Efficient Communication in Smart Homes

Master's Thesis

by

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Abstract

Smart furniture is being more and more common in our homes. This thesis combines the growing interest in smart homes and farming of flowers and vegetables. The goal is to determine and characterize the parameters one has to take into consideration in order to design of a smart system for indoor farming.

A shelf in a module concept is the focus and the piece of furniture that the investigations are starting from. The shelf is supposed to work as a part of the room, dividing or creating new spaces while being a place where flowers, vegetables and herbs can be grown, as well as work as a storage for books and other things. The part with the plants is supposed to be self-sufficient, therefore a suitable system needs to be found, both in terms of communication protocol, sensors and measurements. Three different communication protocols have been studied, Bluetooth, Z-wave and 1-Wire. A literature study has been made to look at other kinds of agricultural systems, to learn more about different parameters, and to find assurance of secure measurements.

A Bluetooth system is tested in small scale to evaluate and see how different growing materials and the materials of the pot and the module can interfere with the signal.

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List of acronyms

BLE	Bluetooth Low Energy
BS	Base Station
D	Directivity
EM	Electromagnetic
EMC	Electromagnetic Compatibility
G	Gain
GATT	Generic Attribute Profiles
IDP	Insulin Delivery Profile
ISM	Industrial, Scientific, Medical
PLE	Path Loss Exponent
RF	Radio Frequency
RMSE	Root Mean Square Error
SHF	Super High Frequency
SIG	Bluetooth Special Interest Group
WSN	Wireless Sensor Network

Popular Science Summary

We see a growing interest for both smart furniture, or Internet of Things, and plants, both flowers and growing our own vegetables and herbs. This Master's thesis tries to point out important parameters when it comes to efficient sensor networks that can automate the management of the plant.

A sensor network is a setup of sensors that are sensing and measuring a certain parameter in its surrounding, for example temperature or humidity, then sending its information to a head node in the network. The head node, or base station, can then make decisions based on the data from the first node to maybe give order to a certain action to be carried out by the same sensor node or another device in the network. A sensor network can contain sensors and actuators that take care of different parameters. This thesis focuses mostly on wireless sensor networks and on finding a good solution in an indoor environment where we can be sure of that the signal can travel and reach to its destination with a satisfying signal level.

The focus for this thesis is a shelf of a modular concept, to make it possible to change size or types of modules. The module for plants is a box of thin metal walls with a volume of 25 l. The box will hold a pot with the plant and electronics and watering system for the caretaking of the plant. When sensors around the plant is gathering data, they will need to send this to the base station of the network. When sending the data wirelessly the materials around the plant and the module will of course interfere with the signal just like everything else in the room. To see how a signal sent from the communication chip can come through, a series of tests were done to evaluate if it was possible to use this kind of chip. The chip used Bluetooth as its communication protocol. The measurements took place in an electromagnetic compatibility chamber, a chamber that can close out all signals from different wireless devices around us, which made it possible to measure a singled-out signal and how it is affected by the materials around it. In the chamber there were the signaling chip and an antenna that received the signal. The antenna was coupled to a spectrum analyzer so that the level of the signal that got trough could be measured. Step by step more materials were introduced, at first a protecting box for the chip and the electronics, then the module and finally a culture

medium for the plants. Soil, water, perlite and clay pebbles were tested one by one and compared to see how high signal level that was let through. The soil gave the lowest signal level, which can be because of the many and dense particles that can interfere with the signal, which is due to that the water content is higher in soil than in the other materials. In some tests, for example when the module was first introduced, the measured signal level was higher than for a chip without the module. One possible explanation for this is that the metal of the module reflected and amplified the signal in the direction of the antenna.

1. Introduction

In today’s environment where we go towards a more digital home and city, new requirements are put on the communication between people, phones, computers, machines and tools. [1] We strive for a surrounding where we reduce the number of wires for communication for a simpler usage of our devices and for the esthetics of the surroundings. Today there are a lot of different communication techniques that all have their advantages and drawbacks and subsequently they are suitable in different surroundings and for different tasks. [2] This thesis strives to investigate the field of communication in an indoor environment for smart homes and give guidelines to some of the obstacles there are and what pitfalls to avoid. Both wired and wireless communication techniques are analyzed and compared to try to find efficient communication and functionality. The main focus is on the wireless communication and what techniques that can be of interest in an indoor perspective.

This thesis is written in collaboration with the startup company *Vissheim*. [4] *Vissheim* started out by developing a smart greenhouse for your living room. It is possible to control the process of the greenhouse and its plants from a web application, watering and lighting are then automated. *Vissheim* is now developing a new product out of the same concept but in larger scale and in a module format to be able to customize it. This thesis uses the module concept *Vissheim* is developing in order to evaluate the efficiency of different communication systems in an indoors environment. [5]

1.1. Background

Wireless communication an indoor environment faces different difficulties. We have for example walls and furniture that partly reflect and interfere with the Radio Frequency (RF) signals from our device. There are also signals from other systems, and these can possibly interfere with our signal. Therefore, wireless communication indoors must be planned and evaluated depending on what the environment looks like to be able to get the functionality required for the intended use. A total wireless environment would for the functionality of the interior design and people’s everyday life be the simplest way of doing it. However, with wireless systems comes draw back in terms of data errors, signal strength, security and cost as well. [3]

In the first product developed by *Vissheim*, their greenhouse adapted for indoor use, almost all communication is wire based, the communication between the microprocessor and the cloud is the only wireless communication used in the little greenhouse. [5] This is both impractical in the construction of the greenhouse as well as the maintenance of it. In a larger scale product, which also is intended to adapt to the room, this is not a convenient solution at all. The new product, which is seen in Fig. 1, is intended to be a larger part of building the room and furnishing, not only a place for growing plants. With it, it is possible to demarcate the room which is convenient in for example a hotel lobby or an open workspace. It will also be possible to integrate other features like storing possibilities or sound absorbent. The purpose is to be possible to customize the size of it and what things it contains; therefore, it needs to be a module concept with smart solutions to have a greater flexibility. From here this thesis takes off, in striving for a smarter solution regarding the communication within this piece of furniture. The vision is to minimize the number of wires to make the system adaptable and flexible and find the most efficient way of communication for this product.

