UNIVERSITY OF VAASA

FACULTY OF TECHNOLOGY

TELECOMMUNICATION ENGINEERING

Sami Seppänen

Wireless Sensor System for Recycling

Master's thesis for the degree of Master of Science in Technology submitted for inspection, Vaasa, 8 of April, 2011.

Supervisor	Mohammed Elmusrati
Instructor	Jarmo Alander
	Petri Välisuo

FOREWORD

This Master's Thesis is a study of wireless sensor network technology in recycling environment. Thesis is combining two technical entities – telecommunication- and automation technology. It has been carried out at the technical faculty of University of Vaasa. The initial idea for the Thesis was provided by *Jarmo Alander*, the Professor of Automation Technology.

I want to express my sincere gratitude to *Prof. Jarmo Alander* for instructions and guidance throughout the work. Appreciation goes also to *Petri Välisuo*, from Automation Technology department, who took his time to read and evaluate this work. Also I wish to thank *Mohammed Elmusrati*, the Professor of Telecommunication Engineering for supervising the work. Additionally I want to thank Kari Kaunonen for his advices concerning electronical part of the work. Eventually I want to acknowledge Marko Metsäranta and Kirsi Mannermaa for their advices and corrections concerning the language of the document.

Vaasa, Finland, 8 of April 2011

Sami Seppänen

TABLE OF CONTENTS

ABBREVIATIONS

A/D	Analog-to-Digital
AES	Advanced Encryption Standard
ASK	Amplitude Shift Keying
BER	Bit Error Rate
CPU	Central Processing Unit
CSMA-CA	Carrier Sense Multiple Access-Collision Avoidance
DVS	Dynamic Voltage Scaling
EEPROM	Electrically Erasable Programmable Read-Only Memory
FEC	Forward Error Correction
FFD	Full Function Device
FSK	Frequency Shift Keying
GTS	Guaranteed Time Slot
IEEE	Institute of Electrical and Electronics Engineers
I^2C	Inter Integrated Circuit
I/O	Input/Output
KBPS	Kilobits Per Second
LED	Light Emitting Diode
LLC	Logical Link Control
MAC	Media Access Control
MBPS	Megabits Per Second
OSI	Open Systems Interconnection
PAN	Personal Area Network
PDIP	Plastic Dual In-line Package
PSK	Phase Shift Keying
RAM	Random Access Memory
RFD	Reduced Function Device
ROM	Read-Only Memory
SCL	Serial Clock
SDA	Serial DAta
SINR	Signal to Interference and Noise Ratio

SNR	Signal to Noise Ratio
SPI	Serial Peripheral Interface
USB	Universal Serial Bus
WPAN	Wireless Personal Area Network
WSN	Wireless Sensor Network

VAASAN YLIOPISTO
Teknillinen tiedekunta
Tekijä: Sami Seppänen
Diplomityön nimi: Langaton Anturiverkko Jätteenkeräykseen
Valvojan nimi: Mohammed Elmusrati
Ohjaajan nimi: Jarmo Alander
Tutkinto: Diplomi-insinööri
Oppiaine: Tietoliikennetekniikka
Opintojen aloitusvuosi: 2006
Diplomityön valmistumisvuosi: 2011 **Sivumäärä:** 76

TIIVISTELMÄ

Tämän työn motivaationa oli tutkia ja suunnitella prototyyppi langattoman anturiverkon käyttämiseksi kierrätysympäristössä. Alkuperäisenä ideana oli kierrätyssäiliössä olevan materiaalin pinnankorkeuden mittaaminen ja tiedon lähettäminen. Työn tuloksena rakennettu prototyyppi voidaan nähdä ensimmäisenä askeleena kohti jätteen kierrätyksen automaattista mittausverkostoa.

Työn taustatutkimus tukee valmiin prototyypin rakenteessa tarvittavaa tietoa. Tutkimukseen kuuluu langattoman ympäristön ongelmien ja haasteiden tarkastelu. Myös langattomia standardeja ja sopivia anturitoteutuksia jätteenkierrätysympäristöön tutkitaan. Valmis prototyyppi esitellään työn viimeisessä luvussa.

Prototyyppi koostuu kahdesta teknisestä kokonaisuudesta: langattomasta verkosta, sekä antureista. Langaton verkko on toteutettu ZigBee-standardia käyttäen kahdella radio moduulilla. Toiseen moduuliin on yhdistetty kaksi ultraäänianturia ja kokonaisuus on kiinnitetty kierrätyssäiliöön. Tässä moduulissa oleva ohjelma tarkastaa antureiden tilan tietyin väliajoin, ja sen mukaan tekee päätöksen säiliön täyttöasteesta. Tämän jälkeen moduuli lähettää viestin radion kautta toiselle moduulille. Lopulta tämä moduuli, tietokoneeseen liitettynä, toimittaa tiedon keräilyorganisaation käyttöön.

AVAINSANAT: langattomat anturiverkot, XBee, Arduino, anturit

UNIVERSITY OF VAASA
Faculty of technology
Author: Sami Seppänen
Topic of the Thesis: Wireless Sensor System for Recycling
Supervisor: Mohammed Elmusrati
Instructor: Jarmo Alander
Degree: Master of Science in Technology
Major of Subject: Telecommunication Engineering
Year of Entering the University: 2006
Year of Completing the Thesis: 2011 **Pages:** 76

ABSTRACT

The motivation of this thesis was to research and design a prototype model of a wireless sensor network application, to be used as an automated detection infrastructure in recycling environment. The initial idea was to measure the level of the surface in a recycling container and transmit the information through a wireless communication system. The prototype is an initial step for recycling companies for building an automated detection network.

Background of the research strongly supports the accomplished prototype. Study includes description of wireless environment with its problems and challenges. It proceeds with consideration of suitable wireless standards and considers most convenient sensor methods for recycling environment. Eventually document presents the prototype combining the studied entities.

As a result, the prototype has two main operating parts: the wireless communication network and sensors. The network was realized with ZigBee standard by using two radio chips as communication nodes. Second communication node is attached to a recycling container and combined with two ultrasound sensors. This node includes a software algorithm, which is polling the state of the sensors regularly and deciding if the container is full. The node proceeds to transmission of the information to other communication node. This node is connected to computer and will transmit the information to be used by the recycling organization.

KEYWORDS: wireless sensor network, XBee, Arduino, sensors

1. INTRODUCTION

1.1. Overview

Wireless Sensor Network (WSN) is a telecommunication system designed to exchange small pieces of information at low bit rate between communication nodes. Similarly to many other technical areas, also wireless communication networks have originally been inspired by military applications, in this case a military surveillance system with low communication and computational requirements. Over time the development of WSN has competed with manually operated radiotelegraphic and packet radio communication and has reached nowadays automatic Wireless Personal Area Networks (WPAN), utilizing spread spectrum techniques with Media Access Control (MAC) layer. (Callaway 2004: 29–35)

Common requirements of a sensor network are a long battery life, low cost and mesh-networking architecture for communication between large numbers of devices in an interoperable and multi-application environment. While radio interface establishes the communication link and information delivery in WSN, an additional device for information gathering is required. This is realized by automatic sensors. (Daintree Networks)

1.2. Motivation and Objectives

Currently recycling companies are following beforehand agreed schedules when collecting recycling material. Trucks follow certain cycles when inspecting each container, without exactly knowing if it is full or not. Sometimes picking up of one container requires several kilometres extra driving. Often these containers are not full. For example when committing a field study with a recycling company a single container requiring around 5 kilometers drive was found empty when inspected. This results among the other resources, lost gasoline consumed by the truck and lost work time of the driver. This waste of resources can be diminished by employing an automated detection infrastructure (Fig. 1). The idea is as follows: the system will detect the fill level of the container and deliver the information to a base station. The information is further delivered to a website, for example, which can be accessed by various browsers, including mobile devices. The route can be optimized ahead according to the fill level of the containers. This System would also bring benefit to those customers of the recycling company, who are required to make a call when containers are full.

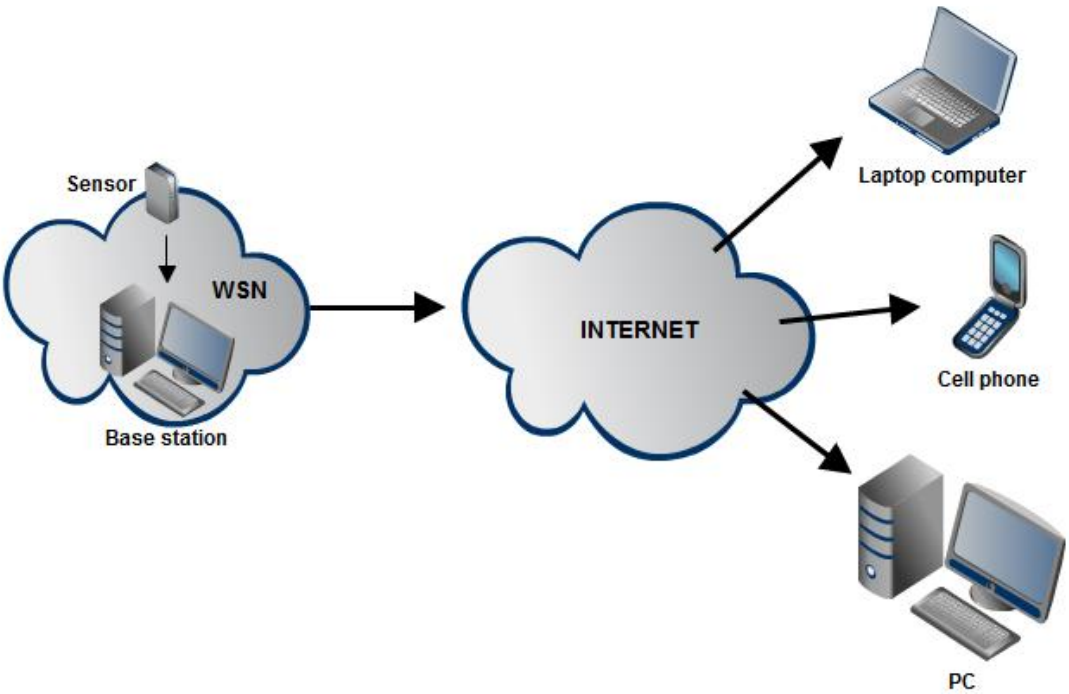


Figure 1. A schematic of the information flow when a sensor in a WSN is wirelessly transmitting to a base station connected to computer. Information will be placed to web page and can be accessed by variety of devices.

The automatic detection system is to be accomplished by combining automation technology and telecommunication engineering. The sensor part of the system is to be built from one to many sensors attached to the recycling containers for detecting the level of the surface. These sensors are to be combined with wireless radio transmitting the level information to a base station located in building on a close range. From the base station the information is delivered further through internet.

This thesis will study and utilize close range wireless network technology combined to sensor or several sensors in recycling environment. Main questions which have to be answered before reaching a prototype model are: which wireless standards and sensors should be utilized? Which development environments can be used? How should the power consumption be optimized?

1.3. Structure of Thesis

This thesis is structured in following order. Chapter 1 introduces the overview of the environment and the objectives of this thesis work. Overall wireless communication environment for the sensor network will be discussed in Chapter 2. This is followed by consideration of suitable technology standard for the communication infrastructure in Chapter 3. Chapter 4 studies the automation detection environment with different detection methods. Chapter 5 investigates the recycling environment for the system. The prototype solution is presented in Chapter 6, which is followed by the conclusion of the work done and visions for the future development possibilities in Chapter 8.

2. WIRELESS SENSOR ENVIRONMENT

In wireless communication, the data between nodes is transferred as an electromagnetic wave over a free space. As the air acts as a radio propagation link name “air interface” is often used. Most familiar forms of electromagnetic radiations are visible light, x–rays and radio waves. Wireless telecommunication systems are based on radio waves, which have the longest wavelength compared to other forms of electromagnetic radiation. As much as air helps in avoiding physical wire infrastructures, it creates a great deal of challenges. This chapter considers the most important phenomena when communicating through the air interface. (Lehto 2006: 51, 81) (Holger & Willig 2005: 90)

2.1. The Modeling of Wireless Channel

Signal fading means that signal is losing its energy (Geier 2005). Phenomenon can appear due to the changes of temperature and humidity, which change the refraction index in different parts of the troposphere. Also environmental obstacles, such as shapes of a terrain, vegetation, structures and electrical characteristics of soil, cause problems. (Lehto 2006: 81)

2.1.1. Diffraction, Scattering and Reflection

When the same signal arrives to receiver by different paths the effect is called multipath propagation. Most common physical reasons causing this phenomenon are diffraction, scattering and reflection. (Holger & Willig 2005: 90–91) (Lehto 2006: 62–64)

Diffraction is best explained by using Huygen’s principle. This principle states that all points in a wavefront can be seen as sources of new waves, since different waves are cancelling the waves that are trying to proceed in sideways. When a waveform travels by a peak of obstacle, the wave bends behind the obstacle. Although diffraction causes problems it can also be an advantage. For example, diffraction is the reason that radio communication to valley is possible. (Holger & Willig 2005: 90–91) (Lehto 2006: 62–64)

Scattering may occur when a wave is hitting a surface. When surface is rough, containing various shapes the wave is reflected to multiple directions. Scattering can happen when wave confronts a fairly large raindrop. (Holger & Willig 2005: 91)

Reflection is a result of a waveform propagating in a medium and hitting a smooth boundary of another medium. Now part of the waveform is reflected back into the first medium while other part is refracted to the second medium. Rest of the energy will be lost as absorption. Multipath propagation due to reflections is the biggest reason for symbol errors, since it distorts the shape of the signal. Probability for receiving a distorted signal can be reduced by using a receiver with multiple physically separated antennas. However, this is rarely an option in a sensor node. (Geier 2005: 75–76)

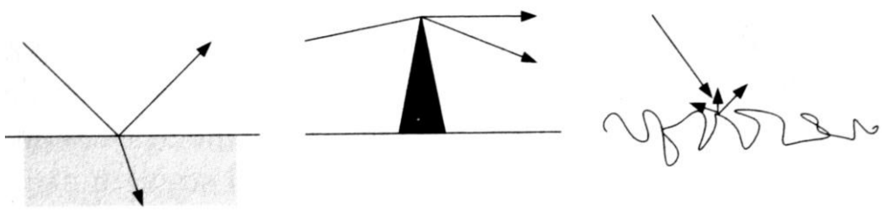


Figure 2. From left to right reflection, diffraction and scattering phenomena illustrated. (Holger & Willig 2005: 91)

2.1.2. Interference

Different waves in the same space are interfering and summing with each other, which is called superpositioning. When two signals reach a receiver at the same phase and frequency, the decoding process of the receiver becomes more difficult and bit errors occur. Interference is usually caused by external signals from other devices emitting radio waves. The main problem is due to devices, which are able to communicate in different frequencies, for example systems using a frequency hopping as their communication scheme. It should be noted that the system itself is also a source of interference to other systems. (Lehto 2006: 60) (Geier 2005: 73–74)

2.1.3. Fading Channels

Selective fading is a form of fading where some of the frequencies fade while increase of amplitude occurs in the others. When the delay, T_d, between two signals is comparable to the time period, T_c, of the carrier, but much shorter than the modulation signal's periodic time, multipath fading occurs. This fading can be modeled as Rayleigh or Rician channels. If the received signal is the sum of signals reflected from numerous objects nearby it can be modeled as Rayleigh fading. As a rule of thumb is assumed that if there exist at least five scattered signals within 100 wavelengths (Gosling 1998: 190) and there is no line of sight between communicating entities, Rayleigh channel is used as a statistical model. For mobile devices the communication is even more problematic since the amplitude and phase of the received signal varies when moving. When the communication channel has a strong dominant element in addition to multipath propagation a Rician distribution is used instead of Rayleigh. It is notable that dominant element can be a sum of line of sight and ground reflections. (Green 1995: 142–145) (Holger & Willig 2005: 96–97)

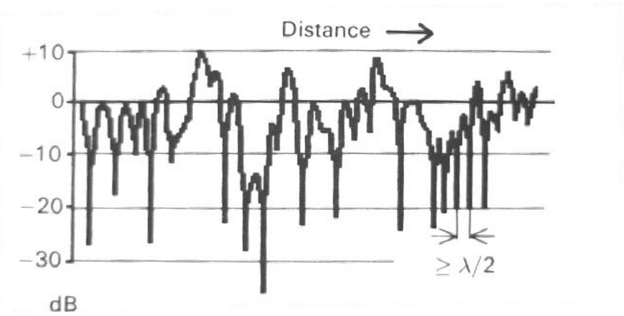


Figure 3. Signal amplitude variation when Rayleigh fading is assumed. (Gosling 1998: 192)

Signal outage probability is an important character measuring the quality of the communication system using channels with fading. Outage is defined as time when the error probability of the communication exceeds pre-defined value or Signal to Noise Ratio (SNR) drops under certain threshold. (Marvin & Alouni 2005: 5, 725)

2.2. Signal Transmission

When signal is transmitted wirelessly in free space between communication devices, the signal is exposed to noise and other interferences. These factors can be diminished by means of Spread Spectrum technique. Before wireless signal can be transmitted it has to be modulated for the channel. This section introduces Spread Spectrum and some of the important digital band pass modulation schemes.

