and FM is that it has better availability. It is relatively less prone to noise and interference, hence a weaker signal at the receiver (RX) of a PM system can be recovered better than in the other systems. Link outage or unavailability in radio systems using PM is far less comparatively, it has high spectrum efficiency with a straightforward increase by an increment in the modulation level such as QPSK, 8-PSK. (Couch 19989: 299; Clark 2000: 63.)

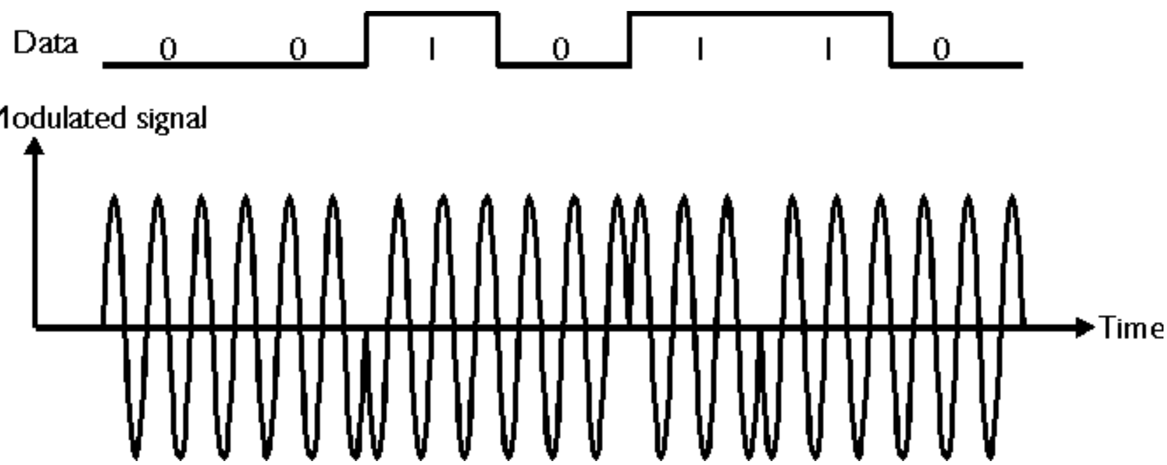


Figure 9. Phase Shift Keying (PSK), (Connection 2000).

2.3.4. Quadrature Amplitude Modulation

Quadrature Amplitude Modulation (QAM), is a hybrid of AM and PM which has a widespread adoption in current technology, making it a very important scheme in wireless technology. Any technique that makes vital and efficient use of the bandwidth or wireless channel such as QAM is a technical breakthrough.

In QAM, digital information is transmitted by a periodic adjustment of the phase and the amplitude of a sinusoidal electromagnetic wave (carrier). At higher modulation levels in PSK such as 16-ary or 32-ary using M-PSK, it becomes impractical due to difficulty in differentiating between two adjacent phases at the receiver due to noise. For this reason, the reasonable thing to do is to use different phases at different amplitudes, for example, for

16-QAM, two different amplitudes could be used with 8-PSK. The constellation diagram of 8-PSK and QAM (see **Figure 10** and **Figure 11**) gives a better insight. (National Instrument 2012.)

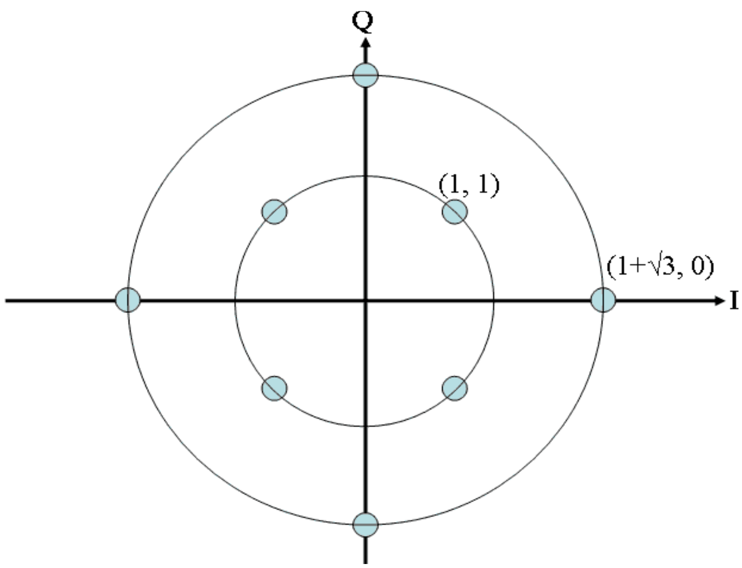


Figure 10. Constellation of 8-QAM.

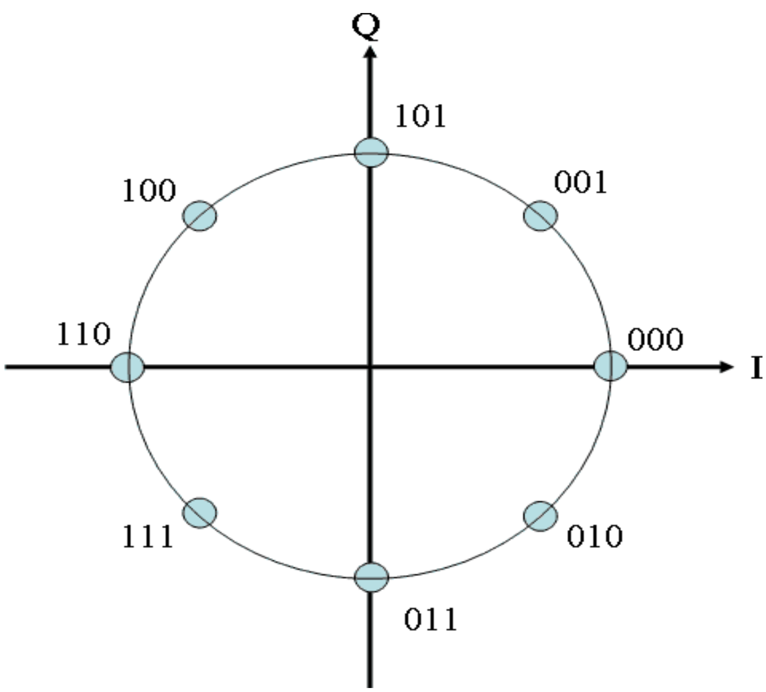


Figure 11. Constellation of 8-PSK.

2.4. Multiple Access Schemes

In a wireless network, for example a number of end users communicating to a base station, the same channel bandwidth has to be shared by the multiple end users and this must be done without interference. For this reason, multiple access schemes need to be applied. Therefore multiple access can be defined as technique(s) allowing multiple end users to access the same channel bandwidth without (or with limited) interference. Frequency Division Multiple Access (FDMA), Time Division Multiple Access (TDMA) and Code Division Multiple Access (CDMA) are the three main multiple access schemes, (Dev 2012). Frequency Hopping (FH) is another multiple access scheme which is a hybrid of FDMA and TDMA, (Clark 2000: 75.)

2.4.1. Frequency Division Multiple Access

In the FDMA technique, the communication channel bandwidth is further divided into sub-channels and each of the sub channel frequency is allocated to a different end-user. Example is in FM radio where multiple FM radio channels transmit at same time but on different frequency channels. (Imthiyaz 2011.)

2.4.2. Time Division Multiple Access

In TDMA technique, the whole channel bandwidth is used by all the end-users but at different time slots. Basically, there is time allocation for each end-user within which period it accesses the whole channel spectrum alone. (Imthiyaz 2011.)

2.4.3. Code Division Multiple Access

In CDMA technique, all end users use the channel bandwidth simultaneously for transmission but signals transmitted by each end-user is separated from the others by a special coding technique as shown in **Figure 12**. All codes are decoded at the reception to identify each particular user. (Imthiyaz 2011.)

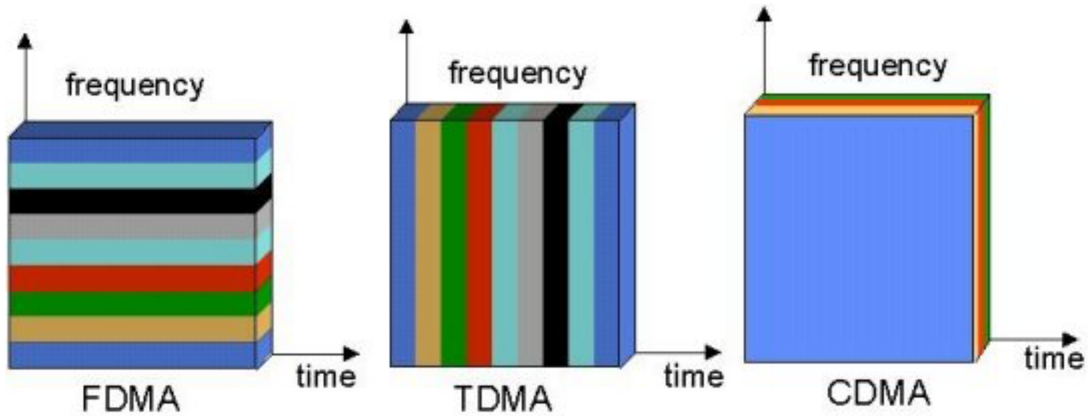


Figure 12. FDMA, TDMA and CDMA techniques, (Imthiyaz 2011).

3. WIRELESS NETWORKS

In this chapter, wireless networks pertaining to this research is considered. The section 3.1 discusses the wireless channel while the section 3.2 discusses the embodiment of wireless sensor nodes. The subsequent sections respectively highlights the ZigBee protocol, Internet Protocol version 6, computer terminal and availability of wireless communication link.

3.1 Wireless Channels

In a communications system there are three main sections (see **Figure 13**), the information source, the communication link and an output (recipient of information). The information from the source is modulated for the channel characteristics by the transmitter (TX) before propagating the information through the channel which in this case is wireless (air). The receiver, upon receiving the information, demodulates it and then hands over the information to the output (end-user). (Davenport & Root 1987: 1; Shannon & Weaver 1963.)

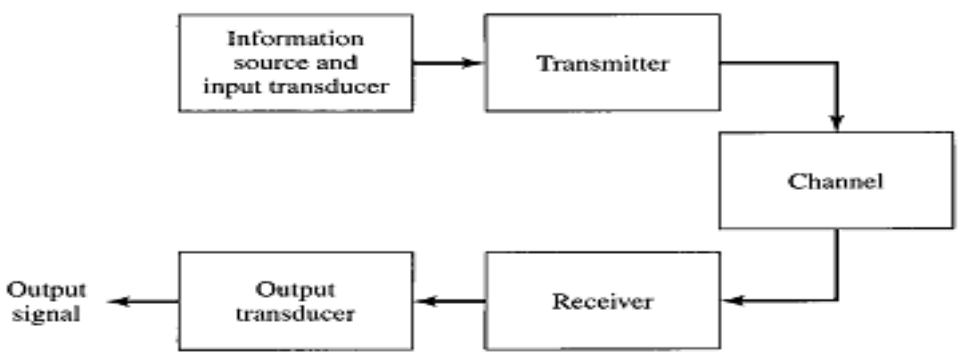


Figure 13. A Functional Block Diagram of a communication system. (Davenport & Root 1987: 1)

Randomness or unpredictability of a communication system comes in three forms: the unpredictability of the information generated by the information source, the random disturbances the channel faces, the misinterpretation of the information by the end-user. Of the three, the wireless channel is the most challenging. The factors making the wireless channel so unpredictable are noise, interference and multipath but what makes these challenge more intriguing is that, these factors change rapidly with time in an unpredictable way due to environmental dynamics. (Davenport et al. 1987: 1–2; Goldsmith 2005.)

Noise in wireless communication is simply unwanted electrical signals. Noise comes from very different sources but they are generally classified into two main categories: natural noise and man-made noise. The natural noise are generated by atmospheric disturbances, extra-terrestrial radiation and random electron movement. The man-made noise are usually produced by other communication systems, ignition and other commutator sparking and AC hum. (Carlson & Crilly 2010.)

Noise in wireless communication affects a radio receiver's ability to receive accurately and decode the correct information signal. The factor known as signal-to-noise (S/N) ratio is an important factor affecting the good reception of information signal, that is, the received signal strength must be more powerful than the surrounding noise. System Noise Figure (f) though, considers external noise factor, antenna circuit noise factor, transmission line noise factor and receiver noise factor as a summation of internal and external noise sources affecting the correct reception of information signal. The **equation 9** shows the system noise factor and **equation 10** is the noise figure which is just a logarithmic representation of the noise factor. (Clark 2000: 135.)

$$F = fa - 1 + (fc \times ft \times fr) \qquad (9)$$

$$f = 10log10(F) \qquad (10)$$

f_a = external noise factor

f_c = antenna circuit noise

f_t = transmission line noise factor

f_r = receiver noise factor

Interference and noise are similar but different. Interference and noise can be same depending on the perspective from which one looks at it. Interference is a meaningful information from the same system under consideration or from another system, but not really the intended information. Considering the definition of noise, interference can be said to be noise but noise in itself has no meaning at all. Some types of interferences are co-channel interference and inter-symbol interference.

Multipath is as a result of a radio signal from a transmitter to a receiver undergoing reflection, diffraction and scattering (see **Figure 14**). Reflection, diffraction and scattering are phenomena due to an encounter of the radio signal with multiple objects in the environment. Reflection, diffraction and scattering creates copies of the transmitted signal and these copies are known as components of the multipath signal. The components of the multipath signal can have the following properties in reference to the line-of-sight (LOS) component of the transmitted signal: attenuated power, delayed time, shifted phase and shifted frequency. The LOS signal and the multipath components are all summed at the receiver and this summation most often produces distortion and fading in the received signal with reference to the transmitted signal, a phenomena called destructive fading. When summation of the multipath components produces rather, a strong received signal, it is called constructive fading. (Goldsmith 2005: 33–64.)

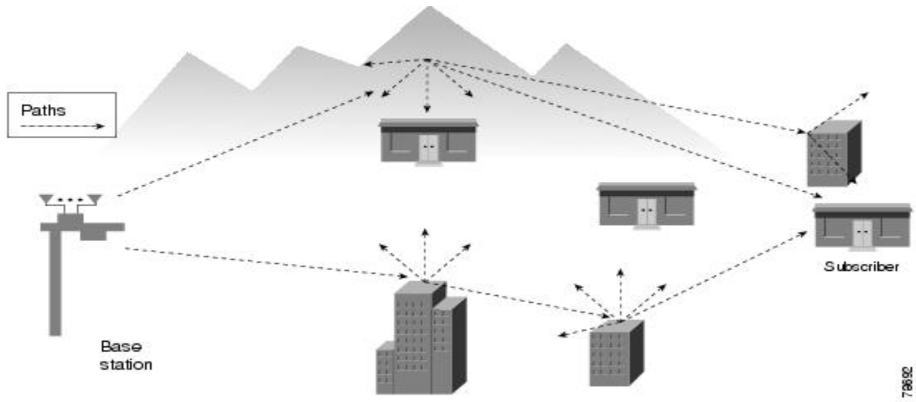


Figure 14. Multipath in wireless communications. (Cisco 2012).

3.2. Wireless Sensor Networks

Wireless Sensor Networks (WSNs) has become a well accepted technology in homes and the industry alike. Applications of WSNs has mainly been monitoring and control of traffic, environment and habitat. Lately, industrial automation is becoming one area quickly accepting WSNs. (Paavola & Leiviskä 2010.)

A wireless sensor network is basically a wireless network of nodes. A node in a Wireless Sensor Network (WSN) consist basically of a microcontroller, a data storage, sensor, a data transceiver and an energy source. The star, cluster-tree and mesh are the network topologies supported by WSNs, with nodes acting as a transceiver or a router working in a multi-hop manner within the network.

Power consumption during operation of a microcontroller may be 1mW/10MHz and 1µW during standby or sleep modes. Radios' employed in nodes usually consume about 20mW in a range of just tens of meters. Increase in distance almost exponentially increases energy requirement for wireless communication while obstructions attenuates the information signal. The mentioned constraints in this paragraph makes energy a limiting factor in WSNs. The following ways are some measures to help minimize the energy consumption in WSNs: eliminate communication or turn of radio in the absence of communication, process data locally in each node, communicate only when an event of interest occurs, turn off radios when uninteresting packets are received, assign some special task to special nodes and then aggregate, compress and schedule data. (Paavola & Leiviskä 2010.)