Fig. 1. The shelf Vimur with five plant modules, one module with a chess game and four storing modules, one of them in the bottom where the white vases are seen. [5]

1.2. Project aim

To investigate and to be able to evaluate different methods and techniques a number of requirements need to be stated and graded.

Flexibility; The product is of a modular concept to be attractive and be adjustable in length and height depending on where it is intended to be used. Depending on environment different types of modules will be used and therefore the production of every shelf has to be customized but not to complex. It is desirable to have as few components as possible that have fixed positions or have specific requirements in production.

Low power consumption; One major goal is to minimize the number of cables and to develop a product that easily can be a part of the room. It is desirable to have a product that is as energy efficient as possible. In wireless systems the use of battery driven sensors and compounds is limited by the lifetime of the batteries. It is important both from an environmental aspect and from a user perspective to have a low power consumption and a long lifetime for the sensors.

Reliability; The need of finding a wireless system, or a suitable combination of wired and wireless, that meets all aspects of reliability in terms of stability and a secure network is crucial. This shelf is supposed to monitor and take care of the plants for a long time. If something goes wrong, or if data doesn't come through, there must be a reliable warning system that alerts the user.

1.3. Thesis Outline

This thesis starts with an introduction to wireless communication and wireless sensor networks to introduce the subject and what metrics that will be the focus of the thesis.

Chapter 3 introduces three possible communication protocols for the shelf Vimur. Then follows a literature study in chapter 4, where three articles in the field of wireless communication and agriculture are studied to search for points of touch with this smaller scale indoor farming.

Chapter 5 introduces the setup for the shelf Vimur and a test to see how the attributes around the plants interfere with the signal sent from the device intended to be used for the wireless communication in the shelf.. In this chapter the test site and the preconditions of the test are analyzed and in chapter 6 follows a presentation of the results. A summary and the conclusions from this thesis work are found in chapter 7.

2. Theory

This chapter gives a short introduction to the techniques used in this thesis. First there is a general introduction to wireless communication and that is followed by a section about wireless sensor networks (WSN), network topologies and routing methods.

2.1. Wireless Communication

A wireless communication system is a system that transmits information between two or more nodes by electromagnetic waves traveling in free space. The history of wireless communication started out in the end of the 19^{th} century by discoveries by men like Alexander Graham Bell, Charles Sumner Tainter, Guglielmo Marconi, Heinrich Hertz, Thomas Edison and William Preece. It is a research field under constant rapid development, that during the last 130 years completely changed our ways of communication. [8][9]

In this report wireless communication is assumed to be communication by radio waves, also referred to as Radio Frequency (RF) signals in this thesis. Most methods discussed will be short-range wireless systems, like Bluetooth.

2.1.1. Frequency Bands

Since wireless communication is used widely and in many different applications the use of it is regulated by national laws and international guidelines. The radio spectrum is divided into different bands and different bands are designated for different areas of use. There are different naming systems for the bands, in Table 1 below one part of the system defined by *Institute of Electrical and Electronics Engineers* (IEEE) is seen. The systems in this thesis are using frequencies in the band called Superhigh frequency (SHF band), which is included in Table 1. The other frequency bands are not considered here. [7]

Table 1. Microwave bands for wireless communication. [8]

f (*GHz*)	Letter Band Designation
1-2	D band
2-4	E, F band
4-8	G, H band
8-12	I, J band
12-18	J band
18-26	J band
26-40	K band

2.1.2. Power and Antennas

The transmitting and receiving antennas are essential parts of a wireless communication system. They convert data sent by electric signals into electromagnetic waves, and vice versa. Free-space electromagnetic (EM) waves can be absorbed by everything in its surroundings, like furniture, plants, people, other antennas and so on. How the free-space EM wave is travelling is of great importance for the knowledge of how the data will get through. This makes the choice of antenna very important. [8]

There is a big diversity of antennas designed to meet different kind of requirements. In an outdoor environment, where a signal is supposed to travel far, it is essential that the signal gets through, whilst for a smaller equipment indoors the design and size of the tool might be more important.

Two antenna parameters are of great importance in this thesis, *directivity* (D) and *gain* (G). Directivity helps us in knowing how great radiation there are in a certain direction. The ratio seen in (1) gives us the directivity, it is dimensionless and always greater than 1. Its value is dependent on the maximum power density, $P(\theta,\varphi)_{max}$, to an average value, $P(\theta,\varphi)_{av}$, observed in the far zone of the antenna. [8]

$$D = \frac{P(\theta,\varphi)_{max}}{P(\theta,\varphi)_{av}} \tag{1}$$

Gain, denoted G, is similar to directivity but takes the losses in the antenna into account. There are always losses due to the current in the conductors of the antenna. In Equation (2) the antenna efficiency k is introduced. An ideal antenna without losses has k = 1. [8]

$$G = kD \tag{2}$$

2.2. Wireless Sensor Networks

Wireless Sensor Networks (WSN) are sensor nodes arranged in a wireless communication network. All nodes have the possibility of communicating with each other and/or to a Base Station (BS). One sensor node can be connected to one or more sensors and the sensors can be sensing temperature, moist, light, motion or other things that in some way are needed to be registered to carry out an action from the environment or register data that continuously needs to be collected. The data collected at a sensor is then routed to a main location, or a BS, to be processed and to possibly make an action to be carried out. [10]

2.2.1. Network Topology

A thing in common for all WSNs are the quest to use as little energy as possible, in order to extend the lifetime of the sensor. A sensor node contains a processor, memory of some kind, a radio transceiver, a power source and connections to at least one sensor, but with the possibility of connecting with more. Because of power saving strategies the most common way of processing the data collected is to route it to the BS that handles the data and sends out a message if any action is needed from one or more of the sensors. The BS can for example be a computer and can further be connected to the cloud to store data or give the possibilities of monitoring the sensor network. The way data is routed in the WSN can differ and the WSN can be arranged in different topologies that gives different hierarchy between the nodes. [11] Following are some methods of routing in WSNs listed;

Point-to-point is a connection between only two devices. It is the simplest way of connection and no more than two devices, e.g. one BS and one node, can connect.