2.2.1. Spread Spectrum

A spread spectrum is a method where transmitted signal is spread over a frequency band, which is wider than the bandwidth of the payload. Essentially each bit is modulated to four signals, which occupies a wider bandwidth. This reduces noise by causing less interference in the frequency bands and results improved SNR. (Holger & Willig 2005: 98) (Gascón 2008)

Direct-Sequence Spread Spectrum (DSSS) is a popular spread spectrum communication scheme. In DSSS a bit data duration t is replaced by a chip sequence. The sequence $c = c_1, c_2, .., c_n$ is sent in case of logical one and $c = \overline{c}_1, \overline{c}_2, .., \overline{c}_n$, for logical zero, where c_i can be either 1 or 0. Each chip particle has duration of t/n where n is a spreading factor. After this the chip is modulated with selected digital modulation presented in following section. (Holger & Willig 2005: 98)

2.2.2. Modulation and Demodulation

Computers exchange digital data as sequences of symbols, which consist of a certain number of bits. In modulation the data is prepared for analogue transmission by attaching digital symbol waveforms to a carrier wave and transmitting through antenna. Most common modulation method is a band pass modulation, where information is modulated into a periodic carrier wave. Modulated signal $s(t)$ can be presented by the following equation:

$$s(t) = A(t)\cos(\omega(t) + \emptyset(t)) \qquad (1)$$

$A(t)$ is an amplitude, $\omega(t)$ is the frequency, and $\emptyset(t)$ describes a phase shift. Based on this formula three different modulation types can be defined. In Amplitude Shift Keying (ASK) the amplitude is altered according to data bits. Mathematically ASK has a following common equation for a waveform s_i:

$$s(t) = \sqrt{\frac{2E_i(t)}{T}} \cos(\omega_0 t + \emptyset) \quad (2)$$

ω_0 is the central frequency, $\emptyset$ is the initial phase, and $\sqrt{\frac{2E_i(t)}{T}}$ presents the amplitude of the *i*:th symbol with symbol energy *E*.

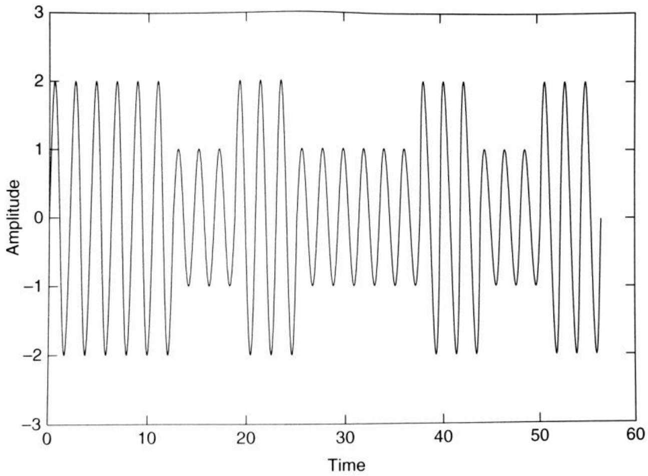


Figure 4. ASK when data string '110100101' is being modulated. (Holger & Willig 2005: 89)

Frequency Shift Keying (FSK) changes the frequency of the carrier according to the data. It can be presented with following equation:

$$s_i(t) = \sqrt{\frac{2E(t)}{T}} \cos(\omega_i(t) t + \emptyset) \quad (3)$$

$\omega_i(t)$ is the *i*:th carrier frequency.

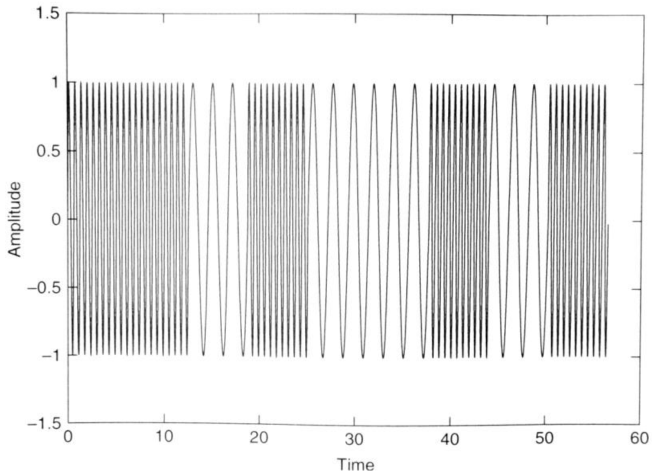


Figure 5. FSK modulation with string ‘110100101’. (Holger & Willig 2005: 91)

Phase Shift Keying (PSK) is the third modulation scheme; it is changing the phase on a bit change:

$$s_i(t) = \sqrt{\frac{2E}{T}}\cos(\omega_0 t + \emptyset_i(t)) \qquad (4)$$

$\emptyset_i(t)$ describes the phase shift of symbol i.

In case of PSK, each phase shift $\emptyset_i$corresponds to a binary value. Simplest form of PSK is the binary PSK (BPSK), in which the phase shift $\emptyset_i$ can have one of the two values – 0 or 180°, corresponding to binary zero and one. (Farahani 2008: 147) (Holger & Willig 2005: 88–90)

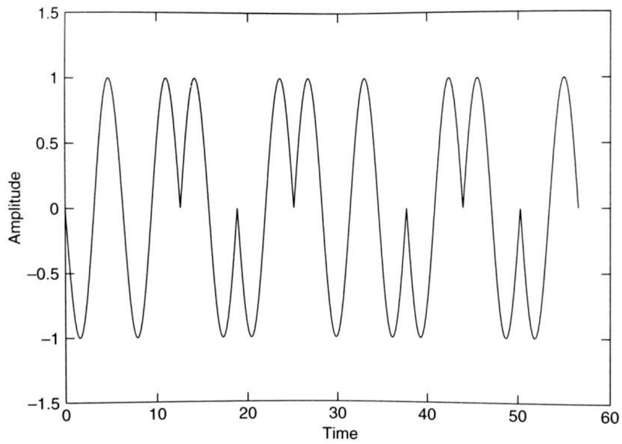


Figure 6. PSK modulation of the data string ‘110100101’. (Holger & Willig 2005: 90)

In demodulation process, a receiver will recover the transmitted symbols from the received waveform. Because of noise, attenuation and interference the received waveform is a distorted version of that transmitted. This reduces the probability of recovering the transmitted signal. A probability of misinterpreting a symbol is called a symbol error rate and a Bit Error Rate (BER) for digital data. Both of these rates are important indicators for considering the system’s performance. (Holger & Willig 2005: 88–90) (Geier 2005: 80)

2.3. Hardware and Power Consumption

A sensor node consists of five hardware entities: radio transceiver, antennas, controller, memory and power supply. Each of these entities is performing individual tasks. This section describes the hardware devices and their tasks in a wireless sensor node. Furthermore, power consumption of each entity is considered. (Holger & Willig 2005: 18–45)

2.3.1. Radio Transceivers

It is clear that in wireless communication network a radio transmitter and receiver are required. Transmitter has to convert a stream of bits to radio waves, while receiver performs the opposite action. Usually these modules are combined into one device called *transceiver*. In many cases transceivers operate in half–duplex mode, which signifies that reception and transmission does not occur at the same time. Usually full duplex is simply not required in WSNs. Besides transmission and reception radio transceiver can perform operations such as transmission power control, received signal strength indication and other defined services to the MAC layer. (Holger & Willig 2005: 21–24)

Power consumption of radio transceiver can be divided to consumption in transmission and reception. For example generation of a signal, modulation and transmission distance affect to power required for transmission. Also electronic components for frequency synthesis, frequency conversion, filter *etc*. need energy. Also amplifier of the transmitter feeding the power requires power. Energy for transmitting packet with n–number of bits can be evaluated with following equation:

$$P(n) = T_{start}P_{start} + \frac{n}{RR_{code}}(P_{txElec} + P_{amp}) \qquad (5)$$

Where P_{txElec} stands for consumption of accompanying circuits that require power before transmission, n refers to packet length, R is the average bit rate and R_{code} is the coding rate. $T_{start}P_{start}$ is starting time of the amplifier multiplied with starting power of the amplifier. P_{amp} is the amplifier's own power consumption.

Commonly transceiver has three modes when being turned on. It can actively receive packets, observe the channel or be in idle mode, which states that node is in 'ready to receive' state. The difference between active mode and idle mode is very small, so it is assumed zero. The equation of energy consumption for receiving a packet becomes:

$$P(n) = T_{start}P_{start} + \frac{n}{RR_{code}}P_{rxElec} + nE_{decBit} \qquad (6)$$

Where E_{decBit} is the energy for decoding a single bit and P_{rxElec} is the power required by reception electronics. (Holger & Willig 2005: 26, 40–42)

Often the transceiver is set to sleep when not used and programmed to work in low duty cycles. Usually transceivers support multiple sleeping states varying in power saving levels. Commonly the startup time rises if the transceiver is completely shut down, instead of using a lighter sleeping mode. (Holger & Willig 2005: 26, 40–42)

2.3.2. Antennas

When considering a WSN in an application level an internal antenna is the most preferred choice, although an external antenna is almost always required. This preference is mostly because of the portability and protection against mechanical and environmental damage. There are several antenna types to be utilized internally. We will consider three types: circuit board trace, metal strip and ceramic component. (Callaway 2004: 201)

Internal Types

A *circuit board trace*, without any additional components, can act as an antenna. However, the low performance due to the series resistance of the circuit boards and the material of the boards add some dielectric loss. Also the noise level caused by other components in the board is higher. A second option is to place a *metal strip* in a circuit board. This increases the performance compared to circuit board trace since the antenna is placed higher than the other components. However, this exposes antenna for other sources of noise. Metal strip antenna type can have a dipole or loop shape. In order to maintain the frequency of resonance within required tolerance, mechanical shape of the wire antenna has to be maintained by physical support. The third option is to employ a *ceramic component* as an antenna. This type is physically smaller than the wire antenna, but more expensive. These antennas are widely utilized in frequency bands such as 915MHz and 2450MHz. (Callaway 2004: 201–202)

Antenna Efficiency

When considering antennas the efficiency is an important factor. It is the ratio of radiated power compared to the total input power of the antenna. Poor antenna efficiency can limit the communication range of the node. This can be coped by increasing transmit power or receiver sensitivity. The antenna efficiency η can be defined with following equation:

$$\eta = \frac{P_{rad}}{P_{input}} = \frac{P_{rad}}{P_{rad}+R_{loss}} \qquad (7)$$

Where P_{rad} is the radiated power and P_{input} is the input power. The derived form is achieved using Thevenin's equivalent circuit where R_{rad} is the radiation resistance of the antenna and R_{loss} the loss resistance of the antenna. R_{rad} can be written as:

$$R_{rad} = 80\pi^2 \left(\frac{L}{\lambda}\right)^2 \quad (8)$$

Where L is the length of the dipole antenna and λ is the wavelength in free space. (Callaway 2004: 193–194)

2.3.3. Controller

Controller is the "heart" of the node and its function is to process all the important data. It handles the sensor readings, delivers packets from the other nodes and executes programs. Controller is called the Central Processing Unit (CPU). Although CPU types such as Digital Signal Processors, Field Programmable Gate Arrays and Application Specific Integrated Circuits could be used, microcontroller is the most common choice. This is due to its low power usage, build in memory and interface flexibility with other devices. (Holger & Willig 2005: 19–20)

Intel StrongARM controller is studied as an example of power consumption. This controller has three modes. In *normal mode* all the parts of the controller are operating and the power consumption can be around 400mW. In *idle mode* the clocks maintaining the controller are stopped and the power consumption is reduced to 100mW. An interrupt will set the controller to the normal mode. *Sleep mode* stops everything except the real time clock. Consumption in this mode is only 50μW. Waking occurs by interruption. (Holger & Willig 2005: 38)

Dynamic Voltage Scaling (DVS) is a sophisticated approach for adjusting the power usage of a controller. In this method the task is being computed only at the speed that is required to finish, in order the controller to meet the deadline. As an example Transmeta

Crusoe processor can be scaled from 700 to 200MHz. At the same time the voltage marginal between logical low and high levels is decreased from 1.65 to 1.1V. Because the power consumption is quadric to the supply voltage the power consumption factor becomes:

$$\frac{700 * 1{,}65^2}{200 * 1{,}1^2} = 7.875$$

The power consumption factor is reduced by 7.875 while the speed is reduced only by 700/200 =3.5 and the required energy is reduced by 3.5/7.875 ≈ 44%. As much as DVS offers very useful power saving scheme, it still has to be applied within the limitations of the controller specifications. (Holger & Willig 2005: 38–39)

2.3.4. Memory

Two kinds of main memory types are employed in sensor nodes. Random Access Memory (RAM) is utilized for storing sensor readings, packets from the network and other changeable data. Although RAM is fast the disadvantage is the information loss when the power supply is disconnected. Another memory type is utilized to store the program sketch, a Read–Only Memory (ROM), Typically Electrically Erasable Programmable ROM (EEPROM) or flash can be applied. Flash memory can also store data in case of RAM is not capable or is to be shut down for some reason. Disadvantages of the flash memory are long reading and writing times and high energy consumption. (Holger & Willig 2005: 21)

The important characteristics of memory when considering the power consumption are the reading and writing times. Usually consumption of these memory operations is assumed to be in a range of 1.2–38.8nAh, which is not a very critical power loss. (Holger & Willig 2005: 39–40)

2.3.5. Power Supplies

Availability of the power is the primary concern in order to keep different parts of the node functional. In sensor network the power consumption follows a straight forwards strategy: power supply has to store energy, provide it in a correct form and additionally, if possible, scavenge it from external sources. The node itself has to exploit the given power at the lowest rate possible. (Callaway 2004: 137–138) (Holger & Willig 2005: 32)

Battery has a finite lifetime, which means that it will stop working at some point in time and has to be replaced, or recharged in case of rechargeable battery. In WSN battery should be physically small and have a highest capacity possible. Typically AAA, AA, button sizes or customized shapes can be utilized. Discharging and charging performance of the battery is affected by basic parameters: voltage (V), current (A) and temperature. The performance also depends on the battery chemistry. One parameter to consideration is the self–discharge factor, describing how fast the battery will drain without energy being drawn from it. This varies between different battery chemistries. Usually nodes are supplied with an indicator for showing the battery status. (Holger & Willig 2005: 33) (Callaway 2004: 140) (Kiehne 2001: 40)

Battery Chemistries

As for many other applications also for WSN a zinc–air technology offers the highest available energy density. Self–discharge behavior of zinc–air is 1% per year and typical voltage 1.4V. On the other hand zinc–air power source is fairly sensitive to atmospheric conditions and its temperature range is from –10°C to 60°C. (Linden & Reddy 2001) (Kiehne 2001: 371–372)

Lithium battery uses lithium as the anode material, while chemistries of cathode and electrolyte differ. Materials such as sulfur dioxide or copper–oxide can be used alongside with lithium. Nominal voltage ranges from 1.5 to 3.8V. Discharge is similar to the Zinc–air battery. Typically the capacity can grow as large as 12000mAh. (Linden & Reddy 2001) (Kiehne 2001: 358–360)

Alkaline-manganese battery is fairly dominant chemistry and is used as a power source in a wide range of consumer electronics. Usually cylindrical or button battery configurations of alkaline-manganese batteries are utilized. Standard voltage of alkaline-manganese battery is 1.5V and capacity varies from 1100 to 22000mAh. (Linden & Reddy 2001)

Lithium–ion chemistry is widely used as a rechargeable battery. Capacity can range from 600 to 160.000mAh. In general voltage can vary from 2.5 to 4.2V. It can operate in temperatures between –40°C to 65°C. Self–discharge rate varies from 2 to 10% per month. (Linden & Reddy 2001)

Energy Scavenging

Energy scavenging is also a possibility to energize a sensor node. There are several techniques for this. A solar cell can be employed to recharge batteries. In outdoors around 15mW/cm^2 can be obtained. Vibrations are a mechanical source of energy and can be exploited from resonating structures, by-passing vehicles or from ventilation systems. The important factor is that the source is vibrating in a low frequency. Depending on the amplitude or frequency the energy gain can vary from 0.1µW/cm^3 to 10000µW/cm^3. Practically a device of 1cm^3 can offer 200µW/cm^3 from 2.25m/s^2, 120Hz source, which can be used to power a wireless transmitter. (Holger & Willig 2005: 34–35)

Also other means of gaining energy from the environment exist. A temperature variation of the air can be converted to energy. Flow of air has been used for a long time in windmills and turbines. However, the size may be a problem in small devices. Also piezoelectric generators can be used when pressure variations are available. (Holger & Willig 2005: 34–35)

2.4. Network Reliability and Security

Uncertainty of data integrity in wireless channels is greater than in wired channels. This is due to the fact that radio waves are moving close to ground surface, which exposes them to several physical distortions introduced earlier. This uncertainty, when signal is received can be described as bit and symbol errors. One way to reduce these is to utilize Forward Error Correction (FEC).

From the security point of view a wireless signal can be protected by means of symmetric or asymmetric cryptography. These algorithms work by combining specific operations with user data and certain key values. Only sender and receiver should know these keys. (Holger & Willig 2005: 96)

2.4.1. Errors in Transmission

The distortion of the waveform causes transmission errors. Since the physical layer frame contains several important parts, even a small distortion in a wave can cause an error.