Callaway (2004: 48–49) offers the following formulas as determinants for the average power consumption in a wireless sensor node.

$$Iavg = Ton \times Ion + (1 - Ton) \times Istby \quad (11)$$

$$Pavg = U \times Iavg \quad (12)$$

I_{avg} = Average current drain

T_{on} = Fraction of time either receiver or transmitter is on

I_{on} = Current drain from the battery when either the receiver or transmitter is on

I_{stby} = Current drain from the battery when both transmitter and receiver are off

P_{avg} = Average power consumption

U = Battery voltage

3.3. ZigBee Protocol

ZigBee is a double-sided duplex wireless communication technology with the following key features: short distance communication, low complexity, low power consumption, low data rate and low cost, (Xin, Yao, Jiang, Yan & Sun 2012). The operating frequency band of the ZigBee is 2.4GHz, 915MHz and 868MHz License-free Industrial, Scientific and Medical (ISM) band. The IEEE 802.15.4 protocol is the basis for the ZigBee technology. The ZigBee union which was set up in 2001.8 proposed the technology and wrote the ZigBee specifications VI.0 in 2004.12. The ZigBee specification defines the upper layers: Network Layer (NWK), Application Layers (APL) of the ZigBee protocol stack while the lower layers: Physical Layer (PHY), Medium Access Layers (MAC) are defined by the IEEE 802.15.4 protocol. (Jin, Qi-Yong & Yi-Huai 2010.)

The ZigBee protocol stack is based on the Open System Interconnection (OSI) seven-layer model but defines only layers 1, 2, 3 and 7 which are relevant for the intended market place (see **Figure 15**).

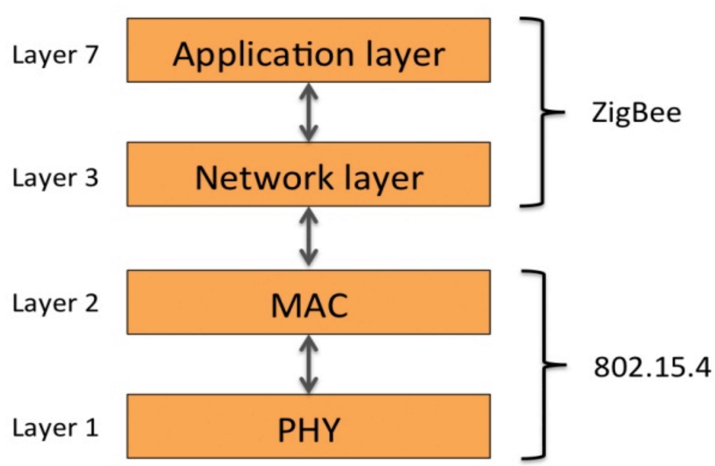


Figure 15. The ZigBee protocol stack, (Wilson 2013).

IEEE 802.15.4 is a standard defined by the Institute of Electrical Electronics Engineers to interconnect ultra low-cost sensors, actuators and processing devices wirelessly, which involves the infrastructure to sense (input) and then as a response (output), affect the physical environment. Typical applications of IEEE 802.15.4 devices are more in its design, which is envisioned to be: industrial control, environmental and health monitoring, home automation, security, location and asset tracking, emergency and disaster response. (IEEE Std 2003; Zheng & Lee 2004.)

The ZigBee Coordinator (ZC), the ZigBee Router (ZR) and ZigBee End-Device (ZED) are the three type of devices utilized by the ZigBee networks. Meanwhile, these devices comes under two main subdivisions: the Full Function Device (FFD) and Reduced Function Device (RFD). (Callaway 2004.)

A ZC is an FFD and its duties are controlling the format and security of the network. Only one ZC is allowed in a ZigBee network. Any device connecting to the network, first has to connect to the ZC. The ZC attains same properties as a ZR after network formation. (ZigBee Alliance 2007.)

A ZR is also a FFD. The duties of the ZR are to extend the range of the network and route the messages inside the wireless network. The ZR has to route and preserve temporarily the ZED messages until the ZEDs are fully power on, hence, the ZR must never go low power mode. (ZigBee Alliance 2007; Yun & Cho 2008.)

The ZED are RFDs with functions of performing specific sensing or control functions in the network. ZED are designed to be low power boards able to run for years on batteries. (Gislason 2008). Since they are sometimes in hibernation, the ZEDs do not route messages in the network. Upon wake up of the ZED, the ZR which handles the routing delivers messages it has saved to it. (ZigBee Alliance 2007.)

FFDs are equipped with full set of MAC layer functions, which enables them to act as a network coordinator or a network end-device. FFDs acting as network coordinators has the ability to send beacons, offer synchronization communication and network joint services. RFDs can only act as end-devices and are equipped with sensors or actuators like transducers, light switches and lamps and may only interact with a single FFD. (Stenvanovic 2007.)

Topologies supported by ZigBee are the star, the tree and the mesh as shown in **Figure 16**.

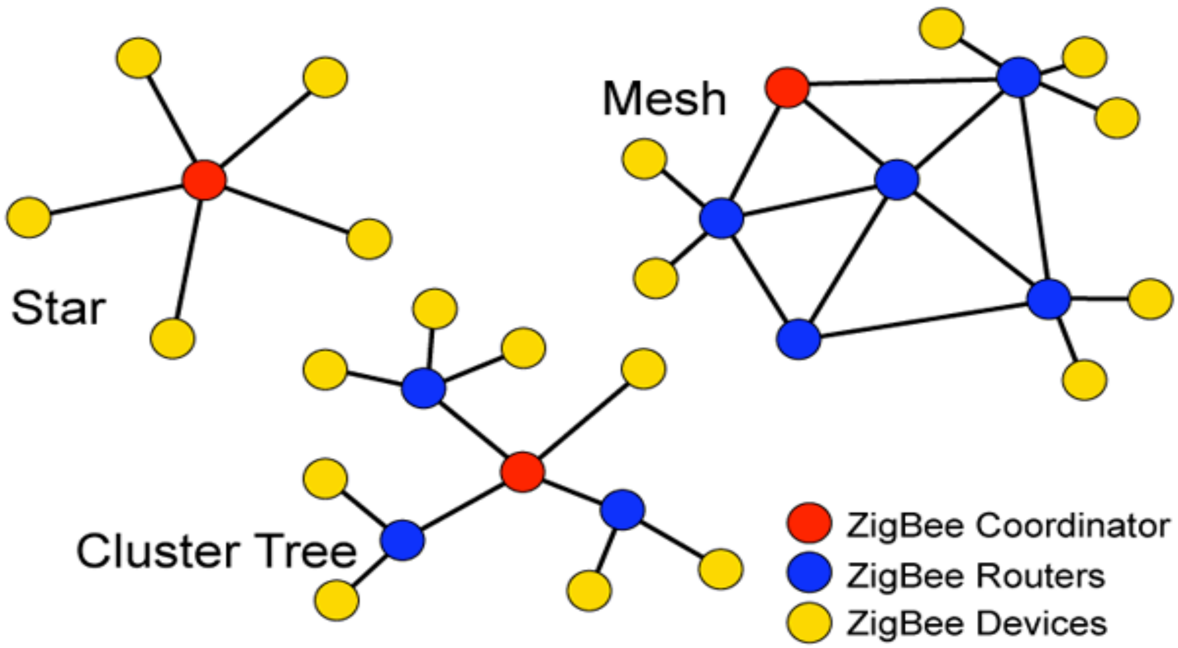


Figure 16. The ZigBee supported topologies (Jean-Wesley, Wayne, Anglade & Marcellus 2012).

In the framework of the ZigBee Alliance, there are two alternative routing schemes proposed. The first is the Ad-hoc On-demand Distance Vector (AODV) routing protocol which is designed for highly dynamic application scenarios in wireless ad-hoc networks. The second is a tree based routing scheme based on hierarchical structure, which is established during network formation phase among nodes. The tree based routing scheme, routes packets from sensors to sink based on the IEEE 802.15.4 topology formation procedure called the parent-child relationship, (Cuomo, Luna, Ugo & Tommaso 2007). The difference between the two schemes is that the AODV is a pure on-demand route acquisition algorithm that broadcasts discovery packets at the need of establishing a routing path while the tree-based routing scheme is proactive and does not use ad-hoc control messages.

3.4. Internet Protocol Version 6

Internet Protocol Version 6 (IPv6) was designed to solve problems including mobility, auto-configuration, and overall extensibility of which the Internet Protocol Version 4 (IPv4) had a lot of shortcomings. The IPv6 provides a much larger addressing space (128-bit addresses) on the internet rather than 32-bit addresses thus allowing 3.4×10^{38} possible addresses. It supports a large range of applications on different devices communicating with each other irrespective of the underlying hardware structure, thus it is capable of handling heterogeneous networks. (TechNet 2014.)

The IPv6 is packet based, hence it uses a connectionless protocol type with capability of fragmenting packets and using addressing schemes which are independent of the network, (Oracle 2010.)

Considering **Figure 17**, the field "Version" is a 4-bit number identifying the version of the internet protocol which in this case is 6. The field "Traffic Class" is 8-bit size, specifying the packet priority. The 20-bit size "Flow Label" field provides a better service for real time applications. The field "Payload Length" is a 16-bit unsigned integer size, holding the size of the data being carried following the IPv6 header, in octets. The field "Next Header" is 8-bit in size, it identifies the header type immediately following the IPv6 header. The "Hop Limit" field is 8-bit unsigned integer size, it is to avoid packets staying in the network forever, the size is decremented by one by each node that forwards the packet so if the hop limit is decremented to zero the packet is discarded. The "Source Address" field is 128 bits in size, it is occupied by parts of the header identifying the source of the data. The "Destination Address" field is also 128-bit size, occupied by parts of the header identifying the source of the data. (Oracle 2010.)

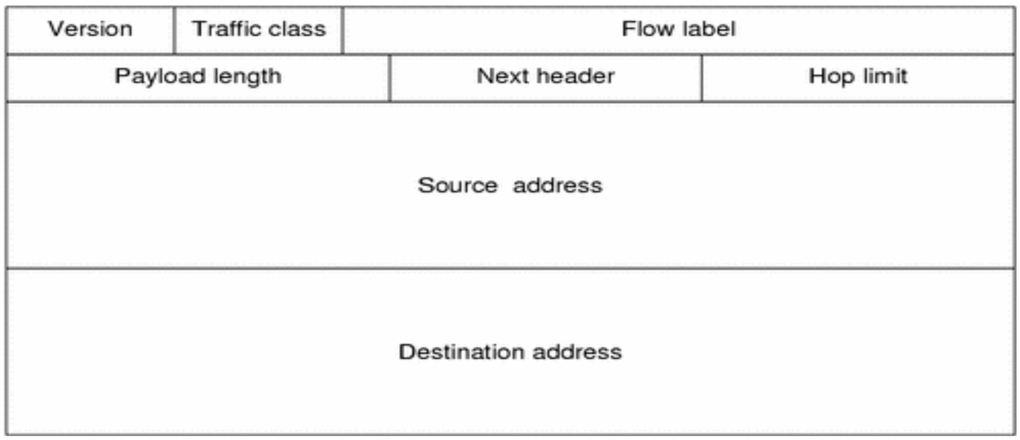


Figure 17. Format of the base header in an IPv6 datagram, (Oracle 2010).

3.5. Computer Terminal

Since the inception of computers in the 1940s, terminals have been around in one way or another. A terminal is basically defined as a monitor and a keyboard attached to a computer system, it is a computer peripheral. It has no memory nor a processor, hence it can never run a software nor store information, it is simply an input/output device which independently serves no purpose unless it is connected to a computer. A terminal can be used in establishing communication remotely and it is relatively an inexpensive way of communicating with remote computers. (Wyatt 1994: 33–37.)

Terminal emulators are more used compared to terminals currently. A terminal emulator is a soft program that emulates a video terminal, usually within another display. A terminal window is a terminal emulator inside a graphical user interface which allows access to a text terminal and its applications such as text user interface and command line interfaces. A terminal follows a protocol such as VT-100 and WYSE 100 to communicate properly with the main computer and these protocol type is dependent on the terminal in use. Terminal emulators also do have protocols with which they communicate such as the Secure Shell

(SSH) and Telnet and these are usually dependent on the operating system. (Wyatt 1994: 33–37.)

3.6. Radio System Availability

Propagation of radio waves over a radio link is said to be reliable if a signal of adequate strength arrives at the receiver for demodulation. Reliability of a radio system depends on the system range and the radio link availability. The constraints affecting reliability of radio system are the transmitter power output, the receiver sensitivity and atmospheric and climatic conditions of the area of operation.

A limited signal attenuation due to atmospheric conditions such as interference from other signals, absorption of signals by gases or rainfall plus sufficient signal power generated at transmitter and a good sensitivity of receiver ensures for a good reliability of a radio link. Of the factors ensuring reliability of a radio link, the atmospheric and climatic conditions are most difficult to define.

Unit of measurement for a transmitter power is usually in Watts (W), milliWatts (mW) or dBm (decibels relative to 1 milliWatt). For receiver sensitivity, the minimum threshold Received Signal Level (RSL) defines the accuracy or quality of reception. The minimum power required for a receiver to achieve a Bit Error Ratio (BER) reception of a digital signal better than 10^{-6} is recommended by Conference of European Posts and Telecommunications Administrations (CEPT) and European Telecommunications Standard Institute (ETSI) to be the receiver threshold. (Clark 2000: 115–122.)

4. HARDWARE AND SOFTWARE DESIGN OF THE MODULE

The wireless communication module has two wireless sensor nodes. One of the nodes control equipments such as lighting, water pump and heaters in the farm while communicating with the other node in the farmhouse. The farmhouse wireless sensor node control some farmhouse equipments such as lighting and alarms. The farmhouse wireless sensor node is connected to a portable computer (the raspberry pi) which gives the farmer access to the node via the internet.

4.1. Hardware

The module as indicated in the last paragraph has two nodes, each comes with its own board, specifically designed to meet its purpose. The sections 4.1.1. and 4.1.2 describes the hardware of the farm and the farmhouse wireless nodes respectively, the section 4.1.3. and 4.1.4. also describes the hardware of the raspberry pi and the Future Technology Devices International (FTDI) Breakout board respectively. The subsequent sections discusses the hardware design of the farm and farmhouse nodes respectively.

4.1.1. Hardware of the Farm Wireless Node

The farm node (see **Figure 18**) used in this thesis is self designed and locally manufactured. The major components of the farm node consist of the ATmega 168 microcontroller, an XBEE radio transceiver, two voltage regulators: the LM7508 and the LD1117AV33, three push buttons, a 16×2 Liquid Crystal Display (LCD), a crystal oscillator, two transistors, four connectors, six Light Emitting Diodes (LEDs), a variable resistor, an external 10V power supply and an AVR-In System Programming (ISP) connector.