Star topology is when all the nodes only communicate with a central device. This is a simple kind of network and the nodes only need to set up one pair of connection to the central device. However, the network gets more restricted in range since all nodes need to be in hearing range of the central device.

Tree topology is composed like the structure of a tree with a root-node that is the top of the hierarchy and communicates with one or more nodes that are one step down in hierarchy. These nodes are further are connected to one or more nodes one level down in hierarch and the nodes are branching out in a tree structure.

Mesh networks are non-hierarchical networks where all nodes have the possibility of communicating with each other. This extends the area of range if messages can travel more than one hop in the network and can be essential in larger area networks.

Two-Tier cluster gives an extended form of star topology. The sensor nodes are connected to local BS that coordinates the nearest nodes in the network and passes on their data to central base station. The link between the local BSs and the central BS are a higher-powered link that operates at another frequency from the one between nodes and local BS. The link can as well be a wired link for communication between base stations. [10]

2.2.2. Routing methods

Since the nodes are limited in processing power, methods for routing is an important part when selecting the network protocol. Depending on what requirements there are on the network, different power saving strategies are suitable in different situations. There will always be a trade-off between simplicity, with a protocol that requires as little processing power as possible, and the problem with redundant data passed on in the system. [11]

Routing protocols can be classified in two ways, either depending on its structure or its way of performing its operations. When classifying depending on network structure we have *flat*, *hierarchical* and *location-based* routing protocols. The classification depending on operations in the network are *multipath-based*, *query-based*, *negotiation-based* and *QoS-based* routing techniques. Below follow some more explanations of the simplest routing method, *flooding*, and some of the above-mentioned categories. [12]

Flooding is a method when all nodes pass the message on. When a node receives a message package it passes it on to all connected nodes except to the node it got the package from. It is a very simple routing method that makes the packages arrive to their destination by the shortest path. If one node is failing, in flooding, the message will still reach its destination through another path since it can be passed on by all nodes. The drawback with this method is that each node receives the message more than once since all nodes passes it on to all possible nodes except to the one it received the message from, and this increases the data traffic in the system.

Flat Network Routing is like the name implies a network were all nodes have the same status and collaborates in their sensing task. In a bigger network it is not possible for all nodes to have their own global ID and the nodes can form regions that the BS can queries to wait for answer.

Hierarchical Routing Protocol is a system where the BS is on top and the nodes are following in a hierarchical system. Nodes gather in clusters and a local cluster-head is taking care of the routing to the BS. The cluster-head has some more processing power and it can gather and combine data before sending it to minimize the traffic to the BS.

Query-Based Routing is when the receiver of information is sending a request to a node for data. It is possible that no sensing is made before receiving a request. All nodes have a list of neighbors and an events table that is updated when an event is taking place. The nodes can use a method to test possible paths before sending a request, to get to know the shortest path. If there is no answer in a certain time the node can use flooding instead.

Negotiation-Based Routing uses a higher level of communication to minimize the data in the network. The decision about communication rout is also taken out of what kind of resources that are available at that moment. Some negotiation-based protocols are spreading a negotiation message to all reachable nodes assuming that they can be or lead to the BS. In this type of protocol, the receiving node suppresses the message if it already has received it. This is done to find a suitable path before sending the real data. [12]

3. Evaluation of Communication Protocols

This chapter focuses on three different communication protocols; a short introduction to the protocol and its network structure and how the protocol can be a relevant choice for this thesis project.

3.1. Bluetooth

The development of Bluetooth started out as a project at Ericsson Mobile Communication in Lund in the beginning of the 90s. Since 1998 when the Bluetooth Special Interest Group (SIG) was founded, the SIG works with the promotion and the continuing evolution and improvement of the protocol. Bluetooth is a royalty-free standard and its specification details are found in IEEE 802.15.1[13]. Bluetooth works on the 2.4 GHz Industrial, Scientific, Medical (ISM) band. The power consumption is low, 0.01 mA up to 100 mA for data-transmission, which is suitable for a sensor network. [14] The standard sets the core specifications for all Bluetooth devices. Then there are a list of Generic Attribute Profiles (GATT) that a device may be using, depending on what kind of device it is, e.g. a person with diabetes can have a measuring device checking on the level of blood sugar and using Bluetooth to send the levels to an app in your phone. This special feature can then need the Insulin Delivery Profile (IDP). A list of GATTs is found in [15].

3.1.1. Network structure

A Bluetooth network can be organized in different ways. It can be a point-to-point network as when a pair of headphones are connected to a phone. However, it is also possible to organize bigger networks with more than two devices.

Instead of the point-to-point communication first developed in the Bluetooth history, a mesh function is integrated since version 4.0 that enables communication networks for wider use. The mesh network structure works at BLE which makes it suitable for a sensor network. A mesh network is non-hierarchal, and all nodes have the possibility of sending and receiving. All nodes in the network have the possibility of connecting to each other. This makes it less vulnerable, if one node breaks, the network finds another path to send its message, the network is by that self-healing. Managed flood-based routing is used in BLE mesh to obtain a simple routing protocol that meets the requirements of a simple and safe network where all messages are delivered. Managed flooding, in contrast to normal flooding, protocols implies that not all nodes servs as messengers. Low power battery driven nodes can be asleep for longer periods, to extend their lifetime, and some main-powered nodes are responsible for passing on the message package. [16][17] Broadcasting is also available as a network feature and is used when one device needs a connection to many others for data sharing. [18]

For BLE there are 40 channels with 2 MHz spacing, Bluetooth is transmitting from 2.402 GHz to 2.48 GHz. Three channels are used for advertising and the other 37 are for data transfer. [19]

3.2. Z-Wave

Z-wave is a protocol for home automation. It was developed in 2001 by the Danish company *Zen-Sys*. In 2008 Z-wave was acquired by Sigma Design. In Europe it communicates on the 868.42 MHz band. Z-wave Alliance is a consortium of companies that invested in Z-wave. They work for development and certification of Z-wave products.