Sync (128 bit)	SFD (16 bit)	Signal (8 bit)	Service (8 bit)	Length (16 bit)	MPDU (variable)

Figure 7. A physical layer frame. (Holger & Willig 2005: 96)

Errors can be illustrated by Figure 7, which shows a typical physical layer frame. A packet loss occurs if synchronization of bit or frame fails in a *Sync* field. SFD indicates a start of MAC Protocol Data Unit (MPDU). Distortion in this field leads to packet loss. If a bit error occurs in any of the remaining fields (*Signal*, *Service* or *Length*) an incorrect header checksum and a packet loss is resulted. Bit error also occurs if any bit in MPDU is wrong. (Holger & Willig 2005: 151)

A term ‘error probability’ is often used when considering the network performance. The probability depends on modulation scheme and ratio of power of signal to noise and interference power. This ratio is measured by Signal to Interference and Noise Ratio (SINR). It describes the power arriving to the receiver compared to the noise power and external interferences from several sources. (Holger & Willig 2005: 95)

2.4.2. Error Detecting

FEC is a method for detecting and correcting an error in a bit stream. It is an open loop technique, meaning that feedback from receiver is not sent. The technique is based on redundancy in a stream of user data. In order to correct a bit, two main coding schemes exist: block coding and convolution coding. (Holger & Willig 2005: 158)

A block coder is using a block of bits with a preset algorithm. Group of bits is combined to a larger block by adding a coded part. Later the block can be checked by the receiver and determined if it is valid or not. *Convolution coding* operates continuously on a chosen number of bits. *Interleaving* can be utilized with both of these two coding schemes. Data packets are taken from FEC encoder and the order of the bits is altered. In this way a possible error burst spreads over the entire packet length. (Holger & Willig 2005: 158, 162) (Langton 2001)

2.4.3. Encrypting a Signal

Encryption process uses complex mathematical processes to encrypt and decrypt data. It is used to hide the information not to be seen or understood by outsiders. WSN uses two different types of encryption: symmetric and asymmetric. (Encryption and Decryption.com 2010)

Symmetric Encryption is using the same secret key for encrypting and decrypting the data. The key can be a number, word or combined random letters and it has to be familiar to both, the sender and the receiver. Usually the key is applied to a message by changing the content in predefined way. Advanced Encryption Standard (AES) is an example of a symmetric encryption algorithm and is usually preferred choice in WSN environment. It uses three key sizes: 128-, 192-, or 256-bit. Depending on the size of the encryption key the algorithm behaves differently. (Encryption and Decryption.com 2010)

Asymmetric Encryption uses different keys for encrypting and decrypting information. While encryption key is public allowing anyone to encrypt a message, the decryption key is only known by the receiver. Commonly these unique key–pairs are set so that each user in a network has a public and private key. As an example of asymmetric encryption RSA (named after its authors Rivest, Shamir and Adleman) algorithm provides the functionality also to the opposite direction. In this way the encryption of the message can be performed with a private key and decrypted with a public key. (Encryption and Decryption.com 2010)

2.4.4. Deliberate Attacks to Network

Although it is not the most concern in WSN the deliberate attacks should also be considered. In system to be designed the physical attack, leading to harming or destroying the node is the greatest concern. In order to prevent this node has to be physically hidden. If an intruder gains a full control of the node he or she can access its memory, compromise the software or in worst case both. This can be prevented by using a special secure memory. Cryptographic means are usually not an option since the processors are not suitable for heavy calculations in practice. (Holger & Willig 2005: 423)

Denial of service means that intruder is trying to disable a sensor service by exhausting it or simply destroying the node. This attack may occur in any layer of a protocol stack. In a physical layer intruder can simply jam the radio communication, by placing a foreign node in close range to send radio signals of the frequency band in the network to cause interference. This can be prevented using robust modulation schemes such as frequency-hopping or direct-sequence spread-spectrum techniques. In a network layer a foreign node can act as a part of the route and drop the received packet or send its own packets or create wrong routes with unnecessary loops. These actions clearly waste energy of the whole network. Countermeasure in this case is an authentication of a node before connecting to a network. In transport layer an attacker can issue a large number of connection setup requests for exhausting the memory. Also it can send packets with wrong sequence numbers, which can result to multiple retransmissions or end the communication. (Holger & Willig 2005: 423–425)

3. SENSOR TECHNOLOGY CONSIDERATIONS

The requirements of the communication system are considered next. The node should be portable, which means low power consumption, in order for a battery to last several years. Our system will have a wireless close range data transmission infrastructure designed to be placed recycling point close to buildings. This requires transmission range of say 50–70 meters. Our device is going to send a simple message with no strict time restrictions, which means that no high data rates are required. All these requirements should certainly be fulfilled with low costs. The wireless technologies presented in this chapter are mostly based on IEEE 802.15.4 sensor network standard. IEEE stands for Institute of Electrical and Electronics Engineers.

3.1. Radio Interface IEEE 802.15.4

The standard is engineered for wireless sensor networks requiring only low bitrates and minimum battery consumption without strict delay guarantees (Holger & Willig 2005: 139–140). IEEE 802.15.4 consists of two physical layers with separate frequency bands: 868/915 MHz and 2.4GHz. The lower physical layer covers both the 868 MHz European band and the 915MHz band, used in countries like the United States and Australia. The higher physical layer is used worldwide. (ZigBee Standards Organization 2007)

The maximum raw data rate of the IEEE 802.15.4 standard is 250kbps, but it can be scaled down to 20kbps or lower for use with sensors and automation (Callaway 2004: 293–294). Standard is designed to minimize power consumption and low-duty cycles allow node to be sleeping up to 99% of time on average depending on the communication model used. The minimum power for transmission is 3dBm and the minimum sensitivity is –92dBm.

The standard utilizes three types of node functionality: Personal Area Network (PAN) coordinator, coordinator and device. *PAN coordinator* operates as the network initiator and as a network controller. It operates directly with any *device* in range. Furthermore, it contains certain amount of memory for routing information and optionally information about all the devices in the network. *Coordinator* can transmit beacons and communicate with a device in range. It may become a PAN coordinator if a new network is established. Device can communicate directly only with a PAN coordinator. On a MAC layer a single node can be defined as a Full Function Device (FFD) or a Reduced Function Device (RFD) (Holger & Willig 2005:140). FFD can function in any of the roles previously listed. (Callaway 2004: 296)

While operating in a network MAC layer provides two techniques for accessing the radio channel, *Carrier Sense Multiple Access-Collision Avoidance* (CSMA-CA) being the most common. Each node in this technique is listening the medium before transmitting and if the energy is higher than a specified level the node waits a random time and tries again. The second technique is called *Guaranteed Time Slot* (GTS), which uses PAN coordinator to assign one or more from a total of 16 time slots. This method is initialized with each node by sending a GTS message to the PAN coordinator, which is responding for a beacon message containing the slot allocated and the number of slots assigned. (Gascón 2008) (ZigBee Standards Organization 2007)

3.1.1. ZigBee

ZigBee specification has been introduced by ZigBee Alliance (Daintree Networks). It is based on IEEE 802.15.4 radio interface. The minimum raw data rate of a ZigBee network is 20kbit/s (Callaway 2004: 293–294). The specification is designed to minimize power consumption and low-duty cycles allowing nodes to be sleeping most of the time. The minimum amount of energy for transmission is 0.5mW and devices can be powered by battery (Gascón 2008). Operating range of the ZigBee node in free space is up to 130 meters (Microwave journal 2009/1). The communication to data gathering sensor can be established through several standards, such as RS-232, RS-485, digital Input/Output (I/O) and analogue I/O. ZigBee is one of the best wireless standards for our system to be considered. (Digi International Inc. 2010)

3.1.2. CHILImodule

CHILImodule is a device for embedded systems. It has a variety of communication interfaces. One of the wireless protocols is ZigBee (IEEE 802.15.4) interface. According to manufacturer the battery life of the CHILImodule can reach up to 10 years. The operating range is not clearly stated, even in the data sheet. However, it can be assumed to reach ZigBee's 130m range. Although CHILImodule is an interesting device entity all of its communication protocols are not required in our system. (CHILIdevices 2010)

3.1.3. 6loWPAN

6loWPAN is a standard using IP version 6 (IPv6) packets over low-power radio. Standard is being developed by 6loWPAN Internet Engineering Task Force (IETF). Data rates of 6loWPAN are 250kbit/s, 40kbit/s and 20kbit/s, depending on the selected physical layer, which can be 2.4GHz, 915MHz or 868MHz. Communication range is fairly short, only some tens of meters. Low power consumption extends the life of the batteries to several years. The low operating range makes 6loWPAN not suitable for our network. (Hui, Culler, Chakrabarti 2009)

3.2. Other Technologies

Stabilized standards usually provide stable platform for designing technological devices. However the study of the wireless sensor technologies should not be totally limited to the known specifications. Couple of other technologies within the area of wireless sensor technology exists out of IEEE 802.15.4 interface.

3.2.1. Bluetooth Low Energy

Bluetooth was originally a standard developed under IEEE, but was later detached from IEEE 802.15.1 working group. It is a wireless technology for short-range communications systems. The original standard is already mature, but Bluetooth Special Interest Group (SIG) has standardized a new extension – Bluetooth Low Energy (LE). The data rate of Bluetooth LE is 1Mbit/s and the power usage varies from 0.01mW to 0.5mW, while retaining the working range of 10m. Bluetooth is a good standard for certain wireless applications in close range. However, the operation range of 10 meters will not be enough to cover the distance required in our system. (Bluetooth SIG 2009)

3.2.2. Z-Wave

Z-Wave is a simple home control stand-alone standard created by Z-Wave alliance. It is designed for residential use with devices such as lamp, light switch, thermostat, curtains, remote control, or motor to drive garage doors. It can be installed and maintained by the homeowner itself. The system is transmitting a small amount of data at a rate of 9.6kbit/s. Typical operating ranges are 30 meters indoors and over 100 meters outdoors in the open air. Z-Wave network contains a mixture of AC powered and battery powered nodes, where battery has several years' of lifespan. Z-wave is a good standard for our network. System is designed to be low cost for mass markets. However, the expensive prices of the development kits make it too costly to be considered. (Z-Wave alliance)

4. AUTOMATION SENSORS

In order to measure the information of the analogue phenomenon, sensors are exploited. Industry is utilizing many physical phenomena and technologies for sensors. It often becomes an issue to find an accurate and robust sensor with specific physical dimensions for the application to be designed. A traditional sensor is commonly built from three parts: sensor, detector and transmitter. Sensors can also transform information to different formats such as electric voltage, current or frequency, before transmission. Energy for the transmitted signal can be taken by use of the energy of the unit which is measured or fed by the controller unit. This section covers some of the basic concepts of sensors. Some of the most common types of sensors are introduced. (Aumala 2002: 81–82) (Fonselius, Pekkola, Selosmaa, Ström & Välimaa 1996: 22)

4.1. Performance Characteristics

Measurement area is defined to be the area between, the lower and the upper limit, where measurements can be carried out with certain accuracy. *Calibration area* defines the range where the output value of the device can be adjusted to match the reference measurement. This process is called calibration. Calibration has to be carried out during the aging of a measurement device, because of the possible drifting. This is accomplished by comparing the values of the sensor to the value of accurate calibrator. (Fonselius, Laitinen, Pekkola, Sampo, Välimaa 1988: 10, 14)

4.2. Strength

Sensors are tools like any other physical devices and they can break, which many times occur when the location of the sensor is changed. So, exposing sensor to physical stress should be avoided. Also too static electricity of current can break a sensor. It is important to know that commonly sensors can tolerate only up to 20% of over load. High voltage exposure can be prevented by protective fuses. A danger for sensor can also be caused by a wrong circuit connection. (Lindeman, Sahinoja 2000: 10)

4.3. Hysteresis

Hysteresis phenomenon means that measurements without material in these different points of time are not the same. In pressure hysteresis this measurement can be experienced by using the same pressure, but measuring it after increased and decreased weight. The measured values are not the same. Phenomenon is caused by the reluctance of a pressure sensing material when retiring to its original position, shape or form after being stressed. (Sensorsone 2010) (Fonselius, Laitinen, Pekkola, Sampo, Välimaa 1988: 10)

4.4. Analogue to Digital Conversion

Analogue to Digital (A/D) conversion is an important stage in wireless communication and analogue sensors. In his book Digital Systems Design with FPGAs and CPLDs (2008), Grout describes A/D converter as: "an electronic circuit that provides a link between the analogue and digital domains". The input signal is in analogue form, which is digitalized.

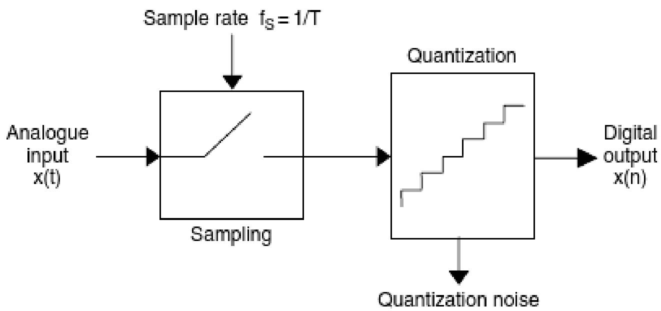


Figure 8. A/D conversion steps of sampling and quantization. (Grout 2008: 569)

A/D conversion (Fig. 8) consists of two main functionalities: sampling and quantization. Firstly the analogue signal is sampled by the use of an ideal sampling block at certain frequency. In general this means that a sample from continuous analogue signal is being picked within certain time intervals. Then signal is put to a quantization block, which quantifies the continuous signal into finite number of values. (Grout 2008: 13, 568)

4.5. Synchronous Serial Communication

While sensor device handles the information reading and possible signal modification a communication bus delivers the information to CPU. In most cases when using micro-controller a serial synchronous buses are used. Serial communication has a clear advantage, it saves space. A chip having serial interconnection does not require as many pin connections as parallel interconnect. Ultimately data can be transferred through one line. However, this causes a challenge of defining when data unit starts and ends. This is solved by synchronizing. (Wilmshurst 2010: 296–297)

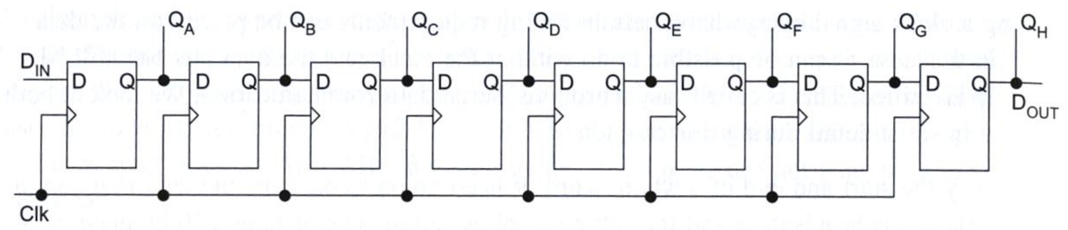


Figure 9. Shift register with flip-flop circuits used in synchronous serial communication. (Wilmshurst 2010: 298)

Synchronous Serial communication can be described by use of shift registers. Figure 9 presents an 8-bit shift register build with flip-flop circuits. Q-output of each flip-flop is input of the previous one. Each clock cycle moves data one flip-flop to the right. Basically it takes 8 cycles to have whole chain full of incoming bits to be read parallel from outputs Q_A to Q_H. There are two good options of bus standards to be implemented in a small-wired environment: Inter Integrated Circuit bus (I^2C) and Serial Peripheral Interface (SPI). (Wilmshurst 2010: 296–297)

I²C

I^2C is a serial bus for short distance communication developed for microprocessors and integrated circuits. It has maximum data rate of 100kbyte/s. The bus uses two wires for communication: Serial Data (SDA) and Serial Clock (SCL). SDA transfers the data while SCL handles the clock signal, which is generated by a *master* device. Both of these lines are bidirectional. Other device type is a *slave*, which can transmit after the master has initiated the connection and reserved the bus for the specific slave. (Article Collection 1997: 8–9) (Paret & Fenger 1997: 26)

The transfer of each bit of data is handled in following way. Each of the lines can be in two states, low (below 1.5V) and high (above 3V). The data on the SDA line is valid or stable while the SCL line is high and no bit changes are allowed. Bit changes in a SDA line are only allowed during a low time of the SCL line. (Fig. 10) (Paret & Fenger 1997: 30) (Article Collection 1997: 11)

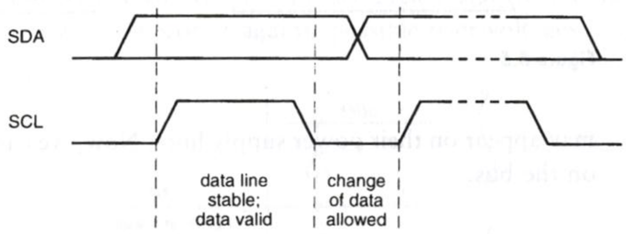


Figure 10. Data validating process on I²C bus is based on the SCL line's state. (Paret & Fenger 1997: 30)

In I²C system the start and stop bits are called start and stop conditions. These conditions are generated by the master device. *Start condition* occurs when the SDA line changes from high to low state, while the SCL stays in high state. *Stop condition* occurs in other way round, while the SCL stays high and the SDA goes from low to high. (Paret & Fenger 1997: 30)

Between start and stop condition a data is transmitted as an 8-bit (byte) data unit, which is more convenient for microcontroller to process. Each byte must be accompanied by an acknowledgement bit on the 9th clock pulse. First 7 bits contain the address of the slave device, which is followed by R/W-bit defining read or write operation to slave. After this the date is being transmitted. (Paret & Fenger 1997: 31–32)

SPI

SPI specifies a serial bus standard communicating through synchronous serial link with full duplex capability. Like I²C also SPI connected devices exchange data by use of master/slave principle. In SPI data can be transferred to both directions simultaneously. (Kalinsky & Kalinsky 2002)

SPI standard defines four signals: Serial CLOCK (SCLK), Master Output/Slave Input (MOSI), Master Input/Slave Output (MISO) and Slave Select (SS). SCLK signal is generated by master device and sent to all slaves. MOSI transfers information from master to slave and MISO from slave to master. Master selects a slave by assigning its SS signal. SPI also defines parameters called Clock Polarity (CPOL) and Clock Phase (CPHA). These parameters specify the edges of the clock signal when the data is captured. Since each parameter has two states four combinations are allowed. (Kalinsky & Kalinsky 2002)

4.6. Sensor Types

The task of our system is to measure the amount of material on a recycling container. This can be accomplished by several methods. The most suitable techniques for sensor in this recycling system would be based on mass, wave reflection, capacitance or inductance. Machine vision is also a promising method based on image processing. On the other hand few of these methods could be combined together by use of sensor fusion concept.