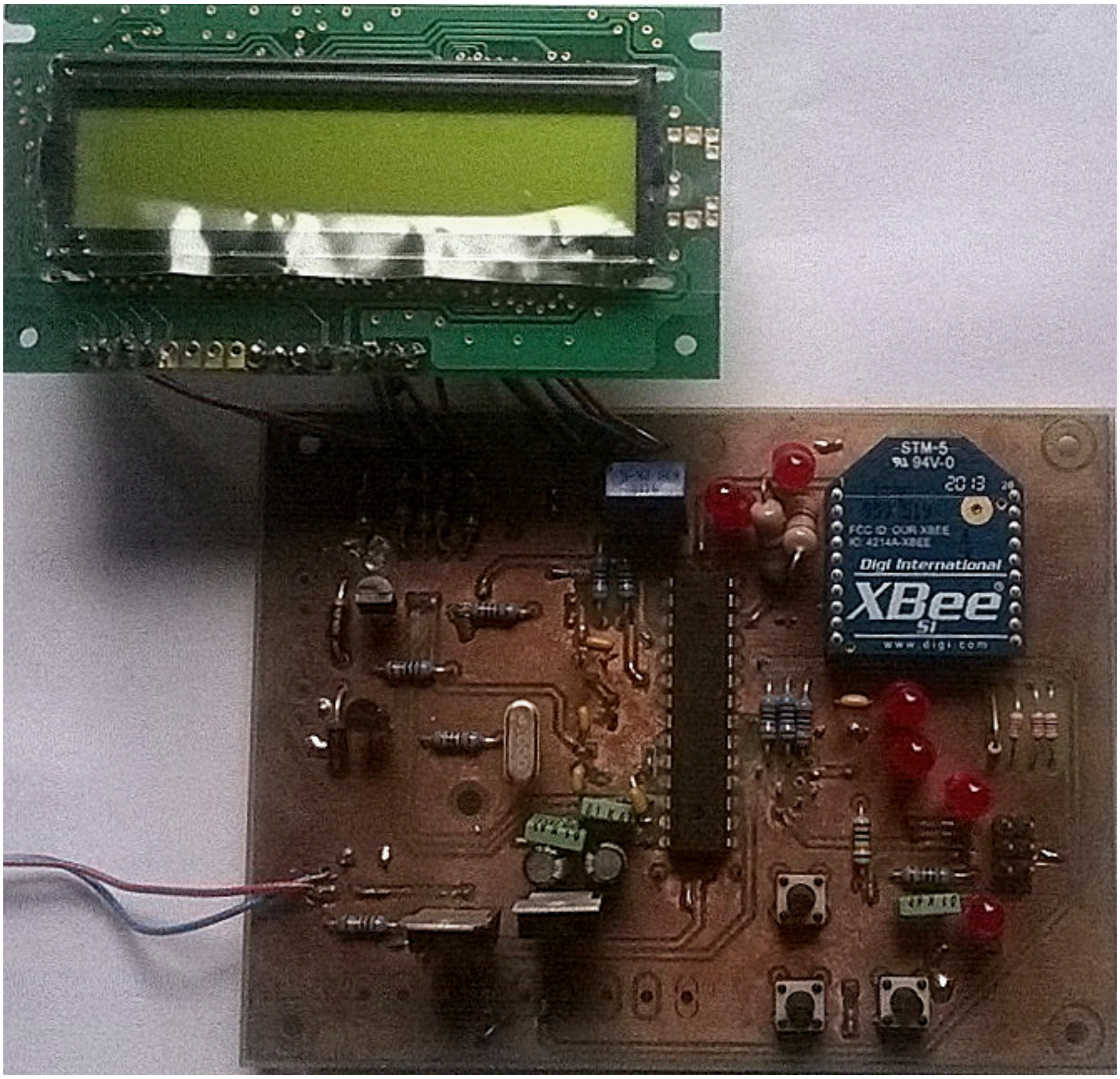


Figure 18. Show the farm node.

The 28-pin Dual in-Line Package (PDIP) ATmega 168 is the microcontroller used in this node. It is produced by the Atmel Cooperation with the subsequent features: 2.7V to 5.5V operating voltage, 23 programmable I/O lines, power consumption of 250µA at 1MHz under operating voltage of 1.8V and 15µA at 32KHz at 1.8V operating voltage when active, 0.1µA at 1.8V in power down mode, -40°C to 85°C working temperatures, 16 Kbytes of in-system self-programmable flash program memory with 10,000 write/erase cycles, a programmable serial Universal Synchronous Asynchronous Receiver Transmitter (USART) and up to 20 Million Instructions Per Second (MIPS) at 20MHz, 6-channel 10 bit Analog to Digital Converter (ADC). (Atmel Cooperation 2011.)

The XBEE is a RF module which operates within the Industrial, Scientific and Medical (ISM) Band. At an operating frequency of 2.4GHz, it is engineered to meet the 802.15.4 standard. It supports PTP, PMP topologies and also supports unicast, multicast and peer-to-peer modes for communication. The following are some of its features: range for outdoor use considering LOS is 90m, range for indoor or urban use is 30m, supply voltage is between 2.8V to 3.4V, RF data rate is 250000bps, serial interface data rate is 1200bps to 250Kbps, transmit power is 1mW (0dBm) and operating temperatures between -40 $^{\circ}$C to 85 $^{\circ}$C. (Digi International Incorporated 2011.)

The 16×2 Liquid Crystal Display (LCD) is an electronic display with 16 characters per line for a maximum of two lines display capability. Its supply voltage, is 5V and it has two registers. The command register, which stores command instructions given to the LCD such as clearing the screen and controlling display and the data register which stores data to be displayed in American Standard Code for Information Interchange (ASCII) value. There are two modes of operation for the LCD: the 8-bit mode and the 4-bit mode. The two modes are purely connection dependent and the elimination of data pins D0 to D3 from the connection of LCD to the Micro Controller Unit (MCU) leaves the LCD in the 4-bit operation mode else it is operating in 8-bit mode. The 4-bit mode of operation is utilized in this thesis. (Vishay 2002.)

The voltage regulator LM7805 is a product of Texas Instrument and the TO-220 surface mount package is used for the farm node. The LM7805 outputs a maximum voltage of 5.20V at 5mA to 1A current with an input supply voltage of 7V to 20V. (Texas Instrument 2003.)

4.1.2. Hardware of the Farmhouse Wireless Node

Figure 19. Show the farmhouse node

The farmhouse node (see **Figure 19**) used in this thesis is also self designed and locally manufactured. The major components of the farm node consist of the ATmega 644P microcontroller, an XBEE radio transceiver, the voltage regulators LD1117AV33, four push buttons, a crystal oscillator, two transistors, four connectors, seven LEDs, an external 5V power supply and an AVR-ISP connector.

The ATmega 644P microcontroller is a product of the Atmel Cooperation and the 40-pin PDIP package is used for the farmhouse node. The following are some features: 32 programmable I/O lines, operating voltages of between 2.7V to 5.5V, power consumption at 1MHz speed under operating voltage of 1.8V at temperature of 25 °C is 0.4mA when active, 0.1µA during power-down mode and 0.6µA during power-save mode, two programmable serial USART, up to 20MIPS throughput at 20MHz, 64 Kbytes of in-system self-programmable flash program memory with 10,000 write/erase cycles, 8-channel 10-bit ADC. (Atmel Cooperation 2012.)

The voltage regulator LD1117AV33 is a product of ST Microelectronics and the TO-220 surface mount package is used for both the farmhouse and farm nodes. The LD1117AV33 outputs a maximum voltage of 3.3V at 10mA current with an input supply voltage of 5V. (ST Engineering 2005.)

The AVR-ISP (see **Figure 20**) is a programmer which serves as an interface, allowing the serial download of codes from the Integrated Development Environment (IDE) to the microcontrollers, it is a product of Atmel Cooperation and the 6-pin connector is used for both boards in this module. The AVRISP comes with a Universal Serial Bus (USB) connection to the PC and a 6-pin connector to the target device. (Atmel Cooperation 2012.)

Figure 20. The AVR In-System Programmer.

4.1.3. Hardware of the Raspberry Pi

The Raspberry Pi (see **Figure 21**) as earlier mentioned in the introduction of this paper, is a single-board computer produced by the Raspberry Pi Foundation. The following are some features: Operating voltage is 5V, Power output is 3.5W, Central Processing Unit (CPU) is Advanced RISC Machines (ARM) 1176JZF-S running at 700MHz, Operating system is Linux, Makes use of a Secure Digital (SD) card or Secure Digital High Capacity (SDHC) card for storage, Memory is 512MB. The raspberry pi has three USB 2.0 ports and an HDMI port for interfacing peripherals such as the keyboard, mouse and display. (Raspberry Pi Foundation 2014.)

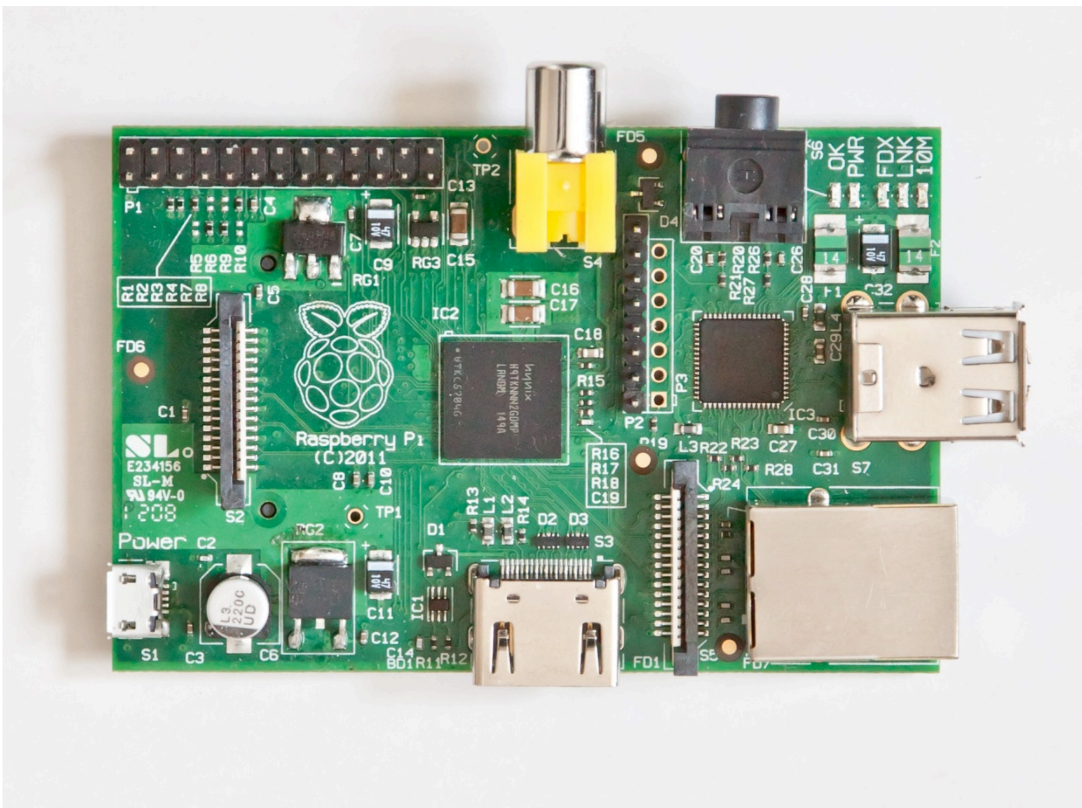


Figure 21. The Raspberry Pi (Readwrite 2014).

4.1.4. Hardware of the FTDI Breakout Board

The FTDI breakout board (see **Figure 22**) is a product of Sparkfun, developed for USB to serial Integrated Circuit (IC). The board has LEDs for serial traffic indication such that Transmit (TX) and Receive (RX) pins are hooked up to these LEDs and are lit when TX and RX are active. The board can be configured to 3.3V or 5V voltage levels. The FTDI chip itself transfers data at rates of 300 to 3Mbaud at Transistor-Transistor Logic (TTL) levels depending on the communication port in use. It has 128 byte buffer and 256 byte buffer for receiving and transmission respectively. It is USB 2.0 full speed compatible and operates within temperatures of -40 °C to 85 °C. (Sparkfun 2014.)

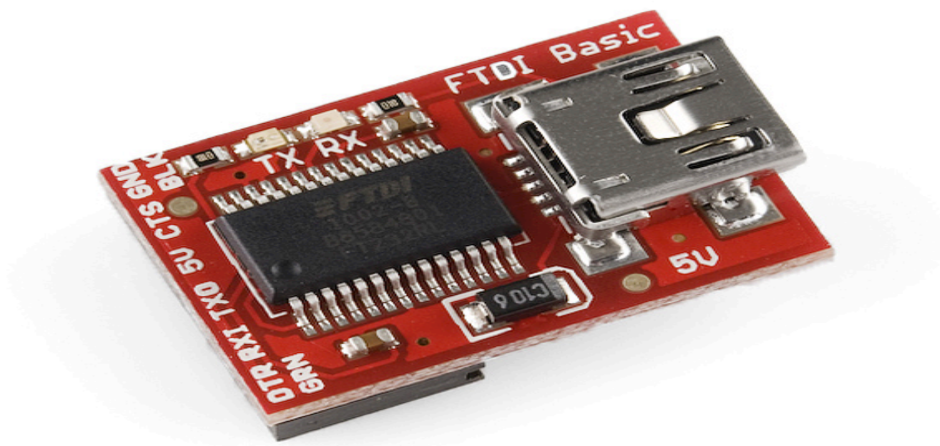


Figure 22. The FTDI Breakout Board, (Sparkfun 2014).

4.1.5. Hardware Design of the Farm Wireless Node

Designing the farm node circuit board that connects the hardware components mentioned in the previous sections was one task of this thesis. The circuit board on which the components of the farm node was mounted as shown in the **Figure 18** was printed in the electronics laboratory in Technobothnia of the university of Vaasa and was designed with the CadSoft Eagle 5.11.0 software. The schematic of the farm board is given in **Figure 23** and **Figure 24.**

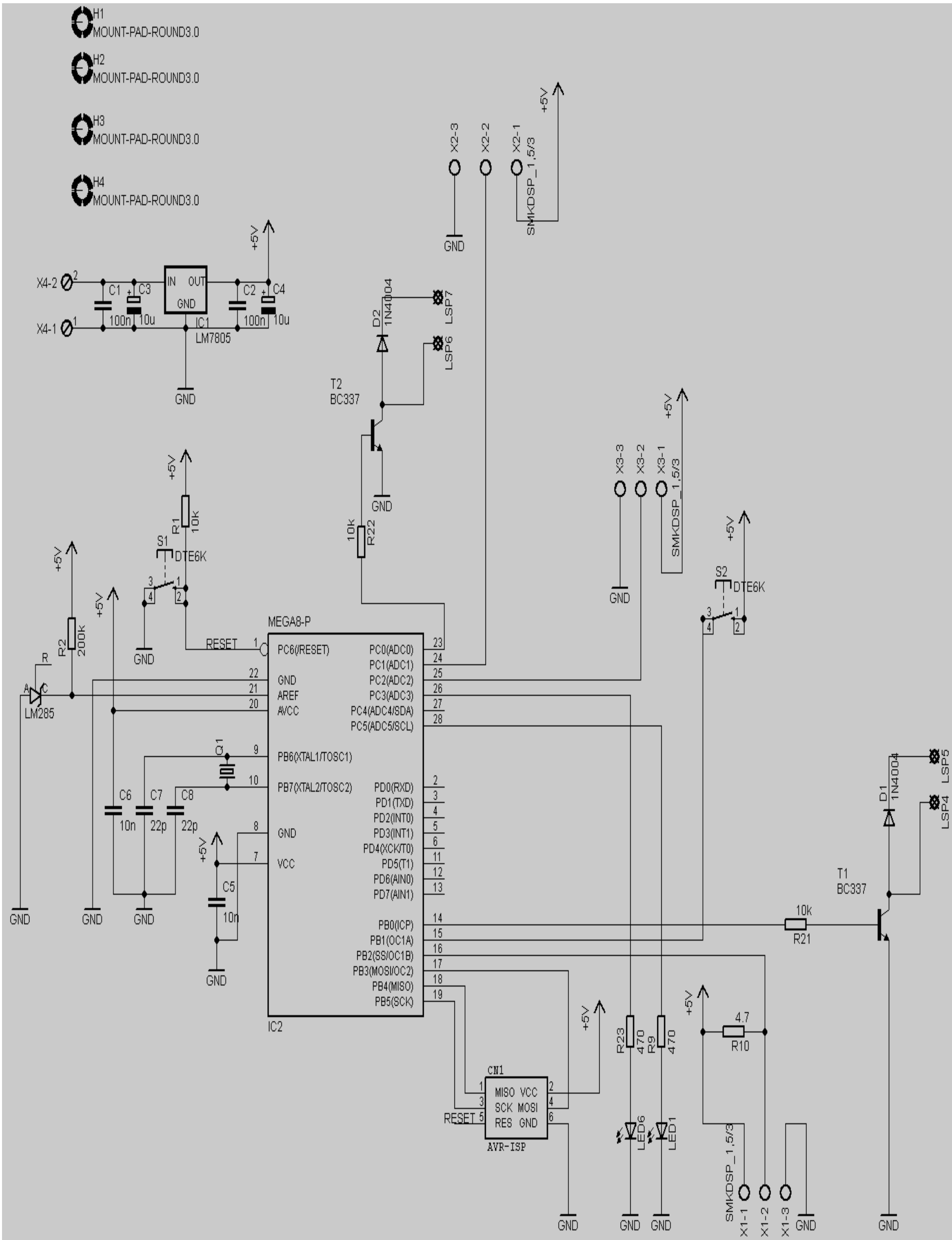


Figure 23. Part of the farm board schematic showing the ATmega 168 I/Os, the AVR-ISP, the main power supply and the microcontroller reset circuits.