3.2.1. Network structure

Because talkback is possible all Z-wave products support mesh network. The network is built around one primary controller and the controller oversees the local home ID. The controller can invite nodes to join the network and, in that way, build up the network. The controller interviews the node to learn about its attributes and the node learns about the home ID and is assigned to a node ID. When more than one node is included in the network the mesh structure is applied. The controller sends a request to all the nodes ones every 24-hour to confirm its position and in that way, optimize the routing of messages. It also asks for status, sensor values, parameters and associations, which is called *polling*.

Battery driven sensors are always at deep sleep if nothing happens to extend lifetime. Essential functions to waken the sensor up is still available if something happens and the node needs to *wake up*. Scheduled wake ups are also performed to be able to report changes to the controller and be reachable for the polling.

A node can be taken away from the network and this is called *exclusion*. In this process the home ID and node ID are set to zero in the node memory and in the controller.

The network is connected to Internet and the network can be controlled through a Z-wave platform. There is one open version of the interoperability layer. [20]

3.3. 1-Wire

The 1-wired communication system is developed by *Dallas Semiconductor* to be a simple system that handles low-speed communication. Each item has a unique serial number that makes it possible to have more than one item working on the same bus. Two examples of 1-wire systems are given below. [21]

3.3.1. 1-Wire and Bluetooth

In [22] a system is described for temperature sensing in a machine rotor. The authors need to do temperature measurements in an environment where measurements are hard to do due to the rotating movements. Temperature sensors are deployed on the rotor connected with 1-wire in a star topology. It all routes to a central point of the rotor. At this location there is a microcontroller that routes the data coming in from the sensors to a Bluetooth module connected to the microcontroller. The Bluetooth module has set up a connection to a PC/base station (BS) that receives the temperature data and monitors the system and its temperature changes. The authors produced and summarized their tests with good measurement results and a stable working system.

3.3.2. 1-Wire Weather Station

In [23] the creators of 1-wire have developed a simpler and more efficient weather station for meteorologists to collect data for weather prediction. A single twisted wire is used for bidirectional data. From the data line the instruments and sensors are parasitic powered with the help of a capacitor and diode half-wave rectifier. Because of the 1-wire system with unique serial numbers for all sensors and instruments, a new gadget is easily added to the bus. It is all controlled by a PC or microcontroller.

3.3.3. Relevance for Vimur

One possibility is to keep some wired connections to gain in terms of reliability and robustness. With inspiration from the solution in [22], all sensors in one module of the shelf could be wired and connected to a Bluetooth module at that spot. The Bluetooth module could then handle the communication of data from the sensors to a BS associated with that shelf. The BS analyses the data and takes decisions, and if an action needs to be carried out the BS sends a request to the associated Bluetooth module that couples to the sensor that shall act.

4. Literature Study

When technology in form of sensor networks and IoT meets the world of plants there are a lot of parameters to consider. Three different articles have been studied to learn more from other agriculture systems that uses sensor networks. All articles have the focus of how to achieve a good environment for plants and to make the farming efficient in yield and water cost for a more environmentally friendly farming.

The articles studied are “Wireless Sensor Networks for Greenhouse Climate and Plant Condition Assessment” (Ferentinos, Konstantinos P., et al)[24], where they study the greenhouse environment, optimize measurements, and determine how the climate differ at different spots in the greenhouse. Next article is “A Crop Monitoring System Based on Wireless Sensor Networks” (Liqiang, Zhao, et al.)[25] where the authors want to develop a system that can run for a long time unattended. They asses what kind of measurements that is needed and give an example of a complementary system to see that the crops are doing fine instead of only relying on the sensor values. The last article in this literature study is “RF propagation investigations in agricultural fields and gardens for wireless sensor communications.” (Balachander, D., T. Rama Rao, and G. Mahesh.)[26]. This article focuses on evaluation of theoretical models for losses in a system deployed in a farming environment.

The aim with the study of these three articles is to find new aspects and measuring points that need to be considered when choosing what kind of system that most suits the case.

4.1. Wireless Sensor Networks for Greenhouse Climate and Plant Condition Assessment

The authors start from the importance of measuring and controlling the conditions in a greenhouse in order to get better productivity, quality and to avoid diseases. Since the environment in a greenhouse is quite extreme, there are some difficulties in monitoring and keeping the temperature and humidity at the same level everywhere in the greenhouse.

The system is based on the open source and low power platform TelosB by UC Berkeley. The sensors in the system are temperature- and relative humidity sensor as well as radiation sensors. The BS included a mote containing an amplifier for better range of communication and a PC for monitoring the results of the measurements.

Their first tests are done in a smaller greenhouse without cultivated plants in order to investigate the outer environments impact on the sensor nodes. Here they show the importance of protecting the nodes enough. Instead of keeping the sensor in a protecting box with mechanical ventilation that very well protects the node, better measurements where achieved with just a metallic shade that reflected the incoming radiation from the outer environment.

The second part of testing was performed in a commercial greenhouse containing cucumber plants. Here the different parts, north, south, east and west sides, of the greenhouse were compared due to the position and heating of the sun during the day. The greenhouse had wet pad/fans system and a heating system, but even though this is present the sun will make the climate a bit different at different positions in the greenhouse. Knowledge about the difference in the climate is important in commercial farming to get a good yield from the plants. Measurements were done with the respect to the changes of the climate during day and night as well as differences between summer and winter periods.