4.6.1. Strain Gauge

Strain gauges are utilized in measuring mass or force. They exploit the stretching of the material when subjected to physical stress. Usually material is a thin strip whose resistance changes depending on the force. Because the thread is very thin it reacts to small changes. Usually with strain gauge measurement an electrical Wheatstone bridge circuit is employed. Figure 11 is presenting a Wheatstone bridge. R_1 and R_2 are specified resistors, R is a potentiometer and R_x is the resistance of the strain gauge. G is a sensitive galvanometric indicating the stability of the bridge. (Aumala 2002: 72)

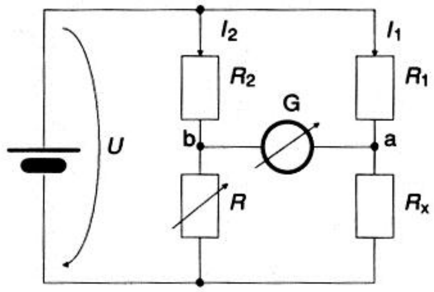


Figure 11. A Wheatstone bridge circuit with a potentiometer *R*, two resistors R_1 and R_2, a train gauge *R* and a potentiometer *G*. (Aumala 2002: 72)

4.6.2. Methods Based on Reflection

Commonly in reflection based detection a wave is propagated to the specified direction. When the wave hits the boundary it reflects back to its source point. By comparing the original wave to the reflected wave many properties of the target can be inferred. The comparison method depends on the detection requirements, but commonly time difference is exploited.

Infrared (IR) is a very much used distance detection method. IR measurement is based on the light reflection ability of the object. When light reflects from an object it differs in power from the original beam. Distance is measured from the time shift of the reflected signal. (Fonselius, Laitinen, Pekkola, Sampo, Välimaa 1988: 88)

Radio waves were widely discussed in the previous chapter as a direct communication method for transferring information between units. However, radio waves can also be used for distance measurement. The principle is based on a device emitting a radio wave. Some of the electromagnetic energy will be reflected back to the device from an obstacle, which depends on the electrical properties of the object. The distance is counted from the time difference. (Räisänen, Lehto 2003: 353–355)

Ultrasound is defined to be a sound which uses frequency above the human hearing range, which is commonly limited to 20kHz. Technology is widely used in medicine with the range of 2–20MHz. Velocity ranges from 6km/s (in steel) to 0.3km/s (Usher & Keating 1996:167). As an example it is used for studying an infant in mother's womb. One of the most important purposes of industrial ultrasound sensor is to measure the levels of the surfaces in containers, typically with liquids when the measurement distances are less than a couple of meters. Also there are applications for collision avoidance and detection of transparent objects. The inner functionality of the ultrasound sensor is as follows: electrical pulse is modified to ultrasound by crystal in transducer and sent orthogonally towards the direction of the surface. When the sound is reflected back to the crystal the time difference is calculated. (Fonselius, Laitinen, Pekkola, Sampo, Välimaa 1988: 87–88) (Ma, Mateer, Blaivas 2007: 49)

Hannu Toroi introduces in Automaatioväylä (6/2010) a system employing industrial ultrasound detection. In this system the sensors are placed outside, on the side of the industrial container with special attachment preserving the acoustic characteristics of the system. Signals travel through the wall and continue through the liquid inside. If there is no liquid on the level of the sensor the signals are completely absorbed. After travelling through the liquid the signal is reflected back to the sensor, which calculates the difference in time. The same kind of sensor can be used at bottom of the container to calculate the time delay of the echo. (Toroi Hannu 2010)

4.6.3. Capacitive Detection

Sensor based on capacitance (Fig. 12) can be used with most material types, except with metals. The operation is based on the electric field, which decreases when an object is close to the sensor head. The sensing part and the body form a capacitor where air acts as an insulator. An object approaching a sensor causes the capacitance value and thus the frequency of an oscillator changes. After adjustable thresholding the amplifier output signal is either ‘on’ or ‘off’. The detecting distance can be determined depending on the environment. (Fonselius, Pekkola, Selosmaa, Ström & Välimaa 1996: 37)

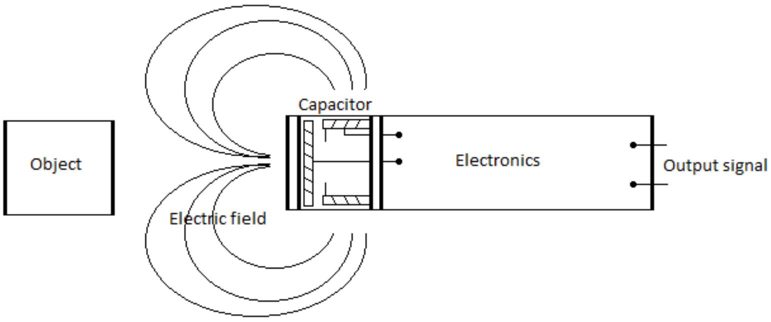


Figure 12. A capacitive sensor is using variation of electric field to detect an object in a close range. (adapted from Fonselius, Pekkola, Selosmaa, Ström & Välimaa 1996: 38)

4.6.4. Inductive Detection

Inductive detection is similar to capacitive detection (Fig. 13). However in this case sensed material is metal. When a metal structured object is getting closer the magnetic field located in the sensing head, weakens. This causes the current in the inductor getting smaller. Electronics part converts the information to output signal, which like in capacitive detection is thresholded either on or off. Distance can vary from 0.5 to 150mm, which depends on the size of the sensing head. (Fonselius, Pekkola, Selosmaa, Ström & Välimaa 1996: 34)

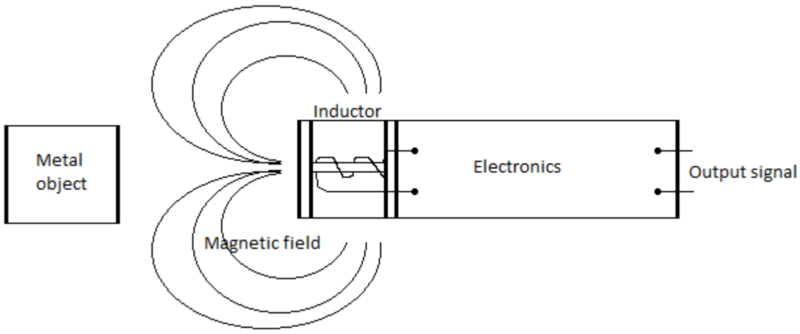


Figure 13. An inductive sensor is detecting a metal object by variations of a magnetic field. (adapted from Fonselius, Pekkola, Selosmaa, Ström & Välimaa 1996: 34)

4.6.5. Machine Vision

Machine Vision is a technology based on an image. Basic concept is that a camera takes a picture and then a computer or human analyses the image. When considering human the analyzing process is more straightforward, based on previous experiences and common knowledge. Computer can try to compare the image to previously defined models and shapes. Usually low- and high-level image processing is combined. Low level processing consists of tasks, which do not necessarily depend on content of the image. These kinds of methods could be for example compression, noise filtering and brightness changes, image smoothing or edge sharpening. These methods are applied for rectangular matrix corresponding to the analogue view, containing values for red, green and blue channels. High level processing is often build by means of artificial intelligence and is based on knowledge of goals. High level vision includes certain formal model of the world for which the digitized image as a reality is compared and matched if possible. (Sonka, Hlavac, Boyle 2008: 5–6, 114–124)

Machine vision contains great deal of difficulties, especially when analyzing the image (Fig. 14). First of all the view of the real situation becomes two dimensional, which results an information loss. For example angles of and relations of the objects are not preserved. Noise complicates the analyzing process by making shapes more uncertain. Image usually contains more data than needed for the analyzing purpose. (Sonka, Hlavac, Boyle 2008: 3–4)

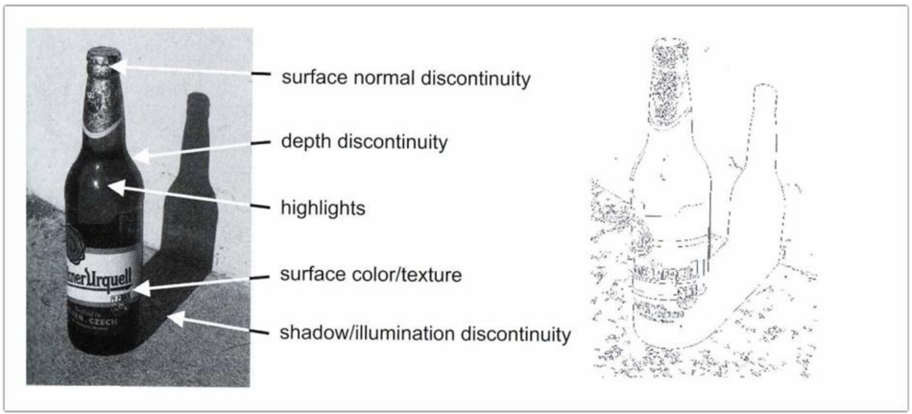


Figure 14. Phenomena in the left image define the sources of the edges. Analyzed edges from the same image on the right. (adapted from Sonka, Hlavac, Boyle 2008: 133)

Edge detection is a regularly used image pre-processing approach. The method is based on detecting the changes of the intensity. Edge detection reduces the image data and makes the main processing lighter. Edge is defined to be a pixel where intensity changes fast. It is a vector property containing both, magnitude and direction. Magnitude in this case is a gradient magnitude and the edge direction rotated –90 degrees when compared to gradient direction. Gradient direction is the maximum growth between black and white (0–255). It is not necessary to take into account the direction. In this case a linear differential Laplacian operator can be used. (Sonka, Hlavac, Boyle 2008: 132–133)

$$\nabla^2 g(x,y) = \frac{\partial^2 g(x,y)}{\partial x^2} + \frac{\partial^2 g(x,y)}{\partial y^2} \tag{9}$$

Equation (10) describes Laplacian operator in mathematical form, where ∂^2 denotes the second derivate with respect to each of the *(x,y)* coordinate points. The main advantage of using the Laplacian operator is that it contains the same properties to every direction, which enables the rotation of the image. Another often used technique for enhancing image edges is unsharp masking. It takes a picture, low pass-filters it and subtracts it from the original one. This emphasises the edges of the original image. (Sonka, Hlavac, Boyle 2008: 133)

4.6.6. Sensor Fusion

Sensor fusion as a concept means combining information directly from a sensor or derived from sensor data. As a result this information is expected to be more reliable than information from a single sensor. This method is used for example to model motion planning of robots. Opposed to indirect fusion, employing the previous knowledge and human interaction, data fusion utilizes direct fusion by using information from a set of sensors using different or same detection methods. (Jitendra 2009: 39, 46)

Sensor fusion cannot be described just as an additive process. This is because it should result an increased accuracy compared to the utilization of a single sensor. Other advantage rises from information redundancy. Although some information is redundant it can prove to be valuable *e.g.* in the case of a partial failure of the system. (Jitendra 2009: 39, 46)

5. RECYCLING ENVIRONMENT

There are several aspects of the environment to be considered before building and placing our desired system. First of all the height, shape and capacity of the waste container vary from different users, which affects to detection of a surface. Secondly, containers are handled by various types of physical treatments, which make it difficult to find a suitable placement for the system. Perhaps the most important question when choosing the sensor is consideration of the type of material placed inside the container. Also environmental matters, such as weather conditions have to be evaluated.

5.1. Containers

Several types of containers are utilized in recycling. The most traditional kind is a plastic container with a lid on top (Fig. 15c). The capacity can vary from 120 to 600 litres. These kinds of containers are usually emptied with an iron fork, located behind the truck. Fork is erected to approximately 110° angle form the ground and by help of additional vibrant moments the material in the container falls to truck silo. A second type is a large metal container whose weight is from 440 to 740kg. This type of container is emptied by lifting the container over the truck cabin. Third most commonly used container type is a round bag placed in a plastic support. Bag lays underground and its size may vary from 0.6 to $5m^3$. This type of bag is emptied by lifting it from a handle and placed behind of a truck where it is opened by pulling a string at the bottom of the bag (Fig. 15b).

a) b) c)

Figure 15. a) Recycling environment for out system, with container and house for PC, b) emptying process of a bag container, and c) emptying process of plastic container. (Lassila & Tikanoja 2008)

5.2. Recyclables

Materials are placed randomly in a container. From the surface detection point of view this is a challenge since the surface is not even. It could be assumed that the smoothness of the surface depends on the size of the average object in a container. However, a larger object can lead to erroneous detecting results. Additionally an important fact is that a container is considered to be overfull if the lid cannot be closed easily.

5.2.1. Kitchen Recyclables

Kitchen recyclables include everyday material from a household, such as bio waste, papers, cardboard packets, small plastic objects and diapers (Kierratys.info). Although these materials are mostly in plastic bags, the container can contain differently shaped surfaces and weights. Container for the kitchen recyclables is exposed to liquids and other substances easily effecting to electrical parts. Since kitchen recyclables form the largest quantity of waste, they are commonly handled in large metal containers.

A sensor type considered for kitchen recyclables could be based on reflection. Mass detection might not be accurate enough for kitchen recyclables.

5.2.2. Recycled Paper and Cardboards

Paper and cardboard materials include among others all the paper material through postal service, such as newspapers, advertisements, envelopes and brochures (Kierratys.info). The surfaces of these containers are more even compared to the kitchen recyclables and the weight is also more predictable. This type of material is stored in smaller plastic containers with usually bigger height than width.

For paper and cardboard container a mass detection could be considered as an option. The mass sensor is to be placed on the base of the container. However, erroneous result could be caused by large objects not reaching the bottom and not filling the container entirely. Sensor based on reflection could be also exploited. Sensor could be placed to the top pointing downwards or it could measure the exceeding of a level in horizontal plane. Once again an erroneous situation could be expected due to a large object placed in front of the sensor's head and disturbing the measurement.

5.2.3. Glass Ware

The glass ware container is used for gathering transparent glass bottles and jars (Kierratys.info). It is rare that a household recyclables include big glass objects, so a surface on this container is more equal. The weight has more variety than recycled paper container, but can be considered to be equally predictable with kitchen recyclables. Although, randomly breaking glass objects will make predictions unreliable.

The reflection based methods could be used also with glass. However the infrared sensing could be problematic due to transparency of the glass objects, but for example the ultrasound can be utilized. Also the capacitive method could be employed for the glass ware.

5.2.4. Metal

Metal containers commonly have metal cans, aluminum folio caps and metal tools. Old kitchen wares such as pots, pans and cutleries etc. are also included in this container (Kierratys.info). The variety of metal material makes it hard to detect a smooth surface and also the weight can vary.

The obvious choice for metal recyclables would be an inductive sensor. One option would be a metal sensor where the sensing head forms an inductive loop. This could be attached to the very top of the container. However possible metallic structural parts have to be taken into account. Also detections based on reflection can be considered. Metal has good reflection ability for light, so the infrared sensing could be used.

5.3. Other Solutions

Applying the machine vision technology requires memory for the images. Sensor detection method based on image could be a universal solution for all types of materials in this particular environment. However, measures have to be taken in order to keep the lens clean. A chip camera with wide angle lens could be placed on top of the container. In the simplest case the captured image would be compressed and send through the communication interface to a central location or to recycling truck to be analysed manually. In more sophisticated method the image would be analysed by using the means of software algorithm. The algorithm can be designed to count the pixels matching the colors of the container and from the amount of the pixels define how much container surface is still visible. In more developed approach the image could be analyzed in order to find the rough edges and through that find the area of the material and count its size compared to whole image.

One simple solution could be to employ a light sensor. In this way the sensor could sense certain amount of light, if the lid would be open. This could be placed close to a hinge where a fairly small amount of light gets to a sensor. However, this depends on how much the angle of the lid changes the amount of light flowing in.

