TAMPEREEN TEKNILLINEN YLIOPISTO
TAMPERE UNIVERSITY OF TECHNOLOGY

MUHAMMAD ASHHAL TAHIR

MANAGEMENT OF MANUFACTURING ASSETS BY DEPLOYING MAINTENANCE-FREE WIRELESS SENSORS

Master of Science Thesis

Examiner: Prof. Jose L. Martínez Lastra
Examiner and topic approved on 29 March 2017

ABSTRACT

MUHAMMAD ASHHAL TAHIR: MANAGEMENT OF MANUFACTURING ASSETS BY DEPLOYING MAINTENANCE-FREE WIRELESS SENSORS
Master of Science Thesis, 76 pages, 6 Appendix pages
April 2018
Master's Degree Programme in Automation Engineering
Major: Factory Automation
Examiner: Professor Jose L. Martínez Lastra

Keywords: Energy Harvesting, Android Application, Manufacturing Systems, Wireless Sensors, Radio Frequency Signal, GSM Signal Strength

In modern manufacturing systems there is ever increasing need for higher efficiency, performance, optimization and requirement for minimal errors in the production process. Advancements in technology have significantly improved the performance of the manufacturing systems and offered advance tools to track manufacturing assets such as pallets. Pallets are extensively used for transportation of raw materials or final products. There are different ways to monitor and track pallets, some of these include using Radio Frequency Identification (RFID) tags, Global Positioning Systems (GPS), barcodes, utilizing wireless sensors such as accelerometers and gyroscopes.

This thesis proposes a methodology for managing manufacturing assets, such as products, by making use of maintenance free wireless sensors. The implementation of this work presents an application developed for detecting and measuring the strength of radio frequency (RF) signals in the surrounding environment. The application is developed as an independent android application that is interfaced with the manufacturing system under test. The android applications acts as a prerequisite for identifying possible radio frequency harvesting points at the assembly line. One of the features of an energy harvester is utilized to harvest the radio frequency signals from sources such as Global System for Mobile Communication (GSM) Signals or wireless access points installed in the environment.

The solution was successfully deployed and tested on the FASTory line, an assembly line consisting of 12 work stations situated at the Factory Automation Systems and Technologies Laboratory (FAST-Lab). By utilizing pallets, the android application is used to create a signal strength map of the assembly line. Based on signal strength map, different locations at the assembly line are identified where radio frequency signals can be harvested for powering the wireless sensors. The energy harvested from the RF signals removes the need for battery replacement of wireless sensors.

PREFACE

'In The Name of Allah, The Most Gracious and The Most Merciful'

A significant amount of effort, hard work and sweat contributes to this dissertation. From deciding the research topic, from implementing different approaches, failing and trying again. This has provided me an opportunity to explore my interests and improve my technical knowledge, writing and time management skills.

I would like to use this opportunity to give my thanks and appreciate all those people who provided their relentless support towards the completion of this dissertation. I would like to give thanks to Dr. Andrei Lobov, who as a supervisor guided me through the problems and offered me his support. I would like to further give thanks to Amalia Moreno Galera for her support in helping me divide my research problem and manage the topics. Also, I want to appreciate and thank Matti Aarnio for his support in helping me with the hardware for my thesis and as well arranging visit to the roof of the university buildings. Also, thanks to my friend Adnan Mushtaq for helping in troubleshoot the problems and issues during the implementation phase. Furthermore, I would like to thank and appreciate Borja Ramis Ferrer for reviewing my thesis and helping me improve it.

My utmost thanks to Professor Jose Lastra for offering me an opportunity to be part of his lab group and in a multi-cultural environment, where I received constant support and motivation to finish my work.

Last but not the least I am very much grateful to my parents. Their never-ending support and prayers for me, helped me achieve my goals.

Tampere, 05.04.2018

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

AC	Alternating Current
AlN	Aluminum Nitride
API	Application Programming Interface
BAP	Battery Assisted Passive
BSSID	Basic Service Set Identifier
CAN	Controller Area Network
CPS	Cyber Physical Systems
CRUD	Create, Read, Update, Delete
CSS	Cascading Style Sheets
DB	Database
dB	Decibels
DC	Direct Current
EMF	Electromotive Force
EMI	Electromagnetic Induction
FAST	Factory Automation and Systems Technologies
FI	Finland
FIFO	First In First Out
GHz	Gigahertz
GPS	Global Positioning System
GSM	Global System for Mobile Communications
GUI	Graphical User Interface
HMI	Human Machine Interface
HTTP	Hyper Text Transfer Protocol
I/O	Input/Output
IoT	Internet of Things
IT	Information Technology
JS	JavaScript
KHz	Kilohertz
LAC	Location Area Code
LED	Light Emitting Diodes
LOS	Line of Sight
MB	Megabytes
MEMs	Microelectromechanical Systems
MHz	Megahertz
NFC	Near-field Communication
PCB	Printed Circuit Board
PEAS	Performance, Measure, Environment, Actuators and Sensors
REST	Representational State Transfer
RF	Radio Frequency
RFID	Radio Frequency Identification
RTU	Remote Terminal Unit
SCADA	Supervisory control and data acquisition
SCARA	Selective Compliance Assembly Robot Arm
SOA	Service Oriented Architecture
SOAP	Simple Object Access Protocol
SSID	Service Set Identifier
URL	Uniform Resource Locator
Vout	Output Voltage

W3C	World Wide Web Consortium
WS	Work Station
WSDL	Web Service Description Language
XML	Extensible Markup Language
ZnO	Zinc Oxide

LIST OF SYMBOLS AND UNITS

Symbol	**Explanation**	**Unit**
G_r	Receiving Antenna Gain	dBi
G_t	Transmitting Antenna Gain	dBi
P_r	Receiving Power	dBi
P_t	Transmitting Power	dBi
m	Mass	kg
R	Distance between Antennas	m
T	Time Period	s
λ	Wavelength	m
a	Acceleration	m/s^2
b	Damping Coefficient	$-$
c	Speed of Light	m/s
f	Frequency	Hz
k	Spring Constant	$-$
s	Laplace Domain	$-$
x	Displacement	m

1. INTRODUCTION

1.1 Background

In the last few centuries, technology has remarkably improved almost every aspect of our lives. Dramatic improvements have been observed in the fields of supply chain, telecommunication, healthcare and industrial manufacturing, to name a few. The focus for this section will be on industry and smart manufacturing.

The industrial revolution started in early 18th century when manufacturing was done with hands and basic tools. Invention of machines to replace the hand tools and the creating of steam engines lead the transition to new manufacturing processes known as the first industrial revolution. Followed by use of electric power in mass production that lead to creation of assembly lines and was termed as second industrial revolution. The factors that lead to the third industrial revolution was the use of information technology and electronics to automate the production lines [1]. In the last few years with new technological developments a term known as fourth industrial revolution is being actively used and it also recognized as an Industry 4.0. Industry 4.0 relates to digitization and interconnection on a wider and more concrete scale. Industry 4.0 further refers to using internet technologies to create smart products, services and production systems [2]. Another aspect of Industry 4.0 attributes to the use of cyber physical systems (CPS) to monitor the physical industrial processes via internet. Using the internet of services various cyber physical systems exchange information and interact among themselves. The cyber physical systems can have different components such as sensors, storage systems, smart machines, actuators and production lines that are capable of transferring information and performing actions independently. This help improves the industrial manufacturing processes, energy management, material usage, life cycle management and supply chain. This leads to appearance of smart factories using (IoT). [3]

Linking the developing technologies such as embedded sensors, real time localizations, and near field communications with internet allows to transform mundane items into smart things that can sense and respond to their environments [4]. This sets the building block for IoT or networked physical objects. These smart systems and devices are easily integrated with the information networks, where they become active members and can relate and connect with their surroundings [5]. In comparison to the traditional production systems, the smart factories based on IoT and digitization offers real time monitoring, as well as advantages in terms of resources, time and cost. These smart factories make use of the sustainable strategies to bring improvement in respect to quality of products, time and efficiency of the process. [6]

Since an industrial revolution began many processes and practices in the manufacturing industry have changed. One of the main aspect of production that has improved a lot are the assembly lines. Assembly is the process in which the parts of the product to be manufactured are added in sequence or processed upon as they move from workstation to workstation until the final assembled product is produced [7]. The whole process is carried out through conveyors, as one of the method of transportation for the equipment. The demand for mass production and highly customizable products gave rise to interconnected network of processes and assembly lines that became essential for the final product being made in the most efficient way possible. This lead to solving the problem of assembly line balancing. Assembly line balancing is defined as a procedure with which used to workloads on an assembly line can be balanced by distributing total workload of any unit involved in manufacturing of a product, that will be assembled between the work stations on the line [8]. One of the common way of transporting these products and parts in the assembly line is the industrial pallets.

Pallet is a flat transport structure that enables the transportation of goods on a conveyor by providing a stable handling and storage of products. Pallet can be made from different materials such as wood, metal or composites. Once the processes on the product are done the empty pallet is sent back to the start of the assembly lines for new products. The most common methods to monitor the movement of the pallets and assets is the use of Radio Frequency Identification (RFID) tags that provides information about the pallets such as location and status. This system however has some concerns such as privacy and global standardization. Thus, there is a need to have a system that continuously monitor the position of industrial assets throughout the process to prevent possible damage and losses.[9]

1.2 Problem Definition

1.2.1 Problem Statement

With the increasing penetration of internet, there are rapid advancements in digital platforms that are enabling growing number of people, devices, places and objects to connect in a way that was not possible before. Internet of Things (IoT) is making such connections between entities possible in almost every area of our lives such as public safety, industries, transportation, digital health and security to name a few.

With IoT a lot of improvement in the production lines and processes is seen. It is a smart choice to keep track of all different kinds of assets and resources in a factory. One such assets are pallets; faults in assembly lines and pallets have been the root cause of faulty products. There are many proposed solutions to address this problem and one of them is to use inertial Microelectromechanical Systems (MEMs) sensors that communicate wirelessly with the network and increase the accuracy of the whereabouts of pallet's position.

However, one big challenge associated with the use of MEMs sensors is that they are usually powered by limited energy sources such as batteries. Thus, there is a need to replace them once the energy is depleted. This regular maintenance of MEMs sensors may lead to increase in manufacturing time and delays. Furthermore, there is a risk of batteries leaking their content to the surroundings and damaging the environment, pallets or sensors. The main emphasis of this dissertation is to develop a user-friendly solution for MEMs sensors under test that will remove the need for regular replacement of their batteries. The research further focuses on identifying and measuring a source of energy that can be potentially harvested to power the MEMs sensors. This will reduce the need for battery replacement for MEMs sensors associated with limited energy resources. Hence, allowing to manage and track the assets in an uninterrupted and efficient way. A manufacturing system will be used as a testbed for implementation and testing of the solution to evaluate the research problem.

1.2.2 Justification of Work

The research and work mentioned in this thesis was developed and performed in the Factory Automation Systems and Technologies (FAST) laboratory, located at the Faculty of Engineering Sciences at Tampere University of Technology.

The reason for carrying out this research requires the need for creating a solution that can power the wireless sensors without the need for regular battery replacement. This will allow maintenance free wireless sensors to be used for managing the manufacturing assets. Thus, ultimately allowing resources and time to be saved. The research focus on creating a solution that can identify and measure the radio frequency signals to create a signal strength map and harvest them for possible energy use by the wireless sensors.

1.3 Work Description

1.3.1 Research Questions

The research problem previously mentioned discusses the challenges associated with limited energy resources of the wireless MEMs sensors and a need to create a solution that reduces the required maintenance of wireless sensors. For the purpose of solving the defined research problem, the research work that is carried out, answers the main research questions mentioned as follows:

1. How the strength of the radio frequency (RF) signals, present in the surrounding environment of manufacturing production line will be analyzed?
2. How to utilize the parameters of RF signals such as signal strength for improving the energy harvesting required for sensor maintenance?
3. How to create a RF signal map for the manufacturing production line based on a specific RF signal source?

1.3.2 Objectives

The research work aims to create a solution focused on providing the user a tool that can be used on a manufacturing production system for detecting and measuring RF signals. These RF signals can be further harvested for use by the wireless sensors. The main objective can be further divided into three sub-objectives mentioned as follows:

1. Develop and implement a solution for measuring the RF signals in the surrounding environment of the assembly lines of the manufacturing system.

2. Create a means of interaction between the developed solution and a manufacturing system for mapping the RF signal strength.

3. Develop a user interface for visualization and monitoring of RF signal strength, in surrounding environment and production line.

1.3.3 Methodology

This section offers a brief summary on the methodology applied for carrying out the research. The start of the research consists of observing and studying existing solutions for energy harvesting methods from various energy sources. Furthermore, study is carried out to review existing tools for measuring RF signals. Based on the observations a methodology is defined as follows:

1. Research and review the existing RF harvesting and measuring techniques.

2. Design and develop a software solution that detects and measures the RF signal parameters.

3. Develop an interface for the user to visualize the signal parameters and strength.

4. Establish communication between the proposed solution and the conveyors of the manufacturing assembly line for successful creation of RF map of assembly lines.

5. Test and validate the RF based energy solution based on the results achieved from detecting and measuring the RF signals.

1.4 Thesis Outline

The thesis is structured in different chapters with details mentioned as follows; Chapter 1 provides a background, defines the problem and sets objectives for the thesis. Chapter 2 offers the necessary background needed for this research work. It discusses the different energy harvesting techniques available, discusses different hardware and web services used. Chapter 3 explains the need for the chosen methodology that will be used for implementing the solution and various tools available at our disposal. How the chosen method is implemented is discussed in the chapter 4. Followed by analysis of results and discussions in chapter 5. The last chapter i.e. chapter 6 is set for concluding the thesis.

2. LITERATURE REVIEW

2.1 Industry 4.0 and Smart Manufacturing

Lately IoT and cloud-based manufacturing have been widely developed allowing intelligent connection among machines and humans. This leads us to the “Industry 4.0” era that is known as the upcoming industrial revolution, which focuses on manufacturing that is based on Cyber Physical Systems (CPS) allowing internal and external network integration. To produce intelligent products and production processes and allow on demand use and sharing of resources. With the growth of customer demand, mass customization, diversification and market globalization has led to the networking, lean manufacturing, agility and interconnection of processes. [10]

According to [11] Cyber Physical Systems have 3 C’s as its core namely Computation, Communication and Control to allow real interaction between real world systems and digital systems as shown in Figure 1 . It interacts through feedback from communication between digital and computational processes.

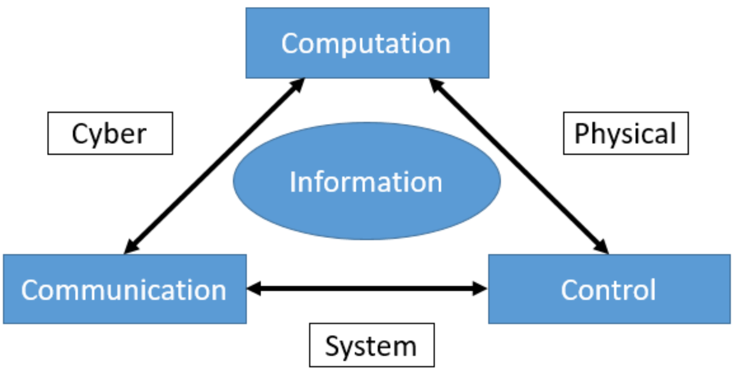

Figure 1 Alliance between 3 C's [11]

Digitization is the basis for intelligent factory as it allows the use of monitoring and networking technology to enhance the information management services in order to improve control of production process [11].

Use of internet in the industry is a main feature of the manufacturing technology. When cyber and physical system interact with each other, the factory is no longer traditional based factory as it can manage devices, allow achieving smart energy consumption, data collection, analysis, processing, monitoring which leads the system to make intelligent decisions.

2.2 Hardware and Devices

2.2.1 Microelectromechanical Systems (MEMs)

Micro-electromechanical systems are a technology that consists of various processes to create miniature systems or devices that combines electrical and mechanical parts. These devices are created using integrated circuits fabrication techniques and range in different sizes from micrometers to millimeters. These devices can sense, actuate and detect changes at a micro level, whose effects can be seen at a macro level [12].

As mentioned by [12] most of the cases MEMs usually consists of micro-sensors, micro-electronics, micro actuators and other micro-structures all of them integrated on same silicon chip. The micro sensors usually detect the changes, the information is processed by the microelectronics, and eventually they signal micro actuators to take certain pre-defined actions or change the environment.

From the early 1950's MEMs have slowly made their way out of the research laboratories to everyday life products. Today, MEMs devices are found in many applications such has projection displays, sensors, telecommunications, biomedical devices, optical displays, pressure sensors, light sensors etc. MEMs can be seen as having an advantage over manufacturing technology, its interdisciplinary nature and using various micromachining techniques have resulted in unprecedented range of applications, devices and synergies across various fields. Different batch fabrication techniques combined with reduced weight, size and cost makes it reliable.

2.2.2 Accelerometers

Accelerometers are traditionally known and used as an instrument for measuring an acceleration. The simplest accelerometer can be described as a mechanical sensing element consisting of a mass that is attached to a suspension system as depicted in the Figure 2 and discussed in [13].