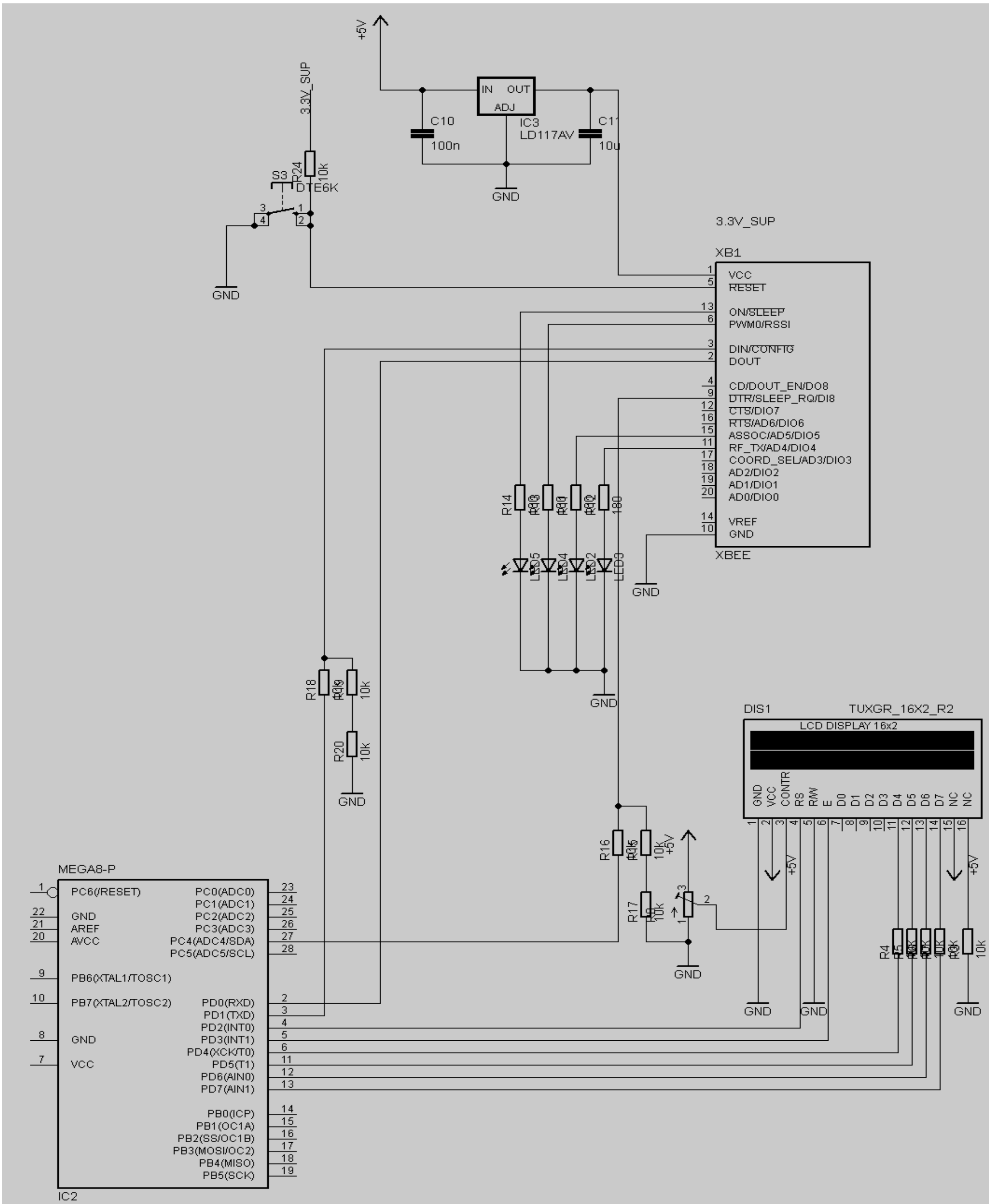


Figure 24. Part of the farm board schematic showing the 16 × 2 LCD circuit and the RF module circuit including its power supply.

The USART of the ATmega 168 is connected to the USART of the XBEE transceiver enabling asynchronous serial communication between the two devices. As indicated in the preceding section, both the ATmega 168 and the XBEE work with a voltage of 3.3V hence the LD1117AV33 would have been enough for the power supply to the board, but the 16×2 LCD works with a voltage of 5V hence the need for the two voltage regulators LM7805 and LD1117AV33 on the same circuit board, the LM7805 serves the whole board and the LD1117AV33 serves the XBEE. The output of the LM7805 is the source for the LD1117AV33 in the circuit. While the 16×2 LCD and the ATmega 168 are connected directly to the output of the LM7805, the XBEE is connected to the output of the LD1117AV33. Since the XBEE transceiver can sink only a maximum voltage of 3.3V, all connections from the ATmega 168 to the XBEE are made via voltage divider circuits as shown in the schematic of the farm board **(**see **Figure 24)**.

There are three pushbuttons on the board, the S1 and S3 are the reset buttons for the ATmega 168 and the XBEE respectively while the S3 is an I/O provision for the board, to be used according to the discretion of the user. The AVRISP works with a voltage of 5V and hence its on-board connector is powered directly from the output of the LM7805. The reset circuit of the ATmega 168 is tied to the reset of the AVRISP as shown in the schematic, hence a reset of the ATmega 168, resets the AVRISP as well. The connector X1, X2 and X3 are I/O provisions on the board and can be used for inputs such as temperature or level sensors, while the transistor circuits for the transistors T1 and T2 are provisions for driving relays for high powered outputs such as water pumps or lighting for the farm.

The PORTC of the ATmega 168 is used as the communication port between the ATmega 168 and the 16×2 LCD. The LCD is included in the farm board to display messages and errors. The variable resistor R8 is used to adjust the contrast of the LCD.

4.1.6. Hardware Design of the Farmhouse Wireless Node

Apart from the design of the farm board, the design of the farmhouse board which connects all the components earlier mentioned comprising the farmhouse node is another task of this thesis. The circuit board on which the components of the farm node was mounted as shown in the **Figure 19** was printed in the ITEAD studio in China. It was also designed using the CadSoft Eagle 5.11.0 software. The schematic of the farmhouse board is given in **Figure 25** and **Figure 26.**

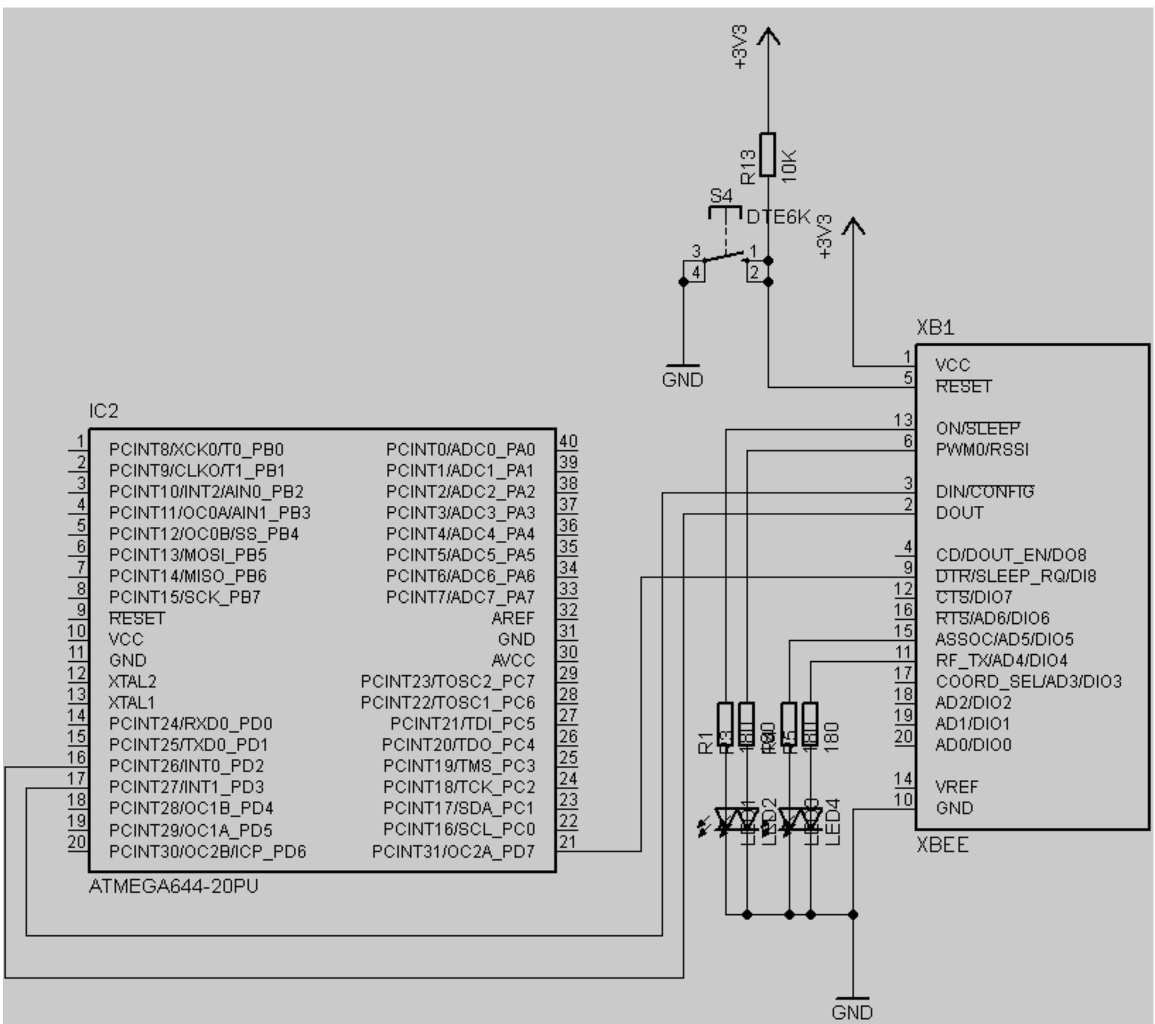


Figure 25. Part of farmhouse board schematic showing the RF module circuit.

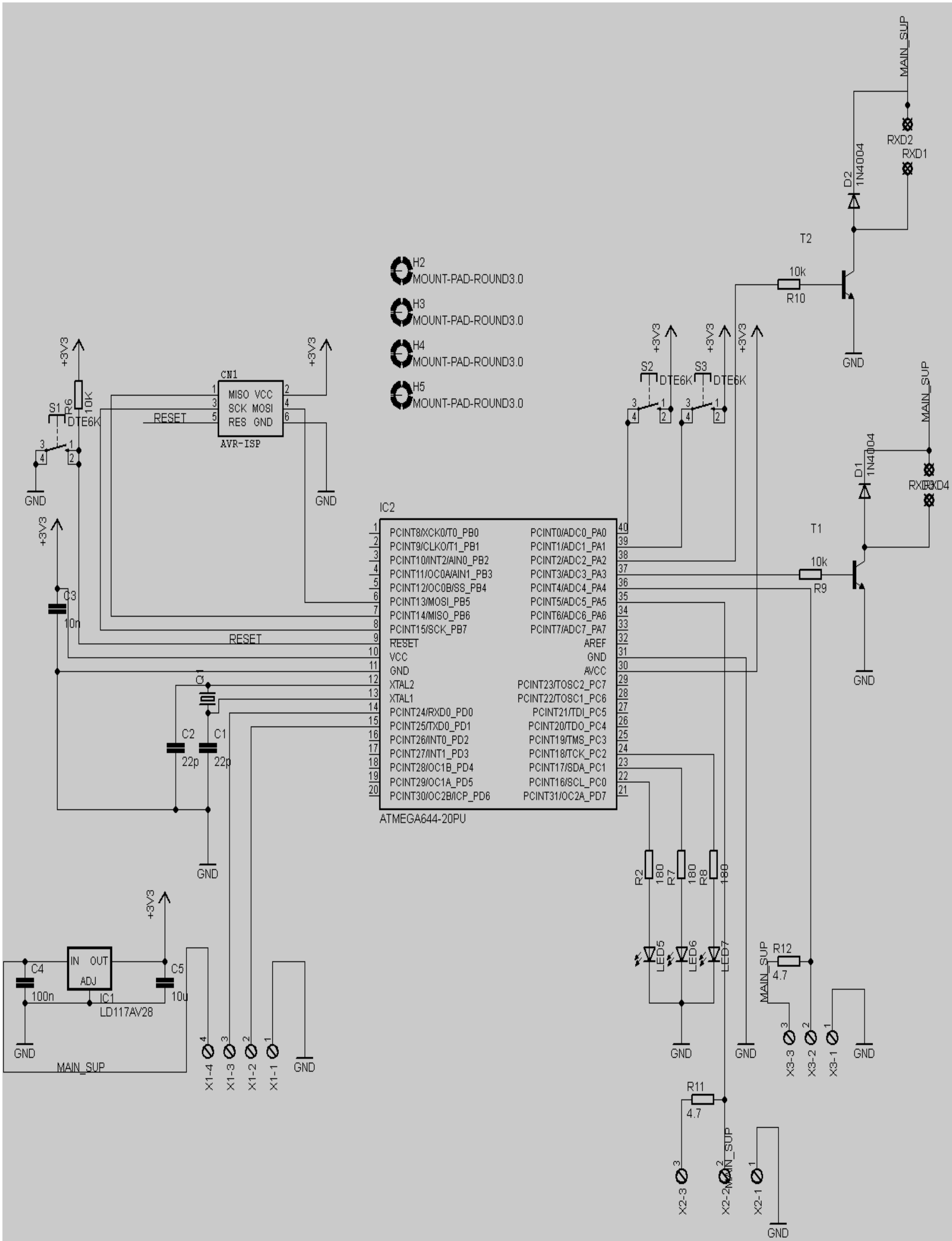


Figure 26. Part of the farmhouse board schematic showing the ATmega 644P I/Os, the AVR-ISP, the main power supply and the microcontroller reset circuits.

One of the USART terminals of the ATmega 644P microcontroller is connected to the USART terminal of the XBEE transceiver to allow asynchronous data transfer between the two components, while the other USART terminal is connected to the connector X1, provisioned to connect to the FTDI chip which interfaces the Raspberry Pi and the node.

The ATmega 644P and the XBEE both source and sink voltage of 3.3V hence the use of the voltage regulator LD1117AV33 for the power supply circuit of the farmhouse board. The LD1117AV33 (see **Figure 26**) takes its input voltage from the connector X1 which connects the FTDI chip to the board. The FTDI chip is powered via the 5V from the Raspberry Pi hence the external power supply here is actually the power from the raspberry pi. The previous sentence withstanding, the board can be supplied with an external power supply through the connector X1 if the node need not connect with the Raspberry Pi.

There are four pushbuttons on the board, S1 and S4 are reset buttons for the ATmega 644P and the XBEE respectively while S2 and S3 are I/O provisions to be used according to user discretion. The reset pin of the AVRISP is hooked to the reset of the ATmega 644P hence a push for resets on the microcontroller also effects a reset on the AVRISP programmer.

The AVRISP works with 3.3V as well hence the on-board connector for it is powered directly from the output of the LD1117AV33. The circuits for the transistors T1 and T2 are provided for connection to relays for driving high powered output devices such as motors and heaters. The connectors X2 and X3 are I/O provisions on the board and can be used for inputs such as temperature and motion sensors.

4.2. Software

The Module as already indicated comprises of two nodes which run independently. The two nodes communicate with each other by wireless serial data transfer via their individual RF modules (the XBEEs). The section 4.2.1 describes how the software of the farm wireless node is designed and the section 4.2.2 also describes the software design of the farmhouse wireless node. The subsequent sections discusses the software of the computer connection to the farmhouse wireless node which allows internet access to the module.

4.2.1. Software Design of the Farm Wireless Node

The farm wireless node as can be deduced, operates under two main tasks: control of outputs such as water pumps, lighting and heaters as a response to input data received or programmed onto the microcontroller (automation), data transmission and reception to and from the farmhouse wireless node (communication).

In the task of automation, the microcontroller which understands the language of binary 1 and 0 only, is loaded with a set of code which is triggered to run by an input command which can be physical such as a push button or a sensor on the board or by a coded input such as a timer or a simple code command to set an input pin high or low.

To transmit or receive data, the node utilizes communication between its microcontroller (the ATmega 168) and the XBEE. The communication between these components is via USART. The ATmega 168 and the XBEE are both equipped with USART terminals. (Atmel Cooperation 2011; Digi International Incorporated.)

