Wireless IoTSP Platform for Smart Factory:Field Device Monitoring and Augmented Reality

Submitted By

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INSTITUTE OF TECHNOLOGY

NIRMA UNIVERSITY

AHMEDABAD-382481

May 2017

Wireless IoTSP Platform for Smart Factory:Field Device Monitoring and Augmented Reality

Major Project

Submitted in partial fulfillment of the requirements

for the degree of

Master of Technology in Computer Science and Engineering

Submitted By

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Certificate

This is to certify that the major project entitled **"Wireless IoTSP Platform for Smart Factory:Field Device Monitoring and Augmented Reality"** submitted by **Mihit Gandhi (15MCEC13)**, towards the partial fulfillment of the requirements for the award of degree of Master of Technology in Computer Science and Engineering of Nirma University, Ahmedabad, is the record of work carried out by him under my supervision and guidance. In my opinion, the submitted work has reached a level required for being accepted for examination. The results embodied in this major project part-I, to the best of my knowledge, haven't been submitted to any other university or institution for award of any degree or diploma.

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This to certify that Mr. Mihit Gandhi (15MCEC13), a student of M.Tech CSE (Computer Science and Engineering), Institute of Technology, Nirma University, Ahmedabad is working in ABB since 01/06/2016 and carried out his thesis work titled **"Wireless IoTSP Platform for Smart Factory:Field Device Monitoring and Augmented Reality"**. He is working at Corporate Research Center, India as an intern under the guidance of Dr. Deepaknath Tandur. He is working on his assigned work and is allowed to submit his dissertation report. The results embodied in this project, to the best of my knowledge, havent been submitted to any other university or institution for an award of any degree or diploma. I wish him all the success in future.

Dr. Deepaknath Tandur
Principal Scientist,
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Statement of Originality

I, **Mihit Gandhi**, Roll. No. **15MCEC13**, give undertaking that the Major Project entitled "**Wireless IoTSP Platform for Smart Factory:Field Device Monitoring and Augmented Reality**" submitted by me, towards the partial fulfillment of the requirements for the degree of Master of Technology in **Computer Science & Engineering** of Institute of Technology, Nirma University, Ahmedabad, contains no material that has been awarded for any degree or diploma in any university or school in any territory to the best of my knowledge. It is the original work carried out by me and I give assurance that no attempt of plagiarism has been made.It contains no material that is previously published or written, except where reference has been made. I understand that in the event of any similarity found subsequently with any published work or any dissertation work elsewhere; it will result in severe disciplinary action.

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Acknowledgements

I want to express gratitude toward **Dr. Deepaknath Tandur** for giving me the chance to work under him, for his persistent support, direction, excitement, and most essentially to believe in me. I have learned a lot and my experience at ABB has been an extremely remunerating one. A debt of gratitude is in order for continually pushing me when I am stuck in this adventure. I could not have imagined having a better advisor and mentor for my M.Tech study. You have been a great supervisor.

A special thanks to my Co Guide at ABB, **Mr. Rahul Gore** and **Mr. Aravind Ingalalli** for giving me significant direction in this work. Much obliged for supporting me in all kind of conditions and trusting in me. Thanks for your support in overcoming numerous obstacles I have been facing through my work.

I also want to express my thanks to ABB Corporate Research Center for providing me the unique opportunity to carry out my thesis in Bangalore, India. I am very glad to work on practical topic from industry. I will miss the free coffee, the free tea, and the free discussion with great scientists in the pantry and Lab.

It gives me immense pleasure in expressing thanks and profound gratitude to **Prof. Monika Shah**, Associate Professor, Computer Science Department, Institute of Technology, Nirma University, Ahmedabad for his valuable guidance and continual encouragement throughout this work. The appreciation and continual support he has imparted has been a great motivation to me in reaching a higher goal. His guidance has triggered and nourished my intellectual maturity that I will benefit from, for a long time to come.

It gives me an immense pleasure to thank **Dr. Sanjay Garg**, Hon'ble Head of Computer Science and Engineering Department, Institute of Technology, Nirma University, Ahmedabad for his kind support and providing basic infrastructure and healthy research environment.

A special thank you is expressed wholeheartedly to **Dr. Alka Mahajan**, Hon'ble

Director, Institute of Technology, Nirma University, Ahmedabad for the unmentionable motivation he has extended throughout course of this work.

I thank my fellow labmates Neeraj, Himashri for the stimulating discussions, for the sleepless nights we were working together before deadlines, and for all the fun we have had in the last one year.Your ideas, thoughts and energy have been inspiring. Special thanks to Dipika for always helping me in making Presentation and figures. Many thanks to all the other friends I have made here.Your friendship has made life at Bangalore a lot easier. Journey of this one year is extremely pleasant with you individuals.

I would also thank the Institution, all faculty members of Computer Engineering Department, Nirma University, Ahmedabad for their special attention and suggestions towards the project work.

- Mihit Gandhi
15MCEC13

Abstract

Internet of Things adoption in traditional and slow changing industrial plants such as power, water, oil-gas and chemical has proven to be beneficial in providing business value by transforming the way data is utilized in decision making and visualization. Typical industrial IoT use cases involve acquiring data from sensor devices in plant and communicating the same to internet for local or remote monitoring and control. The sensor data acquisition in an industrial plant thus becomes paramount as the same acquired data is used for bringing out the underlying knowledge of system. IoT typically requires a local, low power wireless communication to acquire data from sensor devices and local gateway that can be connected to internet for local or remote monitoring and control. This paper describes how Bluetooth low energy (BLE) technology can be used to connect sensor nodes to Internet-based services and applications using gateway in an industrial plant. It also investigates the performance of BLE technology as a local communication for sensor device monitoring.

IoT infrastructure for a smart factory consists of lot of complex software which need to be tested properly. Some software application involve lots of user interactions and some are fully automated based on control signal. With the increase of technology, demand for proper testing methodology has got increased as well. There are lots techniques and tools for software testing. Different tools are used for different applications based on the requirement, technology and type.Among them, one of the most popular technique is model based testing. Due to its advantages of low cost and low time complexity, it is the best suitable approach for most of the applications.

Through the thesis, I have contributed in Internet of Things based Application and Bluetooth infrastructure which is collect data from different sensors via Bluetooth, applied algorithms on that data and generating results from that. Internet of Things based Application is also doing more interactive and immersed interaction with devices using Augmented Reality.

Keywords: Internet of Things (IoT); Wireless Communication; Sensor Monitoring; Device Monitoring; Bluetooth Low Energy (BLE)

Conventions

Typesetting

This thesis is typeset using Latex software.
Font used in this thesis are of Times new roman family.

Referencing

Referencing and citation style adopted in this thesis is ieee transaction(ieeetr).
For electronic references, Last publication date is shown here.

Spelling

The Unites States English Spelling is adopted here.

Units

The Units used in This thesis are based in the International System of Units(SI Units), unless specified.

Abbreviations

RPI	Raspberry Pi
AR	Augmented Reality
IoT	Internet Of Things
SDK	Software Development Kit
API	Application Program Interface
JSON	JavaScript Object Notation
RSSI	Received Signal Strength Indication
CSS	Cascading Style Sheet
IPS	Indoor Positing System
UWB	Ultra-wide Band
BLE	Bluetooth Low Energy
GATT	Generic Attribute
GAP	Generic Access Profile

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Chapter 1

Introduction

1.1 Internet of Things(IoT) for Smart Factory

Transfer a data over the network without any interaction with the machine by using some device as a gateway. Industrial IoT incorporates Machine learning, Big Data Technology, harnessing sensor data, machine-to-machine (M2M) communication and automation technologies that have existed in the smart factory setting for years. Main motive behind Industrial IoT is that smart machines are better than humans at accurately, consistently capturing and communicating data. In Industrial IoT, devices and machines using different protocols and have different architecture. So in this thesis different wireless communication protocol is implemented in different architecture for smart factory.

In this project, mobile phone is working as a gateway for collecting the data from sensors which located at smart factory network. In the context of Wireless Sensor Networks read and collected data from the different sensor and devices is a very hot topic. There are so many different parameters (Temperature, Pressure, Motor Speed etc.) are monitored, so it is difficult if the only PC is collecting data from the different sensors and devices.

Because of this reason, great challenges for this topic are to decide which is the most suitable means for sensors and devices is and how to manage data exchange between mobile and sensor and lastly how to display the data to the user on the mobile phone as well as on the server. This project aims to address these challenges by developing an android application which is working as a gateway. In this approach, it followed Bluetooth as a

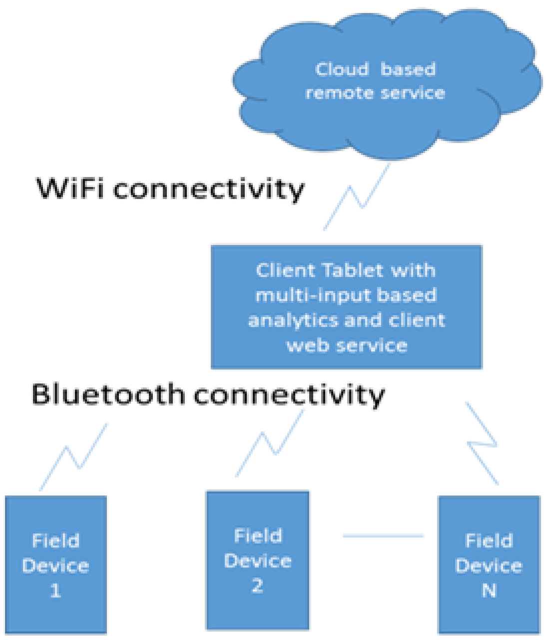

Figure 1.1: Basic Infrastructure

communication protocol between a sensor and mobile phone. Furthermore, the device on which the work has evolved is an Android smartphone, for which the Application has been developed.

1.2 Project Detail

In this venture, Android application is developed which gathers the information intermittently from various sensors and gadgets utilizing Bluetooth as a communication protocol, display the data and information on mobile or any smart device and send that data to the web server periodically,the web server can be stored the data.

In smart factory tracking of people and assets is also a much needed thing nowadays. If industry or company have his own tracking system then it must save time and money for the company. With this Bluetooth infrastructure, tracking of people and assets is also does. Using this web-based application one can do accurate asset management in the factory as well as track the worker in a real time.

Apart from Bluetooth other wireless communication protocol like Wi-Fi, MQTT is also explained in this thesis.Presently days there is diverse Wi-Fi system is there for one industry so checking all the system from the one place is likewise imperative perspective.

For that here created a web application which does range investigation of Wi-Fi system and gives the proposal in various parameters of the system like channel Selection, Load Balancing, Path selection and so forth.

1.3 Problem Motivation

The Internet of Things refers to the networking among day-to-day objects or devices with the internet enabled control system. It is the process of how various things which are connected to the internet interact with each other [1]. There are three steps in Internet of Things applications: capturing data from the object, aggregating that information across a data network and acting on that information. IoT is built on three major technology layers: Hardware (including chips and sensors), Communication (wired / wireless) and Software (including data storage, analytic and front-end applications) [2].

Widespread adoption of IoT has brought in a big change in a way the data is collected, stored and processed through novel techniques to produce value in the best way possible. IoT has successfully penetrated in different domains and industrial plants is one such significant area.

Sensor device monitoring is an important aspect of IoT system. For an IoT system to be successful, it is necessary to have sensor monitoring systems in place which would ensure that the devices are scanned at a regular interval, their health is analyzed and any anomaly with respect to normal behavior is reported to the user accordingly. Any monitoring system invariably performs following operations: security event detection, user notification in case of sensing parameter values crossing the specified normal limit and system alert notifications related to the failure of devices or machines. While designing device monitoring systems, the care should be taken that the system architecture covers all the design aspects pertaining to above mentioned system functions and user gets informed accordingly [3].