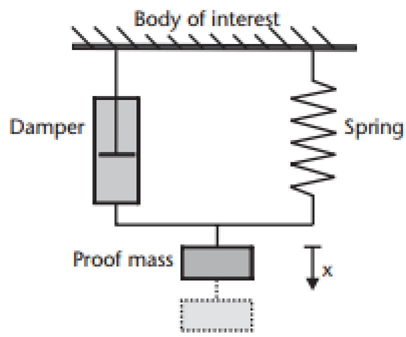

Figure 2 Simple Accelerometer [13]

Any force causing acceleration will deflect proof mass and it can be described mathematically in the Laplace domain as:

$$\frac{\boldsymbol{x}(\boldsymbol{s})}{\boldsymbol{a}(\boldsymbol{s})} = \frac{\mathbf{1}}{\boldsymbol{s}^2 + \left(\frac{\boldsymbol{b}}{\boldsymbol{m}}\right) + \boldsymbol{s}\left(\frac{\boldsymbol{k}}{\boldsymbol{m}}\right)} \tag{1}$$

Where x is mass displaced from its initial rest position, a refers to acceleration that will be measured, m is the mass in kg of the proof mass, b refers to the damping coefficient, s is the Laplace operator and k is known as the spring constant. [13]

Accelerometers can be classified into different classifications mentioned as follows:

1. Capacitive accelerometers work by measuring the displacement of the mass capacitively plus it has various advantages. It offers large output signal, improved sensitivity due to low noise performance and a good stead state response.
2. Piezoelectric accelerometers are usually the macroscopic accelerometers that makes use of piezoelectric materials for detecting the proof mass. It advantages includes providing a higher bandwidth for the sensors that can lead up to tens of KHz.
3. Resonant accelerometers make uses of a proof mass that changes the strain mass in the attached resonator thus changing its frequency. This approach leads to the output frequency to be converted to digital format easily by utilizing frequency counter, thus it is immune to noise.
4. Multiaxis accelerometers measures acceleration across two or three axes simultaneously and are utilized in inertial sensing, medical applications etc.

2.2.3 Gyroscopes

Gyroscopes are known as the devices used for maintaining angular velocity and orientation. In all the gyroscopes a mechanical assembly is made to resonate that excites the minor oscillation in a different assembly or the same one, owing to the Coriolis force. The amplitude of the generated secondary oscillation is proportional to the angular rate of the measured signal. [14]

There are different classifications of gyroscopes, two of them are dual axis and fibre optic gyroscope. The dual axis gyroscope is capable of sensing angular motion on two axes simultaneously. For example, angular motion on y axis causes a Coriolis acceleration about x axis and this in turn generates a tilting motion of the rotor or oscillation. In the same way any rotation about x axis cause the rotor to tilt about y axis, the mechanical dual axis gyroscope is represented in Figure 3 [1].

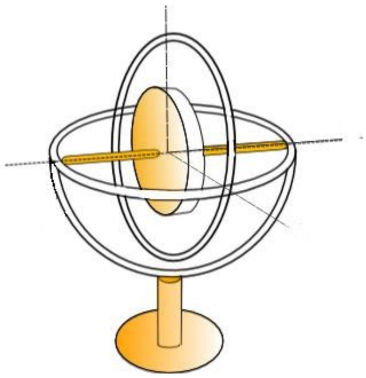

Figure 3 Dual Axis Gyroscope [14]

Fibre optic gyroscope detects differences in orientation by making using of Sagnac effect [15] and acts like mechanical gyroscope. The principle of fibre optic gyroscope is based on the interference of light that goes through a coil of optical fibre that can be up to 5 km long. Fibre optic gyroscope is used for localization applications such as finding the true north as discussed in [16].

2.2.4 RFID Tags

RFID tags is among the many application that uses radio frequency signals to transmit and receive information. RFID tags and sensors work in a range of frequency bands such as 125 kHz, 13.56 MHz, 915 MHz and 2.45 GHz. RFID tags are divided in two different categories such as active tag or passive tag as discussed in [17]. In an active tag there is a source of power onboard usually supplied by a battery whereas passive tag relies on using RF energy to transmit its tag information to the receiver. Passive tags have an advantage of lower cost as compared to active tags. This is an important factor in supply

---

[1] http://www2.eng.cam.ac.uk/~hemh1/gyroscopes/onetofour.html

chain business where there are millions of units that require tags. On the other hand, passive tags face challenge of providing reliable information using a small amount of power. Thus, if assets of higher values are used they are often equipped with active tags.

There are two different kinds RFID tags and they are explained below:

1. Active RFID make use of battery to emit RF energy, even though battery improves the performance it further reduces the maintenance free operational life of the tag. Active tags offer a long range and works well even in unfriendly electromagnetic environments. With a long range the quality of the connection becomes good, but it also poses risk of signal interference with other devices using RF signals in the environment. This leads to challenge associated with accurately determining the tag's location. Various stakeholders such as organization and end users are actively addressing the challenges faced to deployment of RFID tags [17].
2. Passive RFID tags works by reflecting the RF energy or signals to the RF reader and they do not require any batteries to operate. They are low cost devices and have a simple construction. As mentioned in [17] passive RFID tags can be quite small, with the size having that of a small coin. They have a memory of 2 Kbits and can be enclosed in different kinds of materials. One of the most common material used for the RFID tags is the plastic and can be seen in forms of credit cards or bus fare cards.

Figure 4 Common item with RFID Tag

The Figure 4 shows a common item that make use of RFID. It is a transportation card for used collecting fare in public transportation. It is made up of plastic and covered with another soft plastic case. When using the public transport the passenger swipes the card against the RFID reader installed in the bus, tram or train.

2.2.5 Antennas

An antenna is a transducer that converts the electromagnetic waves to electrical power and vice versa. It can work both as a transmitter and a receiver. Transmitter converts the electric signals to radio waves and radiates them to space. Receiver converts electromagnetic waves from the receiving beam into electrical signals. For a two-way communication a single antenna can be used both as a transmitter and a receiver.

2.2.5.1 Basic Parameters for Antennas

Antennas are used for wireless communication that makes use of radio frequency waves. To understand the working function of antennas it is important to know the terms and characteristics of waves. Frequency is defined as the number of cycles or repetitions carried by a wave for specific amount of time. It is described mathematically in equation (2) as discussed in [18].

$$\boldsymbol{f = \frac{1}{T}} \tag{2}$$

Where

- T is the time period, the time after which the wave duplicates itself.
- f is the wave frequency.

The unit for the frequency is Hertz (Hz). Wavelength is defined as the distance between the two consecutive higher points or lower points in a wave.

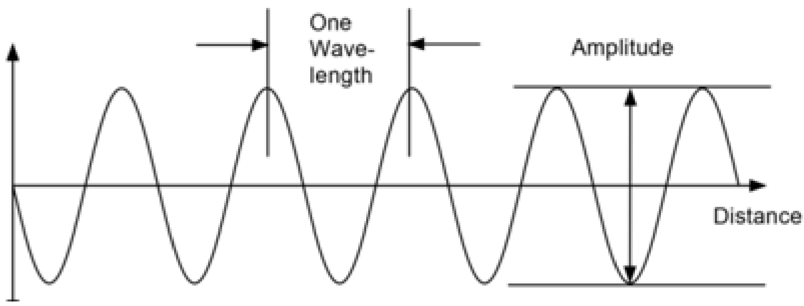

Figure 5 Amplitude and Wavelength [18]

The Figure 5 describes the amplitude and wavelength, whereas wavelength is denoted by λ. The relationship between wavelength and frequency is explained by a mathematical equation in (3) as discussed in [18]. Wavelength has an inverse relation to the frequency of the wave and proportional relation to the speed of the light.

$$\lambda = \frac{c}{f} \tag{3}$$

Where,

- λ is the wavelength
- f is the frequency
- c is the speed of light

Gain for an antenna is explained as the ratio between two radiation intensities. With one radiation intensity in a specific direction to the radiation intensity acquired if the antenna radiates isotropically. Simply it defines how much power an antenna can transmit as compared to that of isotropic radiation. It is measured in decibels denoted as dB.

Radiation pattern is used to define the energy radiated by the antennas into space and is a function of direction. Radiation pattern can either be a power or field pattern. Power patterns are drawn on logarithmic scale and are drawn as a square of magnitude of magnetic and electric fields. Filed patterns are drawn on logarithmic scale as well and plotted as a function of magnetic and electric fields. Antennas are classified into different categories due to their physical structure or frequency of operation or mode of application. Some of commonly used antennas are mentioned as follows.

2.2.5.2 Half-wave dipole Antenna

In [19] dipole antenna is defined as one of the most commonly used antennas. It can also be used as a folded antenna where the conductors are folded to form a cylindrical closed shape. The total length of the wire for this particular antenna is half of the wavelength and thus it is called half-wave dipole antenna. It has a frequency range of 3 kHz to 300 GHz.

The radiation pattern for the dipole antenna is Omni-directional and radiation pattern is used to define the reception or emission of wave fronts at the antenna, specifying its strength. With the radiation pattern at hand, one can simply understand the function and directivity of an antenna. Graphically radiation pattern is plotted as a function of angular position and radial distance from antenna.

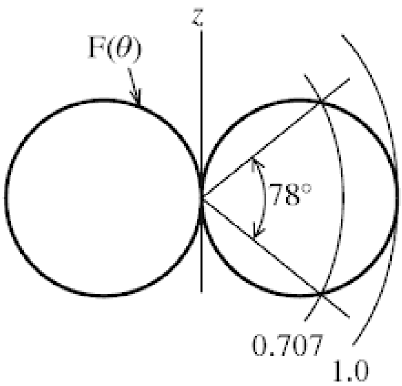

Figure 6 Radiation Pattern in 3D [19]

The Figure 6 shows a radiation pattern for the half wave dipole antenna in three-dimensional view across the z-axis. Similarly radiation pattern can also be view in two-dimensional representation.

2.3 SOA

In [20] Service Oriented Architecture (SOA), is defined as a flexible architecture that combines the business processes through sub-division of larger applications into services. These services are defined as an open piece of functionality having different properties. SOA based services maintains their own state, they can be dynamically placed and are platform independent. The main core of service-oriented architecture is independent of technologies, vendors and products. Furthermore, in [21] Service Oriented Architecture is defined as an methodology that answers the requirements of protocol independent, standards based and loosely coupled computing. However in [22] it is explained as an architectural style utilized for creating interoperable and autonomous systems.

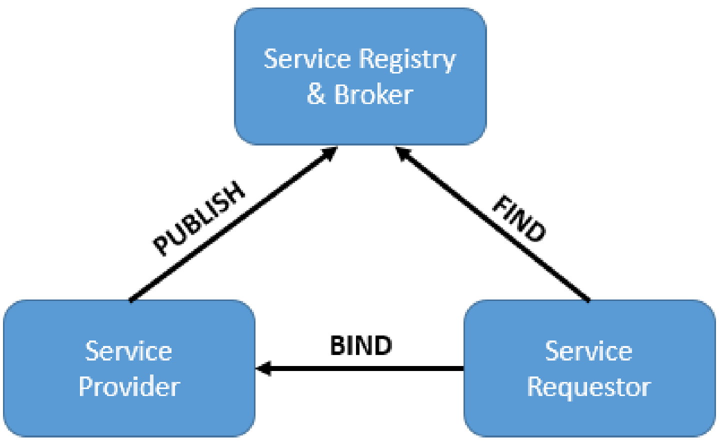

Figure 7 Components of Service Oriented Architecture [22]

The Figure 7 describes the different components of SOA and their interconnection, it has three parts, a consumer, a provider and a service broker. The publisher publishes or announces their services on the registries, where consumers can search and invoke them. The services broker helps the services requester find the desired services. For example if there are more than one service available then a particular service is selected. [22]

The most common adaptation of SOA is by enclosing the software component in web services (WS). There are many advantages of SOA such as easy deployment of components across various networks, having components isolated from each other allows to test various services and debug them individually, flexible reconfigurations of systems and seamless horizontal and vertical communications. [23]

2.4 Methods, Tools and Protocols for SOA

2.4.1 HTTP

In [24] Hypertext Transfer Protocol (HTTP), is described as an application based protocol used for distributive and combined systems. It make use of hyperlinks while interacting among nodes containing text and is the protocol utilized for the exchange of hypertext. By making web services on HTTP all the systems that can connect on the internet become a potential consumer of web services.

It works as a request response protocol in the client server model. An application that is running on the system can be considered a server and a web browser can then act as a client. The client creates a request to server using a HTTP request and then server responds to the client that may include status information of the request and the requested content in its body.

2.4.2 XML

The World Wide Web Consortium (W3C) [25] defines Extensible markup language (XML) as a markup language that uses agreed combination of rules to outline documents that can be read easily both by humans and machines. The XML do not depend on any specific platform and it is a platform independent language that can be accepted by various kinds of systems. It is recommended by W3C and is intended for transporting information as well as organizing and storing it.

Terminology that is used in XML [26]:

- **Element**, it is considered everything from the element start tag to the element end tag, inclusive of both the start and end tags as well.

- **Attributes** are designed to take data that is related to a specific element.
- **XML declaration** is used to begin an XML document.
- **Tag** is known as a markup construct and it starts with <, and terminates with >.
- **Character** are used in XML document and the whole document is a string of characters.

2.4.3 WSDL

The web service description language (WSDL) is based on XML format that is used to define functioning, that is presented by a web service. The WSDL explains how to call a service in terms of machine readable instructions, data formats to be utilized and the parameters that are returned.

A document that is written in utilizers various elements to explain network services [27]:

- **Service** is known as collection of endpoints.
- **Operation** is an explanation of an action that is offered by the service.
- **Port** is known as an endpoint that is made up by merging binding and the network address.
- **Port type** is a collection of operations that are maintained various end points.
- **Message** is the explanation of the communicated data.
- **Types** is a collection of different data types.
- **Binding** is a data format or a protocol for a specific port type.

The WSDL is usually used in conjunction with XML schema and SOAP to offer web services across internet. The client using a web service will read the WSDL file to figure out the actions that are accessible on server. The various kind of special datatypes that are in form of a XML schema are converted into the WSDL file. The client then utilize SOAP to call one of the listed action that are present in the WSDL file.

2.4.4 SOAP

The Simple Object Access Protocol (SOAP), is a messaging communication protocol that is used for the transfer of organized information while carrying out implementation of web services [28]. It is platform independent, based on XML and is a W3C recommendation.

SOAP is based on XML and can be divided into three different parts:

- The Envelope describes the message structure and ways to process it.

- The set of rules needed for communicating various examples of application data types.
- Structure for expressing various kinds of calls and their responses.

Building blocks of SOAP consists of an Envelope element (mandatory) that is used to define the XML document, as a SOAP message. A header element contains the information about header and is not mandatory. A body element is mandatory and contains the call made and its response information. A fault element is optional and consists of errors and status information. All the previously mentioned elements can be viewed in Figure 8.

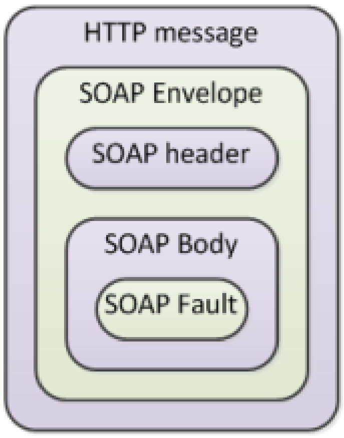

Figure 8 SOAP HTTP Binding [28]

The Figure 8 represents a SOAP binding with HTTP, since HTTP is a valid application layer protocol used to transport SOAP. The SOAP envelope contains a SOAP header and a body. Additionally, inside the body is the SOAP fault that consists of error codes and information for error handling.

There are many advantages with using SOAP**.** Based on its neutrality SOAP can work with any transport protocol. SOAP can easily make use of all the features of XML. SOAP when used in conjunction with the HTTP post and its response exchanges, can easily pass even when firewalls and proxies are deployed. Thus, SOAP do not need to change the existing computing infrastructure. Apart from the advantages there are also some disadvantages associated with the SOAP. The SOAP Protocol is verbose and has a slow speed when parsing from XML. It is difficult to call it from JavaScript and does not return human readable results.

2.4.5 REST

According to [29] Representation State Transfer (REST) is defined as an architectural pattern consisting of a combination of controls that are used in creating a web service. The REST web services offer interoperability between different systems over the internet. There are different set of constraints used by the REST web services e.g. REST has a uniform interface for carrying out all kinds of operations and interactions with the resources. These interactions are usually based on CRUD HTTP methods that translates to Create, Read, Update and Delete. These methods include a GET method request that is used for retrieving data from the resource. A POST method request that is used for producing a fresh sub-resource on the system. A PUT method request that is utilized to modify an already present resource. A DELETE method request that is utilized to remove an already present resource.[29]

The messages in REST that are sent between client and server are self-descriptive and further it provides resource identification through stable and unique identifiers also known as Uniform Resource Identifier (URI). In REST a principle known as HATEOAS (Hypermedia as the engine of application state) is used. This defines that method of interaction or any kind of exchange between client and server is based on hyperlinks i.e. URIs [30].

There is a large trend of using REST based services as compared to SOAP as mentioned in [31]. The communication based on SOAP has processing delays, a higher rate of latency that leads to network traffic. Whereas in comparison, REST is light weight, easy to use, reliable in terms of resistance to failure, can be easily modified and can be scaled to support large number of components.[32]

2.5 Energy Harvesting

The Energy harvesting can be described as a method of deriving energy from exterior causes such as wind, solar, kinetic energy or electromagnetic frequency and storing them for small electronic devices or wearable electronics. Energy harvesting that convert's ambient energy to electrical energy have gathered much interest in commercial and military purposes.

In general energy, is contained in a battery, capacitor or a super capacitor. Capacitors are used in case when there are high spikes of energy present and batteries are used when a constant flow of energy is required.

2.5.1 Piezoelectric Energy Harvesting

Piezoelectric mechanism is one of the widely research technique in the field of mechanical energy harvesters. As discussed in [33] the technique utilizes the property of materials to produce charge or voltage when exposed to stress. Some of the piezoelectric materials are zinc oxide (ZnO), quartz and aluminum nitride (AlN).

In a piezoelectric harvester a weight is placed on the rods having a piezoelectric layer on top of it. Movement of the placed weight from vibrations, forces piezoelectric layer to deform thus, generating electricity. One of the most commonly used system is the cantilever structure that resonates at different frequencies and can induce high stress levels. One such system is shown in the Figure 9.