The USART of the ATmega 168 microcontroller employs full duplex operation with the capability of asynchronous operation, it supports serial frames of eight data bits, one start bit and one stop bit. The hardware supports odd or even parity generation and check. The USART also works in a multiprocessor communication mode. There are three main parts of the USART: the clock generator, the transmitter and the receiver. The clock generator which generates the base clock for the transmitter and receiver, has a logic which consist of a synchronizer for external clock input and this is used by the synchronous slave operation and the baud rate generator (the internal clock generator). The transmitter comprises of one write buffer which allows for a continuous data transfer without delays between frames, a serial shift register, a parity generator and a control logic which handles different serial frame formats. The receiver also comprises clock and data recovery units which is used for asynchronous reception of data, a parity checker, control logic, a shift register and two level receive buffer. The receiver supports the same frame formats as the transmitter and has frame error, data overrun and parity error detection capabilities. (Atmel Cooperation 2011.)

The baud rate generator comprises a register and a down-counter. The down-counter runs at system clock and is loaded with the baud rate register value each time the counter counts down to zero at which point a clock is generated and this clock is the output of the baud rate generator (see **equation 13**). The receiver clock uses directly, the output of the baud rate generator but the transmitter divides it by 2, 8 or 16 depending on mode of operation (asynchronous or not). (Atmel Cooperation 2011.)

$$BAUD = fosc/(UBRRn + 1) \tag{13}$$

f_{osc} = the system clock frequency

UBRRn = baud rate register value

One data bit of one character, start and stop bits for synchronization and an optional parity check bit are the composition of a serial frame (see **Figure 27**). A frame structure is, data bits starting with the least significant bit, preceded by a start bit, followed by a parity bit if that option is enabled and then finally the stop bit(s). A frame has to be complete for transmission and after transmission, it can be directly followed by a new frame, or then the communication line can be set to a state of idle (high). (Atmel Cooperation 2011; Embedds 2011.)

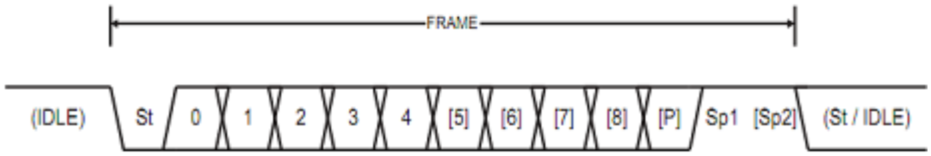


Figure 27. Frame format of message exchange between the ATmega 168 and the XBEE, (Embedds 2011).

Before communication between the ATmega 168 and the XBEE, the USART of the ATmega 168 has to be initialized and this consist of setting baud rate, setting frame format and transmitter and receiver enabling. This procedure can be realized in the sample code provided in the **Appendix 5**. The condition for communication between the ATmega 168 and the XBEE is that the USARTs of the two devices have compatible settings (frame format). The XBEE USART setting follows that of the ATmega 168 by default, hence there is no demand for further configuration. By default the XBEE operates in unicast mode which implies, by default it supports retries. The receiver XBEE upon receiving RF packets sends acknowledgement (ACK) to transmitter XBEE. If the transmitter XBEE does not receive the ACK, it resends the packet up to three times or till the ACK is received (Digi International Incorporated 2011.)

The main task of the program running on the microcontroller on the farm wireless node is in two portions as mentioned in the first paragraph of this section, to automate some functions in the farm and secondly to communicate with the RF module. In its automation task, the ATmega 168, waits for input command(s) such as sensor trigger or a pushed button, receives the input commands, looks up the interrupt routines for a match, if there is a match it runs the set of code for the match which is typically to set some outputs high or low else it waits again for next input command(s). The communication task comprises a transmit and receive routine which run simultaneously. Basically the microcontroller receives data packets from the RF module into the input buffers or transmits data packets from the output buffers to the RF module. **Figure 28** gives a flowchart of the software routine of the ATmega 168.

The main task of the program running on the XBEE RF module is set by default. It is known as the transparent operation mode, where the module acts as a serial line replacement and queues up all of its USART data it receives through its digital input pin for RF transmission, the RF data received from another RF module is sent out through its digital output pin. **Figure 29** shows the routine of the XBEE software.

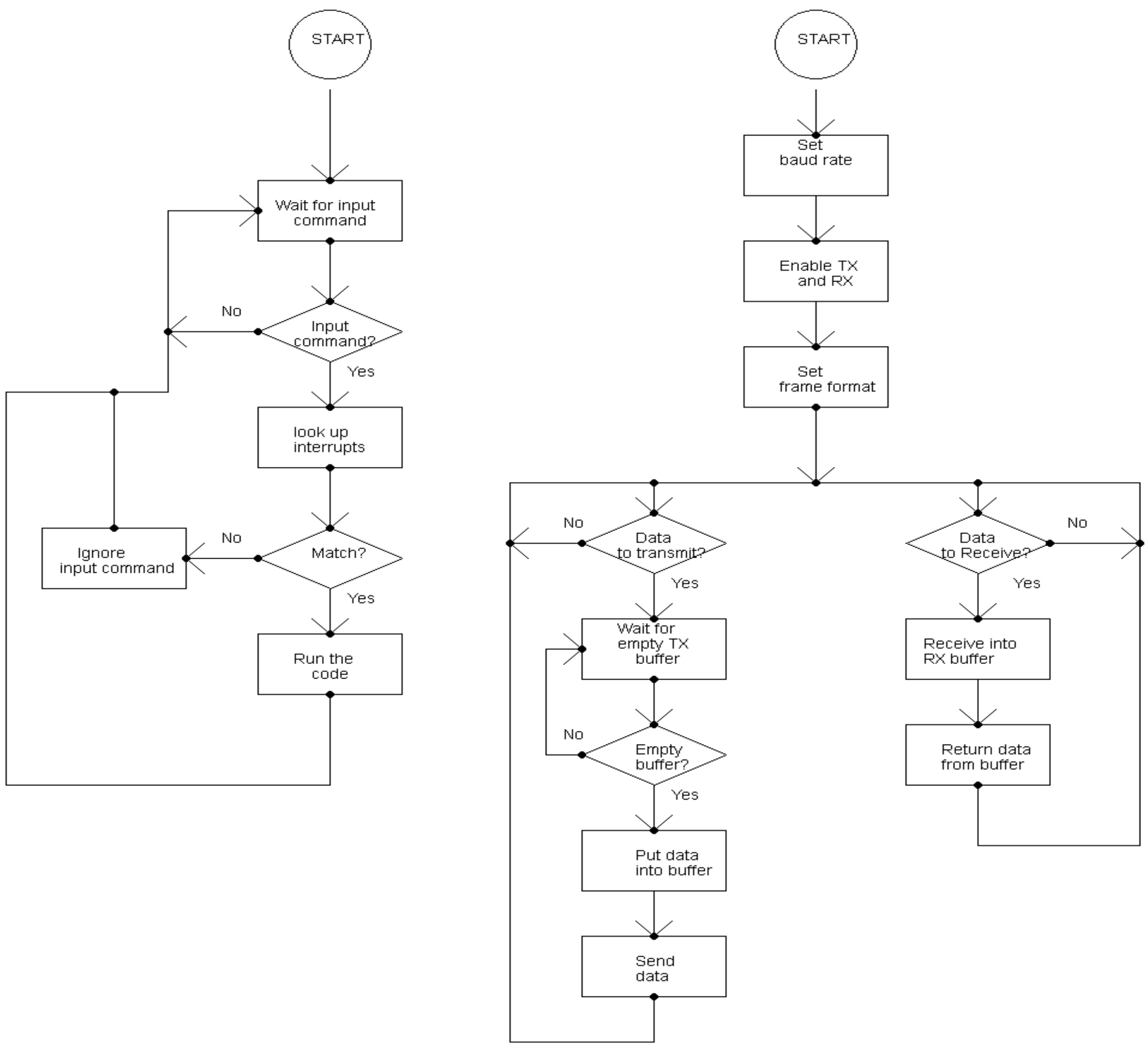


Figure 28. a) The flowchart of the ATmega 168 software routine (automation). b) The flowchart of the ATmega 168 software routine (communication).

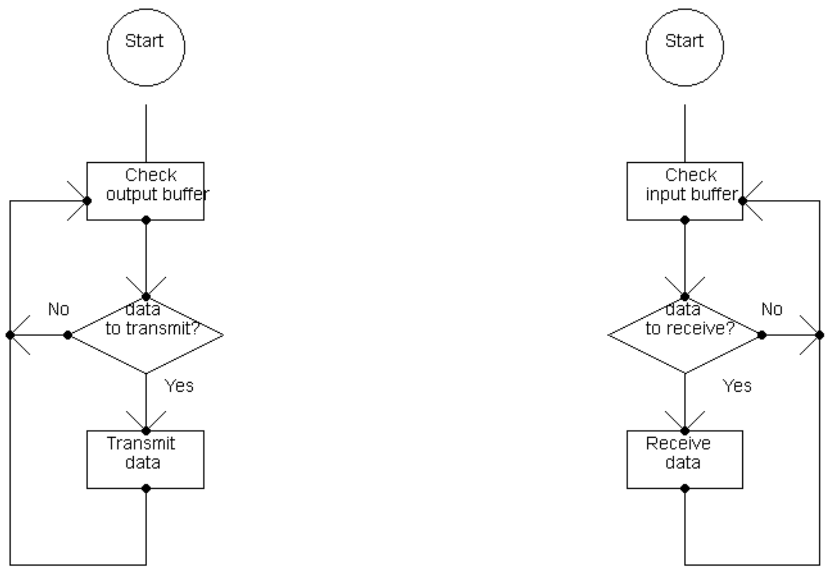


Figure 29. a) The flowchart of the RF module software routine (TX). b) The flowchart of the RF module software routine (RX).

4.2.2. Software of the Farmhouse Wireless Node

The farmhouse wireless node also has two major task as the farm wireless node, automation of some farmhouse equipment such as lighting and alarms, and secondly communication. The communication task is also divided into two main areas, that is, communication between the ATmega 644P and the RF module and communication between the ATmega 644P and the raspberry pi.

In the area of automation, the ATmega 644P microcontroller functions similarly as the microcontroller in the farm node. It is programmed in the C language as well and the same IDE is used. To transmit or receive data from the farm node, the farmhouse node utilizes communication between its microcontroller (the ATmega 644P) and the XBEE. The ATmega 644P and the XBEE are both equipped with USART terminals hence communication between them is via USART. (Atmel Cooperation 2011; Digi International Incorporated.)

The ATmega 644P microcontroller has two USARTs, the USART0 and USART1. They both employ full duplex operation with possibility of asynchronous operation just as in the ATmega 168. It supports the same frame and frame structure as early described in the ATmega 168 and the hardware supports odd and even parity generation and check as well. Each of the ATmega 644P USART functions in exact same manner as the USART of the ATmega 168 considering parity check, baud rate generation and frame structure. The one difference is that each USART of the ATmega 644P is initialized separately. (Atmel Cooperation 2012.)

The communication between the ATmega 644P and the raspberry pi is quite different because the raspberry pi utilizes a USB port for communication hence it is not directly compatible with the ATmega 644P so a USB to serial USART interface (FTDI chip) is employed. With the FTDI chip, there is no USB specific firmware programming required since the entire USB protocol is handled on the chip by default. (Future Technology Devices International 2010). The flowchart of the software routine of the XBEE in the farmhouse wireless node is the same as in the farm wireless node. **Figure 30** and **Figure 31** shows the flowchart of the software routine of the ATmega 644P and the **Figure 32** show the software overview of the whole module.

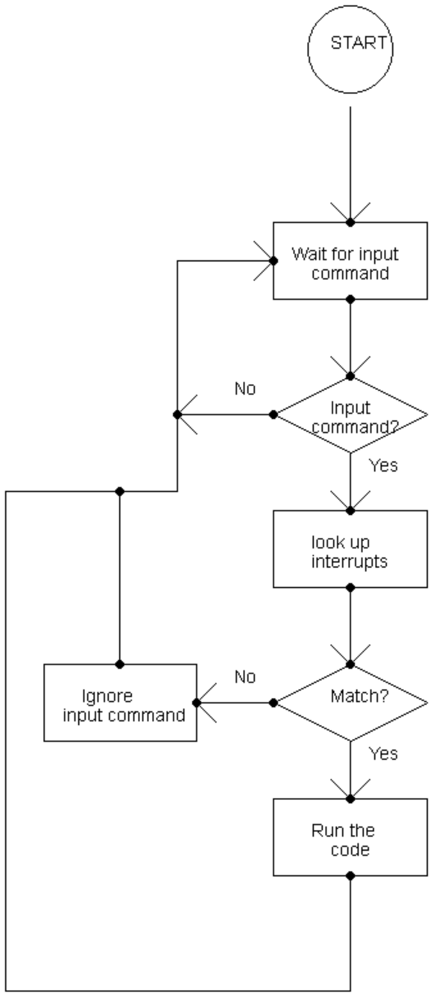


Figure 30. The flowchart of the ATmega 644P software routine. (automation).

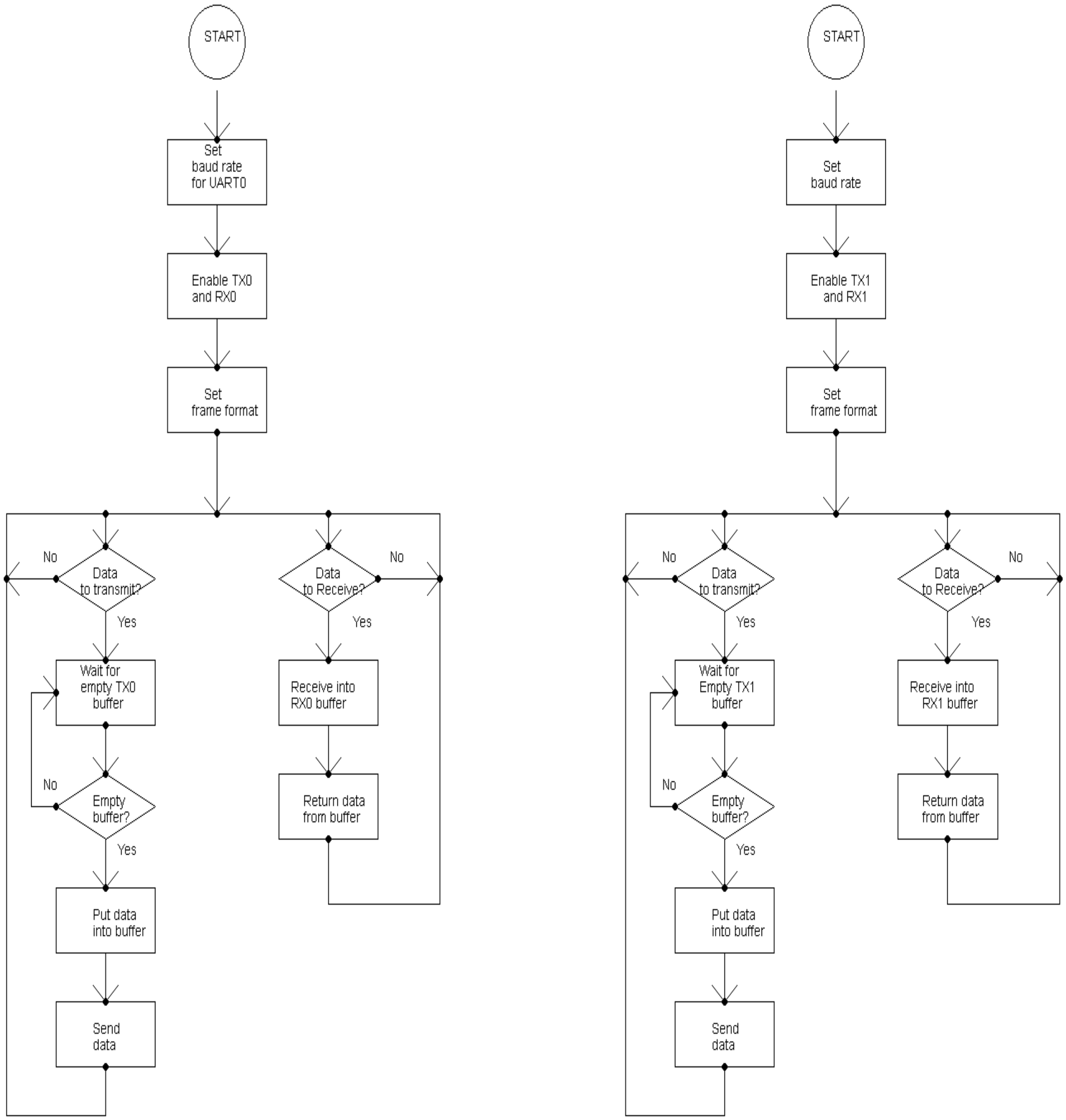


Figure 31. a) The flowchart of the ATmega 644P software routine (communication USART 0). b) The flowchart of the ATmega 644P software routine (communication USART 1).