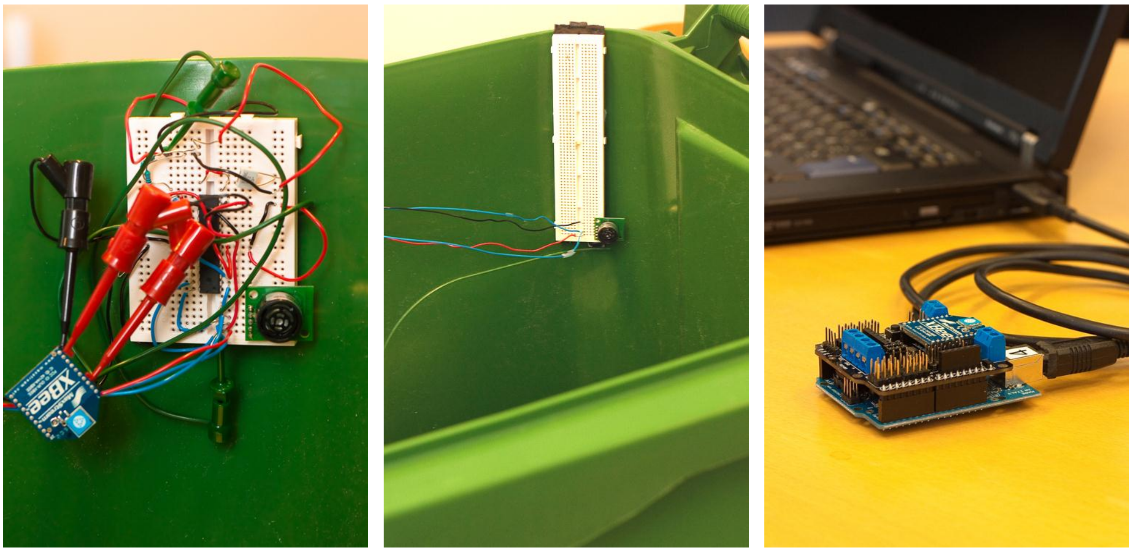
If considering even simpler approach, at least from the device infrastructural point of view, utilization of statistical analyzes could be one way to approximate the fill level of a container. By having statistical information of the level behavior of a container we can calculate and compare this information and make prediction. Calculation could take into account the time of the day, weekday, the annual season (*e.g.* midsummer in Finland is considered to be a peak season for waste collection) *etc*.

5.4. Environment Observations

The common factor for all containers, whichever material it contains is the durability against weather conditions. It is not a scope of this thesis to build a casing for the system, but it is clear that electronic parts should tolerate humidity and temperature variations. Furthermore the container is going to be exposed to mechanical stress including vibrations and bouncing derived due to handling and other possible causes. As an extreme case, while emptied, the container may fall from the fork. It is also notable that especially the lid is subject to strong physical stress in form of shaking, hitting and pressing. It is common that the lid is the first part to break. Also the edge of a plastic container is subject to heavy bending when lifted with the iron fork. Because of stress factors these areas should not be considered as a placement for any system component. Also due to vibrations and other movements the casing should have a good attachment method. It could possibly be in built as a part of the container.

6. PROTOTYPE

Communication infrastructure of the prototype is based on the ZigBee specification. The prototype system consists of a small wireless network, two ultrasound sensors and a recycling container (Fig. 16). The network is formed by two ZigBee based radios taking the roles of an *end device* and a *coordinator*. The sensors are connected to the end device with a data bus and the whole system is attached to the container. The end device communicates with the coordinator, connected to a computer through Universal Serial Bus (USB). Development environment consists of an Arduino open source platform.



a) b) c)

Figure 16. a) The end device's main operating part with microcontroller, ultrasound sensor and XBee radio module connected, b) second ultrasound sensor is connected by wires to end device's main operating part and c) coordinator node connected to computer via USB wire.

6.1. ZigBee Environment

ZigBee is based on IEEE 802.15.4 WPAN standard, which was described in Chapter 3. (Daintree Networks). In order to understand the differences between these two entities it is convenient to bind them to layered Open System Interconnection (OSI) model. While the ZigBee defines a communication on application, transport and network layers, the

IEEE 802.15.4 defines the physical layer and data link layer. The latter is usually divided into Logical Link Control (LLC) and MAC sub layers. (Fig. 17)

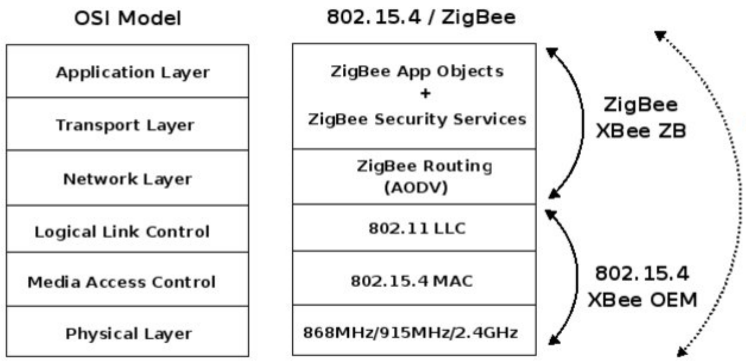


Figure 17. The IEEE 802.15.4 and the ZigBee compared with OSI model. Layers in the 802.15.4/ZigBee entity are different, but comparison to OSI is clear. (adapted from Gascón 2008)

ZigBee, as being a specification for higher layers, on top of the radio interface, offers four additional services: extra encryption, association and authentication, routing protocol and application services. The *Extra encryption* in network layer is defining an additional 128-bit AES. The *Association and authentication* services assure that only valid nodes can join the network. The *Routing protocol* defines a reactive *ad hoc* protocol that has been implemented to do data routing and forwarding process to any node. The *Application services* assure that each node belongs to a predefined cluster and can perform predefined actions. (Gascón 2008)

There are three kinds of roles that a node in a ZigBee network can have: a coordinator, a router and an end device. Basic functions of these roles can be compared to the roles of the IEEE 802.15.4 standard, described in Chapter 3. However, in ZigBee, the coordinator and the router cannot be powered by a battery and they cannot sleep, while the end devices can. (Gascón 2008)

Topologies

Network layer of the ZigBee creates certain topology definitions of the nodes. *Star*, *peer-to-peer* and *tree* topologies are specified in the IEEE 802.15.4 standard. In a *star topology* the devices can communicate with the ZigBee coordinator without connections to each other. Coordinator is responsible for initiating the network by selecting the unique PAN identifier. Identifier is unique only at the near distance of the coordinator. In *peer-to-peer* networks, devices are able to communicate with any other device. In *tree topology* routers relay the messages, while end devices act as leaf nodes without further message routing capabilities. Furthermore in case of tree network the coordinators can grow the network. (Farahani 2008)

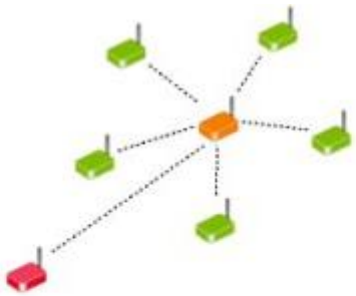


Figure 18. A star topology is commonly used in ZigBee network. It can employ all of the device roles: coordinator (red), router (orange) and end devices (greens). (adapted from Gascón 2008)

6.1.1. Arduino Platform and XBee modules

The prototype environment utilizes an Arduino, an open hardware and software platform for embedded environments. Commonly Arduino requires only a simple, battery powered I/O board with development environment. The main advantages of the Arduino are the mobility due to its small size and easy basic setup. Development software is exploiting programming language based on the 'Wiring', another open source standard. (Scheibe & Tuulos 2008: 261–262)

Arduino Uno Board and ATmega328 Microcontroller

Arduino Uno is an 8-bit development board. It contains 14 digital I/O pins and 6 analogue inputs. Programming of the Arduino board can be accomplished through USB connection, which also supplies the operating power if not supplied by battery. Arduino Uno operates on 5V, though it can output regulated 3.3V. The current of the board is 40mA for each I/O pin and 50mA for the 3.3V pin. The clock rate of the board is 16 MHz. (Arduino 2010)

The development board is equipped with an ATmega328p microcontroller. This CPU has a physical form of 28-pin Plastic Dual In-line Package (PDIP) from which 23 I/O lines can be programmed (Fig. 19). ATmega328p supports both, SPI and I²C buses and contains internal calibrated 8MHz oscillator. Operating voltage can vary from 1.8–5.5V according to datasheet. For considering the environment Atmega328p functions in temperatures ranging from –40°C to 85°C. According to the data sheet the consumption can reach as low as 0.2mA with 1MHz clock speed and 1.8V supply voltage. With the same setup 'power-down' mode consumes 0.1µA and 'power-save' mode 0.75µA. However, for reaching such a low consumptions an external real time clock would be required. (Atmel 2009: 1)

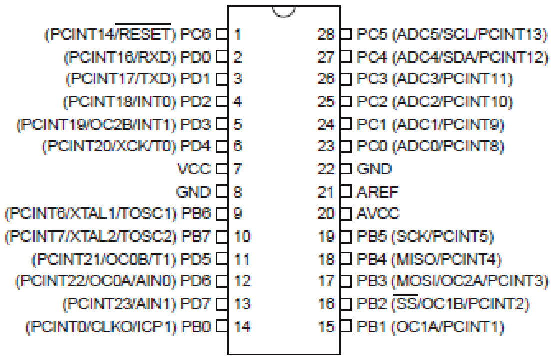


Figure 19. PDIP pin layout of the ATmega328p microcontroller. (Atmel 2009: 2)

XBee Modules

XBee radio module is based on the ZigBee specification. It communicates in the 2.4GHz frequency band with maximum of 250kbps data rate. According to the technical specifications the maximum operating range in outdoor environment is 100m with transmission power of 1mW. Current needed for transmitting is 45mA and the consumption in reception is maximally 50mA. Both of these are estimations when utilizing 3.3V supply voltage. The module contains six 10-bit A/D and 8 digital I/O inputs. The XBee module uses quadrature PSK (QPSK), which instead of BSK's two phases employs four phases (45°, 135°, –45° and –135°), each presenting 2 bits. (Farahani 2008: 147) (Digi International Inc. 2009)

The XBee module contains several sleeping modes for power saving purposes. The two most important ones are ’pin hibernate’ and the ‘cyclic sleep’ modes. The *pin hibernate* is the deepest sleep mode, resulting also the longest wake up time. In this mode the waking up can be activated by changing the voltage level of the pin number 9. In the *cyclic sleep* the XBee radio can wake up after specified time period to check the radio activity. (Digi International Inc. 2009)

Expansion Shield

Expansion shield permits the Arduino Uno board to communicate wirelessly using the XBee modules. Although this is not the most important part of the node it ensures a compact physical packet for the coordinator node. The shield uses RS485 serial bus to communicate with the Arduino board. The expansion shield has corresponding digital and analogue I/O pins and it can output 3.3 or 5V. Through hole soldered platform shield breaks out Xbee's pins. Shield contains three jumpers, which have to be configured correctly after programming phase in order the communication to XBee to be possible. (Arduino 2007)

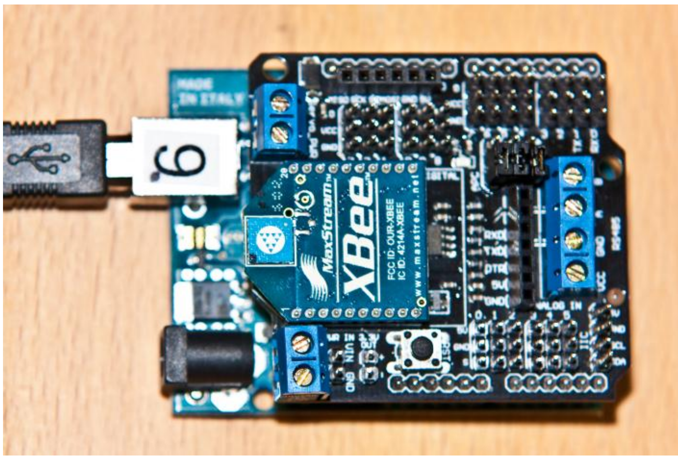


Figure 20. The Xbee module connected to the expansion shield, which is attached to the Arduino Uno Board. Based on this equipment the communication prototype is built.

Arduino Alpha Development Environment

Arduino contains a straight forward software interface (can be found from http://arduino.cc/en/Main/Software). When the board is connected to USB port the driver installation proceeds automatically. When launching the software environment the board and the port to be utilized has to be defined. This can be managed from the 'tools' menu.

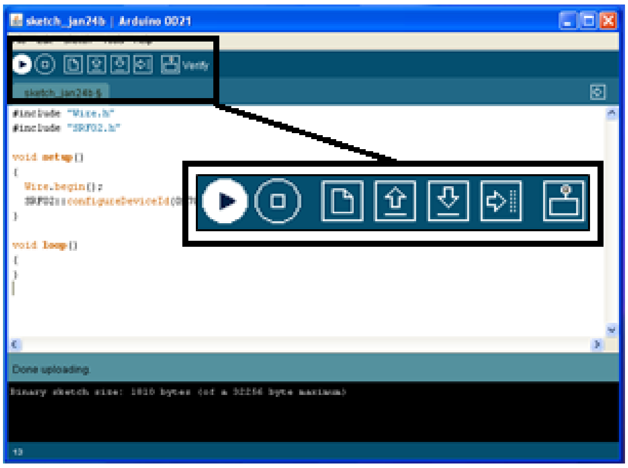


Figure 21. The Arduino Alpha program is used for developing and uploading software to Arduino board. The toolbar of the program is also shown.

From the toolbar line showing in Figure 21, the last three buttons are the most important ones. The 'arrow pointing to the right' icon performs the compiling and uploading of the code to the host device. The last button opens a serial monitor for investigating traffic in the serial port. This is useful when verifying the node operation and performing light weighted debugging. It should be noted that saving the program does not occur automatically on compiling process and it should be done separately by the 'arrow down' icon.

There are two main program sections required in order to execute an Arduino program. An initializing function called `setup()` is performed only once, when the Arduino board is powered up. As an example it can be used to define variables, pins, libraries and to initialize and configure the peripherals. The main section of the program is placed inside of a `loop()` function. This defines the loop which the node will enter after setup and repeat as long as it remains powered. Own functions can also be defined, but the program should always be allowed to return to the loop function. (Arduino 2010)

6.2. Detecting Ultrasound

When using ultrasound as a level detection method the speed of sound in different materials becomes an issue. In most of the cases two types of properties influence to the speed of the wave: elastic and inertial properties. *Elastic properties* are related to the tendency of the material for maintaining its shape and deformation when affected by a force. Steel has a small deformation of shape with a high elasticity. Material such as rubber on the other hand is flexible, and evens a small force causes strong deformation. *Inertial properties* influence on particle level. For example when a force is applied to steel its strong particle interactions prevent deformation. Generally, solids have the strongest particle interactions. This is why sound waves travel faster in solids than in liquids or in gases. The overall functionality of an ultrasound sensor was presented in Chapter 4. (The Physics Classroom 2011)

The prototype utilizes two ultrasonic SRF02 range finders. The device has two interface possibilities – I^2C and SPI (explained in Chapter 4). SRF02 supports multi connection with 16 devices in parallel. Approximate detection range is 15cm with a single transducer. SRF02 has five (Fig. 22) connection pins: power input, SDA, SCL, mode, and ground. SDA and SCL are the lines for establishing I^2C communication. Mode pin is used for selecting the communication mode. In case of serial mode the pin is connected to ground and in case of I^2C left unconnected. When the device is powered on, the Light Emitting Diode (LED) light gives a blink for confirmation. (Robot electronics 2010)

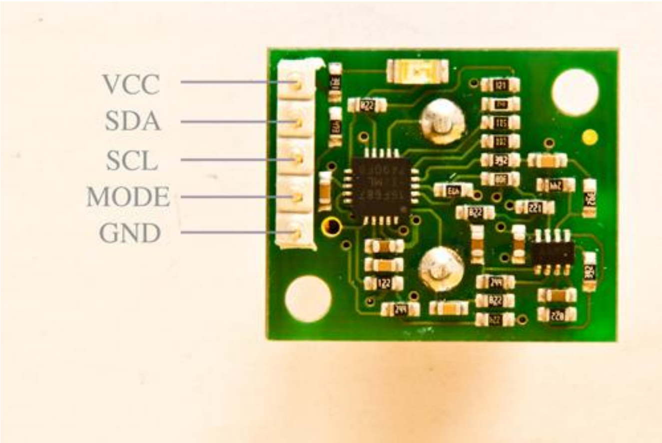


Figure 22. The SRF02 sensor is based on ultrasound. It has five pins for power input, SDA, SCL, mode, and GND.

6.3. The Solution

The functionalities of the prototype are presented in Figure 23. When power is fed to each of the nodes, initialization steps are performed in the `setup()` function. The *end device* connected to sensors contains three main activities. It has to update the status of the sensors, send information and sleep. All of these are performed inside of the `loop()` section. *Update* function contains a feedback loop, which confirms the uncorrupted sensor readings. Also, after sending the information, correct transmission is confirmed. For the purpose of power saving the node is most of the time in the ‘pin hibernation’ sleeping mode.