The climate in a hotel lobby or restaurant cannot be compared to the climate of a greenhouse, but still there are things to learn about how to control and measure the climate for the plants, such as what kind of things that needs to be measured and how to protect the measuring nodes in an accurate way depending on the surrounding. The first and most obvious parameters are the amount of light and water the plant needs, but apart from that relative humidity also plays an important part. Depending on the ambitions for the plants in our shelf, it can be important to know more about the surrounding air. In this article they are measuring the leaf temperature of the cucumber plants in order to identify when condensation can occur on the leaves. This as well as knowledge about the relative humidity can give better conditions for the plant and minimizing risks of diseases on the plants and help in optimizing the water consumption.

4.2. A Crop Monitoring System Based on Wireless Sensor Networks

The authors of this article are taking off in seeking of a system that can improve the efficiency in farming. Their main focus is to develop a system for large scale farming at fields of wheat in China; however, their means is to develop a system that can be used for other crops and in different environments as well.

Two types of nodes are intended to be used, one type for collecting metrological information and another for collecting information about the soil. The nodes collect information about the crops and its environment to give knowledge of how well the farming works and how the climate is affecting. All this for making the agriculture more efficient and well prepared for new challenges in the future.

The goal is a system that will work for a long time unattended. The authors want to achieve this through a low-power system that also will use *image capture platforms*. Images of the fields help and are a good complement to the achieved values from the sensor to monitor the progress of the crops. This concept could be useful for monitoring the plants in a shelf as well. A shelf at an office will be unattended for longer periods sometimes, at holidays for example, and even though sensor measurements show good results a picture is a good compliment to see if anything is failing.

4.3. RF Propagation Investigations in Agricultural Fields and Gardens for Wireless Sensor Communications

The problem stated in this article is the lack of data, models and standard tests to evaluate a WSNs qualifications to be used within agriculture. The authors wish to evaluate RF propagation in this kind of environment. It is known that plants, trees, varying topology and the weather conditions can affect the radio signal. Therefore, it is of good use to be able to calculate and evaluate a system at some extent to choose the right one for the circumstances. This is almost the same problem that is treated in this thesis, only differing in outdoor versus indoor environment.

The authors wish to evaluate three different models; *Early ITU Vegetation*, *Weissberger* and *COST 235*. The predicted loss was calculated for each model and compared to the observed losses at different test sites. The test sites where fields with different kinds of crops and tests were done at both growth and maturity stage. Testing was also done at a garden with coconut trees to see the impact of these trees and do tests to see differences between dry and wet grass. All test sites are located in south of India where the climate imply a high air humidity. The tests were done at the ISM-band.

The *Cost 235*-model clearly gives the best result at growth state, maturity state and in gardens. The losses differ a bit at small distances, but when the distance is greater than 10 meter the Root Mean Square Error (RMSE) is almost zero. The *Early ITU Vegetation* and *Weissberger* shows much poorer results in these tests.

The authors did also calculate a Path Loss Exponent (PLE) from their measurements. Calculations were done for the different sites and growth stages and presented in their conclusions. It was shown that the PLE was reduced at longer distances, which the authors thought to be a consequence of scattering and the signal adding up before reaching its destination.

This article and its presentation of the different models may be helpful in evaluation of the environment. This thesis is focusing on an indoor environment that probably will contain less foliage than in the environment in this article. However, the results from the article gives input in the importance of evaluation and the lower PLE for long distances can be interesting. Scattering occurs in an indoor environment and it does affect the results.

5. Practical work and test of communication system

5.1. Test Setup

The intention of the following tests was to evaluate the RF chip “nRF52832” from *Nordic Semiconductor* and its ability to broadcast a specific Bluetooth signal. The aim of the tests was to evaluate the influence of the nearby environment of the chip, if something or some specific materials disturbed or repressed the broadcasted signal. The tests done in this thesis were carried out at the *Electromagnetic compatibility (EMC) laboratory* at Linköping University, campus Norrköping. [27]

5.1.1. Environment and measuring antenna

Ten different scenarios where tested and compared to a reference measurement. The setup was aimed at resembling the design of one of the modules in the shelf *Vimur*. A module for plants is a part of the shelf and all equipment within it used for the caretaking of the plant. It consists of a cubic container out of thin metal foil, every container holds a pot for the plant, equipment for the watering system, RF chip and other necessary electronics for the network, and the caretaking of the plant. In the test the container did just hold one pot, that is either made of plastic or porcelain. The pot is filled with cultural mediums that differs between the measurements. The container did also hold a RF chip, which is inside a small plastic box that protects the chip. Dimensions for the equipment used in the test are found in Table 2. For most of the tests the box was placed next to the pot, on the opposite side from the antenna, but for one of the tests the box was placed inside the pot, under the culture medium. Also, a pot made from porcelain was tested. To see how the container affected the signal, one test was made with a metallic lid covering the top of the container.

Table 2. Dimensions of equipment used in the tests.

	Length sides (*cm*)	**Height (*cm*)**	**Thickness (*mm*)**
Metallic container	*50*	50	2
Plastic pot	25	30	3
Porcelain pot	17 (diameter)	22	5
Plastic protection box	12	7	2

A horn antenna was used for measuring the quality of the broadcasted signal. The distance from the container to the antenna was approximately 2 meters. For all different test the main setup was the same and measurements were carried out in a way so that the results could be comparable. A spectrum analyzer and a computer were used to visualize and collect the data.

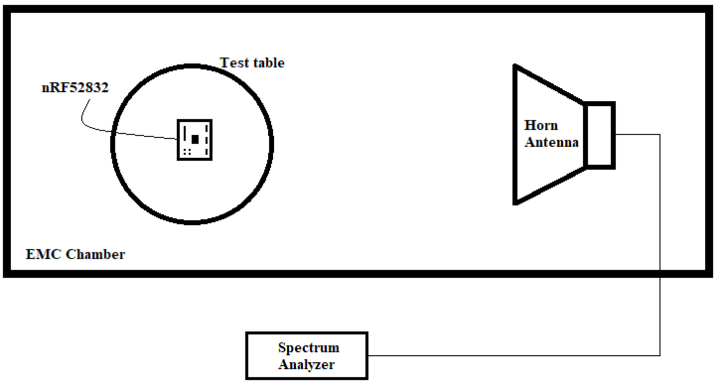

Fig. 2. A basic sketch of the test environment. This is the setup for the reference measurement. When the protection box, the container and pot was used in the test they were added at the table and adjusted in a way so that the position of the chip was not changed.