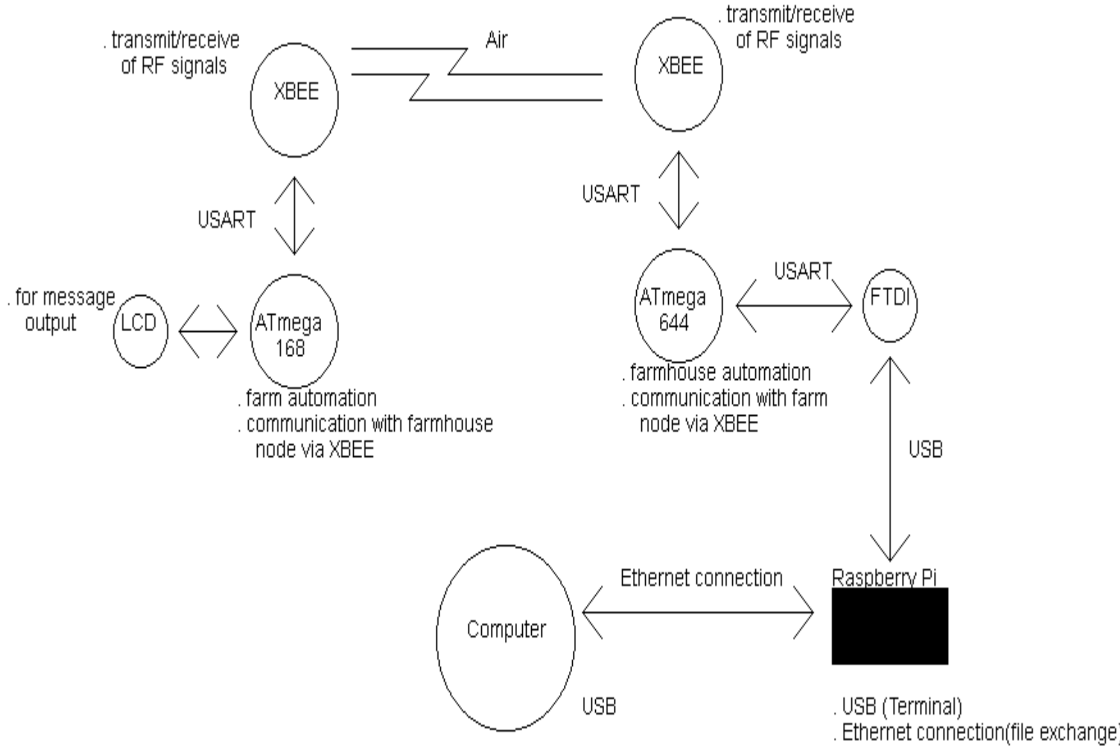


Figure 32. Overview of software implementation and design of the module.

4.2.3. Software of the Raspberry Pi

The components of a computer system can basically be divided into four: the hardware which includes the CPU and memory, the operating system (OS), the application programs which include compilers and database systems, the users such as people, machines or other computers. The operating system is an interface program between the user and the hardware of the computer and it makes for a convenient use of the computer system allowing for an efficient use of the computer hardware.(Peterson & Silberschatz 1985: 1-3.)

The kernel, the shell, the file system and the user programs or commands are major components of the UNIX operating system. The **Figure 33** shows the relationship among the user, the shell, the kernel and the hardware of the UNIX system.

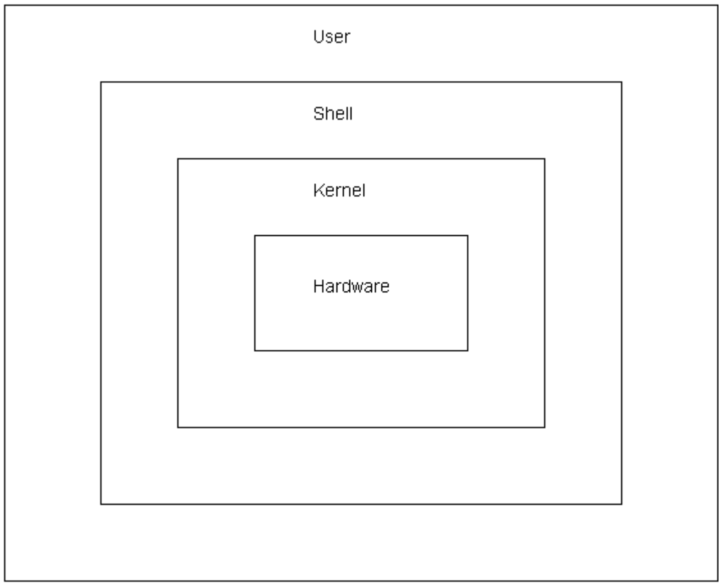


Figure 33. The structure of the UNIX system.

Physical devices are treated as files in a UNIX system, hence permitting common commands for physical devices and ordinary files. In a UNIX system, the file is the basic unit for organization of information. Organizing, storing, retrieving, manipulating and managing information are all done logically by the file system of the UNIX system. The Organization of the files are done hierarchically with files grouped into directories. The shell component of the UNIX system basically reads and interprets the user programs or commands for program execution. The shell is utilized as a command language as well, permitting the user to control when and how to carry out the commands. The kernel is the part of the OS which makes a direct interaction with the computer hardware, providing services that are used by programs and providing insulation between the program and the underlying hardware. The kernel manages the computer memory, controls computer access, maintains the files system and handles interrupts. (Rosen, Rosinski & Farber 1990: 7-10.)

The raspberry pi uses Linux, a "UNIX-like" OS which is a free and open source software with the Linux kernel as the defining component. Since the raspberry pi uses an SD or SDHC card for memory, the Linux OS is to be installed first on the SD or SDHC card and then, the loaded card slotted in the raspberry pi before booting it. (Raspberry Pi Foundation 2014.)

On the raspberry pi runs the SSH terminal emulator. As mentioned in section 3.5**,** the SSH is a network protocol employed for secure data communication between a terminal and a computer in a network, it runs best on UNIX-like operating system like the Linux which makes it a good choice for this thesis work with consideration of the fact that it provides data encryption unlike the Telnet. The SSH's typical usage is to log into a remote machine and then execute commands, but it also supports forwarding Transport Control Protocol (TCP) ports, X11 connections and tunneling. Basically the raspberry pi in this module is connected to the internet and hosts the SSH terminal emulator which in-turn communicates with the farmer's computer in a network (Ethernet) or via the internet when the farmer is out of the farmhouse.

4.2.4. Integrated Development Environment

The WinAVR is the Integrated Development Environment (IDE) used in this thesis and the programming was done in the C language. "According to the official site of the WinAVR, it is a suite of executable, open source software development tools for the Atmel AVR series and it is hosted on the windows platform." It allows the user to write the source code and attach header files, it also generates automatically the makefile for the written code and then with a command, downloads the compiled executable file unto the microcontroller. The source files and header files including the makefiles must be saved to a single location before the compilation can take effect. The **Figure 34.** show the WinAVR environment. The WinAVR includes avr-gcc (compiler), avrdude (programmer), avr-gdb (debugger) which are essential development tools for the AVR. (WinAVR 2014.)

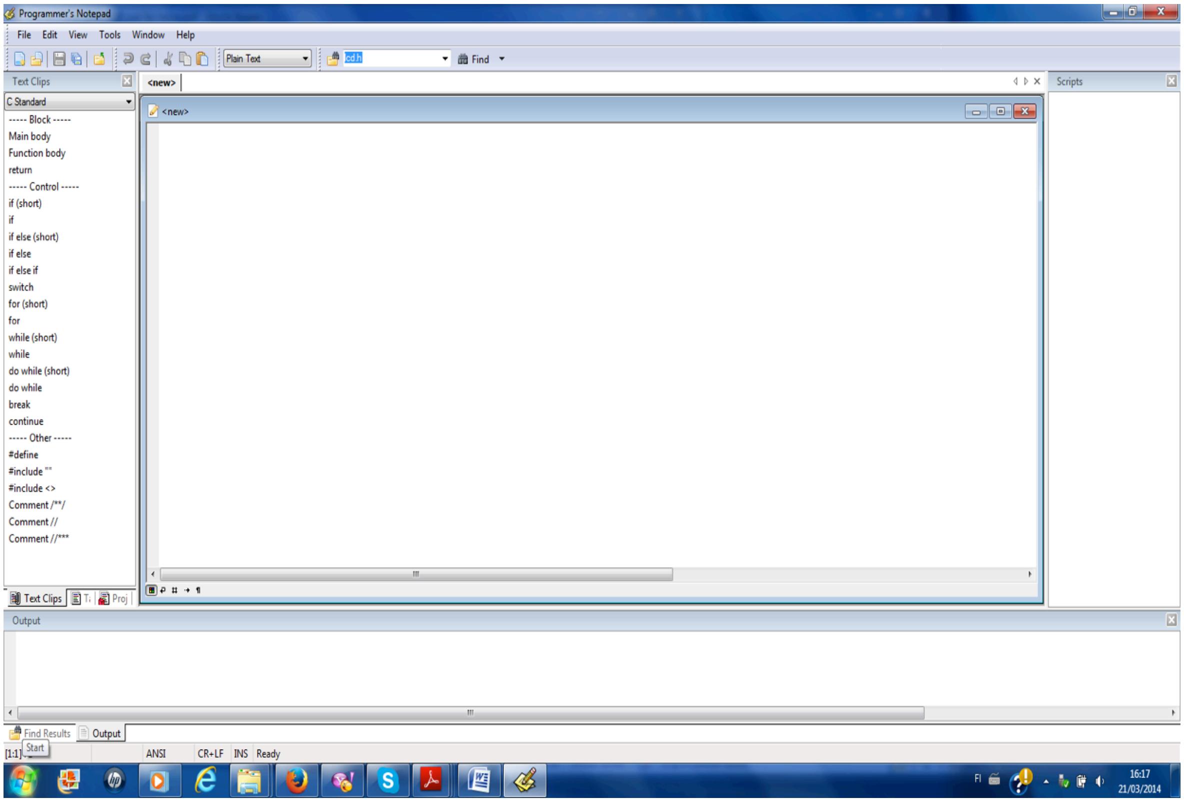


Figure 34. The WinAVR IDE.

5. EXPERIMENTS

5.1. Indoor RSSI Measurements I

In this experiment, the RSSI values of data shared between the farm wireless node and the farmhouse wireless node were measured at defined distances in an auditorium at the Tampere University of Technology. As indicated in the last paragraph, the RSSI value is determined only when there is message exchange between the wireless nodes. In order to have a period of uninterrupted communication, the X-CTU software provides a range test application which demands that, the loopback jumper on the receiving RF module is connected to ensure the transmission of the test data from the receiving RF module to the transmitting one, hence the setup is a simple loopback wireless circuit.

The first set of measurements between the two nodes were taken at LOS with almost no electrical interference. **Table 1** shows results of the measured RSSI values according to distances between 0 and 30m at intervals of 2.5m. At each distance, the RSSI values of 1000 measurements were taken with minimum, maximum and average RSSI values tabulated as in the **Table 1** .

The **Figure 36** show that, the RSSI values generally decrease with increase in distance which is theoretically expected due to the fact that power of transmitted signal decreases with increase in distance. It can be observed that between some distances, the RSSI values changed very little or did not change at all. In the graph below (see **Figure 36**), the RSSI values measured from distances 2.5m and 5m for example were same and between distances 12.5m and 15m for example were only 2dBm apart. After a distance of 30m, no signals were received.

Table 1. RSSI measurements between the two wireless nodes at LOS.

Distance in m	**2.5**	**5.0**	**7.5**	**10.0**	**12.5**	**15.0**
Minimum RSSI value in dBm	-78	-66	-80	-64	-72	-69
Maximum RSSI value in dBm	-58	-59	-62	-59	-62	-64
Average RSSI value in dBm	-65	-65	-68	-63	-68	-66
Distance in m	**17.5**	**20.0**	**22.5**	**25.0**	**27.5**	**30.0**
Minimum RSSI value in dBm	-82	-79	-80	-78	-82	-86
Maximum RSSI value in dBm	-70	-69	-70	-69	-70	-78
Average RSSI value in dBm	-72	-72	-75	-75	-78	-85

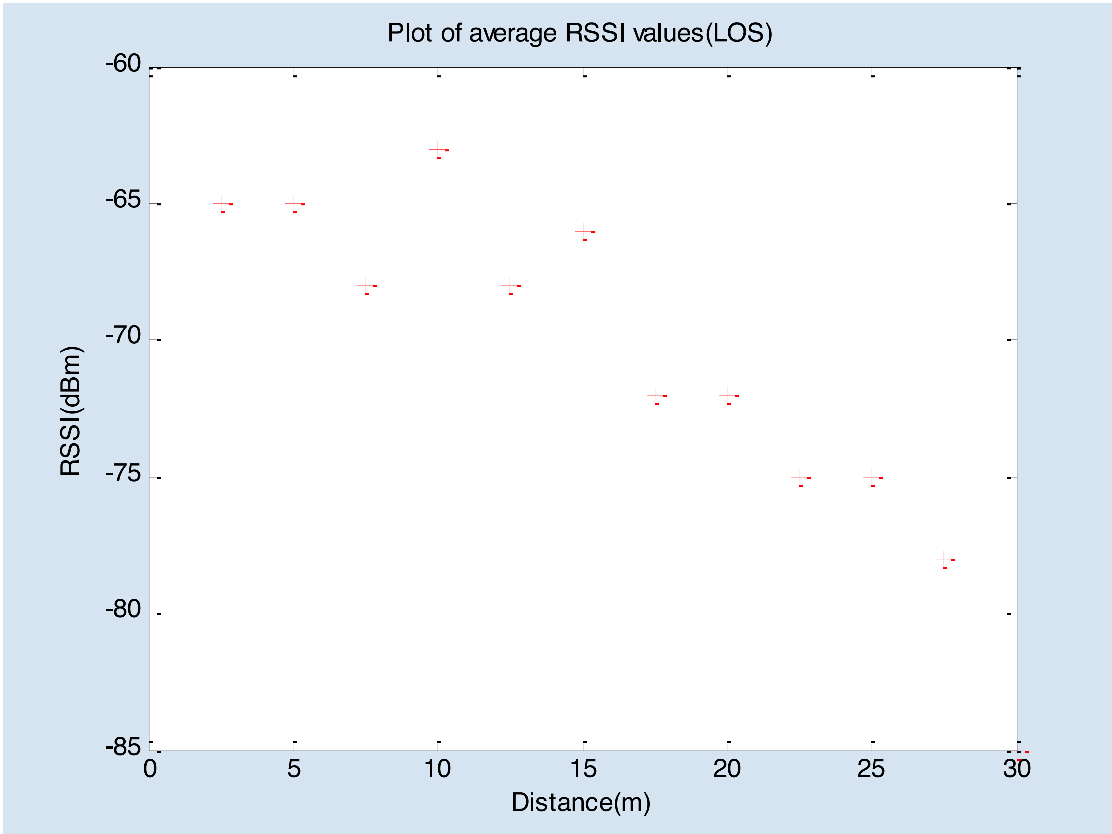


Figure 36. This figure show a graph of the plot of the average RSSI values against the distances from the **Table 1.**

5.2 Indoor RSSI Measurement II

In this second set of measurements, the RSSI values between the two wireless nodes were measured at the entrance to the library of Tampere University of Technology. In this scenario, lots of people were moving frequently in and out of the library. The communication link is not LOS and it depicts an urban environment. The set-up used here was the same as in the experiment of section 5.1.

Table 2 show results of the measured RSSI values according to distances between 0 and 30m at intervals of 2.5m. At each distance, the RSSI values of 1000 measurements were taken with minimum, maximum and average RSSI values tabulated as in the **Table 2**.

Table 2. RSSI measurement between the two wireless nodes, (not at LOS).