The *coordinator* node is required to execute a loop and read a sending buffer, whenever information is available. When it receives information from the end device the coordinator sends confirmation as a response for successful transmission. Coordinator is connected to a computer, so sleeping modes or other energy saving methods are not required.

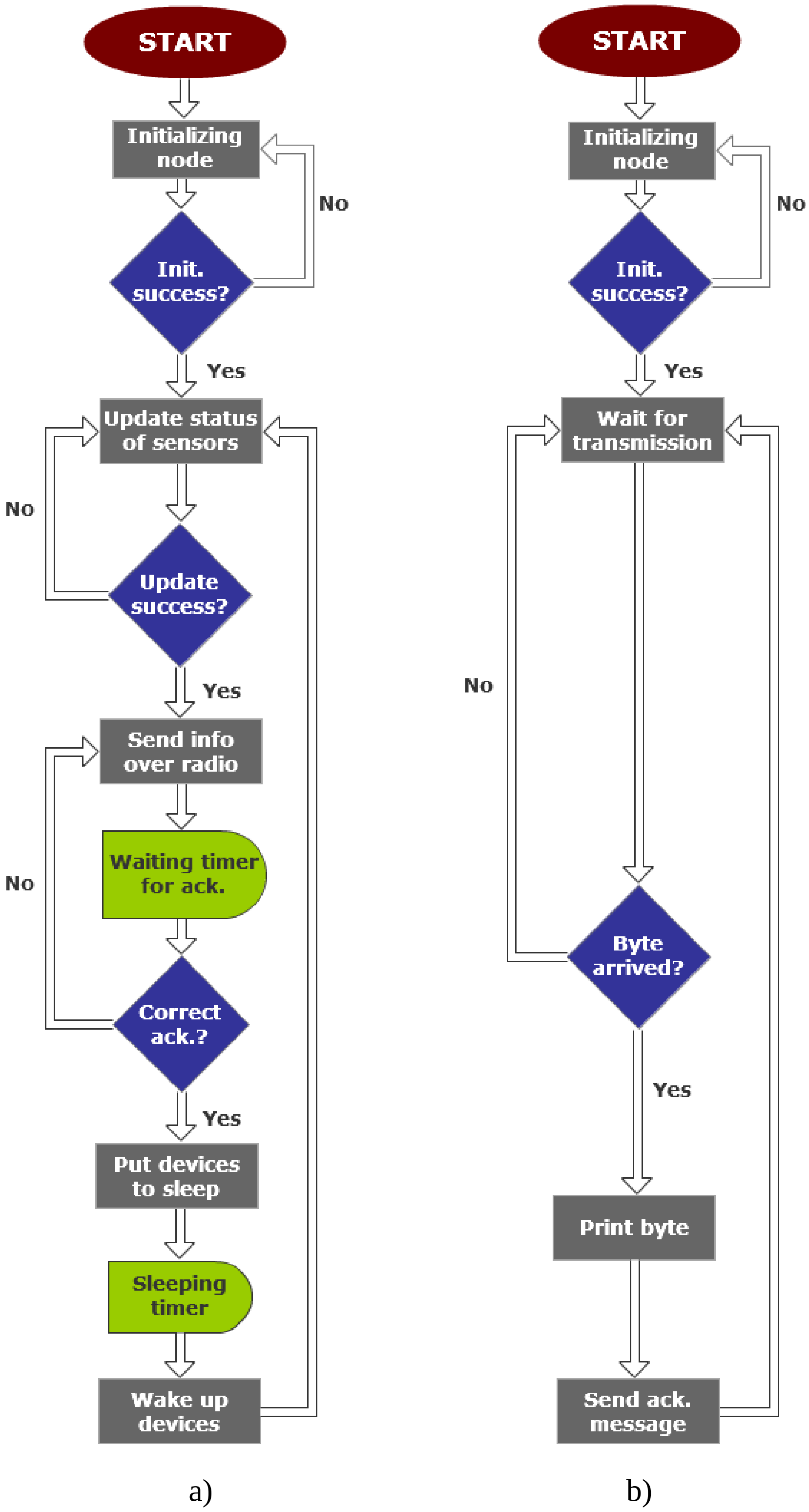


Figure 23. a) Flow chart describes the end device's functionalities, which are 'Initializing node', 'Update status of sensors', 'Send info over radio', 'Put devices to sleep' and 'Wake up devices' and b) the coordinator contains three functions: 'Initializing node', 'Wait for transmission', 'Print byte' and 'Send ack. message'.

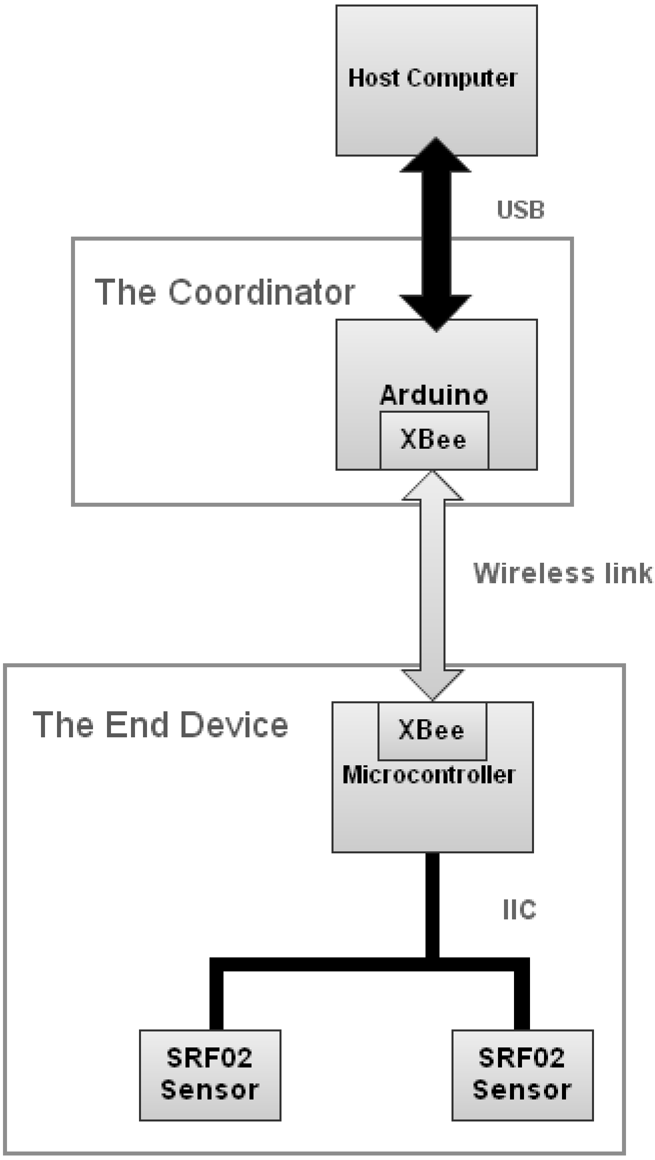


Figure 24. The communication interfaces between parts of the prototype. The host computer is connected to the coordinator with USB wire. The coordinator is communicating with the end device wirelessly through the XBee radios. The end device has two SRF ultrasound sensors connected to it by the I^2C bus.

Figure 24 shows the communication of the prototype. The Arduino Uno board, acting as the coordinator node is connected to the host computer through USB wire, which enables the serial communication, but also feeds power to the coordinator. The end device is communicating with the coordinator through a wireless link established by the Xbee radio modules. The end device is controlled by a microcontroller ATmega328p. Furthermore, the microcontroller has two SRF ultrasound sensors connected by use of the I^2C bus.

6.3.1. Programming

Both nodes contain a different program. However, each of them have similar network definitions. It is notable, that when nodes are being programmed the three jumpers have to be on their left most pins in order to allow the USB communication. For the XBee radio to send and receive, the jumpers have to be placed to the right most pins (Fig. 25).

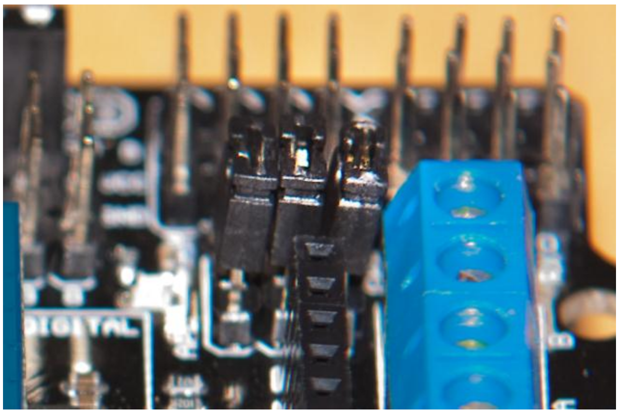


Figure 25. Three programming jumpers on expansion shield placed on XBee communication mode.

Programming Ultrasonic Sensors

Both of the ultrasound sensors connected to the system have a default I^2C bus address of 0x70. This means that two devices in a same system with the same address would result bus collisions when communicating with the host device. By using a small program (Fig. 26) with Arduino's "Wire.h" library the address of the second sensor was changed from default 0x70 to 0x71.

```
Wire.begin();
SRF02::configureDeviceId(0x70, 0x71);
```

Figure 26. A sub routine to change the second SRF02 sensor's I^2C address.

Figure 27 presents charts of example data from one of the SRF02 sensor while increasing the amount of material in the container. The measurement interval was 100ms. Data contains radical changes because the material is momentarily passing in front of the sensor when falling to the base of the container. These changes, if occurring when sensor is measuring the level can lead to a wrong result. Even when the result is calculated as a mean of several measurement values high peak can change the result dramatically.

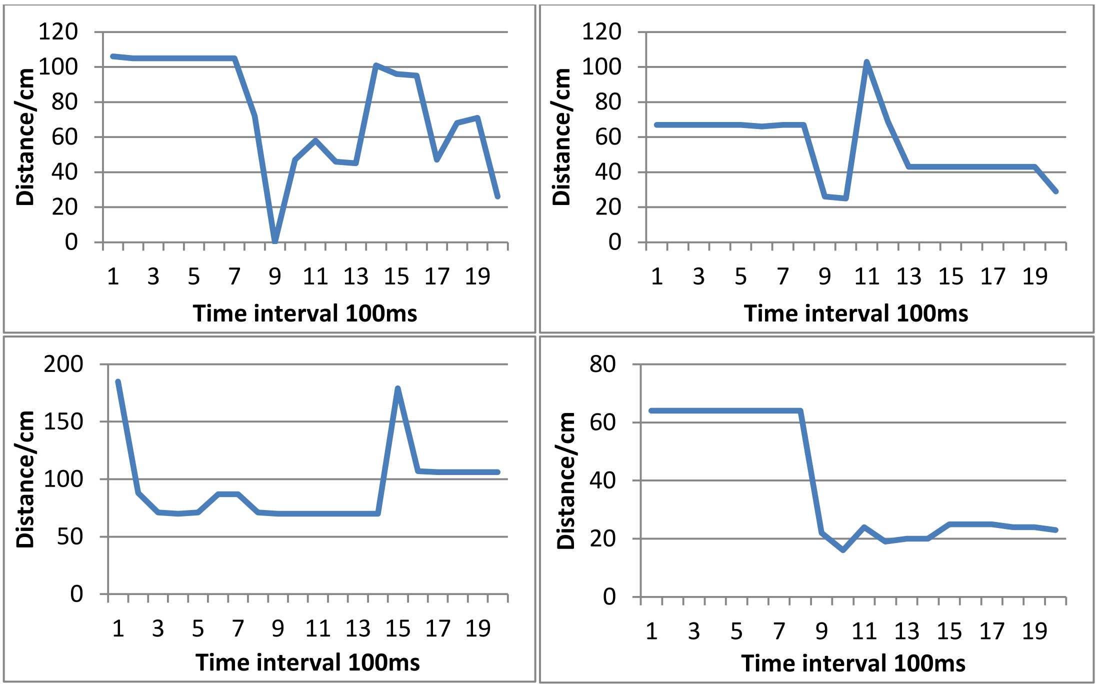


Figure 27. Four cases of the SRF02's echo signal measurements when objects were temporarily passing the sensor head.

In order to avoid these distortions the program algorithm was altered to detect the momentary changes by comparing the sensed value to the previous value. If at least 3 peaks occur the algorithm breaks the loop and sets devices to sleep for a short period of time. This happens until the ten measurements are received. This procedure also prevents detecting external changes and movements of the container, which can disturb the measurement.

Coordinator Device

When the coordinator is powered on, the `setup()` function performs Application Programming Interface (API) commands to the XBee radio module. The common form of the command in (API) is as follows:

AT (prefix) ID (ASCII command) HEX (parameter if required) \r (carriage return)

In order to operate as a coordinator, initialization settings had to be applied to the XBee radio. Settings were set by using the commands in Figure 28.

```
Serial.print("+++");
Serial.print("ATCE1\r");
Serial.print("ATDH0\r");
Serial.print("ATDL1999\r");
Serial.print("ATMY8119\r");
Serial.print("ATID2403\r");
Serial.println("ATCN\r");
```

Figure 28. The commands for initializing setting for assigning the coordinator mode, defining destination addresses and network identification.

For accessing the setup mode of the XBee radio three plus ('+++') signs have to be supplied within 1 second time period. This is followed by ATCE1, which assigns the coordinator role for the device. Commands, ATDH0 and ATDL1999 are used for assigning 64-bit destination address, divided to two 32-bit blocks (high and low). ATMY8119 sets the current node address and ATID2403 assigns the network. ATCN is a command, setting radio to the data mode. All numbers used in the commands are hexadecimal numbers without '`0x`' notation. (Fig. 28)

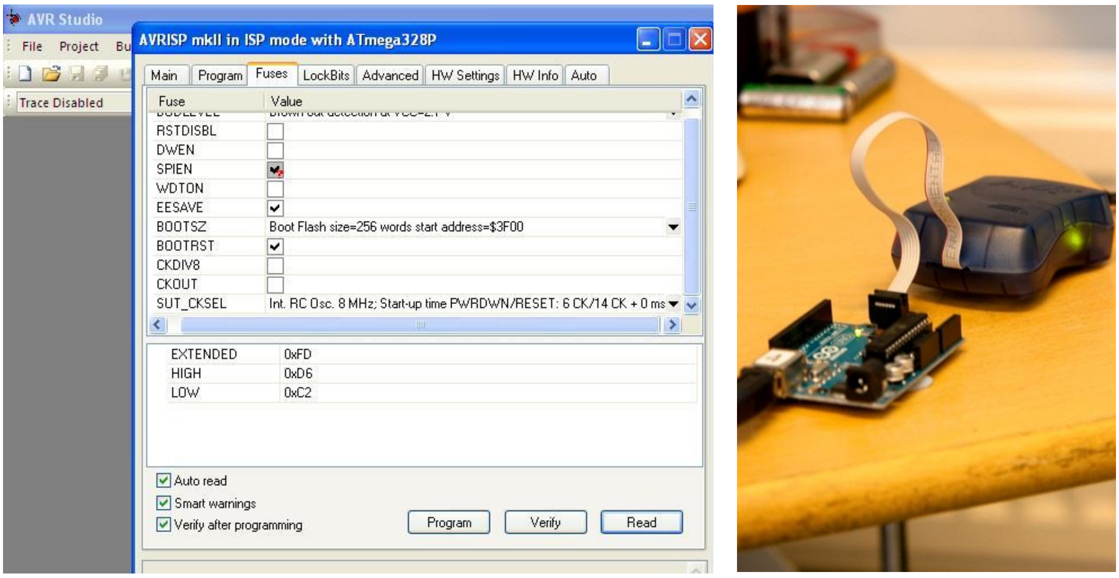
End Device

The configuration of end device follows the same logic as the coordinator device (Fig. 29).

```
Serial.print("+++");
Serial.print("ATDH0\r");
Serial.print("ATDL8119\r");
Serial.print("ATMY1999\r");
Serial.print("ATID2403\r");
Serial.print("ATSM1\r");
Serial.print("ATD70\r");
Serial.print("ATCN\r");
```

Figure 29. The program lines for the end device's initializing of destination addresses, network identification and sleeping mode.

In the end device the destination low address (ATDL) has to be the node address (ATMY) of the coordinator device and vice versa. ATSM1 defines the pin hibernation as the sleeping mode. This is followed by ATD70, which sets the digital pin 7 to zero, for avoiding the Arduino board reset, when setting the device to sleep. (Fig. 29)



a)　　　　　　　　b)

Figure 30. Reprogramming the fuses of the microcontroller. a) AVRStudio shows the fuse settings of the ATmega328p. The 'SUT_CKSEL' was reprogrammed to use internal oscillator and b) AVRISP mk II programming device connected to Arduino Uno. Both of these devices were powered through USB.

Because of the size and power consumption factors the ATMega328p microcontroller was eventually removed from the Arduino board. The microcontroller was getting its clock signal from an external oscillator. Because of this the internal 8MHz oscillator of the microcontroller had to be initialized. This was carried out by reprogramming the 328p's fuses in AVRStudio by use of AVRISP mk II programmer (Fig. 30).