To minimize other unwanted emission from the environment in the evaluation of the direct effects on the signal due to the surrounding materials in the shelf, the test site was a semi-anechoic EMC chamber. In Fig. 2 the setup for the tests is illustrated. However, tests to see how the broadcasted signal are affected by other devices and RF signals are not done in this thesis.

5.1.2. Materials tested

The different materials used in the setup and their composition can influence the signals of the WSN in different degrees. The material of choice does of course affect the growing plants as well. Therefore, it is important to test and know what the material do to the signal to make accurate decisions for the plants in the furniture.

Both culture medium and the material of the pot was tested. Tests were also done to see the effect of the container on the signal. The growing materials that were tested were clay pebbles, water, soil and perlite. The clay pebbles, soil and perlite were dry at all tests. Both a plastic and a porcelain pot were tested.

5.1.3. Communication system and signal used for test

The communication system chosen for *Vimur* is Bluetooth 5, which is described in section 3. The system was chosen due to its ability to form mesh networks and its combability with other devices. One scenario is that more than one shelf in a room are connected to each other and form a network. The aim is that the network is self-sufficient, watering and light is taken care of by the system. However, the desire is that a user has the possibility to connect to the network and check the status of the plants via a mobile device. It should also be possible to check on the plants via an app, therefore the network should be connected to the cloud.

For the tests the device was sending signals at three different channels, *2.402 GHz*, *2.426 GHz* and *2.48 GHz,* alike the procedure when a Bluetooth device is advertising for other devices to establish a connection. The intention was initially to do a circular scan and look at the results in more than one direction. Unfortunately, this was not possible to do at the time when the tests where done, due to the character of the signal.

6. Results

Before introducing the materials and objects used in the tests, the chip and antenna were tested in the EMC chamber to assure that the placement of the chip and antenna gave a good signal. The measurement referred to as reference was when the chip was placed on a table, without the protecting plastic box. The signal from the chip was received by the horn antenna and the strength of the signal was measured by the spectrum analyzer. All of the measured signal strengths are then compared with this reference signal strength. The setup for the reference measurement is shown in Fig. 2.

The aim of the first measurements was to see the effect the protecting box and the module have on the signal level. First the chip was placed in the protection box and placed on the exact same spot and in the same direction as in the reference measurement and the signal was again received by the horn antenna and measured by the spectrum analyzer. Then the same was done when the module was added, it was placed on the table and the protection box with the chip was placed in the module so that it was at the same spot as in the previous measurements.

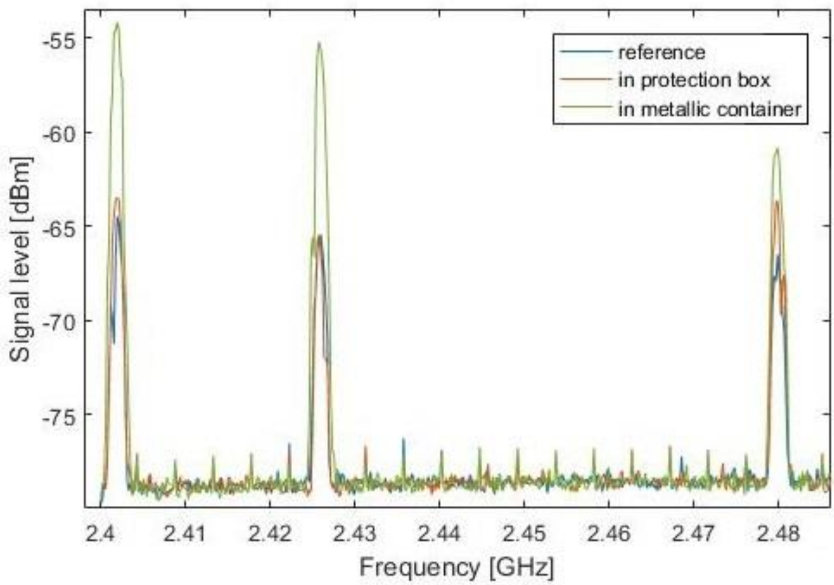

Fig. 3. First measurements to see how the signal was affected by its surrounding.

All measurements were done this way, the chip never changed position, the materials around were adjusted out from this condition so that the horn antenna could receive a signal from the same place in the room and the signal levels measured by the spectrum analyzer could be compared. The signal levels of these measurements are shown in Fig. 3. It is clear that the best signal was achieved when the chip was placed in the module.

Next step in investigating the materials was to see the impact of the material of the pot. For the little greenhouse Vissheim developed earlier they used a plastic rectangular pot. This kind of pot was placed empty in the module, in-between the chip and the antenna. And the signal level was again measured as described above. The same procedure was then carried out with a porcelain pot. The dimensions of the pots are found in Table 2. In Fig. 4 it is seen that the signal levels with both the plastic pot and the porcelain pot are higher or at the same level as the reference. In fact, the measurements with the plastic pot is a little bit higher than without it in the module, this is clearest seen at the peak for 2.48 GHz.