The local communication network used to acquire data from device plays an important role in sensor monitoring system. There are many technologies such as Zigbee, Bluetooth, RFID, Infrared etc. that can be used for data acquisition purpose. Bluetooth is prominent communication technology for sensor device monitoring[4]. Bluetooth wireless technology is a short-range communications system intended to replace the cable(s) connecting portable and/or fixed devices. Bluetooth is found to be superior to other technologies for short distance communication because of wide availability, low cost, low power and ease of deployment.

1.4 Technology and Literature Survey

The Internet of Things is a novel paradigm shift in IT arena. The phrase Internet of Things which is also shortly well-known as IoT is coined from the two words i.e. the first word is Internet and the second word is Things. The Internet is a global system of interconnected computer networks that use the standard Internet protocol suite (TCP/IP) to serve billions of users worldwide. It is a network of networks that consists of millions of private, public, academic, business, and government networks, of local to global scope, that are linked by a broad array of electronic, wireless and optical networking technologies[5]. Today more than 100 countries are linked into exchanges of data, news, and opinions on the Internet. According to Internet World Statistics, as of December 31, 2011, there were an estimated 2, 267, 233, 742 Internet users worldwide (Accessed data dated on 06/06/2013: from the Universal Resource Location http://www.webopedia.com/TERM/I/Internet.html). This signifies 32.7% of the worlds total population is using the Internet. Even Internet is going into space through Ciscos Internet Routing in Space (IRIS) program in the coming four the years (Accessed on 10/05/2012: (http://www.cisco.com/web/strategy/government/space-routing.html). While coming to the Things that can be any object or person which can be distinguishable by the real world. Everyday objects include not only electronic devices we encounter and use daily and technologically advanced products such as equipment and gadgets, but things that we do not do normally think of as electronic at allsuch as food, clothing; and furniture; materials, parts and equipment, merchandise and specialized items; landmarks, monuments and works of art and all the miscellany of commerce, culture and sophistication [5]. That means here things can be both living things like a person, animalscow, calf, dog, pigeons, rabbit etc., plantsmango tree, jasmine, banyan and so on and nonliving things like chair, fridge, tube light, curtain, plate etc. any home appliances or industry apparatus. So at this point, things are real objects in this physical or material world.

In our daily life, we are using many devices like computer, mobile phone, television. Devices are mainly connected by cables. So it becomes a demand of the time to use such a technology through which we can connect to different devices without any cables. Bluetooth wireless technology is a new Radio Frequency transmission standard which can be used to connect to different devices in a short range. Bluetooth technology opens the door to connect to billion devices.

1.5 Thesis Outline

In this proposal, next part we begin with Bluetooth Infrastructure. We are looking at changed remote correspondence conventions. Chapter 3 is demonstrating how Internet of Things (IoT) is helpful for Industry Plants. Chapter 4 clarifies about Implementation of Bluetooth based framework with Augmented Reality. It demonstrates how we convey the connect and play framework to processing plant floor. It likewise gives insights about execution and estimation examination of the foundation.

Taking the track, Chapter 5 clarifies about remote tracking of Assets and people in the industry. Part 6 examine inside and out about important innovation for this venture. Moving further different methodologies for gathering and showing information alongside Augmented Reality is talked about. Section 7 then closes work and indicates future work to be investigated.

Chapter 2

Communication Protocols and Infrastructure

2.1 Wireless Communication Protocols

Factory automation incorporates different modern disciplines including communication information, computer, control, sensor, and actuator engineering in an integrated way, leading to new solutions, better performance, and complete systems. One important component in factory automation is the industrial communication. For interconnection purposes, a factory automation system can be combined with various sensors, controllers and heterogeneous machines using different wireless communication protocols. Many different types of network have been promoted in a factory floor like Control Area Network (CAN), Process Fieldbus (Profibus), MQTT, Modbus, and so on.

Different communication mediums like Bluetooth, ultra-wide band (UWB), ZigBee, Wi-Fi also come with different type of networks.so, how to select a suitable network standard for a particular application is a critical issue. Here shows the comparison between different wireless communication protocols, based on that showed that why we select Bluetooth in our application.[1]

2.2 Comparison between Wireless Communication Protocols

Here introduces the Bluetooth, UWB, ZigBee, Bluetooth Low Energy (BLE), and Wi-Fi protocols, which corresponds to the IEEE 802.15.1, 802.15.3, 802.15.4, 802.15.4, 802.11a/b/g standards respectively. Table 1 summarizes the main difference among the five protocols. In general, Bluetooth, ZigBee, and UWB are intended for WPAN communication (about 10m), while Wi-Fi is oriented to WLAN (about 100m). However, ZigBee can also reach 100m in some applications.[6]

Standard	**Bluetooth**	**UWB**	**ZigBee**	**BLE**	**Wi-Fi**
IEEE Spec.	802.15.1	802.15.3a	802.15.4	802.15.4	802.11a/b/g
Frequency Band	2.4 GHz	3.1-10.6 GHz	868/915MHz; 2.4GHz	2.4 GHz	2.5GHz; 5GHz
Max. Signal Rate	1Mb/s	110 Mb/s	250 Kb/s	720 Kb/s	54 Mb/s
Nominal Range	10 m	10 m	10-100 m	10 m	100 m
Nominal Tx Power	0-10 dBm	-41.3 dBm	(-25) 0 dBm	0-10 dBm	15-20 dBm
No. of RF Channels	79	(1-15)	1/10;16	40(2MHz)	14(2.4GHz)
Channel Bandwidth	1 MHz	500MHz-7.5GHz	0.3/0.6MHz; 2MHz	2 MHz	22MHz
Basic Cell	Piconet	Piconet	Star	Piconet	BSS(Basic Service Set)
Risk of Data collision	High	-	Medium	High	-
Energy needed	Low	High	Medium	High	High

Table 2.1: Comparison of different wireless Protocols

2.3 Why Bluetooth!!

There are such a variety of various choices accessible for the framework like Wi-Fi, ZigBee and so forth yet in this, we created Bluetooth infrastructure. The primary explanation for this is, Latest keen sensors and other shrewd gadgets are Bluetooth empowered. Another thing is execution cost of Bluetooth is low, Power utilization is additionally low and no need of design of equipment and programming in Bluetooth.

2.4 Typical IoT Infrastructure in Industrial Plant

Here we discuss typical IoT infrastructure in smart Factory. Figure 2.1 shows typical IoT system in the industrial plant. The bottom layer of IoT system includes field devices or equipment such as robots, IEDs (intelligent electronic Devices), drives, motors, transformers etc. These are also called assets of the plant which are to be tracked or protected for seamless operation of the plant. This warrants the asset related data to be acquired from the field and sent to a local or remote server for analysis. Typically, the device related data is acquired by local data acquisition unit on the field and sent to a local or remote server in control room using communication protocols.

One example of such device is local communication gateway. The local or remote

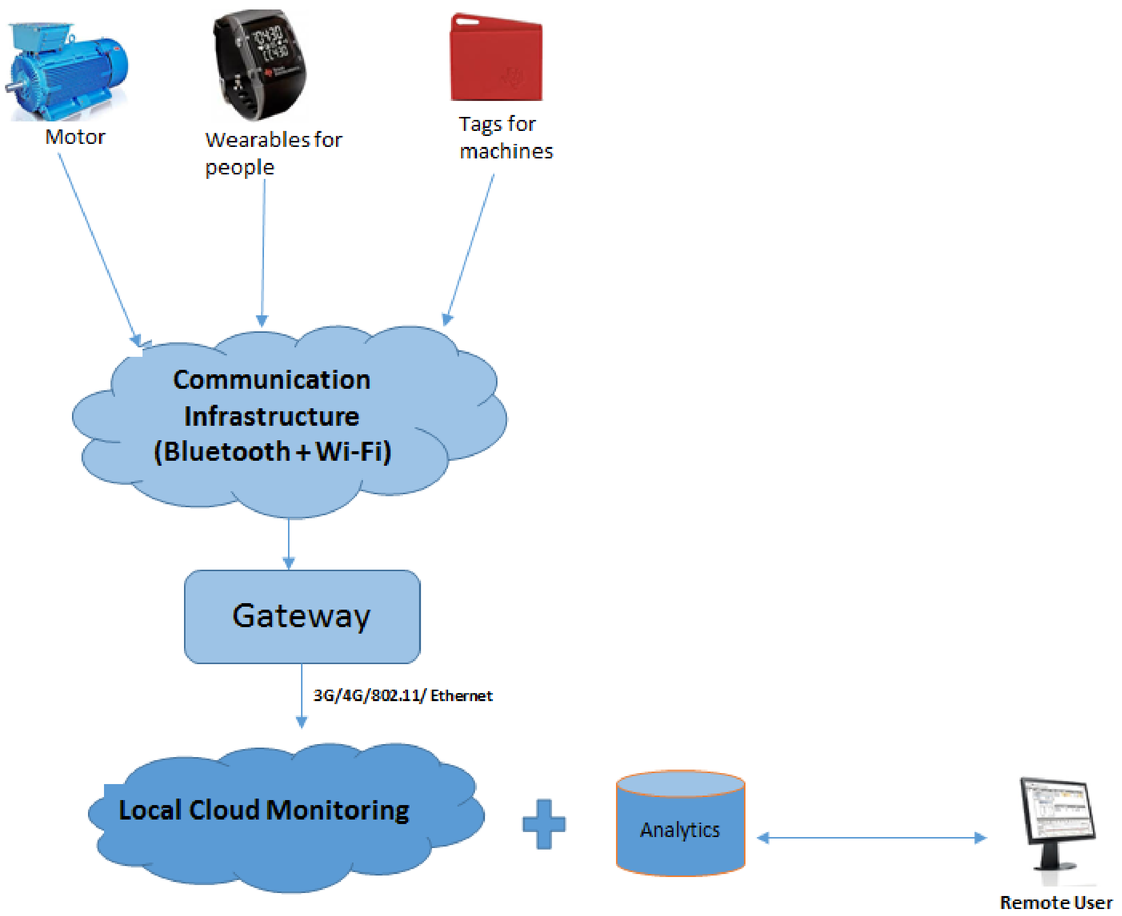

Figure 2.1: Typical IoT system in industrial plant

server is implemented using industrial level computers. Cloud-based storage servers are finding a lot of interest from plant owners for local or remote servers. The communication between sensor devices and on-field data acquisition unit is called local communication. Typical communication technologies used for local plant communication are Bluetooth, Zigbee, RFID etc. The communication between on-field data acquisition unit and a local or remote server is called remote communication. Typical communication technologies used for this communication are 3G/4G/802.11 etc. The data received at the server is used to run various analytics services to make informed decisions.

The server data can be accessed locally or remotely via internet. The output of analytics services is used for various plant functions such as asset tracking, asset health monitoring, predictive maintenance etc. Thus with the Internet of Things, plant owners can give each of their physical assets a digital identity that enables them to know the exact location and condition of those assets in real time. This information is used to make informed decisions such as device replacement, device maintenance etc. IoT in industrial plant thus enables faster time to market, improved productivity and operational excellence.

Chapter 3

IoT for Industrial Plants

Industrial plant owners face constant pressure to achieve the operational and business excellence. They continuously target to reduce the time to market. The growing expectations from industrial plants include smart and seamless assembly process, plant-wide visibility of operations, visibility of equipment health, early identification of security threats, real time notifications of critical plant alarms, events, maintenance etc. However, the variability in plant systems, equipment, manufacturing process, intended functionality and external world interfaces pose huge challenges in terms of equipment interoperability, visibility, and flexibility. Added to this, each plant has a mix of new and old or traditional equipment to work with. All these parameters create barriers to achieve the goals of intelligent industrial plant operation.