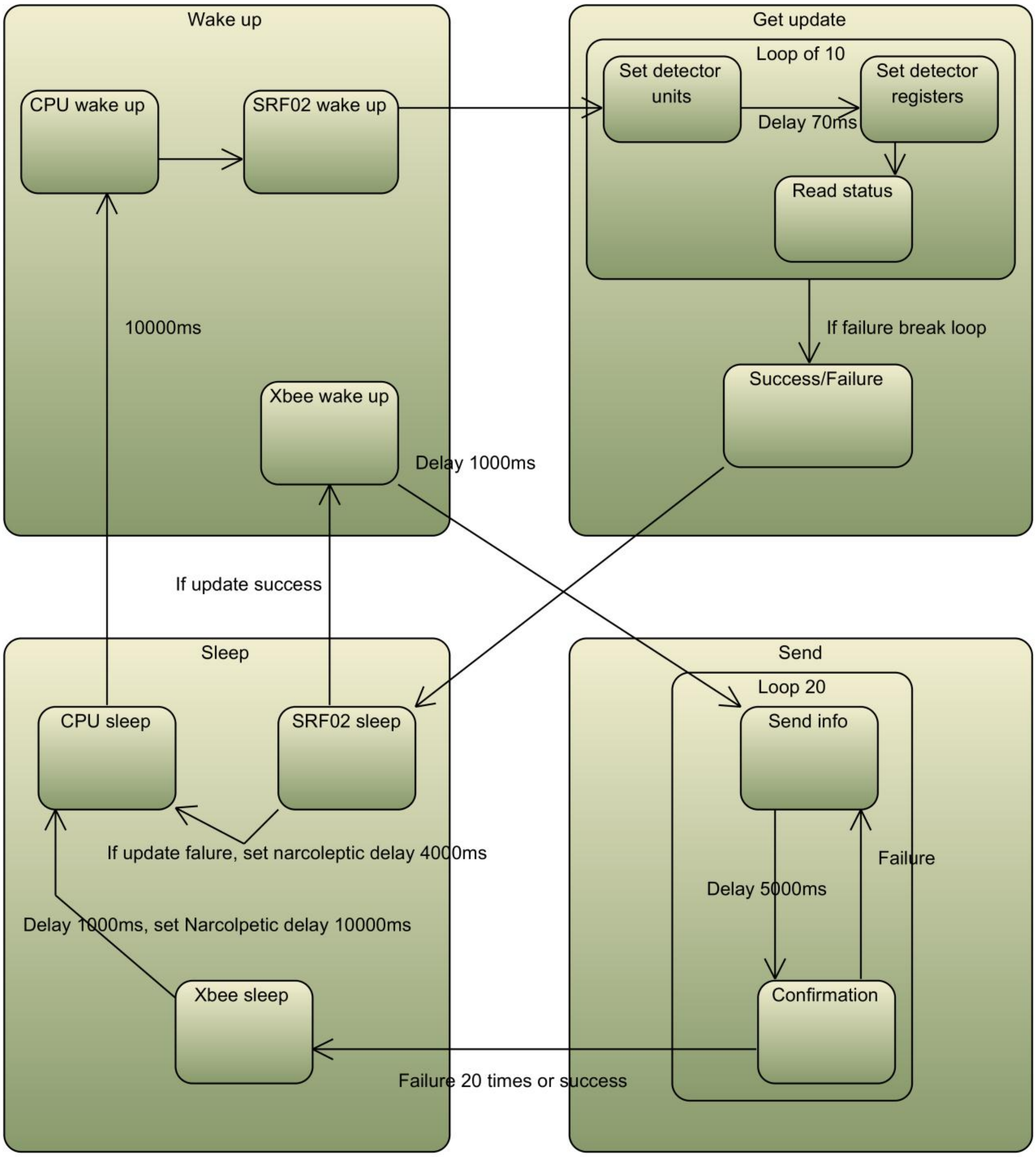


Figure 31. Main program algorithm in the end device is separated to four main states: wake up, get update, sleep and send. Sub routines of these states are also shown in the figure.

From the Figure 31, it can be seen that program can be divided to four main parts. Operation starts from the ‘Wake up’ state, where the CPU recovers from the sleep. The CPU sleep is handled by ‘narcoleptic.h’ library (can be found from: http://code.google.com /p/narcoleptic/), which uses specified delay to keep the microcontroller sleeping. After waking up the CPU feeds power to both of the SRF02 sensors. For allowing time for devices to initialize properly a 500ms delay is added. When the delay ends the algorithm moves to ‘Get update’ state where ten values from both of the sensors are read. The sensor values are then counted as a mean values. Failure leads to abandoning the measured values and the system falling back to the ‘Sleep’ state lasting 4s. When sensor values are obtained, the system enters the ‘Send’ state. However, before moving to the sending state the SRF02 sensors are powered down, since they are not required at that state.

Before sending the information through the radio the decision whether the container is full or not has to be made. The SRF02 sensor’s received echo changes when material is added to container. Normally the delay of the echo should decrease since it takes less time to reach the sensor and value is defined as centimeters. However, since container contains different shapes and surfaces the sound wave can reflect and take more time to reach the sensor, which results increased delay to be sensed. As a resolution if either of the sensors is sensing larger than 20cm measurement change the system will decide container to be ‘full’. (Fig. 31)

According to the decision ‘F’ (full) or ‘L’ (low) message will be transmitted through the XBee. After this the algorithm waits 5s for acknowledgement from the coordinator. The coordinator is set to respond with a corresponding lower case letter ‘f’ or ‘l’, according to the received message. If the confirmation takes more than 5s or does not contain the same value in lower case that of transmitted the radio will retransmit the value. Transmit can happen up to 20 times until the sensor node gives up. Eventually program will enter the ‘Sleep’ state and puts the XBee and the CPU to sleep. CPU’s sleeping state lasts for 10s, until the same cycle repeats. (Fig. 31)

6.3.2. Electronics

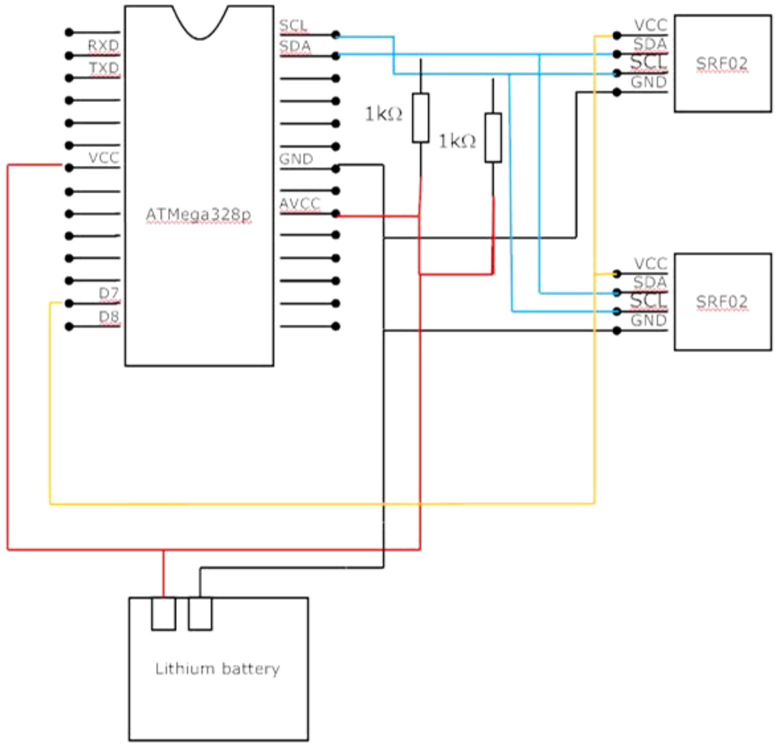


Figure 32. A schematic of the two SFR02 ultrasound sensors attached to the ATmega328p microcontroller in the end device.

The final end device configuration builds up from a small electronical entity. For the sake of clarity the electronical entity is divided to Figures 32 and 33. The ATmega328p microcontroller is wired to both of the SRF02 sensors. According to the I²C standard the SDA and the SCL lines are connected to the CPU's corresponding pins 27 and 28. Devices can be connected in parallel to the shared inputs since device recognition in the I²C bus is utilized by software addressing. The SDA and the SCL lines are connected to power pin of the CPU thorough 1kΩ resistors each. Because digital output pin of the microprocessor can supply enough current, the SRF02s are getting their power from the digital input 7 (D7) pin. Ground (GND) pins are naturally connected to ground. The board is powered by 3.7V lithium battery connected to Vcc pin and to GND pin. Power is also supplied to AVcc, voltage pin for the A/D converter of the CPU. As a recommendation from the chip manufacturer it should be connected even if the A/D converter is not employed. (Fig. 32) (Atmel 2009: 4)

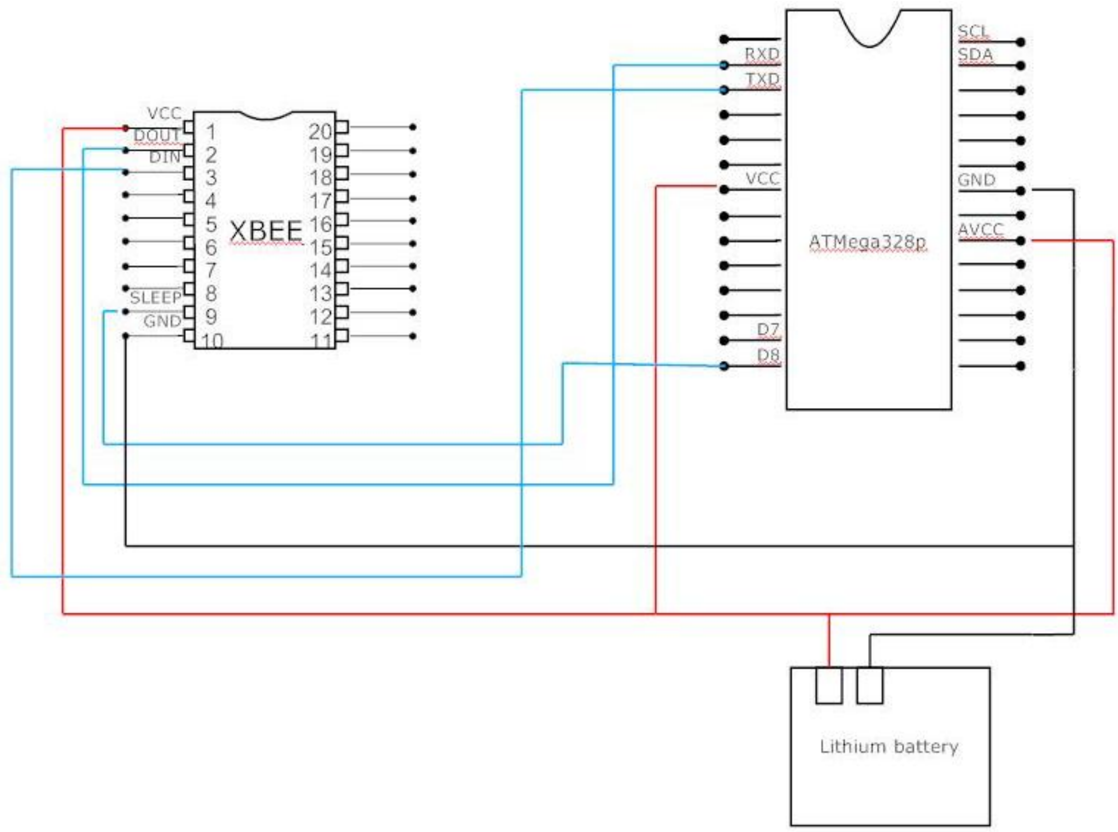


Figure 33. A schematic of the connection between the XBee radio module and the microcontroller.

The XBee radio module is connected to the microprocessor by use of three wires. XBee's 'DOUT' line (pin 2) is connected to microcontroller's 'RXD' line (pin 2) and XBee's 'DIN' line (pin 3) is connected to microcontroller's 'TXD' line (pin 3). Furthermore, the XBee is getting power through pin 1, connected straight to the power source of lithium battery. Additionally, the sleeping pin 9 is connected to microcontroller's digital input pin 8 (D8), for guiding radio's sleeping state. (Fig. 33)

Since the coordinator node, connected to the computer does not have critical size or power consumption requirements it was left to function as the development environment device entity, without physical alterations. (Fig. 16c)

6.3.3. Power Consumption

The final phase of the prototype design was to consider the power consumption. In order to test and confirm the battery life in different kinds of environments and temperatures, a great deal of time would be needed. Because of this the battery life of the system is only calculated from the power consumption.

The Arduino Uno with the Xbee extension shield consumes around 37mA when the node is in sleeping mode. Let's say that we are able to exploit the capacity of 4 AA with the total capacity of 8400mAh. With constant consumption of 37mA and assumption that 80% from battery's capacity can be used we get battery life of:

$$\frac{\frac{8400\text{mAh}}{37\text{mA}} * 0.8}{24\text{h}} \approx 7.5\ days$$

So, concluding that by keeping the device in constant sleeping mode the battery capacity would last one week. It is needless to continue power calculations with this device setting. However, with the final setting of the sensors and the radio connected to the microcontroller, without the Arduino Uno board the consumption in the sleeping mode is 0.380mA. For calculating the battery life again we make a couple of assumption. The system is to be active twice in 24 hours, which means approximately 30 seconds of wireless and 30 seconds of sensor activity. By calculating the amount of seconds in one hour and sharing it between the time portions, taking into account the typical consumptions of the device, we get for the total consumption:

$$\frac{3597.5}{3600} * 0.380\text{mA} + \frac{1.25}{3600} * 16\text{mA} + \frac{1.25}{3600} * 55\text{mA} = 0.404\text{mA}$$

And now we repeat the first calculation, getting:

$$\frac{\frac{8400\text{mAh}}{0.404\text{mA}} * 0.8}{24\text{h}} \approx 693\ days$$

This allows the device to operate nearly two years. Further considerations and reduction of power is certainly possible, but it will be left to the future development.

6.4. Results

The accomplished prototype is one part of automatic information gathering network formed by many WSNs with start topologies (Fig 34). One WSN is formed by several end devices sensing the fill levels of the containers and communicating with the coordinator. All of the coordinators in the system are submitting the information via internet to a central room, which is performing the optimization of the route options according to the information received.

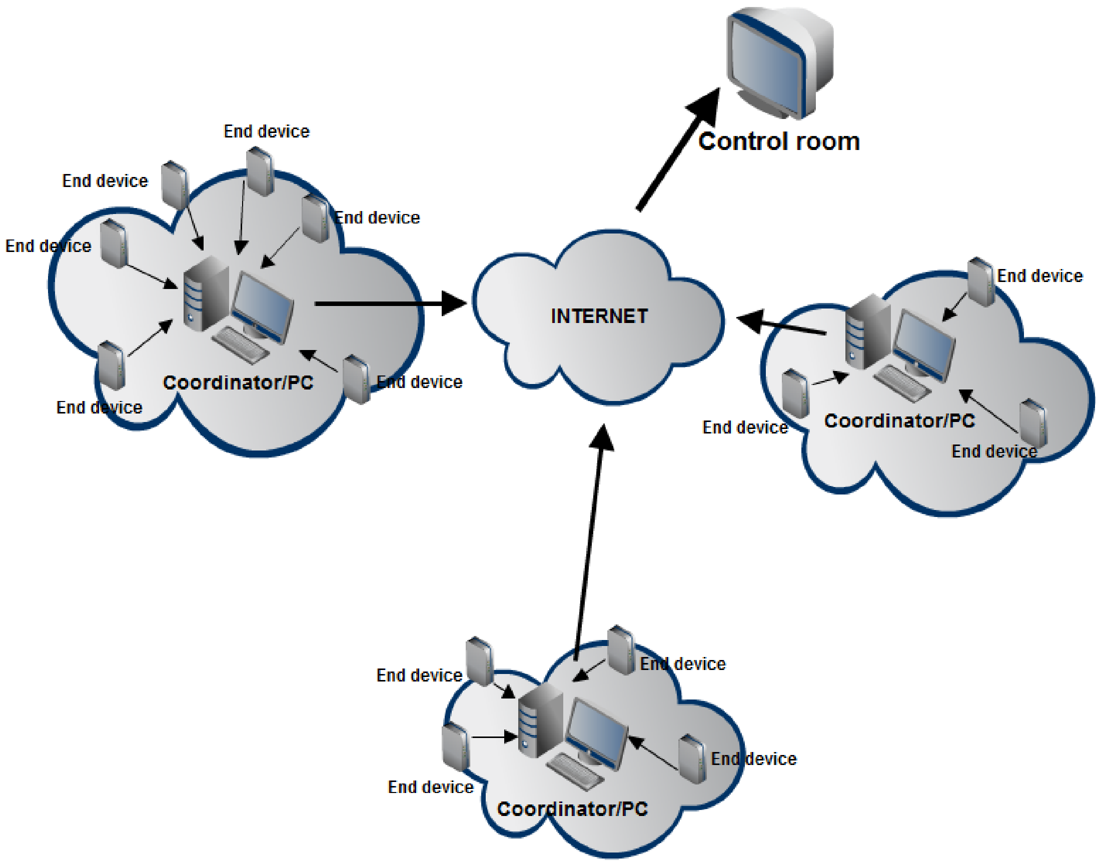


Figure 34. Network sketch includes several WSNs. The end devices are sending information of the fill level of the container to the coordinator connected to PCs. The coordinators of each WSN are placing the information to a web page. The control room can access the web page and optimize the recycling collection routes for the trucks.