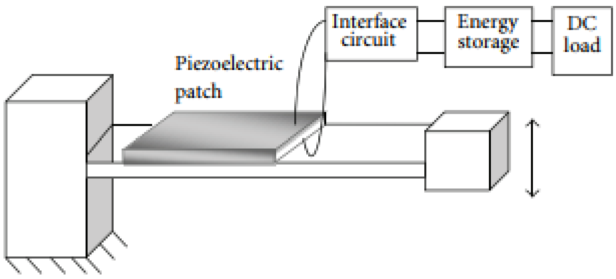

Figure 9 Piezoelectric Energy Harvesting System [33]

As seen in the Figure 9 piezoelectric patch is fixed on the cantilever system that acts under the alternating deformation. When the hosting beam is vibrated a tension is developed in a piezoelectric material, this tension leads to generation of an alternating voltage (AC) between the two electrodes. The AC voltage that is generated can be stored in a storage device by using proper circuitry to enable delivery of harvested electricity.

2.5.2 Radio Frequency Energy Harvesting

The Radio Frequency (RF) energy harvesting is defined as the procedure of transforming the RF signals to electricity. As defined in [34] this technique has become one of the most commonly used solution for powering the energy constrained wireless networks.

In radio frequency energy harvesting, a radio signal is utilized and these signals needs to be present in the frequency range of 300 GHz to 3 kHz. The RF energy harvesting is known as a technique that is termed as wireless energy transfer. There are various kinds of energy transfer techniques, known as magnetic resonance coupling and inductive coupling. These techniques are called near field wireless transmission whereas RF energy harvesting is considered as the far field energy transfer method [34].

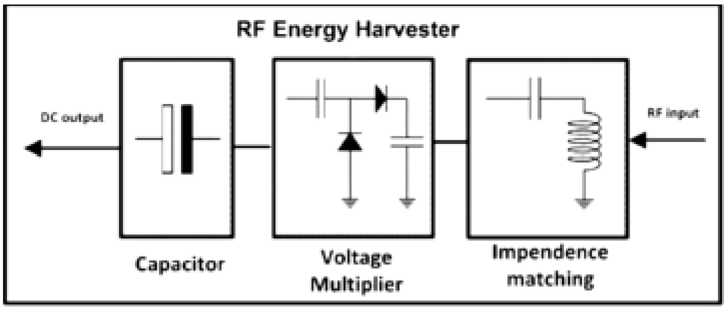

Figure 10 The RF Energy Harvester [34]

The RF energy harvester contains a circuitry that transforms the RF signals present in the space to electricity. The Figure 10 shows a RF energy harvester consisting of three different blocks of circuitry. The antenna can be tune to work on a single or multiple frequency, bands as per the needs, to harvest RF energy. Next to the antenna is the impedance matching circuit that is a resonator and works on the desired frequency to maximize the transfer of power between multiplier and antenna.

Next to the impedance matching is the voltage multiplier and it utilizes diodes that that rectifies the RF signal to DC voltage. To achieve higher efficiency in conversion, diodes with lower built in voltage can be used. Capacitors is used to deliver the continuous flow of power to the load and can store energy in cases when the RF signals are unavailable.

2.5.3 Electrostatic Energy Harvesting

Electrostatic energy harvesting is similar to the principle of parallel plate capacitor. Using the mechanical energy from the surroundings the distance between two parallel plates is changed. Changing the comparative placement of these two plates directs the charges to flow to the external load between the double plates. As explained in [35] the types of electrostatic energy harvester can be distinguished from its physical mechanism. There are two types of electrostatic energy harvesters one that make use of external voltage for biasing. Where an outside bias is used to generate a potential difference among the two parallel plates. In the second kind of electrostatic energy harvester electrets are utilized to generate a potential different among the plates. The Electrets are known as dielectric materials having permanent electrical polarization. The Figure 11 shows different kinds of relative motion between two parallel plates. Arrow shows the direction of motion between the fixed and moving part.

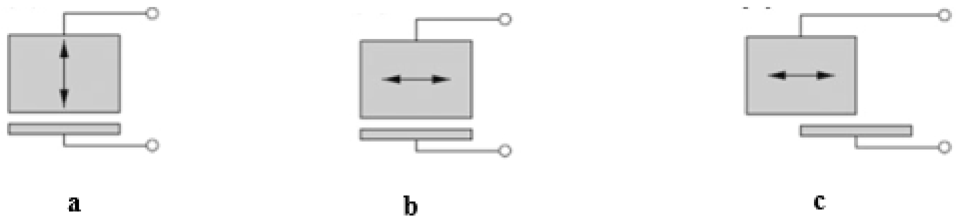

Figure 11 Electrostatic Energy Harvester [35]

2.5.4 Electromagnetic Energy Harvesting

As discussed in [35] Electromagnetic energy harvesting uses the principle of electromagnetic induction (EMI). The EMI follows Lenz's law and an electromotive force (EMF) is generated. This is analogous to creating voltage in a coil by the movement of changing magnetic field through induction using Faraday's law. Typically, a magnetic oscillator is used with a magnetic coil that moves in relative to each other to mechanical excitation.

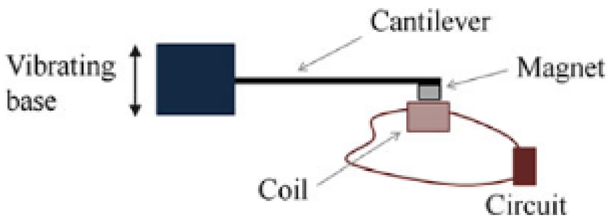

Figure 12 Electromagnetic Energy Harvester [35]

The Figure 12 shows a design for an electromagnetic energy harvester that uses a cantilever in combination with magnetic coil. There is a rigid mass attached to the end of the cantilever that oscillates in response to base excitation. The strength of electrical output depends on the number of coils, magnetic field and relative velocity between magnet and the coil.

2.5.5 Thermoelectric Energy Harvesting

Having environments that have heat flows and natural temperature gradients possess the capacity to produce electricity based on the transformation of the thermal energy to electric energy. The temperature gradient acts as a source for energy conversion and the heat flow delivers power. The thermoelectric energy harvesting method has proven as a resourceful procedure for systems with low power requirements. An example would be a wrist watch that converts the body heat to electrical power to drive the watch. As mentioned in [35] thermoelectric generators are used to generate electricity and are solid state devices without any movable parts. These generators are considered reliable, scalable and silent, terming them as ideal for low energy needs. When a thermoelectric material is exposed to a temperature difference, charges are divided at two ends i.e. hot and cold end. This division of charges at the cold end creates a voltage or an electrostatic potential. Eventually a state of equilibrium is observed between electrostatic repulsion and chemical potential for diffusion and this is known as the Seebeck effect [36], the basis for thermo-electric power generation.

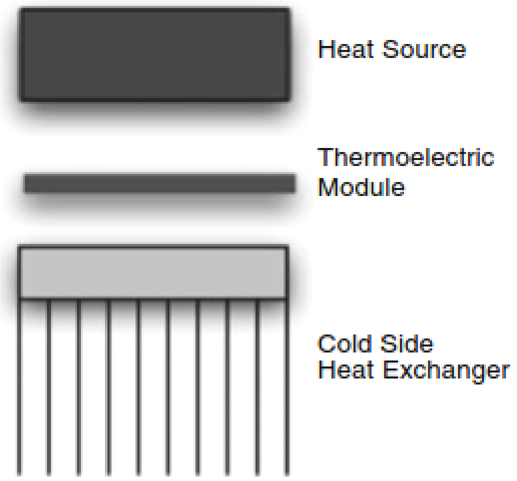

Figure 13 Thermoelectric Energy Harvester [35]

The Figure 13 shows the layout for thermoelectric energy harvester; the heat source is applied to one side of the thermoelectric module and the heat exchanger is present on the other side. The difference in temperature creates a potential difference across the thermoelectric module.

3. APPROACH

This chapter focuses on the phases that the thesis is divided into and the methodology that is used to solve the research problem. The chapter is divided in two segments, the first segment discusses about the overall overview of the system and explains it in detail. The second segment discusses the tools and technologies used that can be utilized for carrying out the approach.

Harvesting RF energy have been successfully implemented by [37] where a prototype is implemented using a Powercast module [38] to harvest energy for low power radio transmitter. The research discuses implementing a RF harvesting system for the wireless sensor network protocol design. Similarly, RF energy can be used in IoT environment for low powered devices and sensors. Another approach for harvesting the RF energy is implemented by [39] where a power beacon acts as the dedicated RF source for the Powercast harvester modules. The harvested power is used to provide communication between the transceiver and the sensor board [39].

Based on this discussion and researched approaches, an approach is designed that will measure the strength of the RF signals and use Powercast harvester module [38] to test and validate the results.

3.1 System Overview

The overall system diagram in the Figure 14 defines the basic overview of the system and is utilized for system planning. This layout explains the flow of information and the possible relationship between different entities that can be created. Thus, allowing for more operational and functional approach of the system. The overall system diagram for the approach used can be viewed as follows:

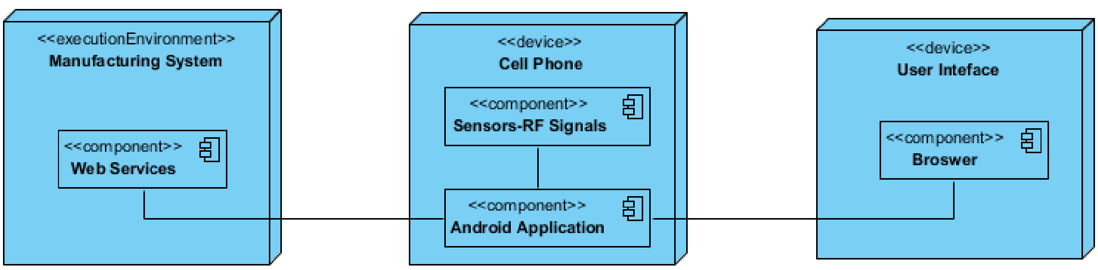

Figure 14 System Overview

3.1.1 Manufacturing System

The Manufacturing system will serves as a use case for the implementation of the selected approach. It will provide an environment for detecting the RF signals and testing the android application for the detection of these signals and their relative strength.

The manufacturing production system can be a small pilot system used for carrying out the manufacturing lifecycle of a product. It may consists of work stations connected in an arrangement with different conveyors that will allow movement of the products on them. The material will be loaded on one of the work stations through a pallet and the pallet moves through different work stations where various operations are carried out to create a final product before unloading it on the last work station. The movement of the pallet through different conveyors will define the determined path for the pallet. Using the determined path for the pallet, a cell phone can be placed on the top of the pallet and run through the path. The android application installed in the cell phone will be used to detect and measure the strength of RF signals at various locations of the defined path.

Several tests can be carried out, based on different RF sources to verify the results taken. This will allow to create a RF signal map based on different RF sources. Based on the RF map, RF signals can be harvested at locations that provides the highest signal strength and the results compared. Thus, allowing to identify the best and worst performing RF sources among them all.

3.1.2 Android Application

The android app needs to be developed keeping in mind the testing environment, and the integration of app with possible manufacturing systems. The manufacturing production system can be interfaced with an android application using the RESTful services [40] and web services.

The android app will use cell phones signal to measure the RF signal being received at it. It will consist of two modes of measuring the RF signals. In the first mode the RF signals are detected from access points or the Wi-Fi signals being spread out from various routers or access points present near the environment. These Wi-Fi RF signals should be in the standard frequency of 2.4 GHz and 5 GHz. In the second mode it will detects the RF signals from GSM frequency band ranging from (800 - 2000) MHz. These frequency bands are used by the cell phone on which the app will be running. The app will offer a user interface that will allow the user to view the signal parameters in real time. Furthermore, app should be able to send data to an API that will transfers the signal parameters to a user in a remote location.

3.1.3 Environmental RF Signals

The RF signals present in the environment are the ones referred to the signals coming from nearby access points and routers near the manufacturing system. It will also include RF GSM signals present in the environment coming the cell phone towers around the premises of the selected testbed. The RF signals have different frequencies, the signals present in the environment are the GSM signals ranging from (800 - 2000) MHz. The other group of signals are the Wi-Fi signals having a standard frequency of 2.4 GHz and 5 GHz.

The strength of the signal will vary at different physical location on the conveyors of the manufacturing system and around it. Knowing the strength of the signals at various physical points will help create a RF signal strength map for the production line.

3.1.4 User Interface

There will be two different user interfaces for the visualization of the signals and its parameters. The first user interface should display on the app itself and it can be used when the app is not being utilized for mapping out the environment. In case it is not used for the environment then the user will be able to instantly see the signal parameter at that physical point.

While the cell phone is being utilized to map out the environment, the signal data from the app can be sent to the user interface that is accessible through a web service. This user interface is created using HTML and CSS. The user interface allows receiving of data from the database whenever a new set of data is stored into it. User can view the updated data on the interface by pressing the refresh button that refreshes the part of the interface with new data.

3.2 Programming Technologies and Tools

The principle of this section is to offer an overview about the tools and technologies that may be utilized to implement the chosen method in this research work. Programming tools such as android studio and Node.js can be used for server-side implementation. Whereas android studio together with HTML, CSS and Angular JS can be utilized for front end and visualization. The tools and technologies mentioned in this section do not provide an exhaustive list. Thus, an additional set of tools and software’s maybe required for implementing the defined approached or when using a different use case.

3.2.1 Android Studio

Android studio is known as the official integrated development environment for the google android operating system. Android studio is mainly used for android development and can be used on Linux, operating system and macOS. Version 3.x is being will be used for this research work as described in [41].

The android studio provides an interface for creating android applications and uses Java as the programming language. Simultaneously it gives access to android software development kit that works as an addition to the code written in Java and lets the code to run efficiently on various android devices.

The android studio will be used to develop an app that is used to measure the RF signal parameters from the access point and from the phone RF signals as well. The app will get access to the sim card parameters of the cell phone and used it to extract the relevant information needed. The android app is then used to establish communication with the selected manufacturing system using HTTPs and Socket.io libraries. Furthermore, android studio can also be used to develop the user interface for the application that provide a user interaction with the app itself.

3.2.2 HTML/CSS

The CSS is the abbreviation for Cascading Style Sheets and it is used for explaining how HTML should be displayed on the interface. With CSS layout of various web pages can be managed at once. It is primarily used to allow separation of content and presentation that further include aspects like colors, fonts and layout. With the separation of format and content, the same markup page can be visualized through various representation approaches.

[2]HTML or Hyper Text Markup Language is defined as the markup language used for designing web applications and web pages. HTML is used to describe the structure of the web page and using HTML images, constructs and interactive forms can be embedded into the rendering page. It can also be used to embed programs that are written in JS that may affect the content and behavior of the web pages. Combination of HTML and CSS can be used for developing the user interface that can be used by the user to visualize the signal strength in different ways such as numerical and graphical.

[2] https://www.w3.org/html/

3.2.3 Node.js

[3]Node.js is an open source platform that is run on JavaScript and for executing the server-side code in JavaScript. It is based on V8 the JavaScript execution engine for Google Chrome. V8 compiles the source code written in JavaScript into machine readable code without the need to interpret in real time. Compared to the traditional web serving methods Node.js works on a single thread, utilizing non-blocking I/O calls that enables it to provide maintenance to several simultaneous connections. It is fast in operation, allows real time web applications to be created with ease, it allows the code to be written for both server and client side allowing exchange of data between server and client with ease. It is easy to code and have an active community of developers that are constantly working to improve it.

Node.js is used to create the server that runs the production line as well as the REST API. The REST API created in the Node.js is used to communicate with the android app through HTTP and socket.io protocols and store the data in the database.

3.2.4 JavaScript

[4]JavaScript allows the server-side code to be implemented using the Node.js. Furthermore, it also hosts and runs the user interface for visualizing the given dataset. JS is called the programming language of the web. It is used to make webpages more interactive and offers online programs. JS supports different programming styles such as event driven, imperative and functional. It is implemented both in client and server side.

---

[3] https://nodejs.org/en/about/
[4] https://en.wikipedia.org/wiki/JavaScript

4. IMPLEMENTATION

The implementation chapter focuses in detail the implementation of the approach mentioned in chapter 3, both at the physical and software level. This chapter discusses the hardware devices used and their characteristics. It discusses different use cases, user interface and functionality of the RESTful API developed. It further describes in detail the interaction between the entities, protocols used, and the different tools involved.

4.1 Production Line

The FASTory production [42] line known as the Factory Automation System and Technology Laboratory is displayed in the Figure 15 and is used as a testbed for the implementation of the approach selected. It consists of ten similar work stations each having a robotic arm and are connected by conveyors. All the work station (WS) are labelled in a similar way as WS1, WS2 and so on until WS12. Work station 1 is used for loading and unloading the pallets, for example loading the paper and unloading the final diagram. Work station 7 is used to load and unload the pallet. Apart from the work station 1 and 7, all the work stations are equipped with 4 axis SCARA robot (SONY SRX-611). All work stations are possessed with conveyors, feeder systems, RFID/NFC readers and safety systems. To utilize communication and function of the robots and conveyor lines, Remote Terminal Unit (RTU) is used known as S1000. The S1000 controller is web service based and is designed and manufactured by [5]Inico Technologies. Various S1000 controllers are deployed in the production line that are responsible for managing different segments of the line such as robots and conveyors. The FASTory line is chosen as it fulfils the characteristics of a manufacturing production system defined in the chapter 3. This will allow to test and validate the selected approach in a real time environment based on the results achieved.

---

[5] http://www.inicotech.com/

Figure 15 FASTory production line

4.2 Pallets

Pallet is known as a portable platform that is used for storing and moving the goods. Pallet can be of varying size and structure, traditionally it is used to transport heavy and oversized objects. However, in the production industry is refer to smaller sized platform that is used to transports materials over the production line or conveyors. Movement of the pallets are automated over the conveyor systems. Different tools are utilized on the conveyor system such as belts, chains or spinning rollers to allow for the movement of the pallets.