The Internet of Things is changing this scenario. It provides with an opportunity for plant owners to continuously improve business innovation and operational excellence. The implementation of the Industrial Internet of Things which connects industrial systems and equipment to internet services makes automation smarter. Just like other domains, IoT can deliver next-generation operational intelligence, supplier quality, asset tracking, real time asset health monitoring and predictive analytics for industrial plants.[7]

3.1 Sensor Device Monitoring

With the steep increase in manufacturing of devices that can exchange data internally or through internet, a huge population of devices that are connected to a network is being enabled every year. The ever increasing number of devices ensure that monitoring every device connected to the network manually is impossible. As internet adoption increased to employ more number of devices including wireless devices, more robust yet simple monitoring systems were employed. The monitoring systems were improved again to suit to cloud technology that has become stronger in last few years. With technology advances in wireless products and hand-held devices such as mobile phones, it has become vital to come up with autonomous monitoring systems that are interoperable with various types of sensor devices.[3] Mobile application based device monitoring systems are thus finding a lot of popularity among IoT applications.

3.2 Local Communication Technology for Sensor Data Acquisition

The selection of local communication technology for sensor data capture depends on the operating environment, communication range, power requirement, cost, data bandwidth, physical size etc. An industrial plant IoT requires industrial grade, low power, low cost and physically smaller devices for its monitoring and control system. The typical distance between sensor devices and gateway in a plant is of the order of centimeters to few meters. Among other wireless communication technologies, Bluetooth was chosen as the technology fits well to industrial sensing application compared to others.

The key features of Bluetooth wireless technology are robustness, low power consumption, and low cost. Bluetooth Low Energy (BLE)[8] has become an important standard for different smart sensor devices, in industrial plant systems. BLE is a version of Bluetooth designed for lower-powered devices that use fewer data. BLE has the ability to exchange data in one of two states: connected and advertising modes. Connected mode uses the Generic Attribute (GATT) layer to transfer data in a one-to-one connection. Advertising mode uses the Generic Access Profile (GAP) layer to broadcast data out to anyone who is listening [9]. To conserve power, BLE remains in sleep mode except when a connection is initiated. This makes it ideal for power hungry applications such field device monitoring in an industrial plant. Another significant feature in Bluetooth low energy compared to other IoT wireless technologies is the support for smartphones and tablets.

Chapter 4

Bluetooth based Infrastructure with Augmented Reality

4.1 Bluetooth based Infrastructure

Fig. 4.1 shows an IoT system for field device monitoring using Bluetooth as a local communication medium. The typical distance of data acquisition from field devices is in the range of few meters and Bluetooth fits very well for such a requirement. Use of Bluetooth communication in various IoT applications is growing due to its low cost, low power and easy to deploy features. Hence nowadays, most of the field devices, sensors and gateways are found to be Bluetooth communication ready. Bluetooth based on-field communication gateway captures the data from field devices. The gateway sends the data to a local or remote server using cellular or 802.11 based communication technologies as the range required for this communication is typically much more than that required for local communication. The data from the server can be accessed locally or remotely using the internet. The data from the server is then analyzed for various applications to make informed decisions related to plant.

The infrastructure involves a number of Bluetooth connected stationary nodes that are spread over the entire factory floor at regular intervals. Each of these Bluetooth nodes can automatically collect the data from every Bluetooth enabled industrial end device in a polling manner and then send this data to the next node or to the control center server. A factory floor operator can then use the tablet enabled with AR application

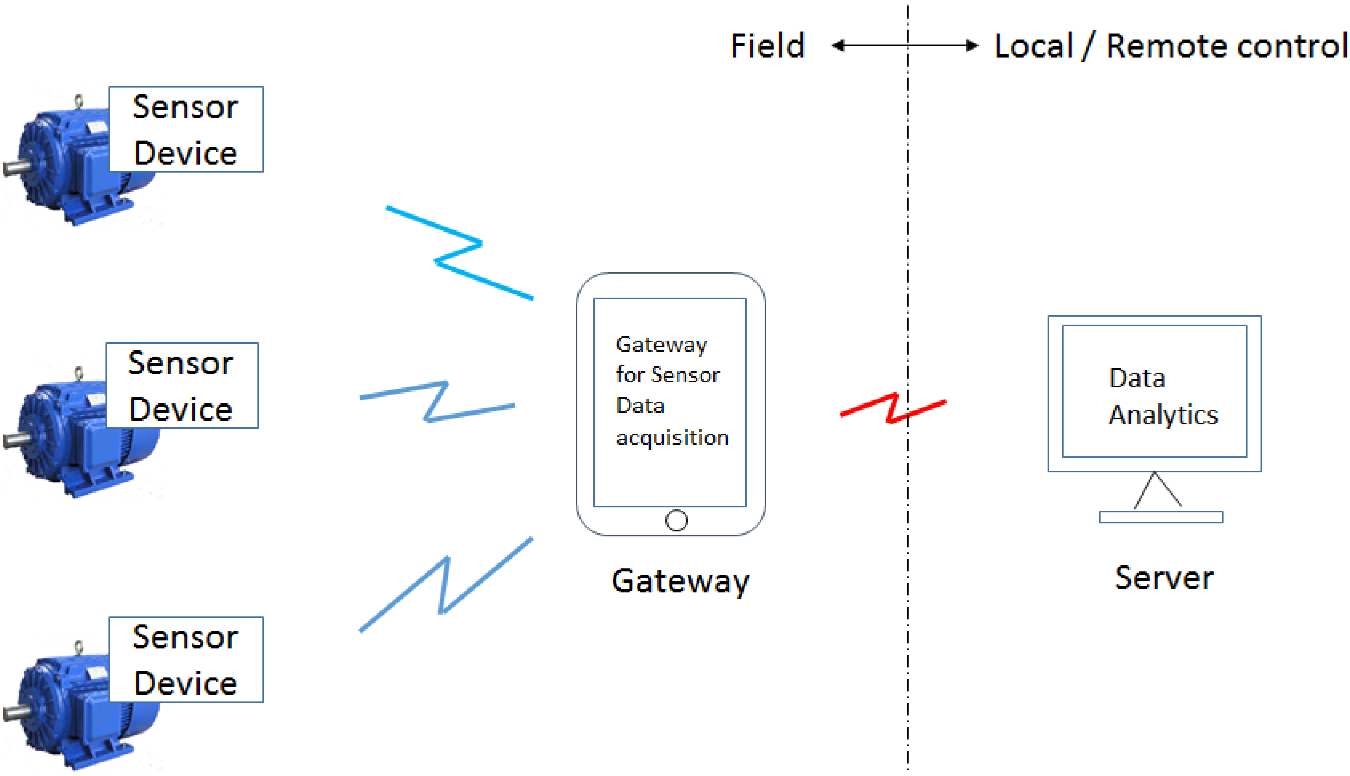

Figure 4.1: Bluetooth Based Android app for sensor device data acquisition

and Wi-Fi connectivity to visualize the status data and if needed also control the related industrial device. The tablet can also act as a Bluetooth infrastructure node where it can automatically poll multiple industrial devices, in addition to its role of an AR enabled device.

The solution utilizes the inherent Bluetooth point-to-point connection between the two devices. Thus the solution can be implemented on any Bluetooth enabled programmable device. The Bluetooth based infrastructure is very quick to setup and does not require expensive networking Equipment. The proposed infrastructure along with AR feature can provide an immersive factory floor experience to the floor operators.

4.2 Augmented Reality

Augmented Reality is an integration of computer made objects and live video that AR camera gets from the environment around the users in real time. There are some AR technology providers that AR application developers can use their SDK or plug-in for development purpose. Vuforia is one of the most known AR technology providers. In order to see the AR content, the users must install the application on their smartphones or use any device which supports the AR technology. The application gets the real time video from the AR camera and processes it, and then computer made objects will be integrated into the live video if the application recognizes any known target. A target is an image or a 3D object.

Augmented Reality systems rely on technologies that recognize and track the physical world around us with the goal to render and visualize virtual objects in that world. The architecture of AR systems differs and can be categorized depending on the scene capturing, detection/tracking method, user interaction, and visualization.

4.3 Proposed System

As we know industry 4.0 comes with automated controlling of field devices in an industrial plant those can be monitored and controlled from the remote location. There are lots of field devices in an industrial plant like Drive, motor, IED, Sensor tag human with wearable etc. To monitor them remotely we need to collect data from them periodically. Data collection can be done through many communication protocols. But we chose Bluetooth as our communication protocol and reason behind this is stated in section 2.3. We have proposed a Bluetooth infrastructure through which data will go to the server automatically without any human effort. This is a plug and play infrastructure that needs to be installed once. Once the setup is done, it will work until any fault occurs.

In the figure 4.2 we have given a block diagram of our wireless infrastructure which is based on Bluetooth.

We deployed this infrastructure in three different ways.

1. With Android application
2. With Server using Bluetooth Infrastructure
3. With Augmented Reality based Application

All three methods explained in subsequent section.

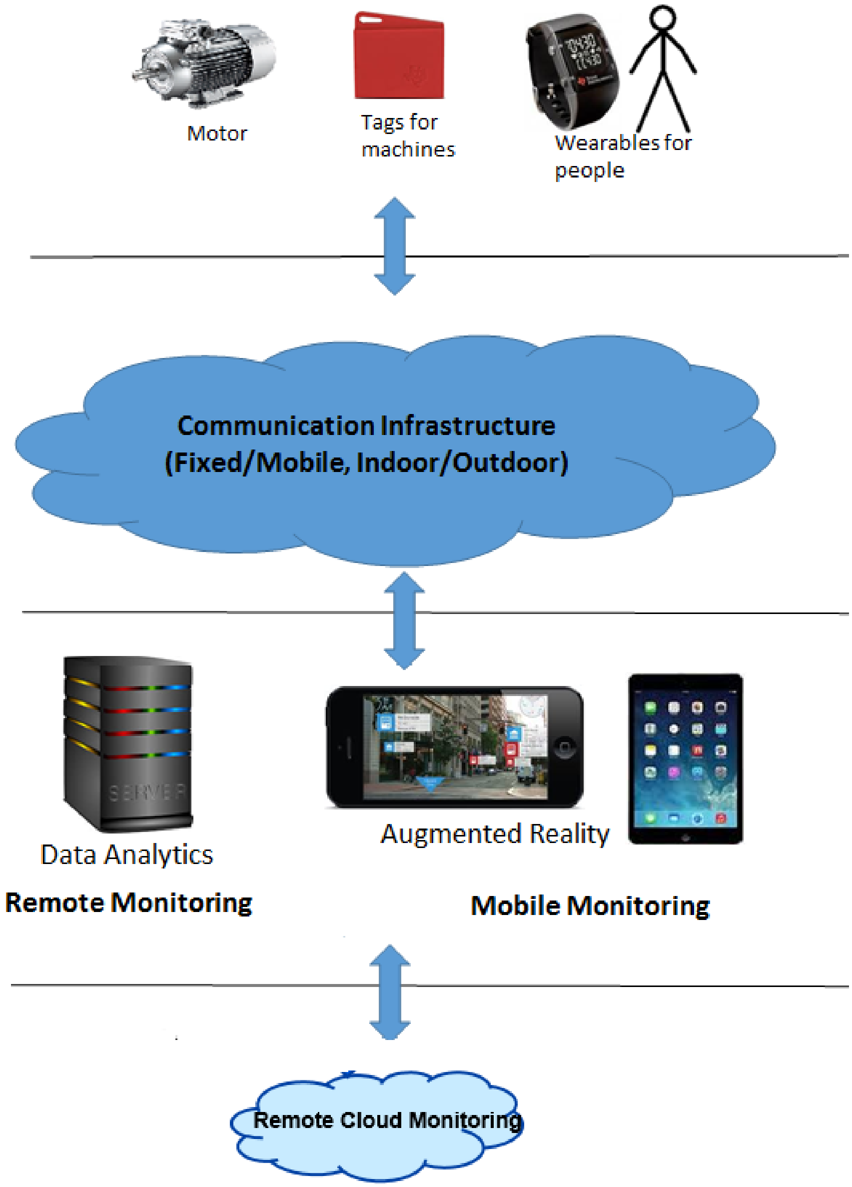

Figure 4.2: Proposed smart factory Architecture

4.3.1 Visualization on Android Application

Right now the Android application is there which can gather information from one device at any given moment and show that on an android application. In this application the association from android to the device is manual and it interfaces with the single device at once. Our proposed framework is computerized the procedure of constant information gathering by means of Bluetooth which ought to be occasional. I need to improve the usefulness of android application to get information from numerous devices in the meantime and send them to the server continuously.