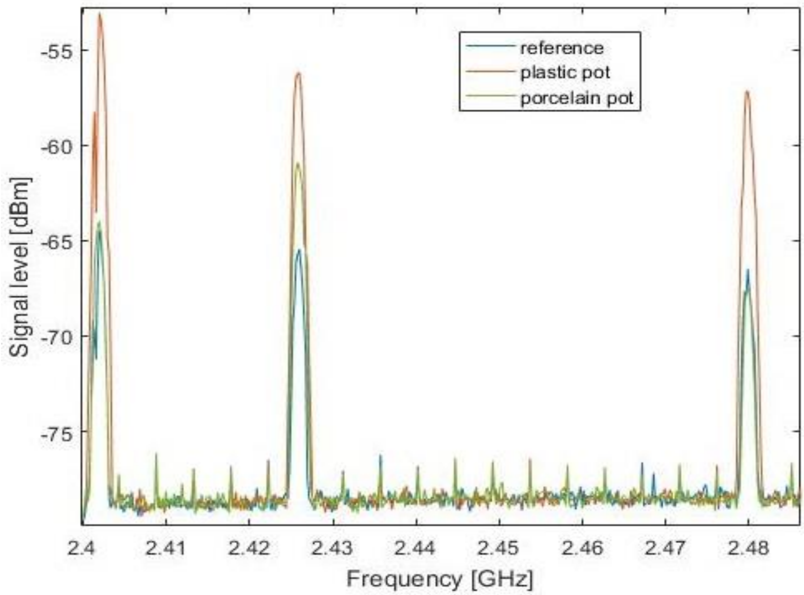

Fig. 4. The effects on the signal using pots of different materials.

The next set of tests is to see the influence of the culture medium. The test setup is the same with the chip in its protecting box placed in the module. The plastic pot is used in these tests and placed in the container. One by one the materials, clay pebbles, perlite, soil and water, was tested and the signal was received by the horn antenna and measured by the spectrum analyzer. In between the tests the pot was cleaned and wiped. The resulting signal levels are seen in Fig. 5, which is divided into (a), (b) and (c) to be able to see the results better. The conclusions drawn from the figures is that soil attenuates the signal at a higher degree than the other culture mediums, in Fig. 5c this result is distinctly seen. The culturing medium resulting in the highest signal levels is perlite, which is a very light material. Measurements with perlite in the pot gave almost the same signal levels as the measurements in the module without a pot present. The reason that soil give the largest attenuation is that the water content of the soil is higher than in the other materials. At the frequencies used in the tests the losses in water are large. Dry soil gives much less attenuation, but the soil must be wet for the plants to grow.

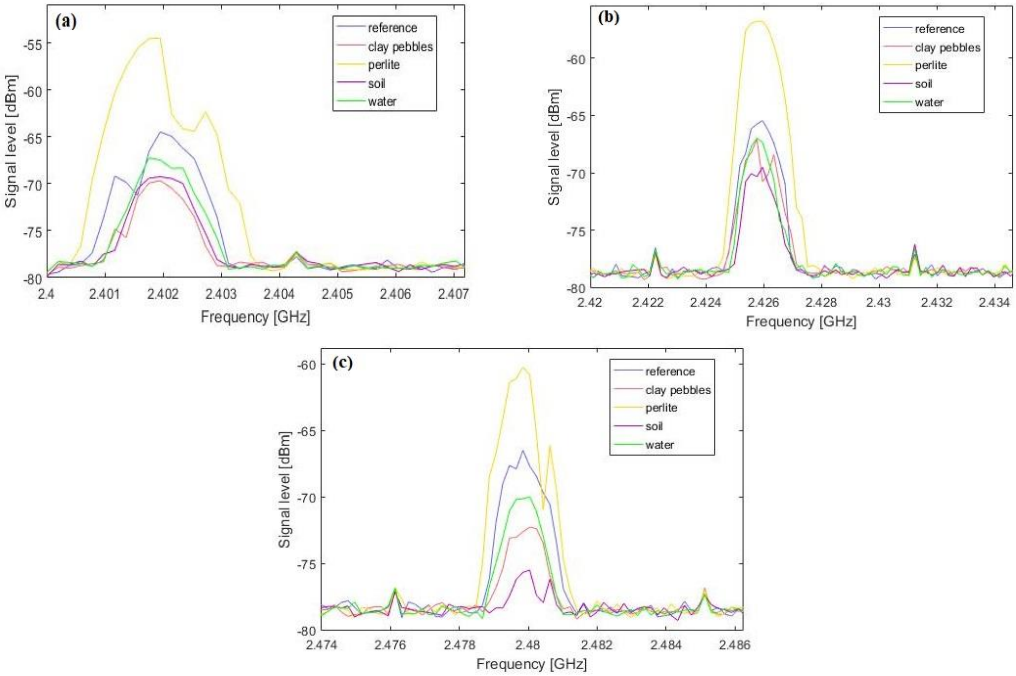

Fig. 5. These measurements indicate how different culture mediums affects the signal. In (a) the channel at 2.402 GHz is seen, in (b) 2.426 GHz and in (c) 2.48 GHz.

To test the effect the position of the chip has on the signal level a measurement was done where the chip first was placed alone on the table in the EMC chamber, then was placed in its protecting box next to a pot filled with soil, and finally in its protecting box inside the pot and soil was put on top and around it. The pot with the chip was placed in the module on the same spot as the protecting box had in the previous tests. The chip was orientated the same way as before. Fig. 6 show the results from these tests, and it is seen that the signal is lower when the chip is surrounded by soil at 2.402 GHz and 2.426 GHz, which is in line with the results that soil is attenuating the signal more than other materials. However, at 2.48 GHz the signal is at the same level for the reference measurement and for the measurement when the chip is placed in the pot, while the measurement with the chip behind the pot with soil is giving a lower signal level.

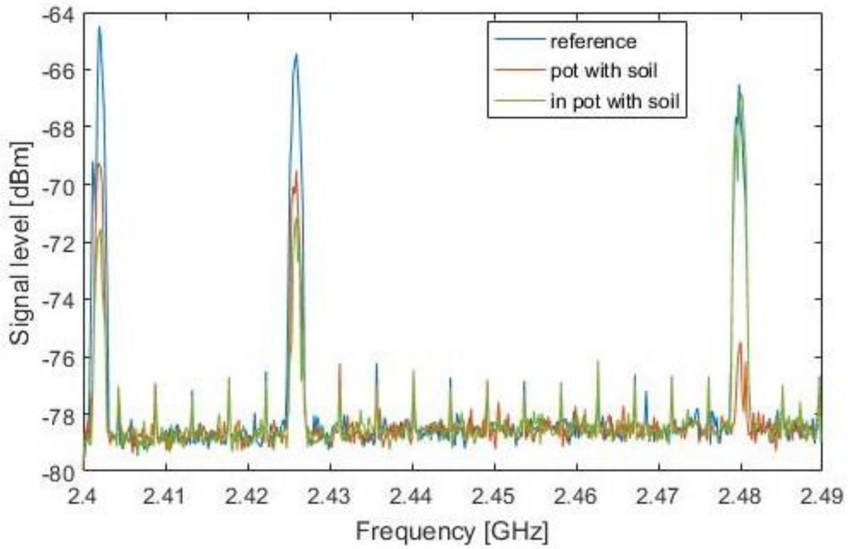

Fig. 6. To see how the position of the chip was important, measurements where done both with the chip in a box beside the pot an in the pot.