The pallets used in the system is especially designed for transporting A6 size sheet. The pallet shown in the Figure 16, can be divided into different parts. It has a lower part that is made of steel frame and is used as an interface between conveyor system and belt. The frame also has small wheels that allow its movement on the conveyor. The steel frame has a hollow box above it that is used for various embedded devices and sensors. The above part is a detachable metal plate that is used for maintaining the paper in a rigid place.

Figure 16 Pallet Bottom (left) and Pallet Top (right)

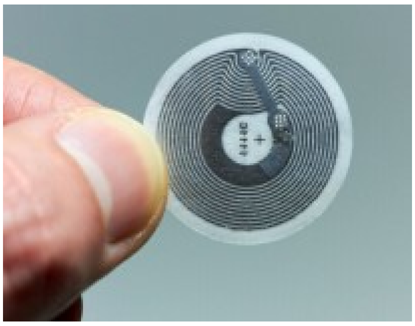

Figure 17 NFC Tag [43]

4.3 RFID Tags

To allow the tracking and scheduling of different pallets production needs facility to recognize the pallets. Thus, the pallets are allocated a passive NFC tag each, that saves the distinctive identification by which every pallet can be recognized. It is a circular tag that is placed inside the hollow surface of the pallet. One such tag is visible in the Figure 17, different NFC tags are placed throughout the production line and whenever a pallet passes over an NFC tag its identification number is read by it. The NFC tag reader is linked by a serial link to the smart RTU terminal i.e. S1000, the RTU broadcast the data to all the subscribers via web services. NFC tag is characterized by its fast speed, low price and a simple interface. [44]

4.4 INICO S1000 Controller

The Inico S1000 controller is a RTU capable of processing field data in real time, it has web-based monitoring and can be integrated to SCADA/HMI or enterprise IT systems. S1000 is specifically made to work in rough environment such as in an industrial setting. Furthermore, it is well-suited with many kinds of signals and signal intensities. It offers built in I/O ports as well as supports expansion modules that can be used to utilized specialty function such as energy monitoring and wireless networking as described in [45].

It consists of a 32-bit CPU that operates at 55 MHz and has an 8 MB flash memory for data and program storage. It can be interfaced with CAN and RS232 serial port, USB 1.1 device port, requires 9-36 V DC power supply. 8 digital and 4 analog I/O's. S1000 can be fully configured with web services by utilizing a web browser. Complete logic, I/O, HMI, web services and various built in apps and modules can be programmed and various web browsers can be configured such as Chrome or Mozilla Firefox. The device is presented in the Figure 18.

Figure 18 Inico S1000 Controller

Additionally, the S1000 can communicate through wireless networks [46] and sensors by using an expansion module known as W1-Z. This module backs the wireless networks using by making use of the ZigBee PRO, a communication standard. It has various functionalities such as consists of IEEE 802.15.4 radio, multi hop routing and 250kbps data rate.

4.5 Wireless Sensors

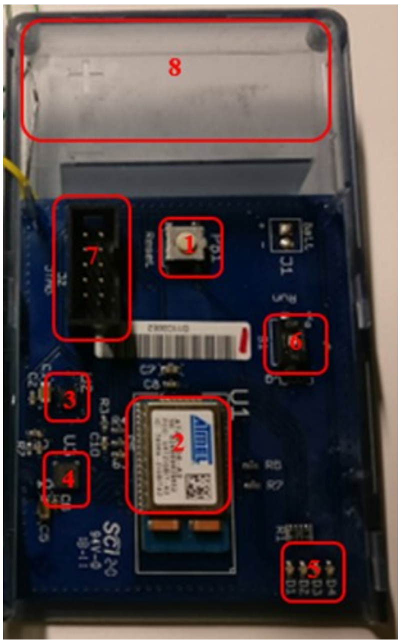

Figure 19 Wireless MEMs Gyroscope & Accelerometer

In the research carried out, wireless embedded devices are used that consist of wireless sensors used to track the position of pallets. These embedded devices are manufactured by Inico Technologies. The Figure 19 displays the dismantled embedded device displaying its PCB hosting various components. The embedded device presents the wireless MEMs sensors consisting of gyroscope and accelerometer. List of components that made up the wireless MEMs sensors are mentioned below that corresponds to the labelled components in the Figure 19.

1. Reset button used to reset the embedded device.
2. ATMEL ZibBit microchip that consists of dual antenna and wireless IEEE 802.54/ZigBee, OEM module with capacity to broadcast in 2.4GHz frequency band. [47]
3. 3-axis accelerometer
4. 3-axis gyroscope
5. Control LEDs
6. Switch button allows the embedded to operate in two different modes such as Run or configuration mode.
7. JTAG programming interface
8. Place for putting 2 AA batteries.

Whereas the characteristics of MEMs gyroscope and an accelerometer is mentioned in Table 1. The table provides a comparison between the gyroscope and accelerometer based on their characteristics.

Table 1 Features of MEMs Sensors [48]

Characteristic	Gyroscope	Accelerometer
Sensor Type	L3G4200D	LIS3DH
Vendors	STMicro-electronics	STMicro-electronics
Scale	250/500/2000deg	±2g/±4g/±8g/±16g
Measured Axes	3-axis	3-axis
Sensor Output	16 bits	16 bits
Input voltage	(2.4-3.6) Volts	(1.71-3.6) Volts
Physical dimensions	4 x 4 x1.1 millimeters	3 x 3 x 1 millimeters

4.6 Software Overview

For the implementation of the approach selected above architecture consisting of RESTful, web services are used as it provides interoperability between different computer systems on the internet. RESTful web services allow predefined set of operations for accessing and textual representation of web resources.

Furthermore, RTUs connected with the FASTory line provides both RESTful [49] and SOAP (DPWS) services [50]. Thus, it offers interoperability between the approach used and the FASTory line. Moreover, Android studio is selected for the development of the app, as it is an open source platform providing access to thousands of literature, tutorials and development support. It is free to use, easy to customizable and is compatible over a range of hardware available. It also provides seamless integration with the RESTful web services, API and databases.

According to the approach [51], the chosen method can be viewed as a design pattern that follows Model-view-controller architectural pattern. This divides the solution into three interconnected parts. It allows the major components for parallel development and efficient code reuse.

- Model- It refers to the central component that is independent of the user interface. It is used for managing the logic, data structures and algorithms for the application. In this approach model is defined as the android application that is defining how the data is acquired from the sensors and processor further for different purposes.

- View – It is the output representation of the information that can be viewed by the user and manipulated as well. It refers to the graphical user interface (GUI) represented in a web page on a browser. HTML and CSS is used for developing the web page that shows the signal parameter in the visual form.
- Controller**-** It connects the model and the view and allows the flow of the information between the two. In this case, it refers to the API and the REST controller that establishes the communication between the different components utilizing various protocols.

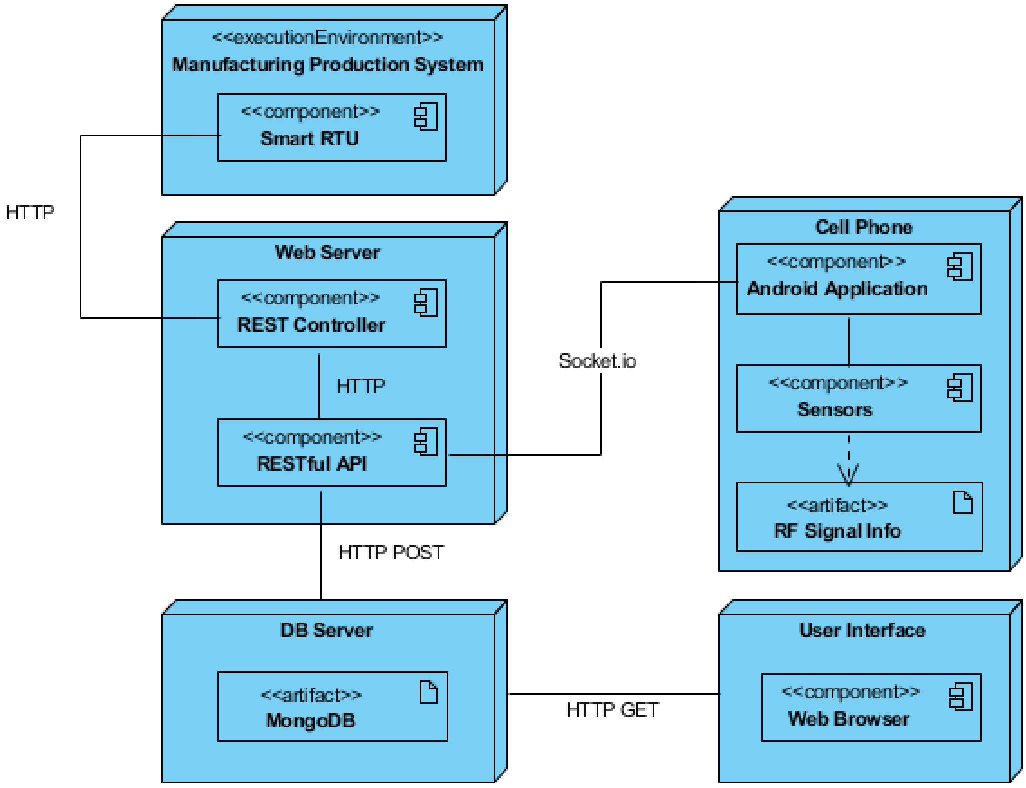

Figure 20 Software View of the System

The Figure 20 depicts the software view of the implemented system for the proposed solution. The view mirrors the MVC approach as mentioned previously. The smart RTU and the assembly line are the part of the FASTory production line and are connected with the server via the web services of their own. The server in the architecture consists of the REST controller, API and the database. The server sends instruction for the movement of the pallet in the assembly line, with cell phone placed on top of the pallet. Android application measures the signal strength at various locations, of assembly line and send the information to the server via the API. The API receives the information regarding the signal strength, then stores it in database. The information that is saved in database can be manipulated and visualized by the user as per its needs.

4.7 Sequence of Data Flow

The Figure 21 displays the sequence of the flow of data and the actions in the architecture. Initially the signals are measured from the ambient. The android application is responsible for measuring the signals. At the same time application connects with the manufacturing system and the events are subscribed. Whenever the pallet moves on the conveyor line the cell phone is placed on it and the application inside will detects the location of the pallet. At different locations on the conveyor the application, send the signal parameters to the API that stores it in the database that can be further visualized in a user interface.

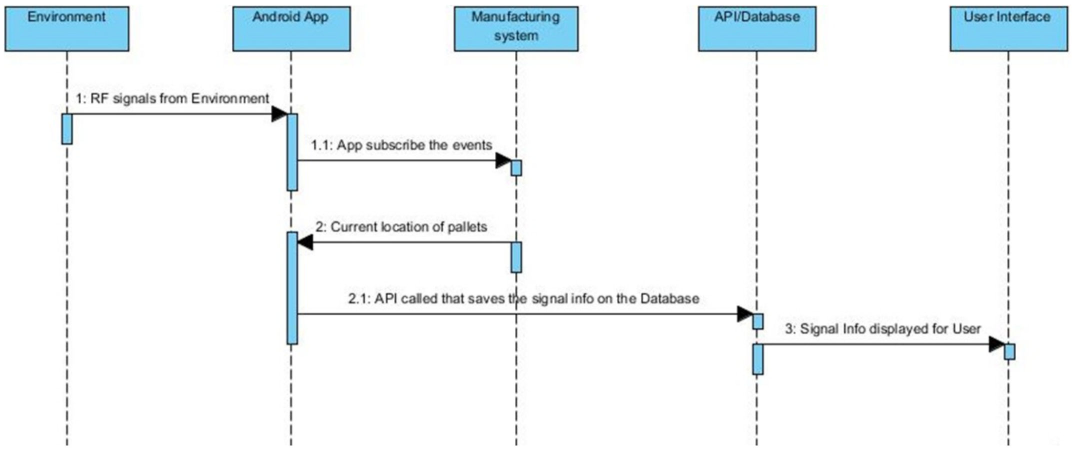

Figure 21 General sequence of Data based on Architecture

4.8 Use Cases

The use cases for the android app are presented in this section. The use cases provide detailed implementation of the different use cases in the android app used for detecting the signal parameters from different sources.

4.8.1 Detecting Wi-Fi Access Points

One of the first step in acquiring the signal data from Wi-Fi access points is to detect the number of access points present near the app user. At the interface of the app, user is provided with a clickable button labelled as ‘Scan Again’ as shown in Figure 22. Once the button is pressed, app detects the number of different Wi-Fi access points present and displays them in a list.

In the background, on the press of a button an activity is executed in the code. The activity that is executed creates a list view. Before a list view is created, app checks if the cell phone Wi-Fi service has been enabled or not. If the Wi-Fi service is disabled, it makes a toast or displays a message on the screen. The message reads as follows ‘Wi-Fi is disabled, making it Enabled’. If using the app for the first time the user will be prompted to provide access to the location and sim services of the cell phone.

After that the app starts the scanning process for detecting the access points. It clears the list view and when the ‘Scan Again’ button is pressed, it displays a pop message on the screen that reads ‘Scanning’. For creating and displaying the list of access points a broadcast receiver class is used. The broadcast receiver class stores the list of access points in an array. It further detects the SSID, its strength level and the frequency of each access point at which it is operating. All this information is displayed to the user in the list as shown in the Figure 22.

Figure 22 After Scan

4.8.2 Connecting to an Access Point

Once the list of the access points is displayed on the interface, user is independent to scroll through the list vertically and can select an access point that he or she wishes to connect with. Selection can also made by comparing the signal strength of all access points and choosing the strongest as per the user needs. The access points with strong signals are the ones that are located in close proximity to the user.

When a user selects a particular access point and clicks it, a dialog box opens as shown in the Figure 23 prompting the user to enter the password for the access point. Once entered, it verifies and the takes the user to a new screen.

Figure 23 Dialog box for Access Point

At the destination screen user is able to observe different parameters for the access point. In this case user successfully connected to the access point with the SSID named as 'ashh'. Different parameters for this access point can be seen in the Table 2.

Table 2 Access point Signal Parameters

Signal Variable	Value
SSID	ashh
BSSID	e6:db:30:01:7f:31
Speed Mbps	72 Mbps
Strength/dBm	-32 dBm
IP Address	1250535616
MAC Address	02:00:00:00:00:00
Frequency MHz	2437 MHz

Access point parameters are accessed using the sensors from the cell phone and displaying it for the user. The user can also visualize the strength of the signal through a speedometer visible on the screen. Strength of the signal is the main variable in focus because it will be used to map out a RF signal map of the production line. The RF map of the production line will help determine where to place the RF energy harvester or beacons for charging the sensors used in conjunction with the pallets.

In the background once the user is connected with access point or the Wi-Fi and if there is no error then the code is executed successfully. After the successful execution a pop-up message will be displayed to the screen for the user that reads as 'Connected'. Then various signal parameters are access from the access point information. These parameters include Service Set Identifier (SSID), also known as the name of the access point, Basic Service Set Identifier (BSSID), link speed in megabits per second Mbps, Received Signal Strength Indication (RSSI) or signal strength, Internet Protocol (IP) Address of the Wi-Fi, Media Access Control (MAC) address and frequency in MHz.

4.8.3 Cell Phone Signal Parameters

Apart from the cell phone signal parameters there are various other kinds of RF signals present in the environment. Among them are the GSM signals or RF signals from the cell phone towers have a significant presence and can also be utilized for RF harvesting. One of the resourceful way of accessing the strength of the signal is by utilizing the sensors of the cell phone and its sim card information. This helps to build in additional information about RF signals working at a different frequency range and speed.

The app interface is divided in different fragments; the first fragment refers to the information associated with the Wi-Fi or access points. At the second fragment all, the information about RF signals that are being received by the cell phone is mentioned. While accessing the signal information from the cell phone requires special permission and access rights needs to be provided in the app code. This is a one-time permission that is provided initially; apart from this, no other verification is required from the user since the user will be accessing the information via its own cell phone.

In the background for accessing and providing the signal parameters. Detailed information is accessed from the sim card regarding the RF signals received at the cell phone. It includes information such as network operator that refers to the network that the cell phone is connected to. Sim operator refers to the company of whose sim card is being utilized in the cell phone. Country info mentions the country code at which the phone network is currently operated. Data state provides a Boolean answer whether the data net is being utilized by the user or not. If it is being utilized then it shows it as connected otherwise it displays disconnected. Signal strength refers to the strength of the RF signal being received at a particular instant. The signal strength varies depending on the distance from the cell tower as well the signal reception at the cell phone. Signal strength is converted into dBm, since many calculations later are carried out where the signal strength is taken as in dBm.

Table 3 Cell Phone RF Signal Parameters

Signal Variable	Value
Network Operator	Saunalahti
Sim Operator	Saunalahti
Country Info	fi
Data State	Connected
Signal Strength/dBm	-86
Cell ID	860152037533831

Table 3 provides a real information about the RF signal parameters. ‘Saunalahti’ is the name of one of the company that provides the cell phone services in Finland. ‘FI’ refers to the country code for the Finland. Since the data net was activated while taking the measurements, thus data state refers to as ‘Connected’. Then there is signal strength that is mentioned in dBm and refers to the instant measurement of the signal strength at that particular moment. ‘Cell ID’ refers to unique number identified assign to the cell phone.

4.8.4 Communication and Data Transfer

Series of steps are followed to allow the android app to communicate with the REST controller. In this situation cell phone, containing the android app is placed on the pallet as it moves on the production line, in this case FASTory production line. Before the app is placed it on the pallet it needs to be connected with the FASTory system. The Figure 24 displays the interface provided to the user. The interface is programmed to gather the ‘Port number’ and the ‘Address’ from the user. Once all the required information is entered, the ‘OK’ button is then pressed by the user. On the click of the ‘OK’ button the app is connected with the RESTful controller that is being run at the server.