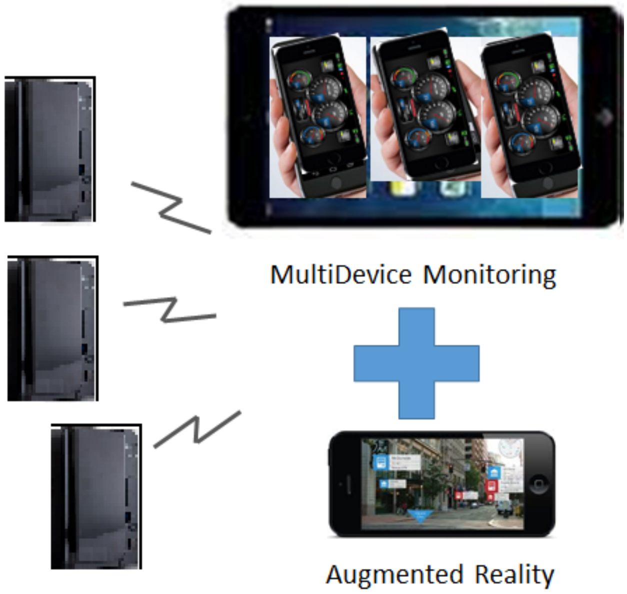

Figure 4.3: MultiDevice Monitoring

Advantage of proposed application is a connection in this is automatic. It can do multiple connections at a time means it can poll the data from all the available device within the range and stored it locally. After storing it locally it can push that data automatically to the server in the specific interval. Figure 4.3 is demonstrating the distinction between current arrangement and proposed arrangement.

4.3.2 Visualization on Server using Bluetooth Infrastructure

This infrastructure one can deploy in factory floor or whole industry plant. Here Raspberry Pi is using as a relay node. A large number of Raspberry Pi are being installed in the industrial plant. There are lots of different types of field devices like Sensor Tag, Wearables, Drives, motors etc. with Bluetooth supportability. Figure 4.4 shows the Bluetooth infrastructure that involves fixed stationary nodes spread over the factory floor at an intermediate distance of 6 meters. In Figure 4.4, there are only three zones each with one fixed node. The node automatically polls all the Bluetooth enabled industrial devices and collects the relevant data from them. For example, the node in zone 1 collects the data from the three industrial devices IED (Intelligent Electronic Device), drive and motor at a preconfigured interval and then forwards the collected data to node 2. Similarly, the node 2 forwards the data to node 3 after collecting the data from all the devices in zone 2. Node 3 finally forwards the data to the control room server via the Ethernet connection. The node within each zone acts like a master for its end devices. It controls the connectivity establishment with every end device. Similarly, a node closer to the server always has a higher hierarchical priority. Thus between node 1 and node 2 as shown in Figure 4.4, the node controlling.node 2 acts like a master for node1. A node does its best effort to maintain a regular connectivity with the device in its zone as well as the neighboring node.

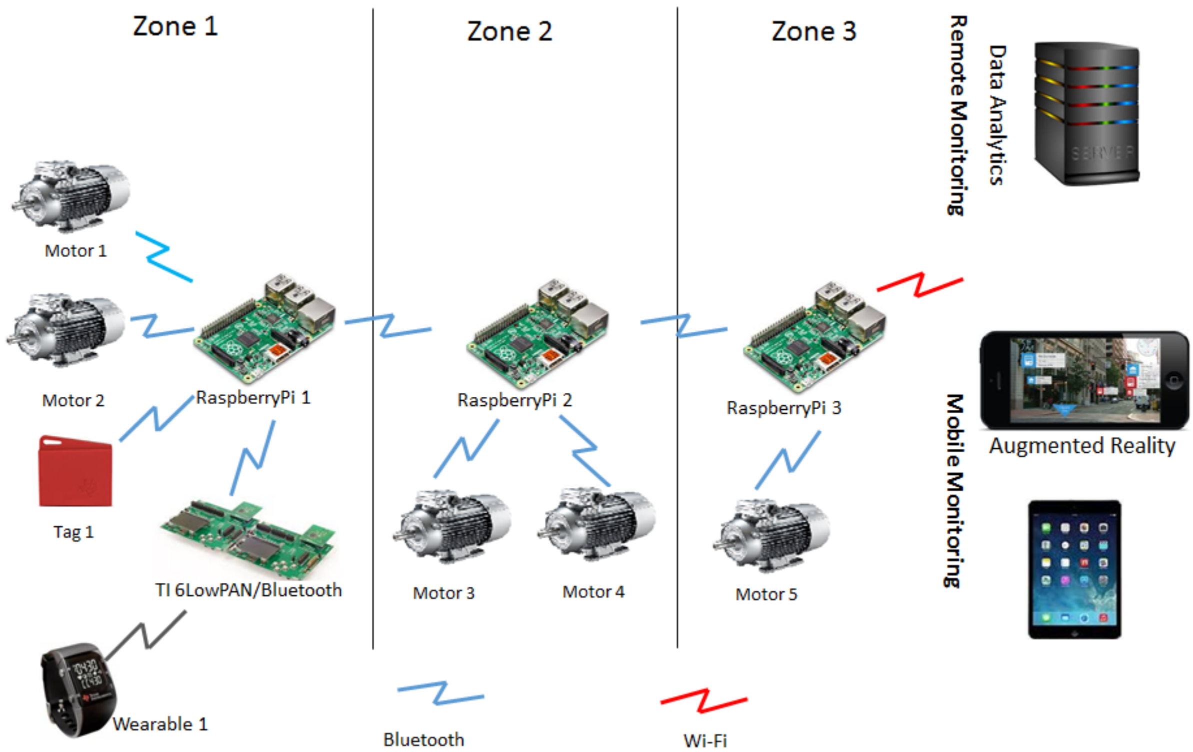

Figure 4.4: Infrastructure with Polling and Hopping of Data

4.3.3 Visualization on Augmented Reality based Application

This is the third method for visualization data of the factorys smart devices. Person go in factory floor with tablet and hover it on smart device, can get all the different details of that particular device. Here he can get static and dynamic both sort of data. Static data of specific gadget like Model No., MAC Address and so forth and continuous data like current, temperature, engine speed and so on. appears with Augmented Reality on the tablet or any smart device. Figure 4.5 demonstrates data of drives with AR Application. Here ongoing information is originating from cloud or web server utilizing Wi-Fi as a correspondence medium. We created AR based application utilizing Unity

IDE and Vuforia libraries.

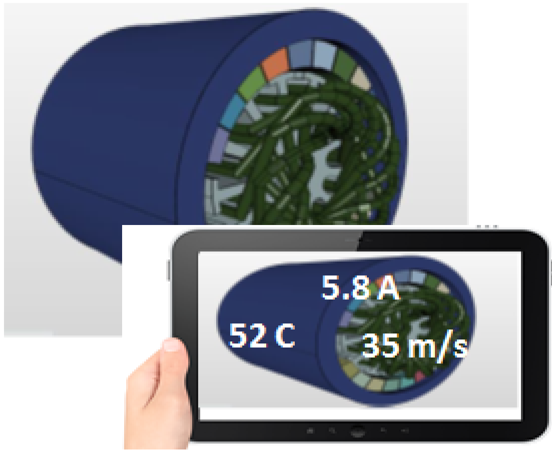

Figure 4.5: Visualization of data with Augmented Reality

4.4 Working of Infrastructure

The end devices continuously wait for the latest data to be pushed to the node. As soon as the connectivity is established with the node, the data from the device is immediately sent to the node. After the transfer of data, the connectivity is immediately closed by the node. The device then once again awaits with its latest data to be pushed to the node during the connection re-establishment in the next round of poll. Thus node 1 polls all the devices in zone 1 one at a time and collects the data from them. Once the device data is aggregated, it then awaits for connection establishment from Node 2. As soon as the connection is established it pushes its data to node 2. Figure 4.6 shows the time based sequence diagram for node 1.

Finally, all the data gets gathered at node 3 and it finally pushes the data to the control room server immediately after polling the final device in its zone. In case of lost connectivity with any device, the node buffers and maintains the previous data with the timestamp of data collection. The buffering is limited by the available of memory in the node. The control room server segregates the data according to the category of device and then it forwards the data to the respective remote application software. For example Data related to motors can be forwarded to the remote motor health prediction monitoring application. The analytical data from the application software are then hosted on the web server. This allows for the data to be accessed by any smart device connected to

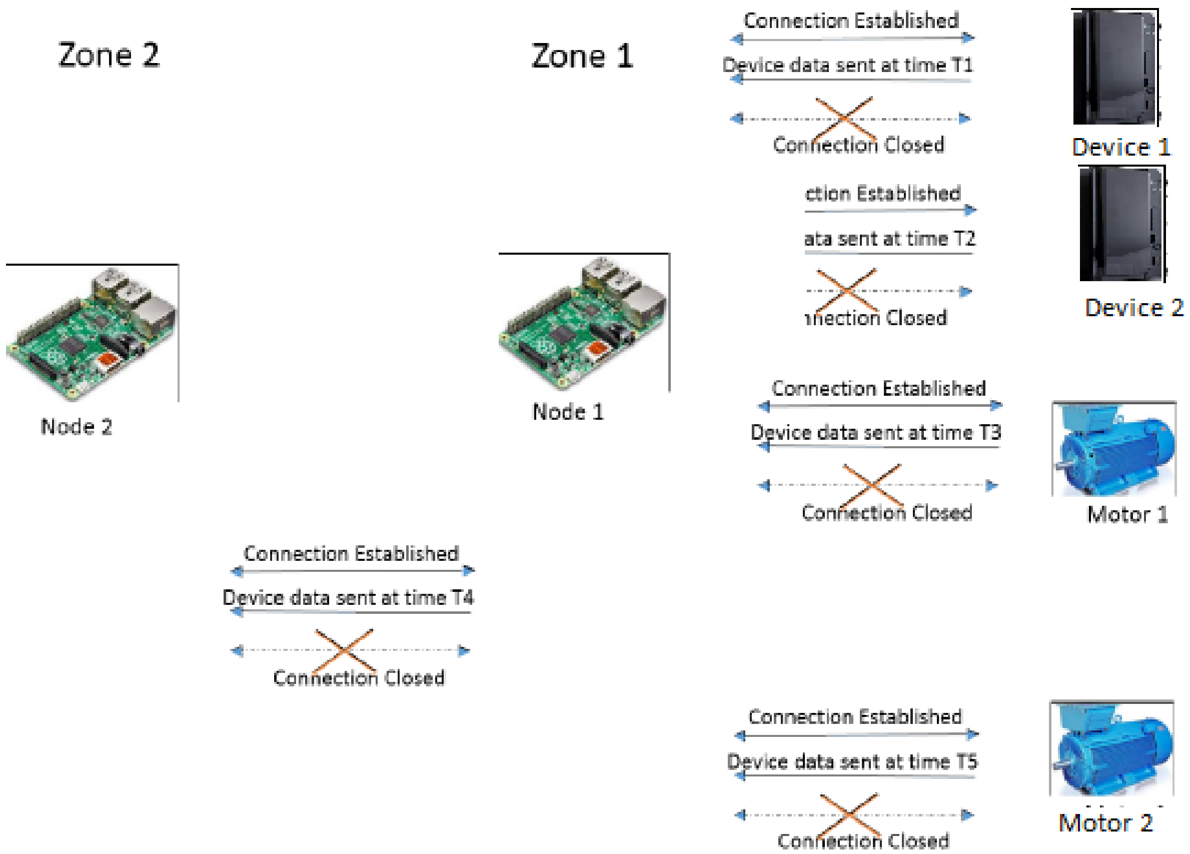

Figure 4.6: Time-Based Sequence Diagram for Node 1

the common WLAN network in the factory floor. Thus a real time information on any of the industrial end device can be provided to the field operator anywhere in the factory. A tablet can be enabled with Augmented Reality feature so that the field worker always has the device context sensitive information whenever the person comes in front of the respective device. Thus an immersive experience with real-time status of the factory can be enabled.