One possibility of the design of the module is that parts of the top also will be covered by the same materials as the sides are made of. Therefore, one test was made when all sides of the module were covered. The chip in its protecting box was placed inside the module and a metallic lid, of the same size as the sides of the module, was placed on top. On two sides of the lid there were a 2 mm gap because the lid could not cover the container fully. The outcome of this test is seen in Fig. 7 and here it is clear that the signal is as good as for an uncovered module. This shows that a design with parts of the top covered to be able to hide some electronics and sensor nodes to give a more esthetic look would be possible.

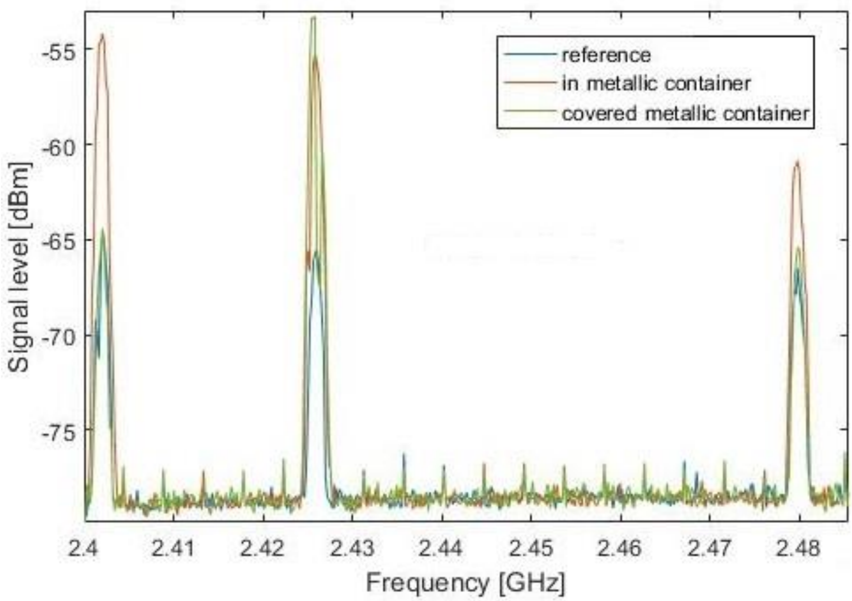

Fig. 7. The signal level when the module is covered.

It is seen in all measurements that the level of the signal is good regardless of the surrounding, in most cases even better than the reference signal. One reason for this can be due to the orientation of the chip. Before the testing started the signal level of the chip was received by the horn antenna and measured by the spectrum analyzer to assure that the signal level was sufficient. However, it might have been the case that the lobe of the signaling antenna was not in the most beneficial orientation. When objects then were introduced in the environment, they increase the signal level at certain spots by reflection, a phenomenon called fading.

From Fig. 4 it is possible to conclude that the ceramic pot attenuates the signal more than a plastic pot. Fading is important in this case too, but due to the type and amount of material it should cancel out more than with the plastic pot. The same can be said about soil, which is seen in Fig. 5.

7. Conclusions and summary of work

The practical work of this thesis can be the beginning of a deeper and more precise investigation of how the surrounding materials interfere and influence the signal of communication in a piece of smart furniture. Unfortunately, these results cannot tell us much about what communication system or what materials that is preferable in this system. The signal that was available for the tests was too varying to get good measurements even though the time for each measurement was long. The initial thought was also to do a round scan to investigate the lobes of the antenna and its polarization, but since the chip was sending at three channels and it was not possible to get a one tone signal that was needed for such a test, this could not be done. A round scan could have given a better picture of the antenna lobe and the signals ability to spread in the room and it had been possible to see if the system had drawbacks in this aspect.

When the module and pot was introduced we got a higher signal level, a similar thing with a higher signal level than was first expected is discussed in the literature study, chapter 4.3. In [26] the authors could establish that they got less path loss over a longer distance due to scattering and the signal adding up before reaching its destination. Here the distance is the same, but more objects are introduced in the test environment, where the signal is likely to scatter.

Moreover, tests with a larger system, more modules and plants as well, would be interesting. Here no attenuation of larger scale in comparison with the reference signal could be seen. An interesting question is what kind of results for the signal can we get in another environment? One option for culture medium is a water-based cultivation. How would that interfere with the signal if the box with the chip is surrounded by water? One question raised that wasn't possible to answer in this thesis was also how the connection between two different chips, or one chip and another device, would look like and how it is affected by the environment.

What can be concluded is that soil was the growing substrate that attenuated the signal the most which in an environment with more than one module and maybe longer distances may be a problem. It could also be seen that the porcelain pot gave a lower signal level than the plastic pot.

Bluetooth as communication protocol was chosen because of its good reputation and being a well-known system that could easily be adopted in different surroundings with other devices present. It would however be interesting to look more at the energy consumption and lifetime when combining Bluetooth with, for example, 1-wire. Can there be different clusters identified that can cooperate to gather data and information about nutrients and light for the plants? If these were wired connections combined with a Bluetooth module in the same way as mentioned in [22], and the Bluetooth module could further handle the connection to a BS that could process the data and decide for actions in the system. The BS could furthermore be coupled to the cloud for monitoring from a distance. Could data traffic and energy consumption be lowered in this kind of system?

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