Figure 24 REST Controller Settings

In the background the address and port is saved in the variables ‘adres’ and ‘prt’. Socket programming is utilized to connect with the server and transmit the data. The data that is transferred to server is the JSON data.

After the connection is made with the server, a POST request is made to the API URL and that transmits the collected data. After making the POST request the status code is also received in the response. All the data is converted to JSON object before sending it to the API where it receives it as a JSON object and further saves it in the database for the user needs.

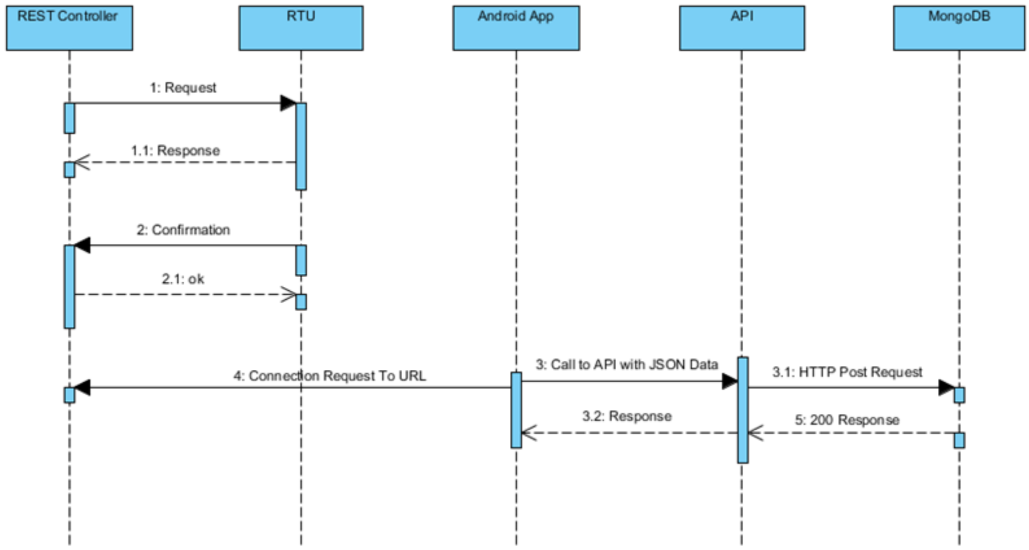

Figure 25 Sequence Diagram showing Flow of Communication

4.8.4.1 Invoking Services

The Figure 25 describes sequence of events that are carried out for the successful communication between the different entities. A request is made to RTU terminal of the conveyor lines from the RESTful controller. If the user wants to carry out an operation, then it should use HTTP POST method defined by the class attribute. Whereas if the class is query then the user can use HTTP GET method to request the information.

In this case HTTP POST request is made then the user can use following body and user will wait for the confirmation message about the operation. The Figure 26 describes the format of the POST request that will be used to carry out the operation. The format consists of destination URL that corresponds to particular operation carried out e.g. by the robot arm or a conveyor.

```
{“destUrl”:”http://example.com”}
```

Figure 26 Format of POST Request

In this scenario RTU send an empty POST request to the provided destination URL and informs about the completion of the operation. A typical example for invoking one of the conveyor zones will look like as mentioned in Figure 27.

```
POST: http://192.168.6.2/rest/serives/TransZone23

Body :{“destUrl” : “http://192.168.123.123:8080”}
```

Figure 27 POST Request

The POST request mentioned in Figure 27 moves the pallet from zone 2 to 3 and if the request is carried out successfully the RTU responds with a 202 code otherwise 404 code is received. The RESTful controller receives the POST request on the URL: http://192.168.123.123:8080 with an empty body.

4.8.4.2 Subscribing Events

After the operation is carried out it is necessary for the RESTful controller to know if the operation has been successfully carried out. In order to know that, RTU provides another feature of subscribing to event notifications. For all the services, similar events can be subscribed that notifies the RESTful controller for the successful completion of the service. For subscribing to the services, a HTTP GET request is used and the format of the request is mentioned in Figure 28.

```
GET: {hostIP}/rest/events
```

Figure 28 Format of GET Request

In order to subscribe to the above mentioned event the user can subscribe to the events in the following way as shown in Figure 29. Where the host IP is followed rest, events and a particular event ID.

```
POST: {hostIP}/rest/events/{eventID}/notifs

Body: {“destUrl” : “http://example.com”}
```

Figure 29 GET Request

The POST request has a destination URL in the body, where the response will be received. Once the request is made, the RESTful controller receives a notification as a POST request with the JSON body. The notification has following information in it, ‘event ID’, ‘RTU ID’, ‘lastEmit’ and ‘payload’. The example in Figure 30 describes the POST request made to subscribe to the change of state of Zone 2 of conveyor 8.

```
POST: http://192.168.8.2/rest/events/Z2_Changed/notifs

Body: {“destUrl” : “http://192.168.123.123:8080”}
```

Figure 30 Change of Zones

The RESTful controller gets the following sample response in the body containing the information in various variables as mentioned in the Figure 31.

```
{"Id":"","senderId":"","lastEmit","","payload":{"PalletID":""}}
```

Figure 31 Sample Response

Similarly the diagram in Figure 32 shows the sequence of events of while subscribing the notifications from the FASTory RTU. Where the event is first subscribed and a response is received for it. Once the event is subscribed a notification is received that is confirmed by the controller.

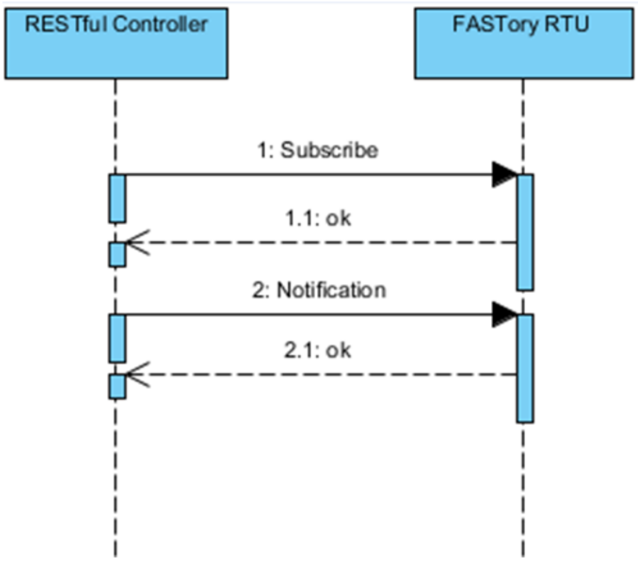

Figure 32 Sequence Diagram for Events

After the events are subscribed, the user makes a connection to the server by entering the address and the port. Once the connection is established user starts the movement of pallet and connection to API by pressing the 'SEND INFO' button. Furthermore, in the Figure 32, as the pallet moves from different conveyors the RESTful controller is notified about the position of the pallet on different zones. On every zone, Android app makes a call to the API and transfers the relevant data that is eventually saved on the database.

4.9 User Interface

User interface allows the possibility of visualizing the signal strength that is being measured using the android application. The android app provides visualization of signal strength for access points as well as the cell phone.

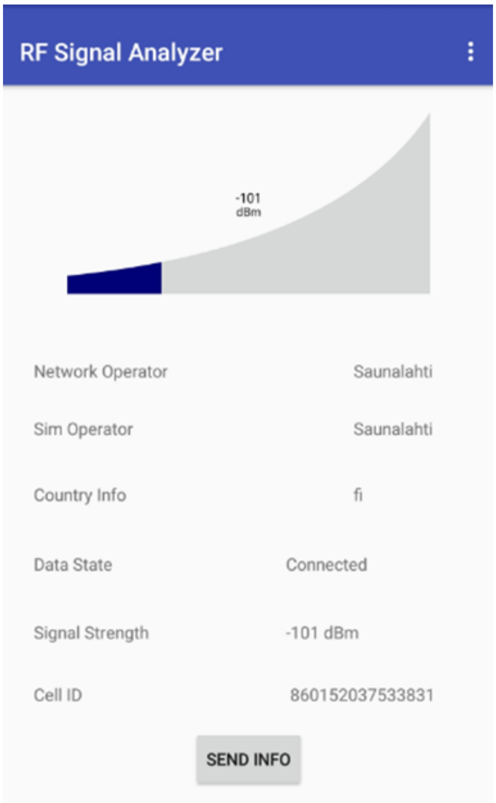

Figure 33 Cell Phone Signal Strength Visualization

The Figure 33 displays the visualization screen for the cell phone parameters. In the screen all the necessary parameters that are being accessed from the cell phone sensors are displayed. On the top is the graph that changes instantly and displays the current signal strength being measured at a particular instant. The graph fills in the space and move upwards when a signal strength increases and move downwards on detecting the weak signal strength. Similarly, the numerical value of the parameter “Signal Strength” also changes instantly.

“SEND INFO” button is provided to enable the connection creation between the android app and the FASTory production line and starts the transferring of data. The user must press it manually for once initially to enable the transferring of data. After that the android app automatically transfers the necessary parameters whenever it reaches a check point of a particular work station.

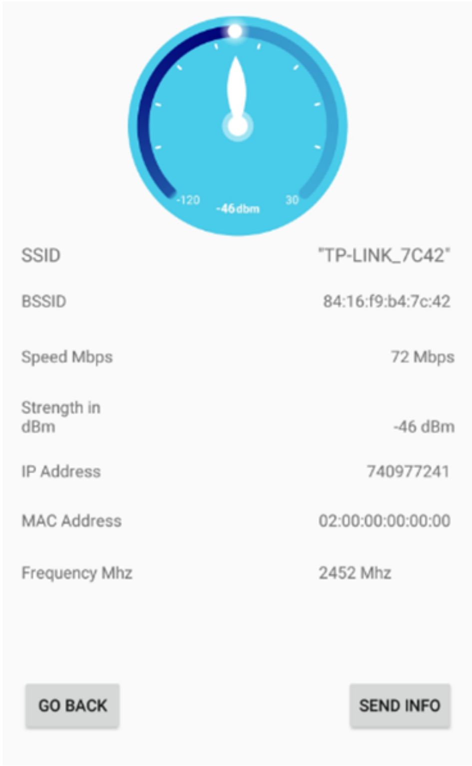

Figure 34 Access Point Signal Strength Visualization

In the Figure 34 the signal parameters for an access point are displayed. It provides the necessary parameters about the access point it is detecting at that moment. The speedometer above displays the strength of the access point at that instant. It changes instantly whenever there is a variation in the signal strength. The speedometer moves to the right when an increase in the signal is detected and moves to the left when there is a decrease in the signal.

"GO BACK" button allows the user to navigate back to the home screen and "SEND INFO" button works in the similar as it did for the cell phone parameters. On pressing this button, the android app sets the connection and start sending the necessary parameters at the successive intervals on the conveyor line of FASTory production system.

All the signal parameters for access points and cell phone are stored in a database. The user can easily access the stored data from the database and can manipulate it as per his or her needs. The data is accessed by using REST API and a particular data then queried from the database. One such example of fetching and visualizing the necessary data to signal strength is mentioned in the Figure 35.

A GET request is made on the URL " /notes" and then a query is made where it search in all the records with records having a field "Strength in dBm" present. After the query all the fields are send to the user and those that are empty are deleted. In this way user can use the list of fields for representing it visually.

The data that is accessed from the GET request is represent visually in Figure 35 and Figure 36 corresponding to cell phone signal strength access points signal strength. This allows the user to see the map of RF signal strength at each work station. This gives an estimation which work station receive strong signal strength and which stations receive weaker signal strength. The signal strength is a function of time and other factors in the environment such as distance, line of sight etc. and will vary accordingly.

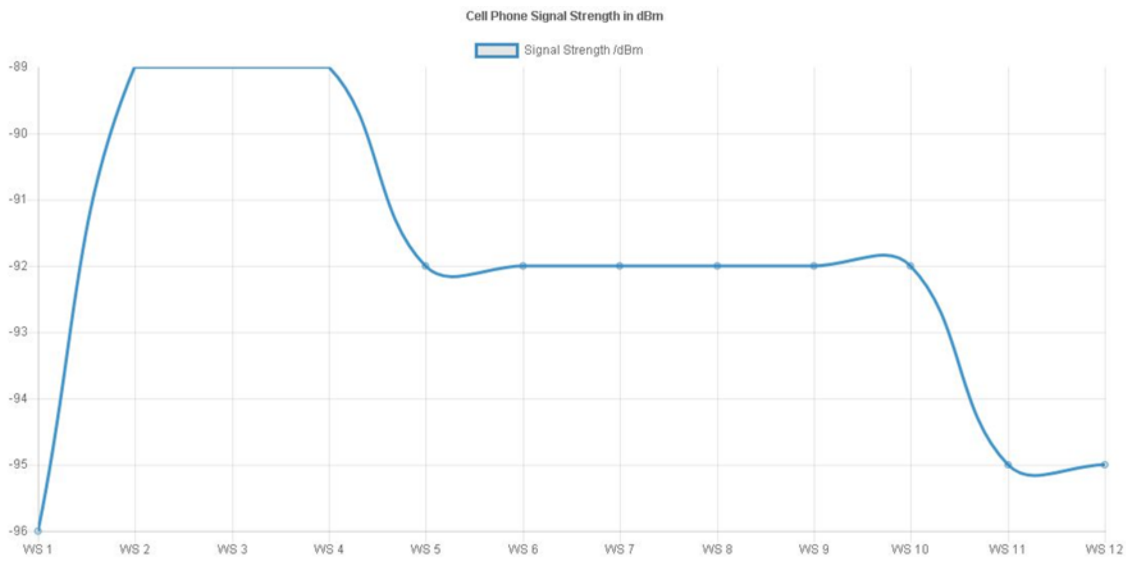

Figure 35 Cell Phone Signal Parameters

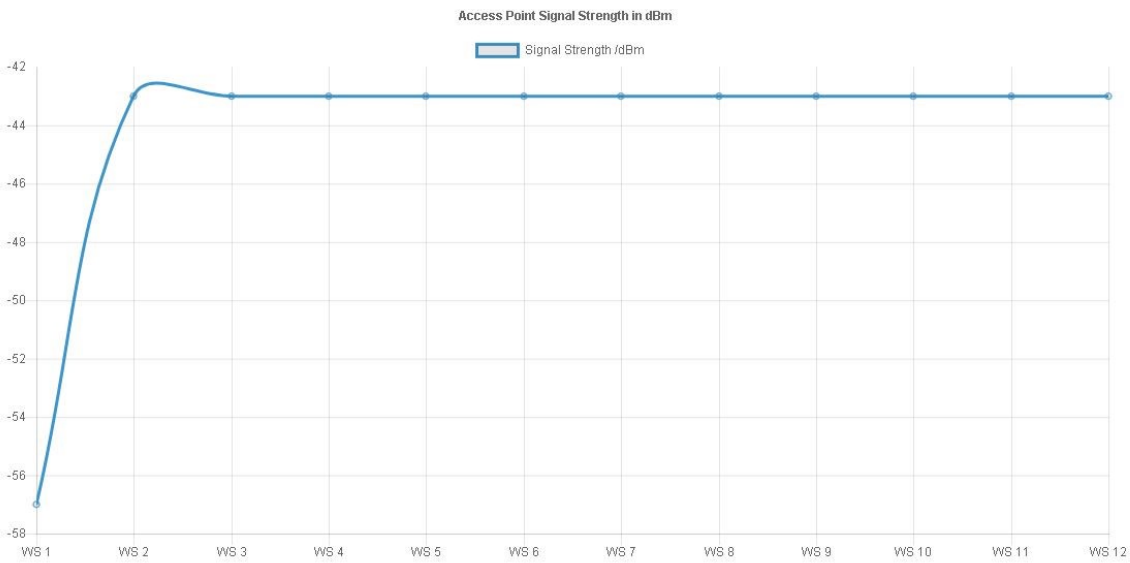

Figure 36 Access Point Signal Parameters

The Figure 35 and Figure 36 displays the visual representation of the signal strength measured from the cell phones and access points respectively. On the x-axis each work station is labelled from 1 to 12 as 'WS X' where WS stands for work station and X represents a numeral from 1 to 12. At the y-axis the strength of the signal is represented in dBm, this signal strength is measured whenever the pallet arrives at a particular work station.

4.10 RESTful API

Many RESTful applications need and uses HTTP requests to perform operations. A simple RESTful API [52] is created using Node.js and Mondo DB. Node.js is selected for this purpose as it is simple to use, faster in execution, works well with networking applications and is light weight.

The RESTful API uses four operations that are termed as CRUD that are commonly used in REST based architecture. The four methods and operations are as follows:

- POST: This is used to update an existing record or enter a new record.
- DELETE: This is used to delete a particular record from the database.
- PUT: This is used to create a new record.
- GET: This is used to provide read only access to the record.

The RESTful API is tested with the Postman to ensure its functionality is working and then is integrated with the server for communication with the android app. The results for each operation for the RESTful API are mentioned in the following sections.