4.5 Performance Measurement and Analysis

Along with inherent limitations of devices and data acquisition systems, external devices existing in the plant can significantly influence the performance of local Bluetooth communication[10]. This was given major consideration while selecting the performance parameters for Bluetooth communication for field device data acquisition. Hence we selected RSSI, power consumption and communication latency as parameters that can affect the Bluetooth communication performance. With the goal of testing the efficiency and performance of the Bluetooth based local data acquisition one additional mobile application was designed to measure the performance parameters such as transmission latency, power consumption, sensor localization etc. The application has the ability to measure transmission time for each data packet from every sensor along with Timestamp. The following sections describe them in more details.

4.5.1 Test Bed for Performance Measurement

Fig. 4.7 shows the test bed developed to assess the performance of autonomous Bluetooth based data acquisition system. Currently the popularity of smart devices has grown increasingly due to rich application features, interactive user interfaces, wide communication options and ease of handling. With the increasing use of smart mobile or tablet in day-to-day life, it has become a crucial part of Internet of Things as well. Smart phones have all the features that are required for Internet of Things like Wi-Fi access point, Bluetooth, different types of sensors. Therefore it is easier to use smart phone or tablet as gateway for data collection.

A prototype of Bluetooth based data acquisition was implemented as a part of experimental setup in which smart device such as mobile or tablet was used as a gateway for acquisition of data from Bluetooth based drive monitoring systems. A smartphone based gateway had an Android application developed that collects data automatically and periodically from multiple drive monitoring units having Bluetooth interface. It was achieved in polling manner for multiple devices. Data collected by the gateway was stored in the local device for analytics and visualization.

4.5.2 Communication Performance Parameters

Measuring the performance of Bluetooth communication network was important to assess its applicability for sensor device data acquisition in industrial IoT plant. A smartphone gateway with autonomous data acquisition APP also had another APP to measure and store Bluetooth performance parameters. The selected Performance parameters have been described in detail below.

1. **RSSI:** Received Signal Strength (RSS, called Received Signal Strength Indication, RSSI) indicates the power present in a received radio signal. It is measured from each received frame as an average value measured during the first eight symbols (preamble) and converted to the RSS indicator[11]. RSSI can be used to estimate

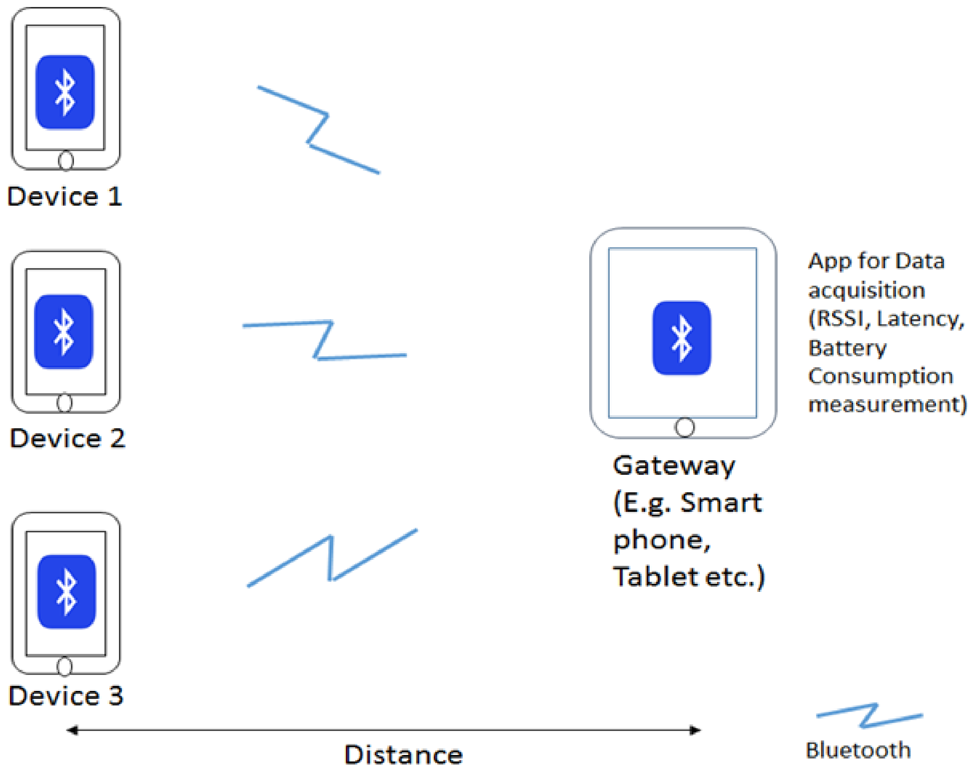

Figure 4.7: Test Bed for Bluetooth Communication Performance Measurement

the distance between smart devices[12]. The characteristic of Bluetooth RSSI value is different due to dynamic environments.

2. **Power Consumption:** Power consumption of BLE gateway is defined as the energy consumed by device for acquiring the data from sensor devices. It can be expressed as energy in Joule or as percentage of total energy consumed by a device for data acquisition. IoT system would like to have low power consumption for all the subsystems.

3. **Communication Latency:** Communication latency is defined as the time delay between data transmitted from a sensor device and its availability at receiving gateway (e.g. smart phone) for further processing. For critical applications, the latency has to be low so that the data can be made available faster at the local or remote control for decision making. For monitoring applications, this requirement is not considered stringent.

4.5.3 Performance Analysis

We conducted number of experiments to measure the performance parameters namely RSSI, power consumption and communication latency. The entire measurement process was automated in order to save the manual effort in conducting experiments and measuring the readings. The analysis of performance parameters based on measurements has been outlined below.

1. **RSSI:** RSSI values were measured for each of the field devices keeping smartphone gateway at a distance of 1 meter, 3 meters, 5 meters, 10 meters, 15 meters and 20 meters.

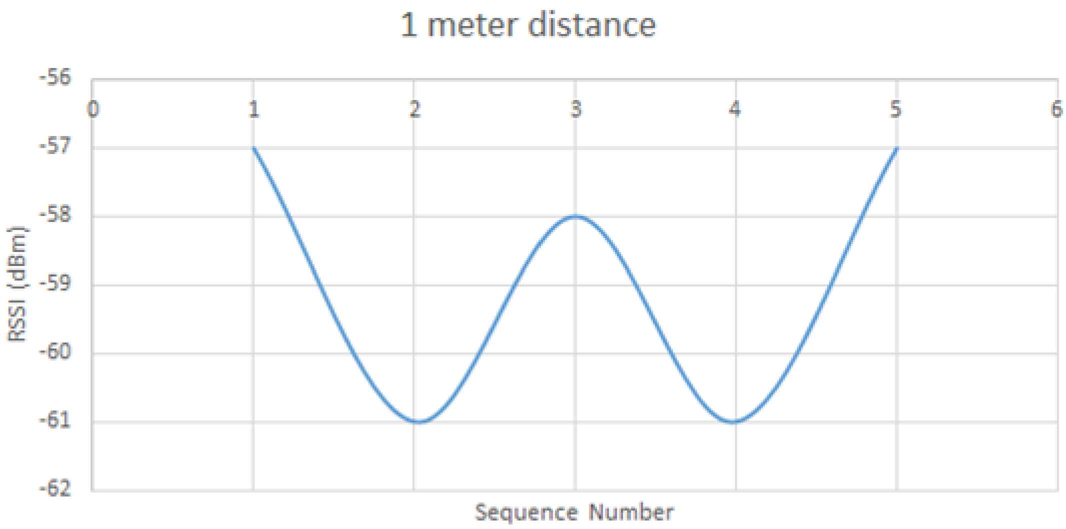

Figure 4.8: Range of RSSI values for 1m distance

- Band of RSSI values for a particular distance: On contrary to to expectation of single RSSI value for a particular distance, it was observed that the RSSI values drift in a range for a particular distance. Fig. 4.8 to Fig. 4.11 show the variation in RSSI values in indoor environment for 1 meter, 5 meters, 10 meters and 15 meters respectively. For example, the variation in RSSI for 1 meter distance is from -57 to -61 dBm whereas it is from -75 to -82 dBm for 15 meters distance. There is always a band of 5 to 6 dBm in RSSI measurement for a particular distance. The variation in RSSI is due to environmental influence on RF communication. However taking large number of sample measurements and employing statistical techniques, the closest RSSI out of sample space can be selected.

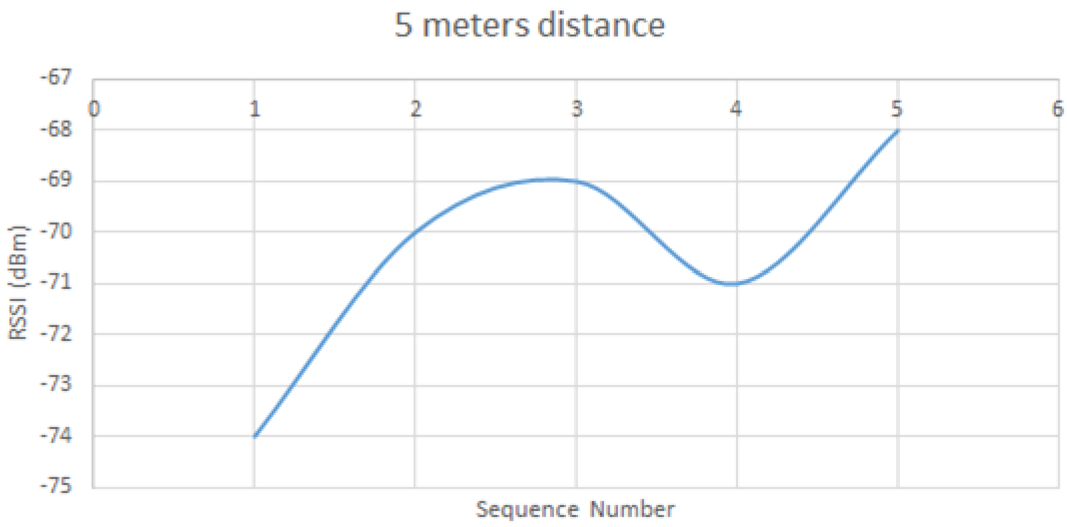

Figure 4.9: Range of RSSI values for 5m distance

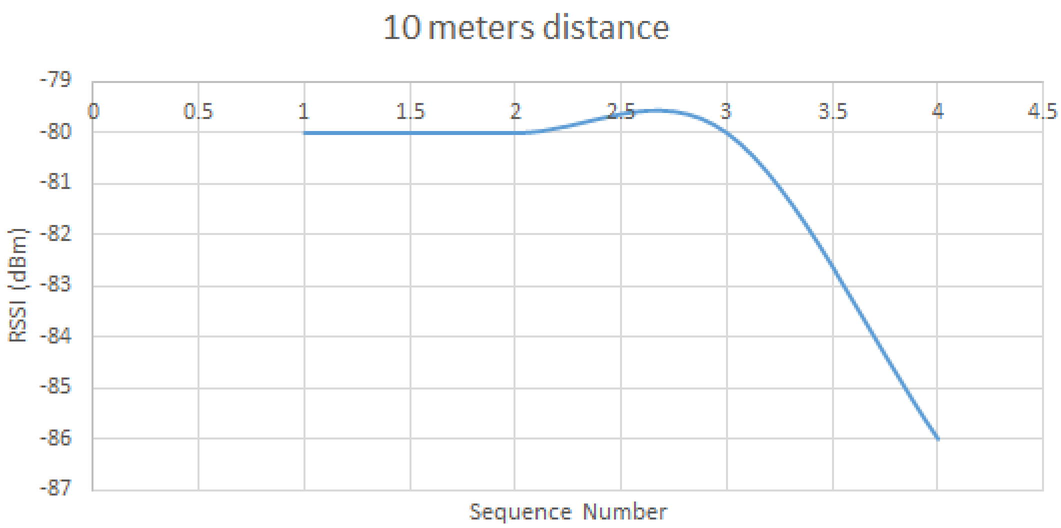

Figure 4.10: Range of RSSI values for 10m distance

- RSSI vs Distance: : RSSI is a key parameter in localization and estimating the distance of an object. The closest RSSI value from measured range of values was calculated using statistical techniques. Figure 4.12 and 4.13 show the relationship of statistically estimated RSSI and the actual distance in controlled indoor and uncontrolled outdoor environment. It can be seen that RSSI follows a decreasing trend as the actual distance increases.The calculated RSSI value was used to estimate the distance based on the triangulation methods.[11] [12]