Distance in m	**2.5**	**5.0**	**7.5**	**10.0**	**12.5**	**15.0**
Minimum RSSI value in dBm	-78	-66	-82	-72	-88	-82
Maximum RSSI value in dBm	-58	-59	-63	-62	-60	-68
Average RSSI value in dBm	-65	-66	-68	-64	-77	-75
Distance in m	**17.5**	**20.0**	**22.5**	**25.0**	**27.5**	**30.0**
Minimum RSSI value in dBm	-85	-74	-74	-84	-80	-88
Maximum RSSI value in dBm	-70	-66	-68	-72	-68	-76
Average RSSI value in dBm	-80	-72	-72	-82	-78	-85

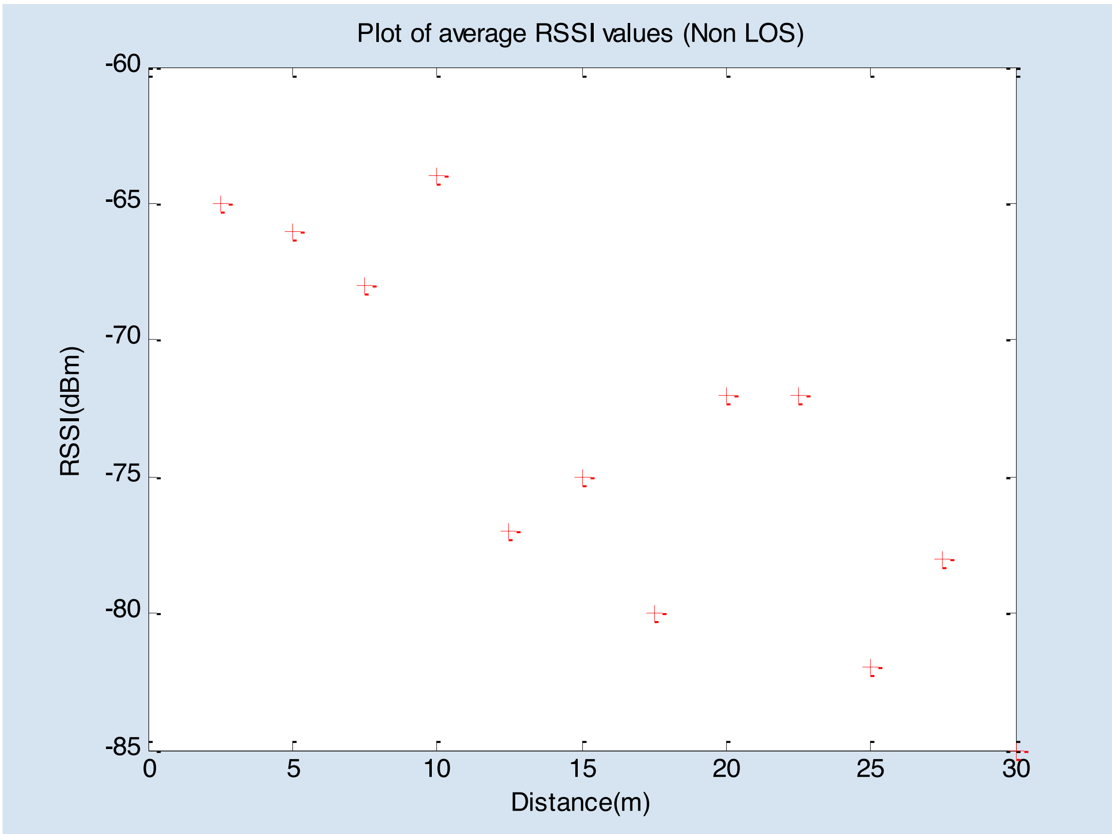


Figure 37. This figure show a graph of the plot of the average RSSI values against the distances from the **Table 2.**

Table 2 show results of the measured RSSI values and the **Figure 37** shows that, the RSSI values do not follow any pattern with change in distance which is theoretically expected. In an urban environment, noise due to the weather and obstacles between the RX and TX determine the RSSI value of data packets, hence though distance has a role in the RSSI values, it is the interferences that mostly affect the strength of the signal. In the above graph, the RSSI values measured at distances 20m and 20.5m were the same. At 10m the RSSI value was higher than the RSSI values at distances 2.5m to 7.5m which explains the dependency of power of data packets on the link quality.

5.3 Percentage of Throughput 1

In this set of measurements, the number of packets sent, number of packets received and the number of data packets lost were collaborated to give the percentage of throughput I. These measurement were measured alongside the measurements made in the indoor measurement I.

Table 3. Percentage of throughput of data packets sent between the two wireless nodes in a LOS.

Distance in m	**2.5**	**5.0**	**7.5**	**10.0**	**12.5**	**15.0**
No. of packets sent	1000	1000	1000	1000	1000	1000
No. of packets received	994	994	995	1000	996	999
No. of packets lost	6	6	5	0	4	1
Percentage of success	99	99	99	100	99	99
Distance in m	**17.5**	**20.0**	**22.5**	**25.0**	**27.5**	**30**
No. of packets sent	1000	1000	1000	1000	1000	1000
No. of packets received	988	872	886	866	933	856
No. of packets lost	12	128	114	134	67	144
Percentage of success	98	87	88	86	93	85

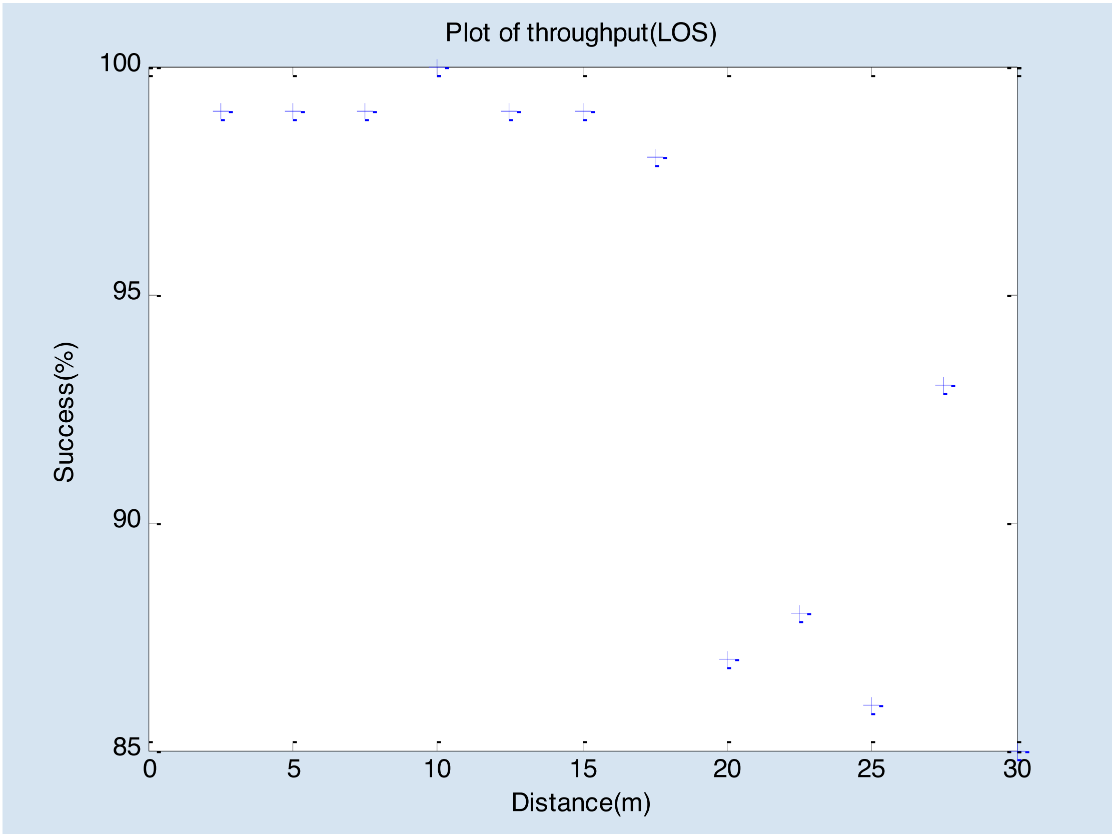


Figure 38. This figure show a graph of the plot of percentage of throughput against distance for a LOS.

The average throughput measurements are shown in **Table 3** and the **Figure 38** shows a plot of the results from this table. The average throughput here is 94% with the maximum data packets lost being 144 out of 1000 data packets sent. This percentage is very high and hence at indoor LOS the RF module can be said to be very reliable and robust.

5.4 Percentage of Throughput II

In this set of measurements, the number of packets sent, number of packets received and the number of data packets lost were collaborated to give the percentage of throughput II.

These measurement were measured alongside the measurements made in the indoor measurement II.

Table 4. Percentage of throughput of data packets sent between the two wireless nodes in a non-LOS.

Distance in m	**2.5**	**5.0**	**7.5**	**10.0**	**12.5**	**15.0**
No. of packets sent	1000	1000	1000	1000	1000	1000
No. of packets received	994	994	995	1000	946	906
No. of packets lost	6	6	5	0	54	94
Percentage of success	99	99	99	100	94	90
Distance in m	**17.5**	**20.0**	**22.5**	**25.0**	**27.5**	**30**
No. of packets sent	1000	1000	1000	1000	1000	1000
No. of packets received	581	793	653	165	681	856
No. of packets lost	419	207	1375	835	319	144
Percentage of success	58	79	64	16	68	85

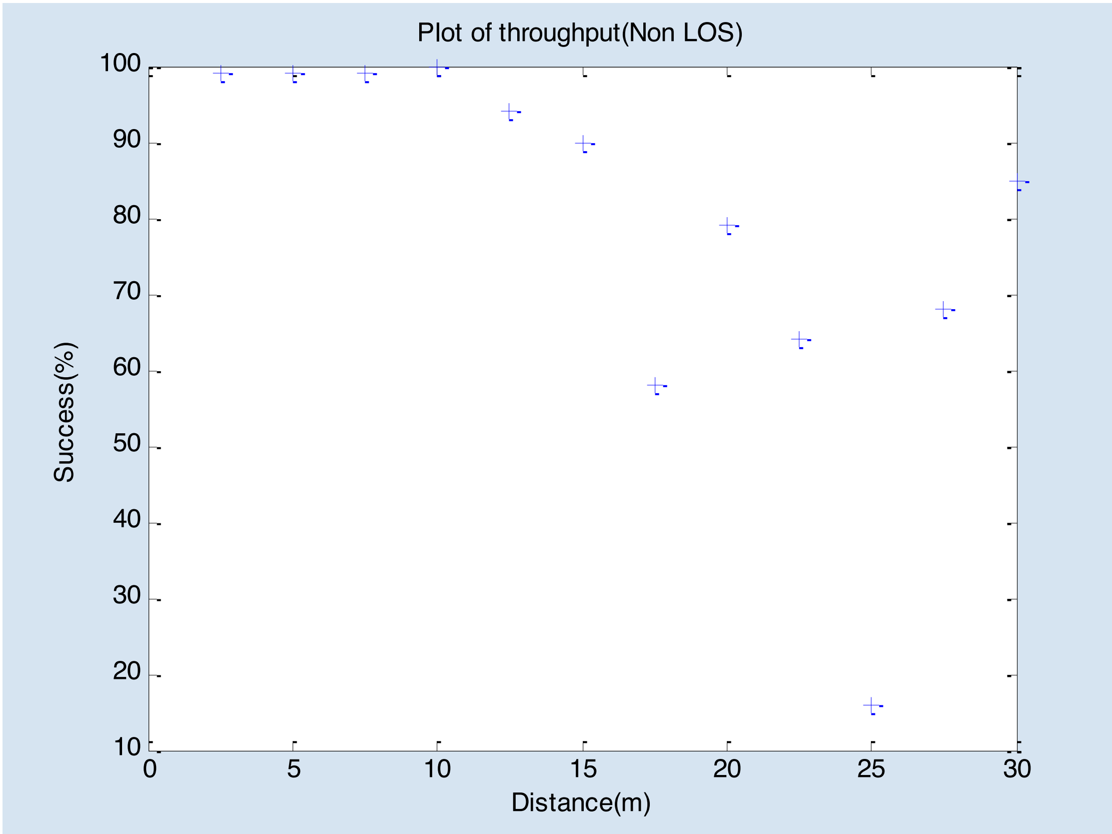


Figure 39. This figure show a graph of the plot of percentage of throughput against distance for non-LOS.

The **Table 4** shows average throughput values out of which the **Figure 39** is plotted. The average throughput here is 79% with the maximum data packets lost being 835 out of 1000. This percentage is quite low and hence at indoor non-LOS the RF module can be said to be quite unreliable and not robust though at short distances between 2.5m and 15m it is reliable.

5.5 Project Testing

In this section, experiment to test the general functioning of the thesis project is discussed. As mentioned in previous paragraphs, this project has two nodes, one for the farm and the other for the farmhouse. The farm node is responsible for automating the farm by controlling equipments such as heater, lighting and pump as response to input sensor trigger, it also has an LCD to display messages. The farm node is also equipped with an RF module which allows the communication between it and the farmhouse node.

The farmhouse node has similar functions as the farm node such as the controlling of lighting and alarm in the farmhouse. The farmhouse node is connected to the raspberry pi and the raspberry pi is connected to the internet and allows the farmer to access and control the farmhouse node and the farm node remotely via the internet from a communication device such as a computer.

In this testing experiment, the farm node switches on a light bulb as a response to a magnetic REED sensor action, it also toggles two output LEDs which represents a pump and a heater while displaying messages on the LCD as a response to commands from the farmhouse node wirelessly.

The farmhouse node also receives commands from the farmer communication device through the internet via a LINUX serial terminal emulator, the CUTECOM. The farmhouse device also sends feedback to the farmer communication device. Lastly, the farmer send a command to the farm node via the internet through the farmhouse node.

The Process as described, tests all the functioning of the thesis project. It confirms the success of the project and might endorse its full functioning on an industrial scale.

6. CONCLUSION AND FUTURE WORK

In this thesis work, wireless automation is realized via two wireless nodes. One of the nodes which is for the farmhouse is equipped with internet connection via a raspberry pi making it possible to access and control the farm node remotely by internet. The objective of this thesis project is to have wireless nodes with the capability of communicating with each other and to control some farm and farmhouse equipment, with an extended capability of accessing these nodes remotely via internet. As mentioned already, technology in farming is very much advanced but this thesis project is to provide another level of technology which gives advantages such as farmer mobility, constant monitoring of farm without the farmer necessarily being positioned on the farm and to reduce farmer poultry relation.

Building this module demanded necessarily, an in-depth electronics knowledge and skills, Programming on a low and high level was also required. Two double-sided circuit boards were developed, each for a node. Each circuit board connects the microcontroller to its peripherals such as the RF module, IOs and the raspberry pi. Each RF module and each microcontroller, required a high level software implementation. The WinAVR IDE was used in programming each microcontroller and the X-CTU software was used in the configuration of each RF module and also to run range test for the RF module. RSSI values were measured and evaluated for specific distances in two different environments. Percentage of throughput were acquired for specific distances.

Analysis and evaluations based on data collected during the reliability test indicates that, the module, in terms of RSSI values and percentage of throughput is more reliable in an indoor LOS use than in indoor non-LOS environment and the maximum indoor range for the RF modules is 30m which confirms the specification in the datasheet.

For a future work on this thesis project, monitoring with a visual of the farm will give a more reliable information on what actually happens on the farm. Adding a camera to the module and expanding the network of nodes will further authenticate the module.