The route optimization problem is known as a theory called *Vehicle Routing* problem. In this theory the vehicles with certain capacities are travelling through different locations where each of them has to return to central location. This optimization problem can, among the others be solved by the means of Genetic Algorithm (GA). GA is global optimization method using evolutionary computation technique. It is imitating the population genetics and natural selection. Simulated Annealing (SA) is another technique using random means for finding the solution. It is based on the annealing process, which describes a solid material to be heated and gradually cooled for crystallizing. The cooling time and the energy states of the atoms are used to find the optimal solution. (Bräysy 2001)

Vehicle routing problem in the solid waste context of logistics is considered in the book The Vehicle Routing Problem (Toth & Vigo 2002: 247-252). Among the other subjects it describes vehicle routing problem in United States. Journal of Applied Sciences & Environmental Management (Ogwueluka 2009) describes the same problem in developing countries. This case study includes both, computational and as well as experience based techniques, where they determine capacities of vehicles and containers. Since the route optimization fall off the scope of this thesis it will not be discussed here further.

7. CONCLUSIONS

In this thesis, the possibilities to use wireless sensor network on a recycling environment was studied. The basic idea rose from the aspect of saving resource by use of automated system. While recycling companies are emptying containers, some of them require several kilometers extra journey. This can result loss of resources if it turns out that containers are not full. Initial concept of the system was to measure the capacity of the material in a container and transmit the information wirelessly to a PC. The system would combine different standards with requirements of low data rate, low power consumption and at least 70 meter communication distance.

When beginning to design this kind of system it is easy to start comparing technology standards and based on the specification choose the most appropriate ones. However, since the system such as this is tailor made it is important to keep in mind the difference between theory and practise. Theory provides good guidelines and system designs, but practical prototype requires consideration and careful testing.

The prototype in this thesis can technically be divided into two parts: telecommunication and automation sensors. Telecommunication entity defines a small distance wireless network between two communication nodes. For this many suitable development environments are available and some of them were considered. Finally the decision fell on ZigBee technology for the node infrastructure. The ZigBee is built on top of the IEEE 802.15.4 standard defining low rate wireless personal area network. ZigBee based Xbee transceivers were used in this work. The most appropriate of the detection method for sensing the level information was considered to be the one based on the reflection of ultrasound. Due to its low cost and availability the ultrasound SRF02 sensor was selected.

Arduino, an open-source and open hardware platform for embedded devices, was selected for a development platform because of its low cost and suggested easy implementability. For the software process the Arduino Uno board was utilized. This was combined with a shield allowing an attachment of the ZigBee radio. The programming was carried out with Arduino specific program and uploaded to board's memory through USB connection from a PC.

The developed software in the end device has four main states: waking up, reading sensors, sending information wirelessly and sleeping. The end device processes the sensor readings by requesting an update from each of the sensors. The final reading is the mean value of 10 measurement values. If reading includes large fluctuation between two values, measurements will be discarded and started from the beginning. When stabile values from both sensors have been received, the state of container is decided and information is transmitted to coordinator node, which is set to listening mode. The end device attempts to transmit 20 times, until it gets acknowledgement from the coordinator. After this the algorithm powers down all of the devices. This cycle is repeating when the node wakes up every ten seconds.

Performance of the prototype corresponds fairly well to the initial idea, when its functionalities are considered. From the power consumption point of view the greatest concern in mobile wireless systems is the sleeping state, since the node will stay in sleep most of the time. In the final prototype the power consumption of the end device in the sleeping state was measured to be 0.380mA, while on the active state consumption rises to 11mA. Radio operates at 250kbps rate, which is quite high for the requirements, but clear disadvantage can only be seen as increased power consumption in the active state.

Arduino as a development environment is highly recommended option compared to traditional C-programming. It establishes communication between different entities, allowing programmer to concentrate on the algorithm development without the need for defining software connections for example for each physical pin. The Arduino programmed microcontrollers can also easily be used separately, detached from the board.

From this study it can be concluded that technically a wireless sensor network can be implemented for recycling environment. It can be seen as an initial step in automating the material collection of recycling to a large network of several WSNs. Concern of its own would be to build a suitably sealed product to be attached in containers to function in harsh environments. The future depends on the willingness of the companies, to invest more resources for the further development.

7.1. Future Considerations

There are some technical aspects that should be considered, when expanding the communicating network. The currently used radio module has fairly low transmission power, which keeps the communication range low. Module should be replaced by a device with more powerful antenna.

Power consumption of the end device was low. Even this level can be reduced by further optimization of the sleeping state of the end device. Current solution uses 'Narcoleptic' sleeping library, which is using the clock of the microcontroller for timed wake ups. External Real Time Clock, consuming 0.01mA could replace this clock, while the microcontroller would be entirely powered off.

The sensor technologies can be further investigated. Especially method based on the machine vision can be efficient. Camera could be for example some of those used in cell phones. However, in case of camera, the system memory would have to be increased in order for saving a still image. This could be managed by the use of a Secure Digital Micro card, with small physical dimensions. The lighting could be established by several LEDs. The concept of sensor fusion could also be the next step on developing the sensor part of the system. Alongside the ultrasound a method based on mass variations or capacitive sensing could be exploited.

Lithium battery of a cell phone was used as a testing power supply in the prototype. This was mostly due to its easier testability and suitable voltage. In the future system could be supplied with several AA batteries, which would bring more capacity to ensure longer life. However, the battery optimization and different chemistries should be carefully tested in different temperatures.

REFERENCES

Arduino (2010). Arduino Uno. [online] [cited 15.11.2010] Available from Internet: <URL:http://arduino.cc/en/Main/ArduinoBoardUno>.

Arduino (2010). Language Reference. [online] [cited 10.2.2011] Available from Internet: <URL:http://www.arduino.cc/en/Reference/HomePage>.

Article Collection (1997). The I²C Bus. Netherlands: Giethoorn-NND. ISBN 0-905705-47-5.

Atmel (2009). ATmega48PA/88PA/168PA/328P. [online][cited 22.3.2011] Available from Internet: <URL:http://www.atmel.com/dyn/resources/prod_documents/doc8161.pdf >.

Aumala, Olli (2002). Mittaustekniikan perusteet. Helsinki: Hakapaino Oy. ISBN 951-672-321-7.

Bluetooth SIG (2009). BLUETOOTH® low energy-technical facts. [online] [cited 4.6.2010] Available from Internet: <URL:http://www.bluetooth.com/SiteCollectionDocuments/Bluetoothlow energyfactsheet.pdf>.

Bräysy (2001). Local Search and Variable Neighborhood Search Algorithms for the Vehicle Routing Problem with Time Windows. Vaasan Yliopisto. ISBN 951-683-915-0.

Callaway, Edgar H. Jr. (2004). Wireless Sensor Networks. Architectures and Protocols. United States: CRC Press LLC. ISBN 0-8493-1823-8.

CHILIdevices International (2010). CHILImodule CDM1540x [online] [cited 7.10.2010]. Available from Internet:<URL:http://www.chilidevices.com/site/products/documents/datasheets/0S4-0000-00100H-CHILImoduleDatasheet.pdf >.

Daintree Networks (2007). What’s so good about mesh networks? [online] [cited 28.5.2010]. Available from Internet: <URL:http://www.daintree.net/downloads/whitepapers/mesh-networking.pdf>.

Dfrobot (2010). IO Expansion Shield For Arduino(V5). [online] [cited 24.1.2011]. Available from Internet: <URL:http://www.dfrobot.com/wiki/index.php? title= IO_Expansion_Shield_For_Arduino%28V5%29_%28SKU:_DFR0088%29>.

Digi International Inc. ZigBee Wireless Standard. [online] [cited 7.5.2010]. Available from Internet: <URL:http://www.digi.com/technology/rf-articles/wireless-zigbee.jsp>.

Digi International Inc. (2009). XBee/Xbee-PRO RF Modules. [online][cited 18.2.2010]. Available from Internet: <URL:http://ftp1.digi.com/support/documentation/90000982_B.pdf>

Encryption and Decryption.com (2010). Encryption. [online] [cited 9.7.2010]. Available from Internet: <URL:http://www.encryptionanddecryption.com/encryption/>.

Farahani, Shahin (2008). Zigbee wireless networks and transceivers. Elsevier Ltd. ISBN:978-0-7506-8393-7.

Fonselius, Jaakko & Laitinen, Esko & Pekkola, Kari & Sampo, Arto & Välimaa, Taisto (1988). Anturit. Helsinki: Painatuskeskus Oy. ISBN 951-37-1480-2 61.

Fonselius, Jaakko & Pekkola, Kari & Selosmaa, Seppo & Ström, Markku & Välimaa, Taisto (1996). Automaatiolaitteet. Helsinki: Oy EDITA AB. 951-37-1834-4.

Gascón, David (2008). 802.15.4 vs ZigBee. [online] Updated: November 17, 2008 [cited 31.5.2010]. Available from Internet: <URL:http://sensor-networks.org/index.php?page=0823123150>.

Geier, Jim (2005). Langattomat verkot - perusteet. Helsinki: Edita Prima Oy. ISBN 951-826789-8.

Gosling, William (1998). Radio Antennas and Propagation. Great Britain: Biddles Ltd. ISBN 0 7506 3741 2.

Green, D. C. (1995). Radio Systems for Technicians. London: Longman Group Limited. ISBN 0-582-24516-8.

Grout, Ian (2008). Digital Systems Design with FPGAs and CPLDs. Newnes. ISBN 9780080558509.

Holger, Karl & Willig, Andreas (2005). Protocols and Architectures for Wireless Sensor Networks. Great Britain: John Wiley & Sons, Ltd. ISBN-13 978-0-470-09510-2.

HowStuffWorks, Inc. (2010). How Radar Detectors Work. [online] [cited 6.7.2010]. Available from Internet: <URL:http://www.howstuffworks.com/radar-detector1.htm>.

Hui, Jonathan & Culler, David & Chakrabarti, Samita (2009). 6LoWPAN: Incorporating IEEE 802.15.4 into the IP architecture. [online] [cited 3.9.2010]. Available from Internet: <URL:http://www.cs.berkeley.edu/~jwhui/6lowpan/IPSO-WP-3.pdf >.

Kalinsky, David & Kalinsky Roee (2002). Introduction to Serial Peripheral Interface. [online][cited 23.2.2010]. Available from Internet: <URL:http://www.eetimes. com/discussion/beginner-s-corner/4023908/Introduction-to-Serial-Peripheral-Interface>

Kiehne H.A (2001). Battery Technology Handbook, 2nd edition. Renningen-Malsheim, Germany: Expert Verlag. ISBN 0-8247-4249-4.

Kierratys.info. Lajittele hyödynnettäväksi (2010). [online] [cited 4.6.2010]. Available from Internet: <URL:http://www.kierratys.info/tieda.php>.

Langton, Charan (2001). Intuitive Guide to Principles of Communications. [online] [cited 9.7.2010]. Available from Internet: <URL:http://www.complextoreal.com/ chapters/block.pdf>.

Lassila & Tikanoja (2008). Lassila & Tikanoja –jäteastiat. [online] [cited 22.3.2010]. Available from Internet: <URL:http://www.lassila-tikanoja.fi/esitteet /jateastia /lib/pdf/ LT-jateastiat.pdf>.

Lehto, Arto (2006). Radioaaltojen maailma. Tampere: Tammer-Paino. ISBN 951-672-350-0.

Lindeman, Keijo & Sahinoja Tapio (2000). Sähkömittaustekniikan perusteet. Porvoo: WS Bookwell Oy. ISBN 951-0-25277-8.

Linden, David & Reddy, Thomas (2001). Handbook of Batteries, Third Edition. New York, USA: McGraw-Hill Professional Publishing. ISBN 978-0071359788.

Loshin, David (1998). Efficient Memory Programming. McGraw-Hill Professional Publishing. ISBN 9780070388680.

Ma, John O. & Mateer, James R. & Blaivas, Michael (2007). Emergency Ultrasound. McGraw-Hill Medical. ISBN 9780071479042.

Marvin, Simon & Alouni Mohamed-Slim (2005). Digital Communication over Fading Channels (2nd Edition). Wiley-IEEE Press. ISBN 978-0-471-64953-3.

Microwave Journal (2009). Extending 2.4 GHz ZigBee Short Range Radio Performance with Skyworks Front-End Modules. [online] [4.6.2010] Available from Internet: <URL:http://www.skyworksinc.com/downloads/press_room/published_articles/Microwave_Journal_082009.pdf>.

Ogwueluka, T.C. (2009). Route optimization for solid waste collection: Onitsha (Nigeria) case study. Journal of Applied Sciences & Environmental Management [online] Vol. 13:2, [4.4.2011]. Available from Internet: <URL: http://www.bioline.org.br/request?ja09020>. ISSN 1119-8362.

Paret Dominique & Carl Fenger (1997). The I²C Bus. England: John Wiley & Sons Ltd. ISBN 0471962686.

Raol, Jitendra (2009). Multi-Sensor Data Fusion with MATLAB. CRC Press. ISBN: 978-1439800058.

Robot electronics (2010). SRF02 Ultrasonic range finder – Technical Specifications. [online] [cited 10.2.2010]. Available from Internet: <URL:http://www.robot-electronics.co.uk/htm/srf02tech.htm>.

Räisänen, Antti & Lehto, Arto (2003). Radio Engineering for Wireless Communication and Sensor Applications. ISBN 9781580536691.

Sensorsone (2010). Pressure Measurement Glossary. [online] [cited 1.11.2010]. Available from Internet: <URL:http://www.sensorsone.co.uk/pressure-measurement-glossary.html>.

Scheibe, Jurgen & Tuulos, Ville (2008). Mobile Python: Rapid Prototyping of Applications on the Mobile platform. John Wiley & Sons, Ltd. ISBN 9780470515051.

Sonka, Milan & Hlavac, Vaclav & Boyle, Roger (2008). Figure Processing, Analysis and Machine Vision. United States: Thompson Learning. ISBN 978-0-495-08252-1.

The Physics Classroom (2011). Sound Properties and Their Perception. [online][cited 24.2.2011] Available from Internet: <URL:http://www.physicsclassroom.com/class/sound/u11l2c.cfm>.

Toroi, Hannu (2010). Siistiä mittaustekniikkaa. Automaatioväylä 6/2010, 35.

Toth, Paolo & Vigo, Daniele (2002). The Vehicle Routing Problem. United States: SIAM. ISBN 0-89871-579-2.

Usher, M.J & Keating D.A (1996). Sensors and Transducers – Charasteristics, Applications, Instrumentation, Interfacing. Great Britain: Antony Rowe Ltd. ISBN 0-333-60487-3.

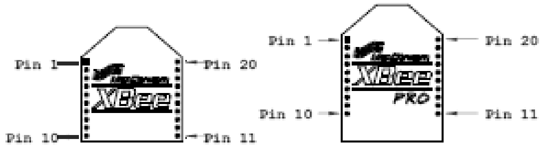
Wilmshurst, Tim (2010). Designing Embedded Systems with PIC Microcontrollers. Elsevier Ltd. ISBN 978-1-85617-750-4.

ZigBee Standards Organization (2007). ZigBee Specification. [online] [cited 2.6.2010]. Available from Internet: <URL:http://www.zigbee.org/zigbee/en/spec_download/spec_download.asp?AccessCode=1744930817>.

Z-wave Alliance (2010). Technical Questions. [online] [cited 3.6.2010]. Available from Internet: <URL:http://www.z-wave.com/modules/xoopsfaq/index.php?cat_id=2>.

APPENDICES

A1. XBee Module



Pin #	Name	Direction	Description
1	VCC	-	Power supply
2	DOUT	Output	UART Data Out
3	DIN / **CONFIG**	Input	UART Data In
4	DO8*	Output	Digital Output 8
5	**RESET**	Input	Module Reset (reset pulse must be at least 200 ns)
6	PWM0 / RSSI	Output	PWM Output 0 / RX Signal Strength Indicator
7	PWM1	Output	PWM Output 1
8	[reserved]	-	Do not connect
9	DTR / SLEEP_RQ / DI8	Input	Pin Sleep Control Line or Digital Input 8
10	GND	-	Ground
11	AD4 / DIO4	Either	Analog Input 4 or Digital I/O 4
12	**CTS** / DIO7	Either	Clear-to-Send Flow Control or Digital I/O 7
13	ON / **SLEEP**	Output	Module Status Indicator
14	VREF	Input	Voltage Reference for A/D Inputs
15	Associate / AD5 / DIO5	Either	Associated Indicator, Analog Input 5 or Digital I/O 5
16	**RTS** / AD6 / DIO6	Either	Request-to-Send Flow Control, Analog Input 6 or Digital I/O 6
17	AD3 / DIO3	Either	Analog Input 3 or Digital I/O 3
18	AD2 / DIO2	Either	Analog Input 2 or Digital I/O 2
19	AD1 / DIO1	Either	Analog Input 1 or Digital I/O 1
20	AD0 / DIO0	Either	Analog Input 0 or Digital I/O 0

* Function is not supported at the time of this release

Figure A1. XBee radio module’s pin order and description (adapted from Digi International Inc. 2009).