Fig. 4.14 shows the comparison of actual and estimated distance in a controlled indoor environment. The estimated distance based on RSSI values matches closely

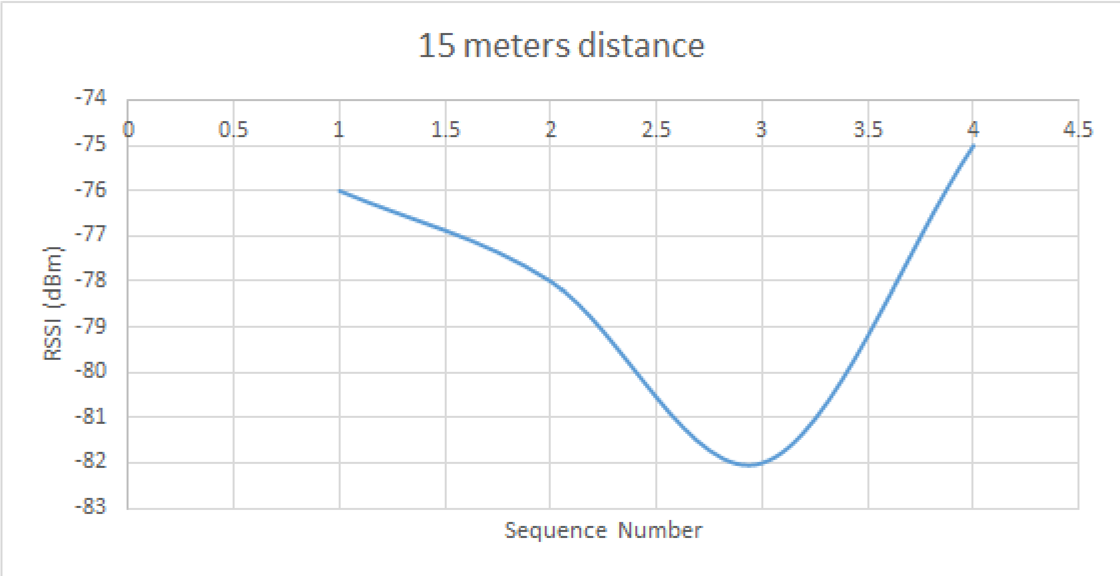

Figure 4.11: Range of RSSI values for 15m distance

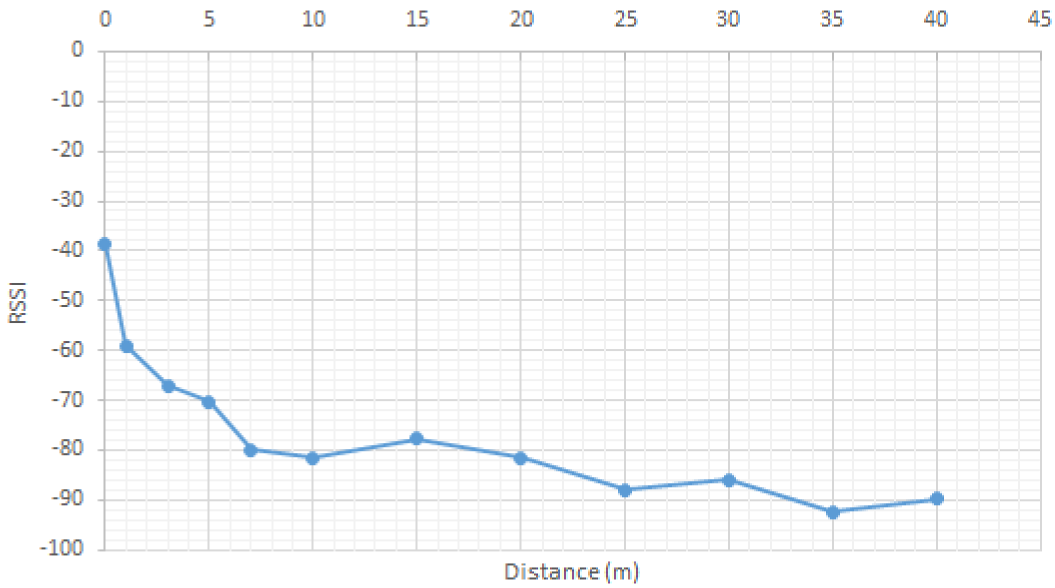

Figure 4.12: Indoor: RSSI Vs Actual Distance

with actual up to the distance of 25 meters. The figure also indicates an error in actual distance estimation. For indoor, it is less than 1 meter for actual distance up to 15 meters. Fig. 4.15 shows the actual vs estimated distance in an uncontrolled outdoor environment. The estimated distance based on RSSI values matches closely with actual up to a distance of 20 meters. The figure also indicates an error in actual distance estimation. For outdoor, it is less than 2.7 meter for actual distance up to 15 meters. This proves that our smartphone based data acquisition system can estimate the distance between field device and data acquisition unit i.e. smartphone

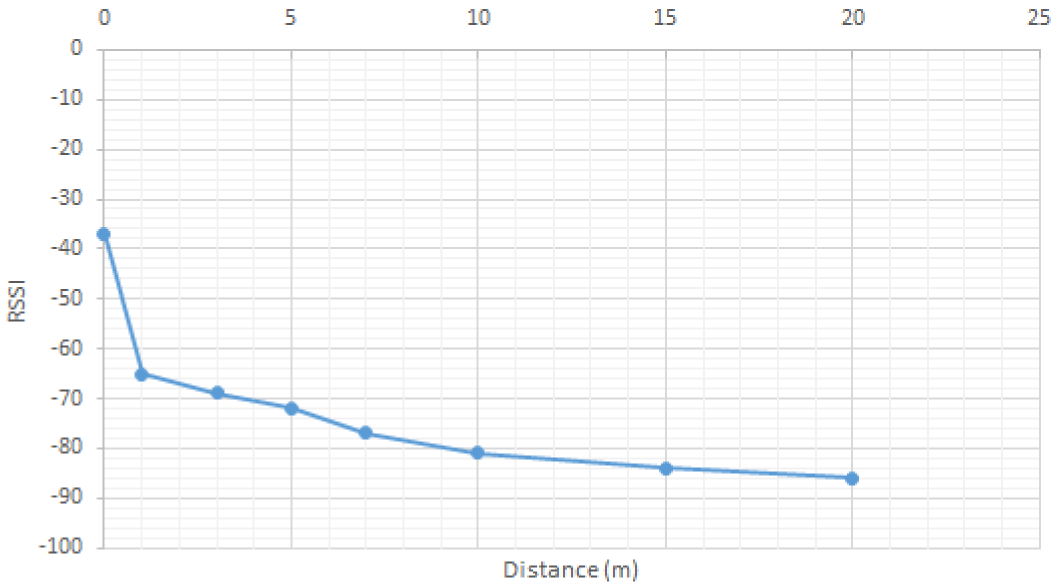

Figure 4.13: Outdoor: RSSI vs Actual Distance

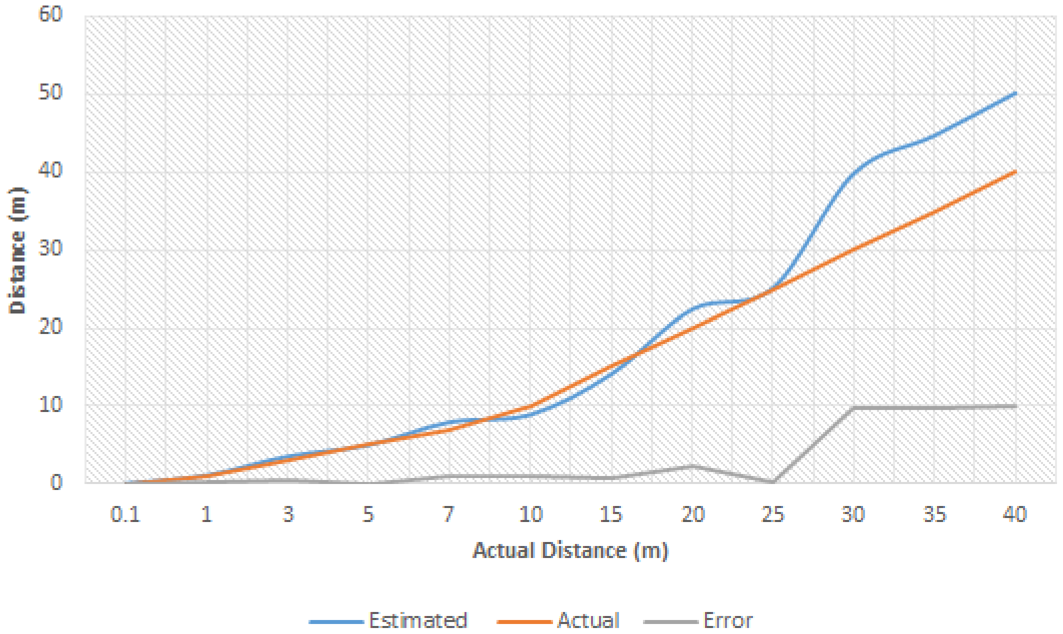

Figure 4.14: Indoor: Actual vs Estimated Distance

gateway up to 20 meters in indoor and 15 meters in an outdoor environment with certain minimal deviation.