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APPENDIX 1. Partlist of the Farm Wireless Node

Part	Value	Device	Package	Library	Sheet
C1	100n	C-EU025-030X050	C025-030X050	rcl	1
C2	100n	C-EU025-030X050	C025-030X050	rcl	1
C3	10u	CPOL-EUB45181A	B45181A	rcl	1
C4	10u	CPOL-EUB45181A	B45181A	rcl	1
C5	10n	C-EU025-030X050	C025-030X050	rcl	1
C6	10n	C-EU025-030X050	C025-030X050	rcl	1
C7	22p	C-EU025-030X050	C025-030X050	rcl	1
C8	22p	C-EU025-030X050	C025-030X050	rcl	1
C10	100n	C-EU025-030X050	C025-030X050	rcl	1
C11	10u	C-EU025-030X050	C025-030X050	rcl	1
CN1	AVR-ISP	AVR-ISP	AVR-ISP	omat	1
D1	1N4004	1N4004	DO41-10	diode	1
D2	1N4004	1N4004	DO41-10	diode	1
DIS1	TUXGR_16X2_R2	TUXGR_16X2_R2	TUXGR_16X2_R2	display-lcd	1
H1	MOUNT-PAD-ROUND3.0	MOUNT-PAD-ROUND3.0	3,0-PAD	holes	1
H2	MOUNT-PAD-ROUND3.0	MOUNT-PAD-ROUND3.0	3,0-PAD	holes	1
H3	MOUNT-PAD-ROUND3.0	MOUNT-PAD-ROUND3.0	3,0-PAD	holes	1
H4	MOUNT-PAD-ROUND3.0	MOUNT-PAD-ROUND3.0	3,0-PAD	holes	1
IC1	LM7805	78XXS	78XXS	v-reg	1
IC2	MEGA8-P	MEGA8-P	DIL28-3	atmel	1
IC3	LD117AV	LD117AV	TO220L1	v-reg	1

LED1		LED5MM	LED5MM	led	1
LED2		LED5MM	LED5MM	led	1
LED3		LED5MM	LED5MM	led	1
LED4		LED5MM	LED5MM	led	1
LED5		LED5MM	LED5MM	led	1
LED6		LED5MM	LED5MM	led	1
LM285		TL431CLP	TO92-CLP	v-reg	1
LSP4	LSP13	LSP13	LSP13	solpad	1
LSP5	LSP13	LSP13	LSP13	solpad	1
LSP6	LSP13	LSP13	LSP13	solpad	1
LSP7	LSP13	LSP13	LSP13	solpad	1
Q1		CRYSTALHC18U-V	HC18U-V	crystal	1
R1	10k	R-EU_0207/10	0207/10	resistor	1
R2	200k	R-EU_0207/10	0207/10	resistor	1
R3	10k	R-EU_0207/10	0207/10	resistor	1
R4	10k	R-EU_0207/10	0207/10	resistor	1
R5	10k	R-EU_0207/10	0207/10	resistor	1
R6	10k	R-EU_0207/10	0207/10	resistor	1
R7	10k	R-EU_0207/10	0207/10	resistor	1
R8		R-TRIMM3339P	RTRIM3339P	resistor	1
R9	470	R-EU_0207/10	0207/10	resistor	1
R10	4.7	R-EU_0207/10	0207/10	resistor	1
R11	180	R-EU_0207/10	0207/10	resistor	1
R12	180	R-EU_0207/10	0207/10	resistor	1
R13	180	R-EU_0207/10	0207/10	resistor	1

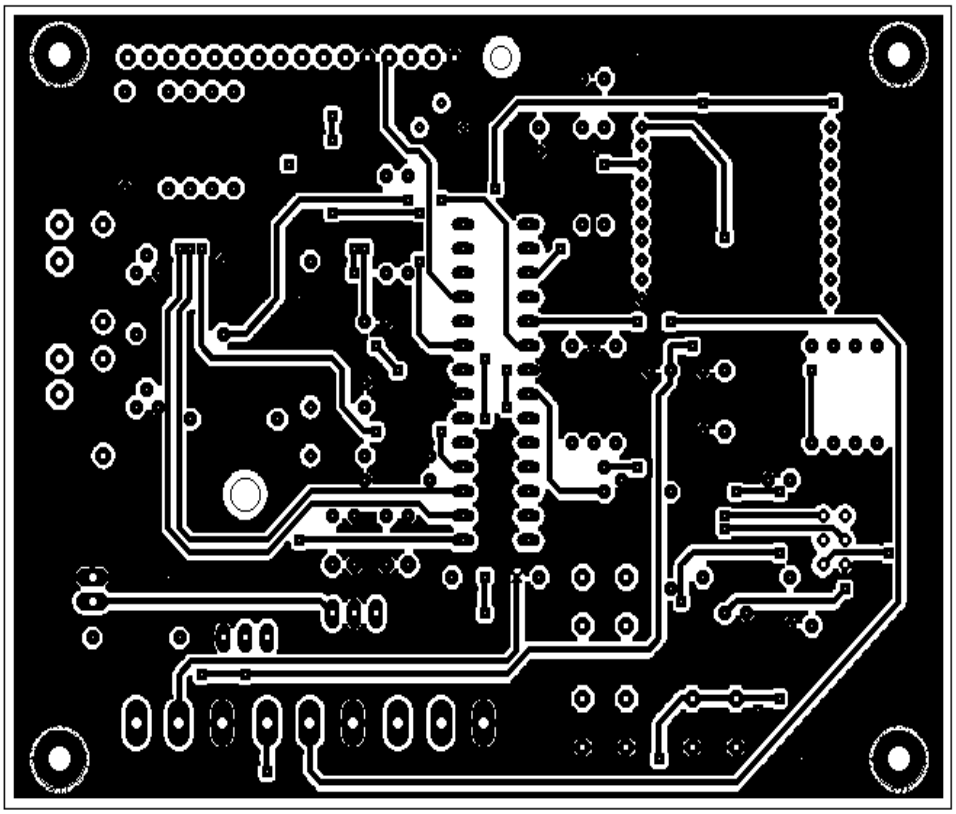
R14	180	R-EU_0207/10	0207/10	resistor	1
R15	10k	R-EU_0207/10	0207/10	resistor	1
R16	10k	R-EU_0207/10	0207/10	resistor	1
R17	10k	R-EU_0207/10	0207/10	resistor	1
R18	10k	R-EU_0207/10	0207/10	resistor	1
R19	10k	R-EU_0207/10	0207/10	resistor	1
R20	10k	R-EU_0207/10	0207/10	resistor	1
R21	10k	R-EU_0207/10	0207/10	resistor	1
R22	10k	R-EU_0207/10	0207/10	resistor	1
R23	470	R-EU_0207/10	0207/10	resistor	1
R24	10k	R-EU_0207/10	0207/10	resistor	1
S1	DTE6K	DTE6K	DTE6K	switch-misc	1
S2	DTE6K	DTE6K	DTE6K	switch-misc	1
S3	DTE6K	DTE6K	DTE6K	switch-misc	1
T1	BC337	BC337	TO92	transistor	1
T2	BC337	BC337	TO92	transistor	1
X1	SMKDSP_1,5/3	SMKDSP_1,5/3	SMKDSP_1,5/3	con-phoenix-smkdsp	1
X2	SMKDSP_1,5/3	SMKDSP_1,5/3	SMKDSP_1,5/3	con-phoenix-smkdsp	1
X3	SMKDSP_1,5/3	SMKDSP_1,5/3	SMKDSP_1,5/3	con-phoenix-smkdsp	1
X4		MPT2	2POL254	con-phoenix-254	1
XB1	XBEE	XBEE	XBEE	maxstream	1

APPENDIX 2. Partlist of the Farmhouse Wireless Node

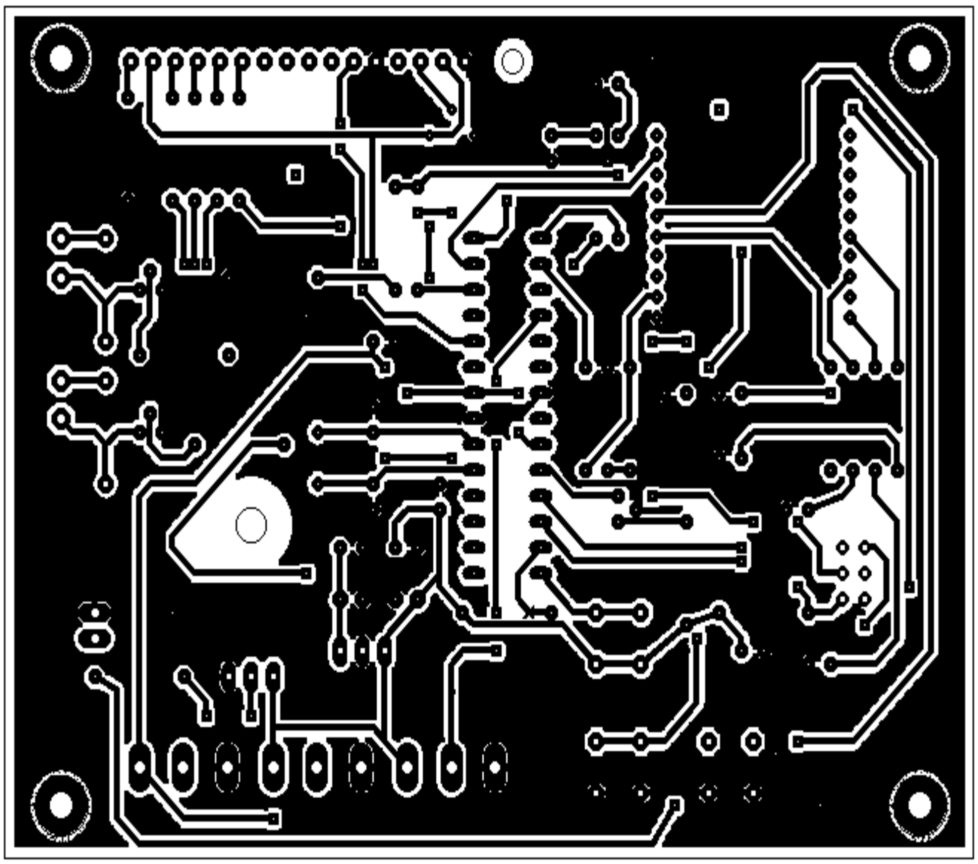
Part	Value	Device	Package	Library	Sheet
C1	22p	C-EU025-030X050	C025-030X050	resistor	1
C2	22p	C-EU025-030X050	C025-030X050	resistor	1
C3	10n	C-EU025-030X050	C025-030X050	resistor	1
C4	100n	C-EU025-030X050	C025-030X050	resistor	1
C5	10u	C-EU025-030X050	C025-030X050	resistor	1
CN1	AVR-ISP	AVR-ISP	AVR-ISP	omat	1
D1	1N4004	1N4004	DO41-10	diode	1
D2	1N4004	1N4004	DO41-10	diode	1
IC1	LD117AV28	LD117AV28	TO220L1	v-reg	1
IC2	ATMEGA644P-20PU	ATMEGA644P-20PU	DIL40	atmel	1
LED1		LED5MM	LED5MM	led	1
LED2		LED5MM	LED5MM	led	1
LED3		LED5MM	LED5MM	led	1
LED4		LED5MM	LED5MM	led	1
LED5		LED5MM	LED5MM	led	1
LED6		LED5MM	LED5MM	led	1
LED7		LED5MM	LED5MM	led	1
Q1		CRYSTALHC18U-V	HC18U-V	crystal	1
R1	180	R-EU_0207/10	0207/10	resistor	1
R2	180	R-EU_0207/10	0207/10	resistor	1
R3	180	R-EU_0207/10	0207/10	resistor	1
R4	180	R-EU_0207/10	0207/10	resistor	1

R5	180	R-EU_0207/10	0207/10	resistor	1
R6	10K	R-EU_0207/10	0207/10	resistor	1
R7	180	R-EU_0207/10	0207/10	resistor	1
R8	180	R-EU_0207/10	0207/10	resistor	1
R9	10k	R-EU_0207/10	0207/10	resistor	1
R10	10k	R-EU_0207/10	0207/10	resistor	1
R11	4.7	R-EU_0207/10	0207/10	resistor	1
R12	4.7	R-EU_0207/10	0207/10	resistor	1
R13	10K	R-EU_0207/10	0207/10	resistor	1
RXD1	LSP10	LSP10	LSP10	solpad	1
RXD2	LSP10	LSP10	LSP10	solpad	1
RXD3	LSP10	LSP10	LSP10	solpad	1
RXD4	LSP10	LSP10	LSP10	solpad	1
S1	DTE6K	DTE6K	DTE6K	switch-misc	1
S2	DTE6K	DTE6K	DTE6K	switch-misc	1
S3	DTE6K	DTE6K	DTE6K	switch-misc	1
S4	DTE6K	DTE6K	DTE6K	switch-misc	1
T1		MPSA92-NPN-TO92-CBE	TO92-CBE	transistor	1
T2		MPSA92-NPN-TO92-CBE	TO92-CBE	transistor	1
X1		MPT4	4POL254	con-phoenix-254	1
X2		MPT3	3POL254	con-phoenix-254	1
X3		MPT3	3POL254	con-phoenix-254	1
XB1	XBEE	XBEE	XBEE	maxstream	1

APPENDIX 3. Farm Wireless Node (Board)

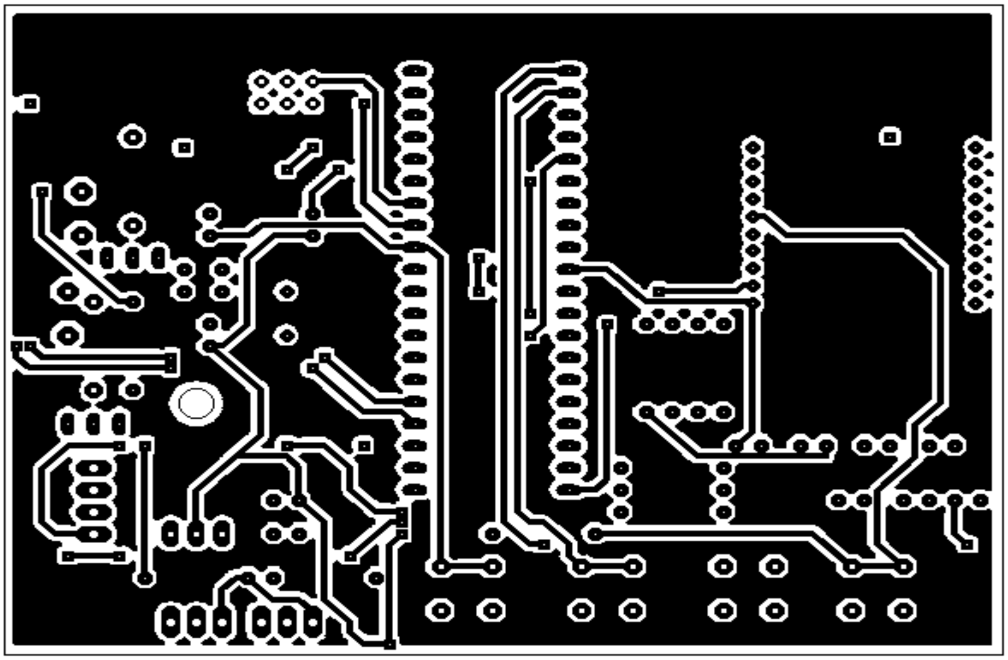


Farm Board (Top)

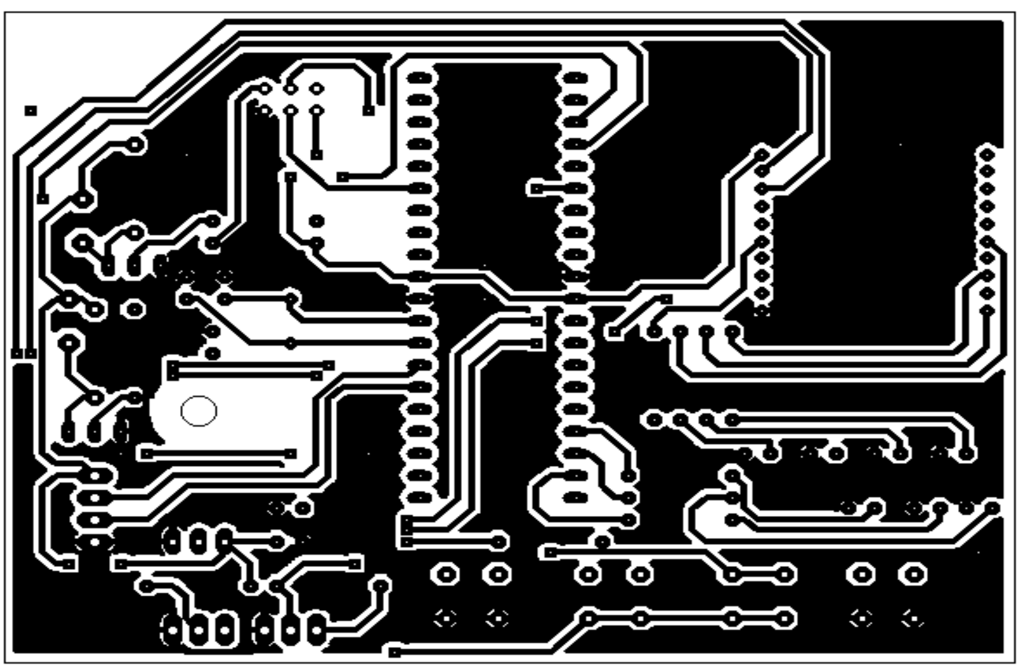


Farm Board (Buttom)

APPENDIX 4. Farmhouse Wireless Node (Board)



Farmhouse Board (Top)



Farmhouse Board (Bottom)