4.10.1 POST Request

The following POST request is made with the body mentioned in Figure 38. The body contains the message 'we are sending data from the tietotalo lab'. The URL in the request is where the API is active.

```
POST: http://localhost:8081/notes


Body: {


   "title": "we are sending data from the tietotalo lab"

}
```

Figure 38 POST Request

4.10.1.1 Response

The response is received as shown in Figure 39. The response consists of status that mentions whether it was a success or a failure and time in milliseconds after which the response is received. In the Figure 39 we can see the data is mentioned in the title and a unique id is assigned to the received data.

```
Status: 200 OK, Time: 2329 ms

{
  "title": "we are sending data from the tietotalo lab",
  "_id": "5a56417bccf31d0d5434397a"
}
```

Figure 39 Response

4.10.2 GET Request

The GET request in Figure 40 is made to the data with a unique ID. The ID is same as created previously while making the POST request. The GET request contains the URL where the API is available and then the ID to retrieve the data.

```
GET: http://localhost:8081/notes/5a56417bccf31d0d5434397a
```

Figure 40 GET Request

4.10.2.1 Response

The response is received is mentioned in the Figure 41. The response contains the status that mentioned whether the operation carried out, is termed either as a failure or a success, and the total time that is taken to receive the response. Furthermore, in the body unique ID is mentioned that corresponds to the same data item that was being accessed. The text field is null and in the in the title the message can be seen that was saved previously.

```
Status: 200 OK, Time: 100 ms

{
  "_id": "5a56417bccf31d0d5434397a",
  "text": null,
  "title": "we are sending data from the tietotalo lab"
}
```

Figure 41 Response

4.10.3 PUT Request

The PUT request shown in the Figure 42 is made to the same unique ID and contains an updated message in the body. The message that will be used to update the data item is mentioned in the title field.

```
PUT: http://localhost:8081/notes/5a56417bccf31d0d5434397a

Body: {

   "title": "we are sending data from the tietotalo lab and making
an update using the PUT method"
}
```

Figure 42 PUT Request

4.10.3.1 Response

The response received is shown in the Figure 43 after the PUT request is made and it can be seen the information is updated. The response contains the status code that mentions that the operation was a success and the time taken to receive the response. In the body, in the title field the delivered message can be seen that updates the particular record as mentioned previously.

```
Status: 200 OK    Time: 556 ms

    {
       "title": "we are sending data from the tietotalo lab
    and making an update using the PUT method"
    }
```

Figure 43 Response

4.10.4 DELETE Request

The DELETE request as shown in Figure 44 is made. It again uses the same unique ID that is used in previous requests. The request URL consists of the URL where the API is active and then followed by the ID of the data item to be deleted.

```
DELETE: http://localhost:8081/notes/5a56417bccf31d0d5434397a
```

Figure 44 DELETE Request

4.10.4.1 Response

The response received can be seen in the Figure 45 that confirms that the data stored at the unique ID has been deleted. The response contains of the status code i.e. 200, that signifies that the operation was successful and the time taken to receive the response. Furthermore in the body it mentions Note, followed by its ID and then mentions that is has been deleted!

Status: 200 OK   Time: 349 ms

Note 5a56417bccf31d0d5434397a deleted!

Figure 45 Response

4.11 RF Harvester Module

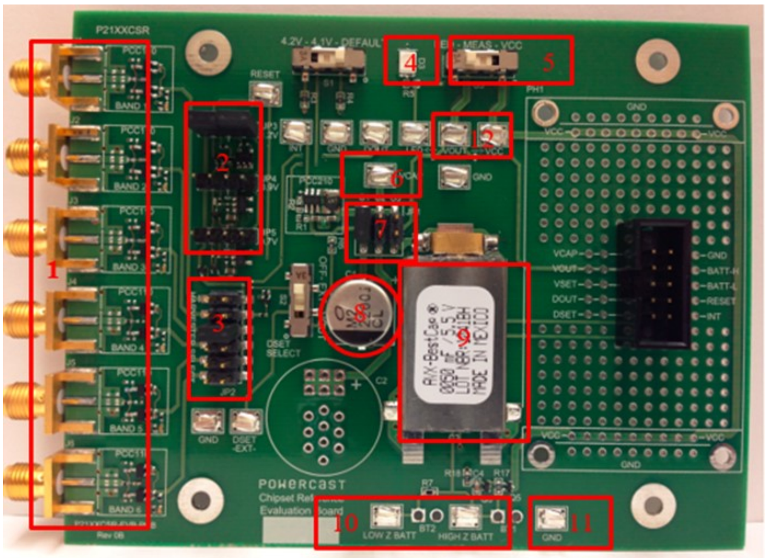

Figure 46 RF Harvester

The Figure 46 shows a harvester module on a PCB. The harvester module mentioned is one of the off the self-module present in the market and is being utilized in this research work. Each component of the harvester module is labelled with the number and described below.

1. RF input power is delivered through these six connectors, antennas are plugged in one of these connectors that takes in the RF signal from an RF source nearby. Each connector connects with an antenna that works on a specific band of frequency. Starting from the top to bottom, the list of frequencies corresponding to each connector are as follows: The strength of RF signal should lie in the range of Min (-15dBm) to Max (+15 dBm) for a safe operation. The harvester module will work outside these but with reduced efficiency.
2. With this selector the boost convertor can be turned on. It consists of a four-pin header, and a two 2-pin jumper. The jumper is moved to select the desired onset voltage. User can set the threshold voltage to, 1.2 V, 0.9 V or 0.7 V.
3. This is a selector consisting of two pin header and one 2-pin jumper. User plugs in the jumper on the pin header corresponding to each of the six frequency bands.
4. This is a test LED that lets the user know if the harvester module is working. The LED turns on when the voltage across the capacitor reaches approximately 0.7 V.
5. This is a switch that corresponding to three different functions, selecting LED turns on the LED for observation. By using the MEAS option, the current can

be measured between two different test points, such as, Vout and LED or Vout and Vcc.

6. The terminal for checking the output voltage of the capacitor.
7. A selector is used to select storage capacitors such as 2200uF electrolytic capacitor, 50mF super capacitor and the third option where the user can add a different capacitor of his/her own choice on the board.
8. This refers to the 2200uF electrolytic capacitor.
9. This refers to 50mF super capacitor.
10. This refers to the connection points for charging the low impedance and high impedance batteries.
11. Ground connection.
12. Connection for the output voltage.

Furthermore detail of different frequency bands at which the harvester board operates is mentioned in the Table 4. The different frequency bands corresponds to different RF sources that can operate on these mentioned bands.

Table 4 Harvester Frequency Bands [53]

Sr. No.	Frequency Band Names	Frequency Band in (MHz)	Centre Frequency in (MHz)
1	GSM-850, Uplink Frequency	(824 – 849)	836.5
2	Wi-Fi	(2400 – 2500)	2450
3	GSM-1900 Uplink Frequency	(1850 – 1910)	1880
4	GSM-1800 Uplink Frequency	(1710 – 1785)	1747.5
5	GSM-850 and Europe RFID, Downlink Frequency.	(865 – 894)	879.5
6	GSM-900 and ISM USA Uplink Frequency	(925 – 960)	904

RF harvester module is an important part of the implementation for testing and verifying the results from the android app developed for measuring the RF signals. Harvester module complements the measurements from the app and allows testing the signals in the environment for possible energy harvesting. The strength of the signals in the environment will provide a certain threshold of the voltage generated after harvesting the RF signals. This will help determine on how much the signal strength needs to be increased to allow the sufficient harvesting of RF signals needed to power the wireless sensors.

The general overview of the harvester module is needed to understand its functionality and to determine what aspects can or may influence the result of the voltage generated. The block diagram in the Figure 47 provides an overall functionality of the harvester module with functionality of each component explained in detail.

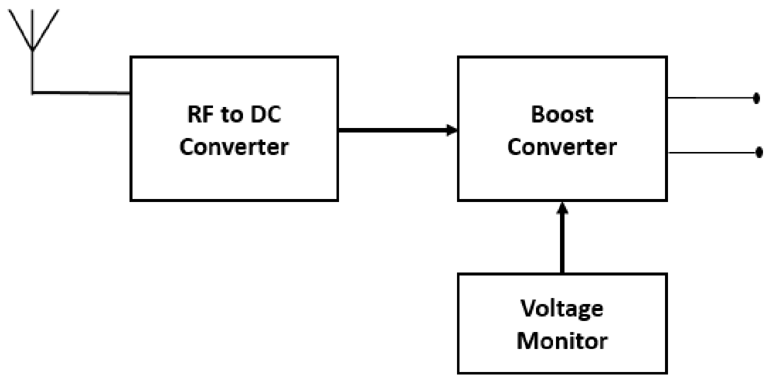

Figure 47 Block Diagram for Harvester Module

The input provided to the harvester module is received from the antenna in an unbalanced form. Antenna used can be any 50Ω standard or custom antenna suitable for the frequency range at which the harvester module is operating. RF input needs to be isolated from the ground; in case of the antennas considered as DC antennas, ground a high-Q DC blocking capacitor needs to be added in series to resistor.

The circuitry in RF to DC converter takes the RF input and converts it to the DC signal. The signal generated is very weak and required amplification by the Boost Converter, to make it useful. The voltage detectors monitor the DC power. User can select among the list of options for voltage needed, as well, the user can select a capacitor from the three capacitors present for storing the voltage.

Once a particular capacitor is selected, the boost convertor charges up the capacitor and is stored in the capacitor allowing it to be used at the user's discretion. The user can utilize the voltage by connecting the components directly on the circuit board or by connecting rechargeable batteries for recharging. The voltage monitor allows the user to know when a voltage is present, further it can be used to disconnect the voltage present at the output. This is carried out before storage capacitor reaches its lower limit i.e. Vmin, thus saving energy and improving the rechargeable time.

Setting Output Voltage

The option marked as 'DEFAULT' allows the Vout (output voltage) to be at 3.3V. Output voltage can also be adjusted to one of the two-labelled options 4.1V and 4.2V. Apart from this user can also adjust to a unique voltage in the range (2.0-5.5) Volts, just by altering the two resistors, R1 and R2, used with the output voltage. The resistor-voltage equation mentioned in (4) can be used for measuring the output voltage.

$$\boldsymbol{R2} = \frac{\boldsymbol{R1}}{\left(\frac{\boldsymbol{Vout}}{\boldsymbol{1.21}}\right) - \boldsymbol{1}} \tag{4}$$

R1 is set to 1MΩ that is connected between Vout and Vset. This allows to calculate different values for R2 based on the values of Vout. Three different values of R2 such as 578.9 kΩ, 418.7 kΩ and 404.7 kΩ are used to calculate three different sets of voltage for Vout. The corresponding values of voltage are 3.3V, 4.1V and 4.2V.

4.12 RF Antenna

The antenna used for testing the harvester is a GSM Omni directional antenna having a bandwidth of (824 - 960) MHz [54]. The Figure 48Figure 1 represents the GSM Omni directional antenna used to harvest the RF signals.

Figure 48 Omni Directional Antenna

In Finland, the GSM frequency that is deployed is E-GSM-900 known as Extended GSM-900 band and comprises of standard GSM-900 band, as well. It has an uplink frequency in the range of (880.0-915.0) MHz and downlink frequency having a range of (925.0-960.0) MHz [55]. The RF harvester module makes use only of the downlink frequency of the E-GSM-900 band; RF harvester module has a center frequency of 879.5 MHz [38]. Specifications of the GSM antenna are mentioned as follows in the Table 5.

Table 5 Antenna Specifications

Title	Value
Gain	2 dBi
Frequency Range	824-896MHz OR 890-960MHz
VSWR	≤1.5
Max input power	50 W
Input impedance	50Ω
Antenna Length	75mm
Polarization	Vertical
Operating Temperature	-45℃ to +75℃
Color	Black
Directionality	Omni-directional
Connector	SMA Plug right angle
Weight	15g
Bandwidth	70/180

5. RESULTS AND DISCUSSION

5.1 GSM Measurements

The direction of this chapter, is to analyze the outcomes received from chapter 4 i.e. implementation and use them as a basis to test out the RF harvester. The discoveries made during the results and implementation are mentioned along with the limitations present. The results discussed in this chapter consists of signal survey of the test environment in the FASTory lab and that is the production line. Numerical and quantitative calculations are made to achieve the desired results, their significance and analyze them in scope of the thesis.

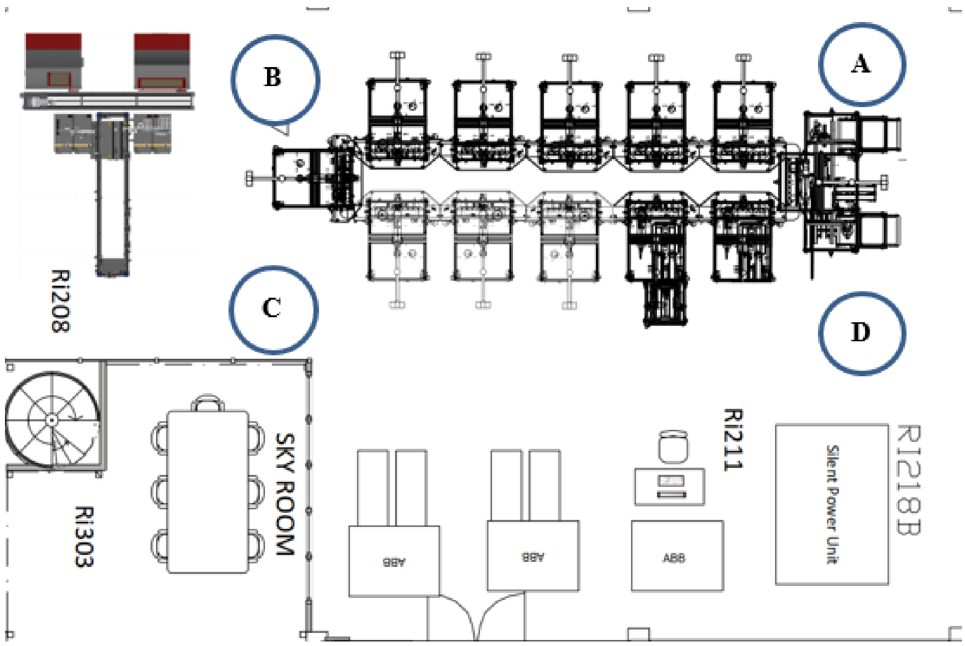

Figure 49 Layout of FASTory Laboratory

The Figure 49 shows the layout of the FASTory lab, the FASTory line can be seen in the layout consisting of the 12 work stations placed in a rectangular arrangement. There are four points represented by circles around the FASTory production line namely A, B, C and D. These four points are the test points where minimum and maximum signal strength for the android cell phone is measured based on utilizing services of different cell operators.

The cell operators that are used for different test cases are [6]Elisa, [7]DNA and [8]Telia with their respective signal strength mentioned below in the Table 6, Table 7 and Table 8. These are the commonly used cell operators providing their services in Finland. These operators provide services by erecting network of cell towers geographically around the Finland. The cell towers are denser in urban areas and less dense in rural areas. The signal strength mentioned in the tables are measured in a common unit of dBm that allows the comparison to be made easily.

5.1.1 Elisa

Table 6 Signal Strength Elisa

Test Point	Min Signal Strength (dBm)/3G	Max Signal Strength (dBm)/4G
A	-107.34	-104.36
B	-103.35	-104.36
C	-104.36	-107.33
D	-102.38	-102.37

5.1.2 DNA

Table 7 Signal Strength DNA

Test Point	Min Signal Strength (dBm)/3G	Max Signal Strength (dBm)/4G
A	-103	-105
B	-105	-106
C	-100	-104

[6] https://elisa.fi/
[7] https://www.dna.fi/
[8] https://www.telia.fi/

D	-101	-107

5.1.3 Telia

Table 8 Signal Strength Telia

Test Point	Min Signal Strength (dBm)/3G	Max Signal Strength (dBm)/4G
A	-108	-109
B	-106	-108
C	-105	-106
D	-109	-111

In telecommunication 3G refers to third generation and 4G refers to 4th generation. One of the difference between the two is the utilization of the technologies. For 3G this include using technologies such as WCDMA, EV-DO and HSPA among others. For 4G this refers to technologies such as LTE, WiMax and UMB. In comparison to 3G, 4G have a much higher speed such as 100 Mbps when a user is moving. In case if the user is stationary then the speed is 1 Gbps. Whereas 3G speeds at current, are 14Mbps of downlink and 5.8Mbps of uplink. [56]

The Figure 50 gives a location of the Elisa cell towers located near the FASTory lab. An app named openSignal [57] is used to identify the location of the nearest cell tower connected with the cell phone. The nearest Elisa cell tower is few meters away from the cell phone. In this case the connected cell tower in Figure 50 has a CELL ID of 5023 and a location area code (LAC) of 3050. Two other Elisa cell towers are also visible in the map.

5.1.4 Cell Towers Distribution

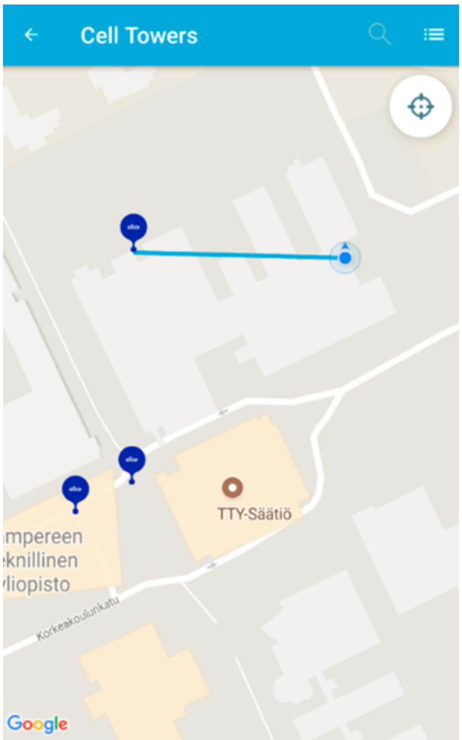

Figure 50 Elisa Cell Tower Location

After identifying the nearest cell tower, the strength of the incoming signals is then measured. Initially cell phone is run in the 3G mode and signal strength is noted over a period of 30 minutes with intervals of 10 seconds each. Then the phone is switched to the 4G mode and the signal strength is measured again over the same interval of time. A visual representation of the signal strength vs time is represented in the Figure 51. In 4G mode, the maximum signal strength that was measured is -96 dBm, achieved only when the cell phone is pointed towards the direction of the cell tower and the minimum signal strength that was measured is -104 dBm. In 3G mode the maximum signal strength that was measured is -101 dBm and the minimum signal strength that was measured is -108 dBm.