2. **Power Consumption:** We performed a detailed analysis of energy consumption of a smartphone that was acting as a gateway. We showed how the different components and applications within smartphone contribute to overall power consumption. The multiple experiments indicated that the sensor data acquisition application re-

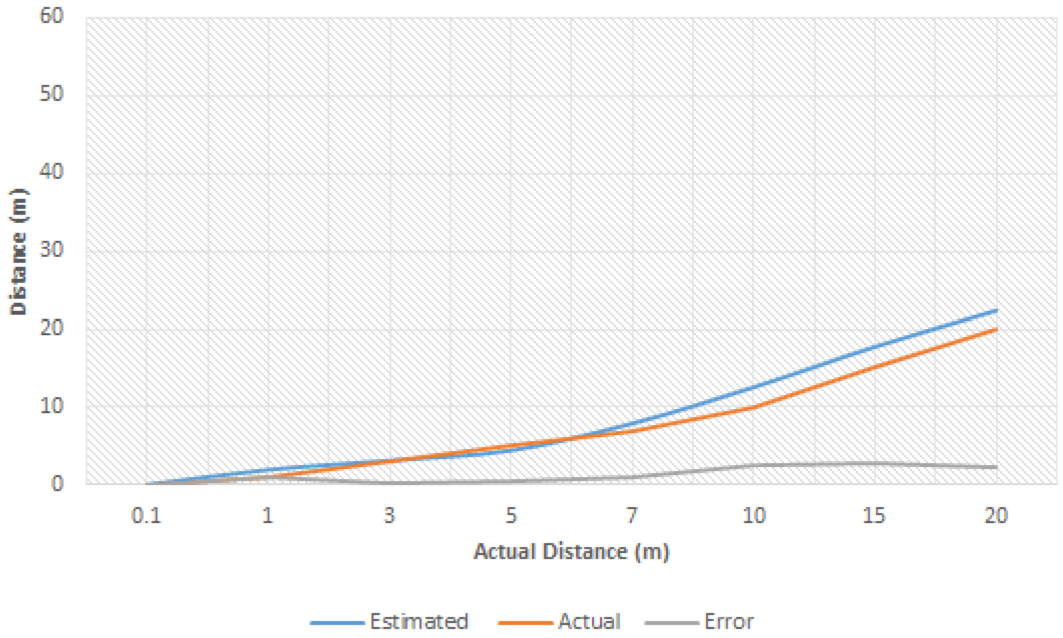

Figure 4.15: Outdoor: Actual vs Estimated Distance

siding on smartphone consumes less than 2 MWh energy (mean = 1.63 mWh, standard deviation = 0.22). The contribution of sensing application is within 2 percent (mean = 1.69 percent, standard deviation = 0.11) of the aggregate consumption.

3. **Communication Latency:** The custom mobile application undertook multiple readings of communication latency by placing gateway having sensing application at various distances (1-15m) from sensor devices. The analysis shows that the latency for distance up to 15m is always less than 76ms (mean = 34.96ms, standard deviation = 20.92).

4.6 Infrastructure for TI SensorTag

In this infrastructure, we included TI SensorTag (CC2650) also. It has 10 different type of sensors like Ambient Temperature, Object Temperature, Gyrometer, Magnetometer, Accelerometer, Pressure, Humidity etc. This tag is useful for collecting data from those devices which does not have Bluetooth support but then also you want to collect data of that device using our infrastructure. So TI Sensor Tag put on those devices, then in our infrastructure, Raspberry Pi collects data from all the different sensors in the polling manner and sends it to the web server. From web server remotely people can visualize real time as well as historic data.

In this framework initially, we put the sensor tag on the devices for which we need

Figure 4.16: Sensor Data in Graphical format

TimeStamp	MAC Address	Object Temp(°C)	Ambient Temp(°C)
13:39:18	a0e6f8b71100	16.3	22.6
13:40:36	a0e6f8b71100	16.3	22.6
13:40:50	a0e6f8b71100	18.5	22.7
13:41:59	a0e6f8b71100	16.4	22.8
13:42:13	a0e6f8b71100	15.8	22.9
13:42:28	a0e6f8b71100	17.8	23.2
13:44:06	a0e6f8b71100	17.0	23.3
13:42:28	a0e6f8b71100	17.8	23.2
13:44:06	a0e6f8b71100	17.0	23.3

Figure 4.17: Sensor Data in Tabular format

to gather the information. On Raspberry Pi, we begin the application which collects the information from every one of the sensors in which lies in its range utilizing Bluetooth as a correspondence medium and put away that information in a log file. Like this, we put Raspberry Pi in the entire factory floor. Along these lines, all Raspberry Pi gathers distinctive parameters from various sensor tags.Raspberry Pi sends that information to neighbor Raspberry Pi utilizing Bluetooth. Last Raspberry Pi is sending that to web-server utilizing Wi-Fi or Ethernet as a correspondence medium.

On the server, we getting that information utilizing PHP script and isolate that information in an independent document of specific sensor label utilizing python scripts. On the web page, information can be appeared in graphical and in addition forbidden configuration. For showing diagram on website page here Google API is utilized and for the forbidden arrangement JavaScript is utilized. In this way, individuals have both noteworthy and also ongoing information on the web server. All approved individuals from their smart device can visualize that information on their smart device.Figure 4.16 and 4.17 demonstrates that on site page how sensor Data look like in a tabular and graphical frame.

Chapter 5

Assets and People Tracking

It has been considered a fact that GPS performs too poorly inside buildings to provide usable indoor positioning. So we need to consider other methods to implement indoor positioning/navigation effectively. An indoor positioning system (IPS) is a system to locate objects or people inside a building using radio waves, magnetic fields, acoustic signals, or other sensory information collected by mobile devices. There are several commercial systems on the market, but there is no standard for an IPS system. IPS systems use different technologies, including distance measurement to nearby anchor nodes (nodes with known positions, e.g., Wi-Fi access points/Bluetooth beacons), magnetic positioning. They either actively locate mobile devices and tags or provide ambient location or environmental context for devices to get sensed.

Here we proposed Android Application for personal navigation based on a particular floor map of factory which shows real time position of people whom you want to track. Another web based application we proposed for remotely tacking of Assets and People.

5.1 IndoorAtlas for Person Tracking

Indoor atlas is an indoor navigation solution which mainly uses buildings predictable magnetic fields. As said the idea behind Indoor Atlas is that buildings have predictable magnetic fields caused by structural steel, wiring, machinery, ductwork, etc., and by recording the variations and filtering out magnetic noise, we can characterize an entire building and use that data to figure out where the device might be within that environment. Wi-Fi and Bluetooth data can also be used to improve accuracy.

The Indoor atlas provides SDK to develop indoor navigation application for both android and iOS platforms. I used Indoor atlas SDK and developed an indoor navigation application. The important phase in the Indoor atlas based solution is mapping phase. Mapping is recording sensor data in known positions using map-creator. After completing the mapping phase the sensor data will be uploaded to Indoor atlas server for generating the positioning map. After completing this mapping phase we can use our android app for indoor navigation. The app will monitor the current sensor data and communicate it with Indoor atlas positioning server to get the location fix.

5.2 Location Tracking of Assets

Assets and people tracking in the industries is very important things. It increases organization and efficiency of industry. Through asset and people tracking you will always know the exact location of your companys Assets as well as workers exact location.

Here we proposed a framework for area following of Assets and individuals. Figure 5.1 demonstrates the Bluetooth foundation that includes settled stationary hubs like Raspberry Pi spread over the manufacturing plant floor with a separation of the scope of Bluetooth. In view of that separation we isolate the processing plant floor into various predefined zones and from the server, we track the Assets and individual that as of now they are in which zone. The hub naturally looks over all the Bluetooth empowered mod-

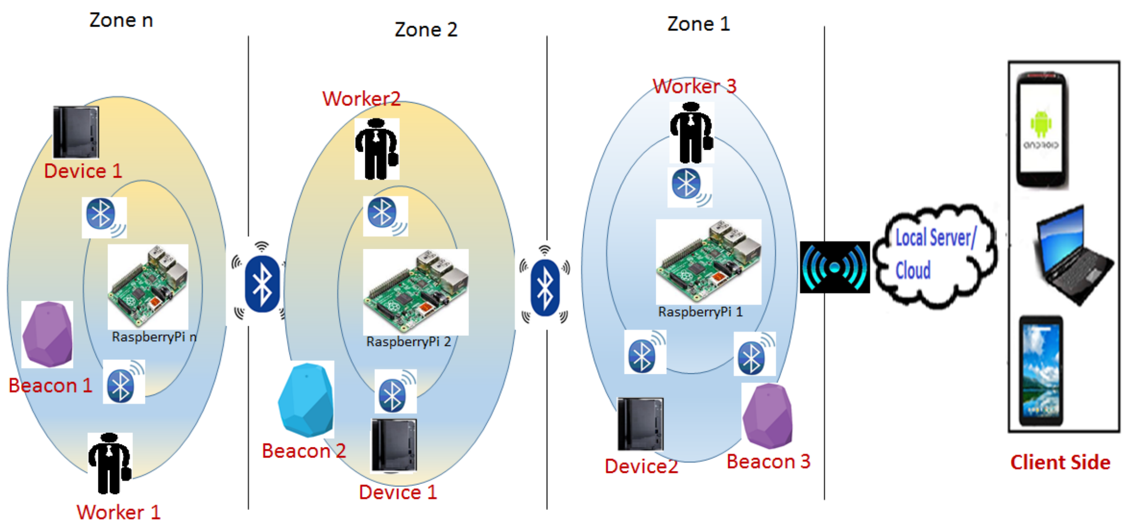

Figure 5.1: Infrastructure for Assets and people tracking

ern Assets which you need to track and in a surveying way, gathers the RSSI esteem from them. For instance, the hub in zone 1 gathers the RSSI values from the modern gadgets which are in their Bluetooth Range at a preconfigured interim and in view of RSSI esteem it decides surmised separation of Assets from that specific hub. From that point forward, it advances the gathered information to hub 2. Additionally, the hub 2 advances the information to hub 3 in the wake of gathering the information from every one of the gadgets in zone 2. Hub 3 at long last advances the information to the control room server by means of the Ethernet association. The hub inside each zone demonstrations like an ace for its end gadgets. It controls the availability foundation with each end gadget. So also, a hub nearer to the server dependably has a higher progressive need.

Time Stamp	Device Name	MAC Adress	RSSI	Distance	Zone
16:43:48	Worker 2	E9:C3:DF:BB:23:F0	-67	5 Meters	Zone1
16:43:49	Motor	F0:D5:BF:F7:86:44	-72	10 Meters	Zone1
16:43:18	-	E8:B1:FC:AA:21:38	-83	> 20 Meters	Zone1
16:44:18	Flowmeter	F0:E6:CH:D8:73:F1	-71	20 Meters	Zone1
16:44:18	Drive	00:24:2C:C1:07:8E	-74	10 Meters	Zone1
16:44:19	Service Port	6C:B7:F4:5D:4D:E3	-81	10 Meters	Zone1
16:44:19	Motor	F0:D5:BF:F7:86:44	-72	5 Meters	Zone1
16:45:50	-	F6:C1:FA:BB:53:94	-93	> 20 Meters	Zone1
16:45:50	Digital Monitor	F0:24:2D:D5:17:6F	-73	10 Meters	Zone1
16:45:54	-	E5:D5:77:AD:G6:55	-67	5 Meters	Zone1
16:42:48	Worker 1	E8:B1:FC:AA:23:E0	-67	10 Meters	Zone2
16:42:49	Motor	F0:D5:BF:F7:86:44	-72	20 Meters	Zone2
16:43:18	-	E8:B1:FC:AA:21:38	-83	> 20 Meters	Zone2
16:43:18	Flowmeter	F0:E6:CH:D8:73:F1	-71	10 Meters	Zone2
16:43:18	Drive	00:24:2C:C1:07:8E	-74	20 Meters	Zone2
16:43:19	Service Port	6C:B7:F4:5D:4D:E3	-81	> 20 Meters	Zone2
16:43:19	Worker 2	E9:C3:DF:BB:23:F0	-74	20 Meters	Zone2
16:43:50	-	F6:C1:FA:BB:53:94	-93	> 20 Meters	Zone2
16:43:50	Digital Monitor	F0:24:2D:D5:17:6F	-73	20 Meters	Zone2
16:43:54	-	E5:D5:77:AD:G6:55	-67	10 Meters	Zone2

Figure 5.2: Table showing Tracking of Assets and people

As a correspondence medium, we are utilizing Bluetooth for a sweep and survey the information and Wi-Fi for sending that information to the server. At the server side, there is an online application shape where you can track the individual and all the diverse Assets of an industry. Any approved individual can visualize that information from their smart device without heading off to a server room.

At the server side observing of benefits and individuals following is happen. so Figure 5.2 demonstrates the table that how we can screen gadget and individuals following with time stamp. At the specific time, you come to realize what gadget is in which zone.

Chapter 6

Relevant Technologies

In this part the main technologies used in this project are introduced. The main technologies were Android, Bluetooth, JSON (Java Script Object Notation), Raspberry Pi with Raspbian Operating System, HTML, JavaScript, CSS (Cascading Style sheet) for webpage designing and MYSQL database.

6.1 Android

Needless to say, android is a well-known open-source operating system based on the Linux kernel, and although it is available for many platforms, it is best suited for smartphones. It is developed by Google, and it currently holds the lead in terms of number of devices with a version of this OS.

Developing a basic application in Android is rather simple. The main language used is Java, but other languages such as XML are important too. The easiest way to an Android application is to use the official Android Development Tools (or ADT) plugin for the Eclipse IDE. This plugin contains everything needed to develop and deploy an application to any Android device connected to the computer.

It is not the purpose of this project to explain the intricacies of the Android OS and its internal architecture since there is more than enough literature on the subject and doing so would be redundant.

6.2 Bluetooth

Bluetooththe main technology used as the base of this projectis a standard wireless technology for short distance data exchanging. It has been among us for quite a long time, and since its invention in 1994 by Ericssona telecommunications vendor and cell phone manufacturer it has undergone many revisions and modifications. Yet, its core features remain unchanged: a low cost wireless replacement for cables on phones, headsets and other devices.

Additionally, its low power consumption and fast connection setup make it perfect for small sensor devices and even sensor networks as well. Not surprisingly, it has been the main protocol used in the Personal Area Networks for many years. Again, its simple yet useful features such as fast device discovery in the near surrounding or high rate data transfers make this protocol very suitable for such environments. Although during the first decade since its invention it underwent a steady growth, it has not been until recentlywith the introduction of Bluetooth Smartthat it has regained interest.

6.3 JSON

JSON is a standard text format based on a non-strict subset of the JavaScript scripting language for exchanging information, very easy to understand and generate by human. It is completely independent from any programming language and many programming languages like Java, C, Java Script, PHP, Python can decode it. The structure of a JSON content is a collection of keys and values where a value also can be a pair of keys and values or an array of the same keys for many times. In this application, the data are transmitted between the server side web application and the client application in JSON format using HTTPS protocol.

6.4 Raspberry Pi

Raspberry Pi is a credit card sized single-board computer which are Bluetooth enabled. In that we can install any Operating system like Raspbian, Debian, RISC OS, Windows 10 IoT Core, Android etc. In my infrastructure I am using it as a relay nodes which can collect the data using Bluetooth and send it to the next Raspberry Pi.

6.5 TI Sensor Tag

The TI Sensor Tag IoT kit gives the idea of cloud-connected product idea. The TI Sensor Tag includes 10 low-power MEMS sensors in a tiny red package. The new Sensor Tag is based on the CC2650 wireless MCU, offering 75% lower power consumption than previous Bluetooth low energy products. This allows the Sensor Tag to be battery powered, and offer years of battery lifetime from a single coin cell battery.

The Bluetooth low energy Sensor Tag includes iBeacon technology. This allows your phone to launch applications and customize content based on Sensor Tag data and physical location. Additionally, the Sensor Tag can be enabled with ZigBee/6LoWPAN technology.

TI Sensor Tag contains 10 sensors including support for light, digital microphone, magnetic sensor, humidity, pressure, accelerometer, gyroscope, magnetometer, object temperature, and ambient temperature.

6.6 Vuforia SDK and Unity Engine

Vuforias SDK includes different recognizable real world objects, so-called trackables .The detection and tracking algorithm uses Natural Feature Detection and Tracking, which allows the system to match visible elements in the image with targets in a predefined set. Different elements have different ease of being recognized, characterized by the detail level and repetitiveness. The current trackables Vuforia handles are image targets, cylinder targets, multi targets, frame markers and words.

The Image Target marker or the object marker has to be entirely visible for the detection, but could be partly occluded during tracking. When the marker is detected, Vuforia returns a trackable result containing references to the matching target, a status (i.e. unknown, undefined, not found, detected or tracked) and a pose matrix. The pose matrix represents the current position and orientation of the marker with respect to the cameras coordinate system. The content rendering can be done using Unity3D. Vuforia provides an extension package to Unity that allows developers to use vision detection and tracking within the Unity Integrated Developer Environment (IDE). Unity is originally a cross-platform 3D game engine .It allows for the creation of simple geometrical objects such as spheres, cubes or rectangles, but is essentially a tool to enable behavior of 3D models imported from 3D programs i.e. Blender or Maya. The behavior of the models is specified using scripts written in either C or JavaScript. Unity3D comes with different licensing types depending on the number of extra features one is interested in. The basic version is free and allowed to be published both privately and commercially.

6.7 JavaScript, HTML, CSS

HTML, CSS (Cascading Style Sheets) and JavaScript are three core technologies of World Wide Web content production. All modern web browsers support this three technologies without the need for plug-ins. HTML can embed programs written in a scripting language such as JavaScript which affect the behavior and content of web pages. Inclusion of CSS defines the look and layout of content. In JavaScript we can use AJAX technology. If you dont want to reload the whole html page but only some part of HTML page you want to reload then AJAX is very useful for that.CSS is generally used for user Interface of the webpage. Using CSS changes to the graphic design of a document (or hundreds of documents) can be applied quickly and easily, by editing a few lines in the CSS file they use, rather than by changing markup in the documents.

Chapter 7

Conclusion and Direction of Future Work

In this chapter we highlight the main conclusions in section 8.1 and list some suggestions for further research in section 8.2.

7.1 Conclusion

The work done is an infrastructure of Bluetooth as a communication protocol. Our basic infrastructure needs many parameter to be considered. In this Bluetooth discovery phase required lot of energy, so I must have to propose an algorithm to minimize the energy usage. Bluetooth communication supports only some fixed distance like 10 meters. In the large industrial plant we have to install lots of Raspberry pi. So we need to follow proper routing algorithm so that packets can choose lowest path and also ensured no packet loss. One of the most important parameter is packet delay. Since the whole infrastructure is supposed produce real time data. Based on those data, devices will be monitored. So packet delay should be minimized. We implemented Bluetooth based infrastructure which can be used as common platform for all the Bluetooth enabled devices. In This work I created a local server so that users which are connected on the same network can easily access all the data from the server. The setup can also be used to track the people inside the building. This infrastructure will aid in understanding communication based on Bluetooth, Wi-Fi etc. It will be easy for the user to add a new device to the existing setup and observe the effect in the network. The user can easily introduce or remove a device from the existing setup.

Our implemented android application is able to poll multiple Bluetooth devices to collect data periodically. The app can be used by in-field mobile personnel to monitor and configure field devices. The study will help in understanding app performance figures in terms of connectivity limits, agility, range limits, bandwidth, etc. In order to perform the performance measurement we have noted down these parameters- Battery consumption, latency (round trip time for each packet), and RSSI and distance measurement. RSSI is important because based on the value of RSSI, distance can be measured. As the distance increases RSSI will decrease resulting into higher packet latency.

7.2 Further Research

The following are some of the interesting directions for further research:

1. **Test infrastructure by adding more sensors and devices:** In the next step more sensors and different devices add to infrastructure and test infrastructure in terms of failure detection, performance, errors, efficiency etc. This process will undergo several phase of software testing since the whole infrastructure consists of heterogeneous components of different software. so research is open in terms of calculate different parameters like power consumption of the android app etc. other thing is to measure the performance analysis in terms of connectivity limits, range limits, bandwidth, etc.

2. **Long Range wireless communication protocols include in the infrastructure:** Now short range communication protocol are using in infrastructure for collecting data, so, In future also add data which is collected using long range communication protocol like LoRA, Zigbee etc. in this infrastructure. If LoRA is added in this infrastructure then the range of infrastructure will become few kilometers.

So this are the different research areas in which further computing can be done in future.

Appendix A

Appendix

A.1 Setup Guide for Bluetooth based Infrastructure

Here we discuss about how to setup Bluetooth based infrastructure in Industry or Factory floor. Figure A.1 shows the basic setup of the infrastructure. There are some steps person has to follow for setting up the infrastructure, which are as below:

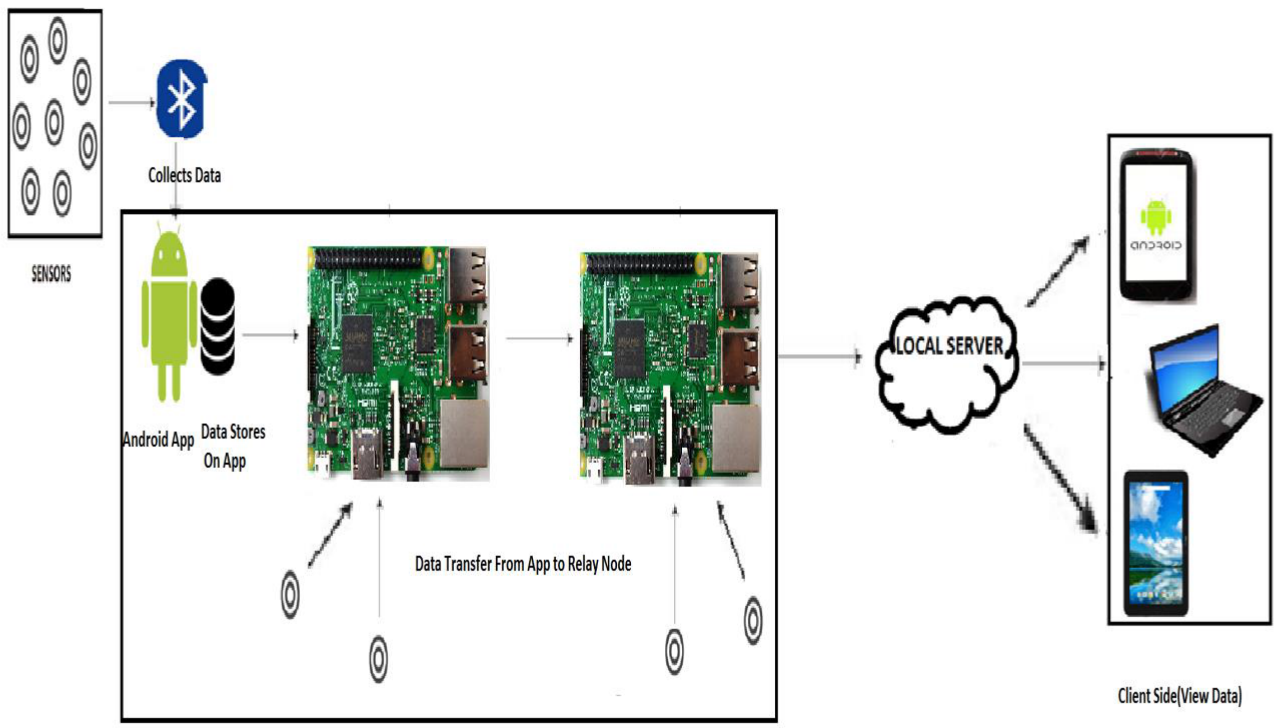

Figure A.1: Basic Setup of infrastructure

1. you have to turn on Bluetooth in all different sensors and devices for which you want to collect data in the factory floor.

2. You have to set Raspberry Pi according to you factory floor. Divide Factory floor in different zones.In Each zone put one Raspberry Pi and start application in Raspberry Pi.

Figure A.2: Tablet Showing the Trend Data as Fetched from the Server

3. We know that range of Bluetooth is 10-15m so make zones in factory floor such that maximum distance between two Raspberry Pi is 15m and all the sensors and smart devices are also lies in respective zone's Raspberry Pi's Bluetooth range.

4. After running application on Raspberry Pi, Pi will automatically collect data from all the devices in that particular zone and send that data to the next Raspberry Pi in specific interval. Last Raspberry Pi is sending that data to the web server.

5. On the server you visualize the data in different format like real time data on graphical format and historic data on tabular format.

In figure A.2, It shows how people can visualize data from their smart devices. It showing trending data on tablet which fetched from the server.

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