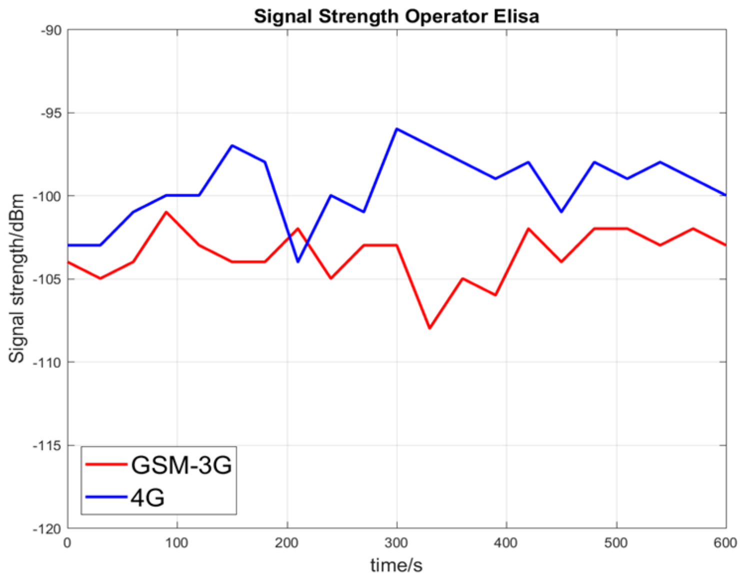

Figure 51 Signal Strength vs Time for Elisa

Similar tests are carried out with operator's DNA and Telia, the Figure 52 shows various cell towers for DNA near the FASTory laboratory. In the map one of the cell tower is connected with the user. The user is connected with the cell tower having a Cell ID number of 5023 and the location area code of 3050. The Figure 53 displays the strength of the signal measured over time for the DNA cell operator.

Figure 52 DNA Cell Tower location

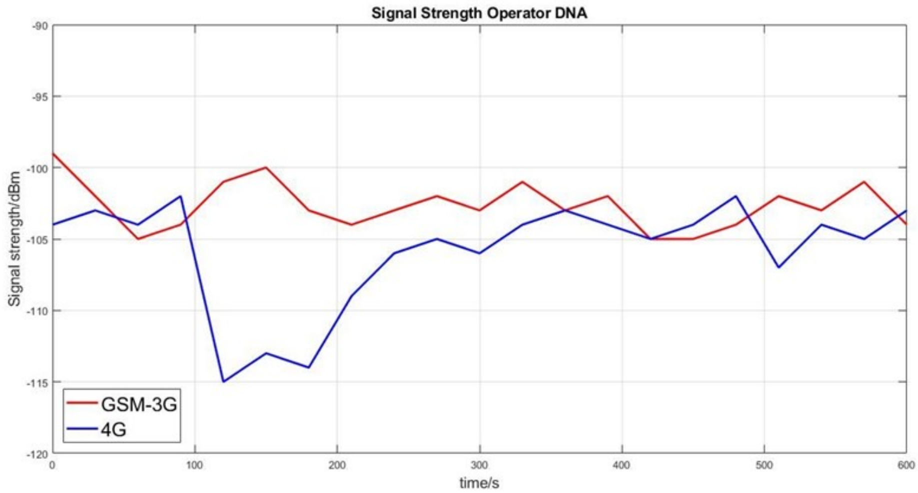

Figure 53 Signal Strength vs Time for DNA

The curves in the graph in Figure 53 are the signal strength measure in dBm and are a function of time. The red curve represents the signal strength measured when the cell phone is operating on a 3G mode. Whereas the blue curve represents the signal strength measured with the cell phone running in 4G mode. The maximum signal strength in 3G mode is -99 dBm and the minimum signal strength is -105 dBm. For the 4G mode the maximum signal strength is -103 dBm and the minimum as -115 dBm. Similarly Figure 54 shows the cell towers detected for cell operator Telia and their locations on the map. In the map it can be seen among the two cell towers of Telia one of them is connected with the user. The CELL ID of the connected cell tower is 167036 and Location Area Code (LAC) of 5002.

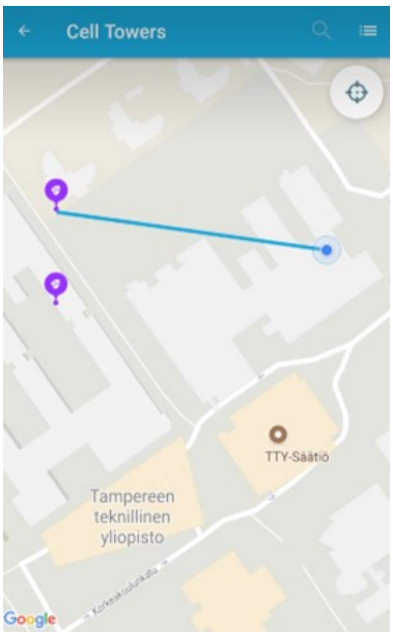

Figure 54 Telia Cell Tower Location

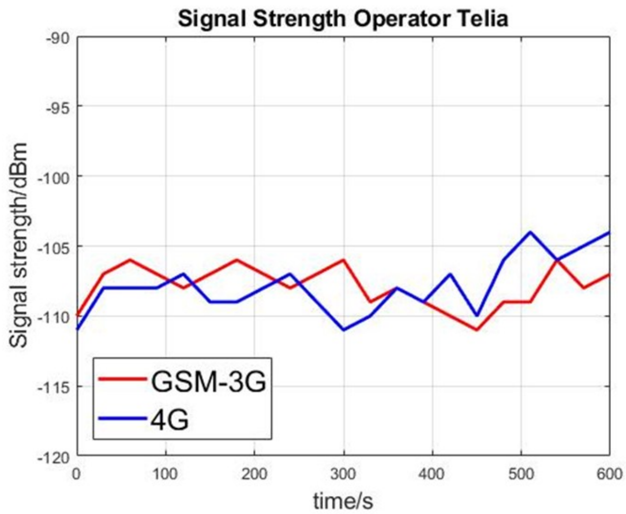

Figure 55 Signal Strength vs Time for Telia

The Figure 55 displays the signal strength vs time for Telia measured in a duration of 30 minutes. The curves in the graph represents the signal strength measure in dBm and are a function of time. The red curve represents the signal strength measured when the cell phone is operating on a 3G mode. Whereas, the blue curve, signifies the signal strength measured when cell phone is running in 4G mode. The maximum signal strength in 3G mode is -106 dBm and the minimum signal strength is -111 dBm. For the 4G mode the maximum signal strength is -104 dBm and the minimum as -111 dBm.

5.2 Power Calculations

Friis transmission equation discussed in [58] needs to be utilized in order to determine how much power was transferred from the cell phone to the RF harvester. For this purpose, parameters for both the source and the harvester module needs to be known as mention in the Table 9. Friis transmission equation is described in (5).

$$\boldsymbol{P_r = \frac{P_t G_t G_r \lambda^2}{(4\pi R^2)}} \tag{5}$$

Where,

P_r= Power received

P_t= Output power of the transmitting antenna

G_t= Gain of the transmitting antenna used

G_r= Gain of the receiving antenna

$\boldsymbol{\lambda}$ = Wavelength

R = Distance among the antennas

Table 9 Table Parameters for RF Harvester and Cell Phone

Cell Phone Parameters	Value	RF Harvester Parameters	Value
Model Number	One plus 3 Europe	Model Number	P21XXCSR-EVB
Antenna Gain	0-3 dB	Antenna Gain	2 dBi or -0.15 dB
Frequency	E-GSM-900 (925-960) MHz	Frequency	N/A
Power transmitted	30-33 dBm	-	-

5.2.1 Calculations

A. Where frequency = 925 MHz, distance between antennas = 0.33 m, antenna gain 0 = dB, and power transmitted = 30 dBm.

   Power received at the RF harvester module = **7.71 dBm**

B. Where frequency = 960 MHz, distance between antennas = 0.33 m, antenna gain 3 = dB, and power transmitted = 33 dBm.

   Power received at the RF harvester module = **13.40 dBm**

From the calculations above it can be seen that the range of the power received at the RF harvester lies between 7.71 dBm to 13.40 dBm. The theoretical range, roughly estimated is between 0.5W to 2.0W and is comparative to the average power of a GSM network waves or a mobile phone. Powercast power calculator [59] has also been utilized in estimating and completing the power calculations. However, in reality the power received is much less due to the losses occurring on different factors.

5.3 Test Cases

5.3.1 No Obstacle

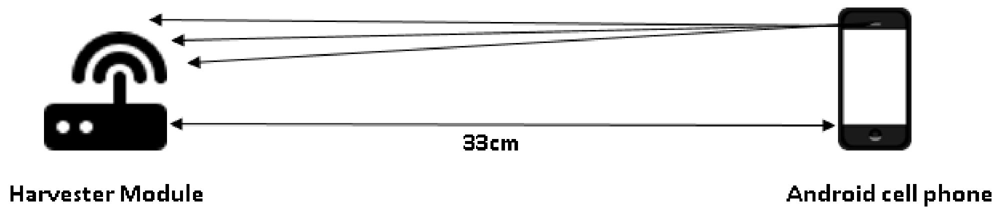

Figure 56 Harvester Test Case 1

In the very first test case, scenario in the Figure 56 phone is placed in the line of sight of the harvester module. The cell phone is moved around the harvester module antenna so that the RF signals from the cell phone falls within the radiation pattern of the omni directional antenna. Once the RF signals falls among the range of the radiation pattern of antenna it starts resonating with the antenna and antenna starts receiving the signal.

The phone is initially running on 3G mode with no downloads and data net deactivated. The capacitor in the harvestor module charges up but the charge in the capacitor is not sufficient enough to power up the test LED present on the harvestor board itself. Eventually data net is activated with the phone making download through the data net and it runs on the 4G mode. This increases the intensity of the received RF signal at the phone, the harvester module in turn make use of this harvested RF signal and charges up the capacitor. The voltage across the capacitor reaches upto 0.73 volts, sufficient enough to make an LED blink for a second. As the LED blinks the capacitor dicharges right away and then again starts charging up. This continues as long as the source of RF signal from the cell phone is present.

As we move the cell phone near the harvester, the blinking rate of an LED increases as capacitor charges and discharges quickly. As we move the cell phone away from the harvester module the blinking rate of LED decreases, this is due to the inverse square law of electromagnetic radiation [60]. With low intensity of RF signals, the capacitor needs more time to charge up thus reducing the blinking rate of LED. As we move the phone further away from the harvester module the blinking rate of LED keeps decreasing until the LED switches off, the maximum distance at which the LED still keeps blinking is 33cm. Any distance more than this the LED simply switches off as the intensity of RF signal is not enough to charge the capacitor to turn on the LED.

5.3.2 Obstacle Present

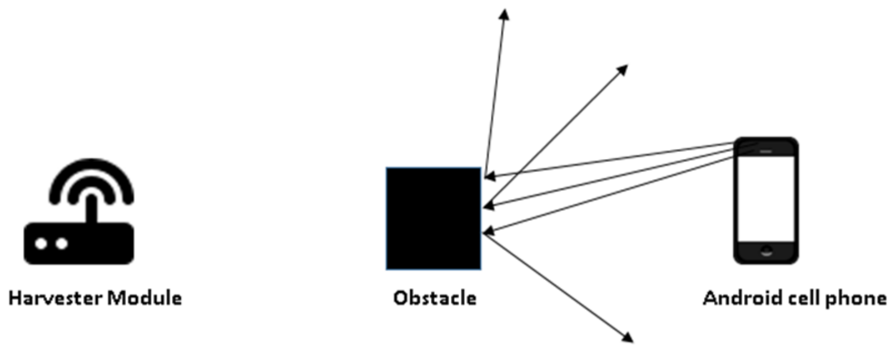

Figure 57 Harvester Test Case 2

In the second test case, Figure 57, an obstacle is present between the cell phone and the harvester module. It is observed that the obstacle considerably blocks and scatter the RF signals arriving from the cell phone into the environment. Thus, little or very less amount of RF signals reaches the harvester module. With small amount of RF signals the capacitor charges up to a very small amount of charge and this amount of charge is not sufficient to make an LED blink. Furthermore, when the obstacle is removed, the path for the RF signals is cleared and it then starts charging up the harvester module and eventually LED starts blinking.

5.3.3 Multiple Sources

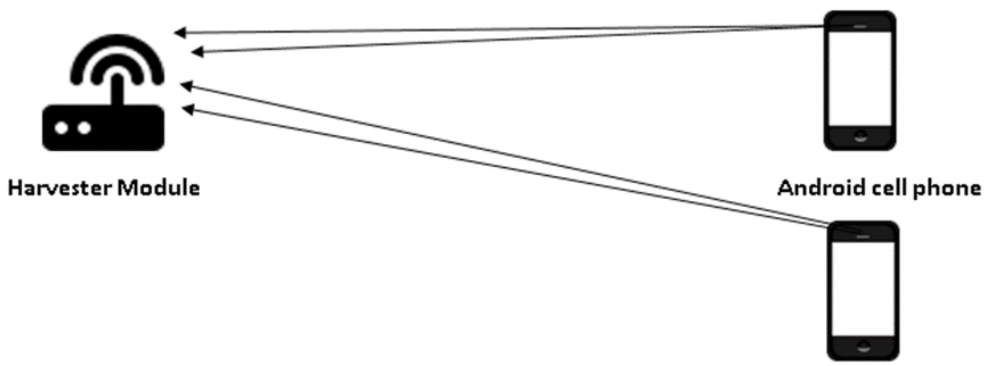

Figure 58 Harvester Test Case 3

In 3rd test case, Figure 58, multiple sources of RF signal are used i.e. two cell phones are used and placed at the same distance away from the harvester module. Both the cell phones are running in 4G mode. During the observation, no considerable changes are observed by the presence of second source of RF signals. The capacitor takes same time and stores the same amount of charge as with one cell phone present. The LED blinks at the same rate as observed previously with one cell phone. This leads to the conclusion that increasing the strength of RF signal has the only effect if compared with the number of RF sources.

5.3.4 Harvester Module Stacked on top of Cell Phone

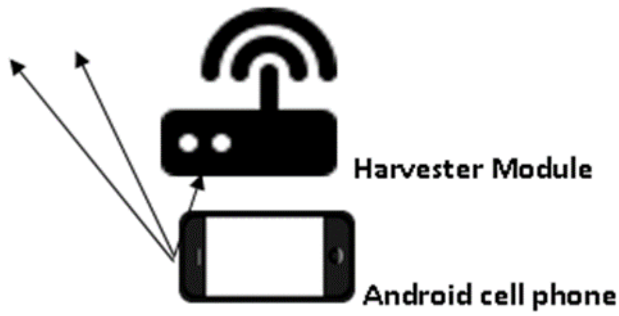

Figure 59 Harvester Test Case 4

In the last i.e. the fourth test case, Figure 59, harvester module is placed on top of the source of RF signal. This placement mimics the real-life placement of pallet and the sensor consisting of gyroscope and accelerometer. With this arrangement, the bottom of the harvester module itself blocks some of the signals, while the remaining signals make it near the radiation pattern of the antenna. These signals are harvester and charges up the capacitor.

5.3.5 Capacitor Charging

As the harvester module starts working and converts the RF signal to the DC current. The 2200uF electrolytic capacitor starts charging up as the voltage around it starts increasing and decreases suddenly when it discharges to power up an LED. The graphical representation of the charging up of the capacitor is represented in Figure 60 in terms of voltage vs time.

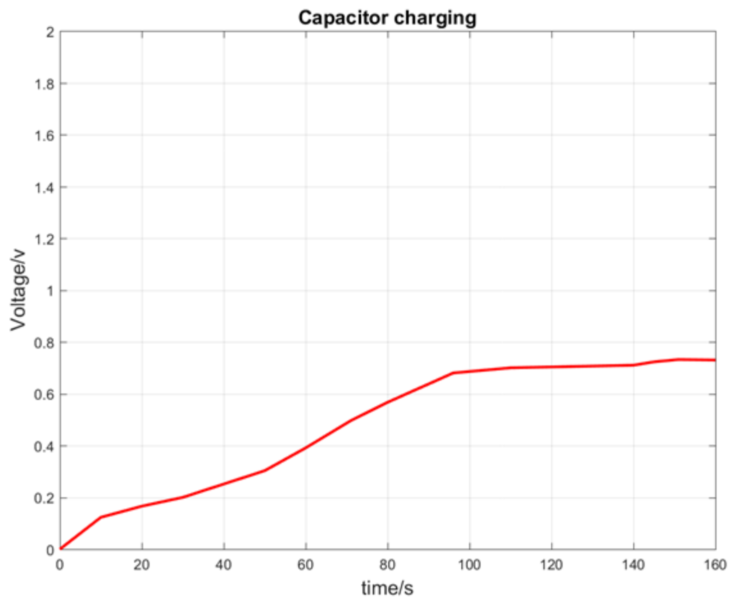

Figure 60 Voltage vs Time for Capacitor

6. CONCLUSION

This chapter summarizes the research work carried out during duration of the thesis. It further mentions the accomplishments that are carried out through the implementation and tests. As all systems and solutions have limitations, the proposed solution in this thesis is no different. There are also some challenges and limitations associated with RF energy systems. In the end, there is a mention for the future prospects, if the system needs to be expanded or adapted to different uses.

6.1 Accomplishments

RF Signal Measurement

One of the objectives includes creating a solution that measures the radio frequency (RF) signals in the environment. in the proposed solution android app is developed and tested that successfully measures the RF signals in the ambient environment mainly RF signals from access points (Wi-Fi) and cell phones. In the approach, the proposed solution makes use of the cell phone sensors to detect and measure the signal parameters that are required for the knowing the strength of the signals.

Visualization of RF signals

The android app successfully accesses the signal parameters from cell phone signals or the Wi-Fi access points. The strength of the signals is successfully visualized through graphs that makes it visually comprehensible for the user. The rest of the parameters are transferred as JSON (JavaScript Object Notation) objects. The JSON is a format used for the exchange of information, since it can be easily read and written by humans.

Communication between Android App and FASTory Line

The proposed solution is then successfully integrated with the FASTory assembly line by making use of the protocols that allows successful communication between each other. Communication between the android app and the FASTory line is of significance since the assembly line serves as the testbed for creating an RF map. The RF map for the assembly lines helps decide what places are there on the assembly line where the signal strength is the strongest and can be utilized for harvesting. Furthermore, it also provides an insight into different locations on the conveyors that can be served as a spot for putting RF beacons. Placing the RF beacons or RF transmitter provides strong RF energy that can be harvested and have a significant amount of voltage required to power up the wireless sensors.

6.2 Challenges and Limitations

The proposed solution has successfully met the objectives of the thesis. However, there are certain challenges and limitations associated with the system. Initially the proposed solution or the android app developed is customized for the FASTory line. However, the android app can be utilized in generic physical environments for measuring signal strength but with limited functionality. The proposed solution makes used of the WI-FI access points and the cell phone signals as the source of RF energy. The other RF energy sources are not taken into account and thus cannot be used to harvest the energy.

The RF harvester module requires a straight, line of sight (LOS), among itself and the source of RF energy; with no line of sigh present, the RF harvester cannot harvest the energy. Furthermore, there needs to be a minimum distance between the RF harvester and the source of RF energy. If the distance between the two are more than 33 cm, then the signals for RF harvester are out of range and can no longer be utilized for energy harvesting.

There is a significant loss of energy during the operation that is limited by various factors. This leads to the energy being harvested quite less than the estimated harvested energy. Additionally, since the RF harvester operates on a range of frequencies, this leads the user to test different antennas for testing and eventually selecting the one that provides the best efficiency for energy harvesting. In addition, the current source of RF energy is not reliable as it varies sufficiently with time and possess limited amount of energy. Thus, a dedicated RF energy source with high-energy RF signals is required for harvesting the needed voltage for powering the wireless sensors.

6.3 Future Prospects

The current thesis work focuses on using the android app for the FASTory line and using different protocols for the communication. In the future android cap can be extended with additional functionalities that allow the user to use it any physical environment. Similarly, app can be equipped with functionalities that allows the user to know the location of the nearby cell phone towers that the phone relates to and getting signals from. Furthermore, a dedicated RF source can be provided that gives strong RF signals that can be harvested to get the voltage that is needed for powering up the wireless sensors.

REFERENCES

[1] "The Fourth Industrial Revolution: what it means and how to respond". World Economic Forum. Retrieved 2018-03-20.

[2] Wollschlaeger, Martin, Thilo Sauter, and Juergen Jasperneite. "The future of industrial communication: Automation networks in the era of the internet of things and industry 4.0." IEEE Industrial Electronics Magazine 11.1 (2017): 17-27.

[3] Hermann, Mario, Tobias Pentek, and Boris Otto. "Design principles for industrie 4.0 scenarios." System Sciences (HICSS), 2016 49th Hawaii International Conference on. IEEE, 2016.

[4] Kortuem, Gerd, et al. "Smart objects as building blocks for the internet of things." IEEE Internet Computing 14.1 (2010): 44-51.

[5] Miragliotta, Giovanni, Alessandro Perego, and Angela Tumino. "Internet of things: smart present or smart future." Proceedings of XVII Summer School Francesco Turco (2012).

[6] Westkämper, E. and Jendoubi, L., 2003, June. Smart factories-manufacturing environments and systems of the future. In Proceedings of the 36th CIRP International Seminar on Manufacturing Systems (pp. 13-16).

[7] Becker, Christian, and Armin Scholl. "A survey on problems and methods in generalized assembly line balancing." European journal of operational research 168.3 (2006): 694-715.

[8] Scholl, A. and Becker, C., 2006. State-of-the-art exact and heuristic solution procedures for simple assembly line balancing. European Journal of Operational Research, 168(3), pp.666-693.

[9] Louis, D., 1963. Pallet for industry. U.S. Patent 3,092,046.

[10] H. Kagermann, “Change Through Digitization – Value Creation in the Age of Industry 4.0”, in: Albach, H., H. Meffert, A. Pinkwart, and R. Reichwald, eds., Management of Permanent Change, Springer, New York, 2015, pp. 23-45

[11] Tao, F., Cheng, Y., Da Xu, L., Zhang, L. and Li, B.H., 2014. CCIoT-CMfg: cloud computing and internet of things-based cloud manufacturing service system. IEEE Transactions on Industrial Informatics, 10(2), pp.1435-1442.F

[12] Prime Faraday Technology Watch An Introduction to MEMS (Microelectromechanical Systems) Loughborough University Loughborough PRIME Faraday Partnership 2002.

[13] Beeby, Steve, et al. MEMS Mechanical Sensors, Artech House, 2004. ProQuest Ebook Central, https://ebookcentral.proquest.com/lib/tut/detail.action?docID=231651.

[14] Scarborough, J.B., 1958. The Gyroscope. Interscience Publishers Limited.

[15] Post, E.J., 1967. Sagnac effect. Reviews of Modern Physics, 39(2), p.475

[16] A. Albrecht and J. Petereit, "Application of an off-the-shelf Fiber Optic Gyroscope based Inertial Measurement Unit for attitude and heading estimation," *2017 IEEE SENSORS*, Glasgow, 2017, pp. 1-3.

[17] Weinstein, R., 2005. RFID: a technical overview and its application to the enterprise. IT professional, 7(3), pp.27-33.

[18] De Mayo, B., 2015. Wave properties. Morgan & Claypool Publishers.

[19] Stutzman, W.L. and Thiele, G.A., 2012. Antenna theory and design. John Wiley & Sons.

[20] Papazoglou, M.P. and Van Den Heuvel, W.J., 2007. Service oriented architectures: approaches, technologies and research issues. The VLDB journal, 16(3), pp.389-415.

[21] F. Jammes and H. Smit, "Service-oriented paradigms in industrial automation,"

IEEE Trans. Ind. Informatics, vol. 1, no. 1, pp. 62–70, 2005.

[22] Huhns, M.N. and Singh, M.P., 2005. Service-oriented computing: Key concepts and principles. IEEE Internet computing, 9(1), pp.75-81.

[23] Ramis, B., Gonzalez, L., Iarovyi, S., Lobov, A., Lastra, J.L.M., Vyatkin, V. and Dai, W., 2014, July. Knowledge-based web service integration for industrial automation. In Industrial Informatics (INDIN), 2014 12th IEEE International Conference on (pp. 733-739). IEEE.

[24] Lin, G.C., Desmond, K.E.T., Htoon, N.T. and Thuat, N.V., 2011. A Fresh Graduate's Guide to Software Development Tools and Technologies. Chapter-10: Service Oriented Architecture, School of Computing, National University of Singapore.

[25] W3.org. (2018). Extensible Markup Language (XML). [online] Available at: https://www.w3.org/XML/ [Accessed 3 Apr. 2018].

[26] Bray, T., Paoli, J., Sperberg-McQueen, C.M., Maler, E. and Yergeau, F., 1997. Extensible markup language (XML). World Wide Web Journal, 2(4), pp.27-66.

[27] Ankolekar, A., Burstein, M., Hobbs, J.R., Lassila, O., Martin, D., McDermott, D., McIlraith, S.A., Narayanan, S., Paolucci, M., Payne, T. and Sycara, K., 2002, June. DAML-S: Web service description for the semantic web. In International Semantic Web Conference (pp. 348-363). Springer, Berlin, Heidelberg.

[28] Lobov, A. (2017). ASE-9476 FIS: SOAP and CAMX (IPC-2501), Tampere University of Technology.

[29] Wilde, E. and Pautasso, C. eds., 2011. REST: from research to practice. Springer Science & Business Media.

[30] Cesare Pautasso, "REST vs. SOAP: Making the Right Architectural Decision," 2008.

[31] Iarovyi, S., Mohammed, W.M., Lobov, A., Ferrer, B.R. and Lastra, J.L.M., 2016. Cyber–physical systems for open-knowledge-driven manufacturing execution systems. Proceedings of the IEEE, 104(5), pp.1142-1154.

[32] Mumbaikar, S. and Padiya, P., 2013. Web services based on soap and rest principles. International Journal of Scientific and Research Publications, 3(5), pp.1-4.

[33] Nechibvute, A., Chawanda, A. and Luhanga, P., 2012. Piezoelectric energy harvesting devices: an alternative energy source for wireless sensors. Smart Materials Research, 2012.

[34] Lu, X., Wang, P., Niyato, D., Kim, D.I. and Han, Z., 2015. Wireless networks with RF energy harvesting: A contemporary survey. IEEE Communications Surveys & Tutorials, 17(2), pp.757-789.

[35] Elvin, N. and Erturk, A. eds., 2013. Advances in energy harvesting methods. Springer Science & Business Media.

[36] Adachi, H., Uchida, K.I., Saitoh, E. and Maekawa, S., 2013. Theory of the spin Seebeck effect. Reports on Progress in Physics, 76(3), p.036501.

[37] Seah, W.K. and Olds, J.P., 2013. Wireless sensor network powered by RF energy harvesting: design and experimentation. School of Engineering & Computer Science, Victoria University of Wellington, New Zealand.

[38] Powercast Corporation, “Powerharvester receivers and powercaster transmitters”, last accessed on : 04 Apr 2018. [Online]. Available: https://www.powercastco.com/products/

[39] Aziz, A.A., Tribudi, D., Ginting, L., Rosyady, P.A., Setiawan, D. and Choi, K.W., 2015. RF energy transfer testbed based on off-the-shelf components for IoT application. 한국통신학회논문지, 40(10), pp.1912-1921.

[40] Pautasso, C., Zimmermann, O. and Leymann, F., 2008, April. Restful web services vs. big'web services: making the right architectural decision. In Proceedings of the 17th international conference on World Wide Web (pp. 805-814). ACM.

[41] Developer.android.com. (2018). Download Android Studio and SDK Tools | Android Studio. [online] Available at: https://developer.android.com/studio/index.html [Accessed 3 Apr. 2018].

[42] Tut.fi. (2018). FASTory - Tampere University of Technology. [online] Available at: http://www.tut.fi/en/fast/fastory/index.htm [Accessed 3 Apr. 2018].

[43] Bermejo, C. and Hui, P., 2017. Steal Your Life Using 5 Cents: Hacking Android Smartphones with NFC Tags. arXiv preprint arXiv:1705.02081.

[44] Ok, K., Coskun, V., Aydin, M.N. and Ozdenizci, B., 2010, November. Current benefits and future directions of NFC services. In Education and Management Technology (ICEMT), 2010 International Conference on (pp. 334-338). IEEE.

[45] Inico S1000 User Manual. (2018). [ebook] Inico Technologies Ltd. Available at: http://www.inicotech.com/doc/S1000%20User%20Manual.pdf [Accessed 3 Apr. 2018].

[46] User Manual 6LowPAN modules. (n.d.). Inico Technologies Ltd.

[47] Mouser Electronics. [Online] http://fi.mouser.com/ProductDetail/Atmel/ATZB-24-A2/

[48] SEDLACEK, T. (2012). A REAL-TIME POSITIONING SYSTEM OF MANUFACTURING CARRIERS DEPLOYING WIRELESS MEMS ACCELEROMETERS AND GYROSCOPES. Master of Science. Tampere University of Technology.

[49] Ramis, B., Gonzalez, L., Iarovyi, S., Lobov, A., Lastra, J.L.M., Vyatkin, V. and Dai, W., 2014, July. Knowledge-based web service integration for industrial automation. In Industrial Informatics (INDIN), 2014 12th IEEE International Conference on (pp. 733-739). IEEE.

[50] Sleman, A. and Moeller, R., 2008, April. Integration of wireless sensor network services into other home and industrial networks; using device profile for web services (DPWS). In Information and Communication Technologies: From Theory to Applications, 2008. ICTTA 2008. 3rd International Conference on (pp. 1-5). IEEE.

[51] Burkhardt, J., Schaeck, T., Henn, H., Hepper, S. and Rindtorff, K., 2001. Pervasive computing: technology and architecture of mobile Internet applications. Addison-Wesley Longman Publishing Co., Inc.

[52] Masse, M., 2011. *REST API Design Rulebook: Designing Consistent RESTful Web Service Interfaces*. " O'Reilly Media, Inc."

[53] P21XXCSR-EVB. (2017). [ebook] PowerCast. Available at: http://www.powercastco.com/wp-content/uploads/2017/01/P21XXCSR-EVB-Datasheet-v1.3.pdf [Accessed 3 Apr. 2018].

[54] Rfsupplier.com. (2017). RF coaxial connectors,adapters, cable assemblies,aluminum enclosure,3G/GSM/WI-FI /GPS antennans | Shenzhen think send music Electronics Co., Ltd.. [online] Available at: https://www.rfsupplier.com/ [Accessed 3 Apr. 2018].

[55] Frequencycheck.com. (2017). Finland Wireless Frequency Bands and Carriers. [online] Available at: https://www.frequencycheck.com/countries/finland [Accessed 3 Apr. 2018].

[56] Kumaravel, K., 2011. Comparative study of 3G and 4G in mobile technology. IJCSI International Journal of Computer Science Issues, 8(5).

[57] Play.google.com. (2017). 4G Wi-Fi Maps & Speed Test. Find Signal & Data Now. (Beta). [online] Available at: https://play.google.com/store/apps/details?id=com.staircase3.opensignal [Accessed 3 Apr. 2018].

[58] Friis, H.T., 1946. A note on a simple transmission formula. Proceedings of the IRE, 34(5), pp.254-256.

[59] Powercast Co. (2017). Power Calculator - Powercast Co. [online] Available at: http://www.powercastco.com/power-calculator/ [Accessed 4 Apr. 2018].

[60] Heald, M.A. and Marion, J.B., 2012. Classical electromagnetic radiation. Courier Corporation.

APPENDIX A: ANDROID APPLICATION CODE

DETECTING AND CREATING LIST FOR Wi-Fi ACESS POINTS

```
private void scanWifiNetworks(){


                arraylist.clear();

                getActivity().registerReceiver(wifi_receiver, new
IntentFilter(WifiManager.SCAN_RESULTS_AVAILABLE_ACTION));


                wifi.startScan();


                Log.d("WifScanner", "scanWifiNetworks");


                Toast.makeText(this.getActivity(), "Scanning....", Toast.LENGTH_SHORT).show();


            }
```

```
BroadcastReceiver wifi_receiver= new BroadcastReceiver()
        {
          @Override
          public void onReceive(Context c, Intent intent)
          {
            Log.d("WifScanner", "onReceive");
            results = wifi.getScanResults();
            size = results.size();
            getActivity(). unregisterReceiver(this);
            try
            {
              for (ScanResult scanResult : results) {
                //int level = WifiManager.calculateSignalLevel(scanResult.level, 5);
                arraylist.add(scanResult.SSID + " \t\t\t\t\t\t " +scanResult.level+" dbm  " +
scanResult.frequency + "  MHz");
                adapter.notifyDataSetChanged();
                System.out.println("Level is " + level + " out of 5");
              }
            }
            catch (Exception e)
            {
              Log.w("WifScanner", "Exception: "+e);
            }
          }          };
```

CONNECTING TO ACCESS POINT

```
AlertDialog.Builder adb = new AlertDialog.Builder(
                wifi.this.getActivity());
            adb.setTitle(String.valueOf(parent.getItemAtPosition(position)));
            adb.setMessage("HEllo HELLO");
            //Context context = mapView.getContext();
            final String ssid = String.valueOf(parent.getItemAtPosition(position));
            final EditText input = new EditText(wifi.this.getActivity());
            adb.setView(input);
            adb.setPositiveButton("Connect", new DialogInterface.OnClickListener() {
              public void onClick(DialogInterface dialog, int whichButton) {
                String value = input.getText().toString().trim();


                WifiConfiguration wifiConfig = new WifiConfiguration();
                wifiConfig.SSID = "\"ashh\"";
                wifiConfig.preSharedKey = "\"purple77\"";
```

ACCESSING SIGNAL PARAMETERS

```
  //if wifi connected then show TOAST and start new Activity
if(abc) {
                Toast.makeText(wifi.this.getActivity(), "Connected",
Toast.LENGTH_LONG).show();
                WifiInfo wifiInfo = wifiManager.getConnectionInfo();
                int level = WifiManager.calculateSignalLevel(wifiInfo.getRssi(), 5);
                wifiInfo.getLinkSpeed();
                whole_data = wifiInfo.getSSID()+ " \t " +
                    wifiInfo.getBSSID()  + " \t " +
                    wifiInfo.getLinkSpeed()+ " \t " +
                    wifiInfo.getRssi()+ " \t " +
                    wifiInfo.getIpAddress()+ " \t " +
                    wifiInfo.getMacAddress()+ " \t " +
                    wifiInfo.getFrequency();
                Intent i = new Intent(wifi.this.getActivity(), wifiChild.class);
                //Create the bundle
                Bundle bundle = new Bundle();
                //Add your data to bundle
                bundle.putString("ssid", whole_data);
                //Add the bundle to the intent
                i.putExtras(bundle);
                startActivity(i);
              }
```

```
//we are just getting permission from user for phone access
            if (CheckPermission(phone.this.getActivity(), Manifest.permission.READ_PHONE_STATE)) {


              phone_data = abcd.getNetworkOperatorName()+ " \t " +
                    abcd.getSimOperatorName() + " \t " +
                    abcd.getSimCountryIso()+ " \t " +
                    abcd.getDataState()+" \t "+
                    cellSignalStrengthGsm.getDbm() +" \t "+
                    abcd.getDeviceId();
            } else {
              RequestPermission(phone.this.getActivity(), Manifest.permission.READ_PHONE_STATE,
123 );
              phone_data = "";
            };
```

COMMUNICATION AND DATA TRANSFER

```
public static void ConnectToServer(){
    try{
       socket2 = IO.socket("http://"+adres+":"+prt);
    }catch (URISyntaxException e){
       throw new RuntimeException(e);
    }
    socket2.connect();
    socket2.on("message",handleIncomingMessage);
    check();
 }
```