B.TECH. PROJECT REPORT

on

IoT Mesh Framework for Precision Farming

by

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IoT Mesh Framework for Precision Farming

PROJECT REPORT

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in

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Candidate's Declaration

I hereby declare that the project entitled "IoT Mesh Framework for Precision Farming" submitted in partial fulfilment for the award of the degree of Bachelor of Technology in Electrical Engineering completed under the supervision of Dr Gourinath Banda, Associate Professor, Computer Science and Engineering, IIT Indore is an authentic work.

Further, we declare that we have not submitted this work for the award of any other degree elsewhere.

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(160002044)
5/12/2019

Certificate by BTP Guide

It is certified that the above statement made by the student is correct to the best of my knowledge.

Dr Gourinath Banda
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Preface

This report on "IoT Mesh Framework for Precision Farming" is prepared under the guidance of Dr Gourinath Banda.
This report aims at explaining my work in the field of Internet of Things and Wireless Sensor Networks(WSN) to develop a novel platform that can be used for large scale data ingestion from multiple WSNs. We present our motivation and approach towards the problem, the hardware and software stack, and the implementation steps. I have tried to the best of my abilities and knowledge to explain the content in a brief but informative manner.

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I wish to thank Dr Gourinath Banda for his kind support and valuable guidance. His insight and inputs were crucial to the success of the project and kept me motivated. I also would like to thank Kanishk Mishra, Founder, DataCulture Farms Pvt Ltd for sponsoring the project. It was through your dedicated and adept thought-process which made this project a success. I would also like to thank all faculty members in the Discipline of Electrical Engineering for their invaluable support and guidance during presentations.

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Abstract

India suffers from one of the lowest per capita productivity in agriculture with drastically lower yields than even our BRICS counterparts. Precision Farming aims to solve the same by making sure that every resource is used just as much as required for optimal utility and maximum output. The current solutions are not designed for the Indian market and are too expensive to be considered viable. IoT coupled with WSN can enable a low cost, high impact solution customized for the Indian conditions. In this project, we present a Cloud-based platform for large scale data ingestion and device management customized for Precision Farming applications. The proposed 3 layer architecture provides a low-cost solution that reduces infrastructure costs through edge-computing and mesh-based Wireless Sensor Networks (WSN). Google Cloud Platform(GCP) is selected as the cloud provider to mitigate the high cost and risk of maintaining a reliable high availability backbone. The project was successful in designing and implementing the proposed platform and reduced the cost per hectare 10 fold compared to existing solutions.

Contents

List of Figures

List of Tables

Chapter 1

Introduction

1.1 Motivation

Issues in the agricultural sector of India include everything from low per capita productivity, lack of skilled labour, high cost of cultivation to insufficient soil management. Farming in India is still dependent on techniques which were evolved hundreds of years ago and doesn't involve technology in the decision-making process to optimize the use of resources.

India ranks first in the world with highest net cropped area [1] with close to 50% of the Indian workforce involved in agriculture and yet it contributes only 17% to the GDP. As seen in statistics provided by the Food and Agricultural Organization of the UN [2], the yield rates(tonnes produced per hectare) for India's primary crops are drastically lower than even BRICS counterparts and have seen little to no growth in the last three decades (ref. Figure 1.1).

The issue is not limited to just India, population explosion is a threat to the food security of the world. Several studies have shown that global crop production needs to double by 2050 to meet the projected demands from the rising population, diet shifts, and increasing biofuels consumption [3]. The crop yields need to be pushed worldwide to meet these rising demands.

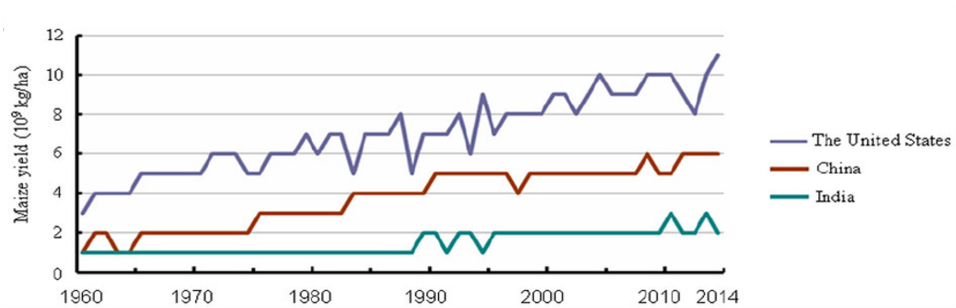

Figure 1.1: Maize yield of India since 1961 [2]

1.2 Problem Definition

Crop farming is still a very labour intensive process in India and the tools and methodologies used in farming have been obsolete for decades. The current decision-making process during farming is based on tradition and habit with very little science and technology involved. There's a dire need to optimize our farming methods. There are a lot of farm inputs that not only decide the cost of farming but the crop output as well [4].

Precision Farming(PF) is the use of technology to make sure that every resource is used just as much as required for optimal utility and maximum output[5]. The current PF solutions incur high initial capital costs which discourage farmers to adopt this method of farming. Moreover, India with its unique pattern of land holdings, poor infrastructure, socio-economic conditions and demographic conditions have limited its adoption [6]. The need is of a PF platform which is designed for the Indian market and is inexpensive and accessible to the farmers.

1.3 Precision Farming

Precision farming is the adoption of a set of practices that use technology to improve the efficiency and yield on a per square meter basis. Also known as satellite farming or site-specific crop management (SSCM), PF is a farm management concept based on observing, measuring and responding to the environmental conditions that model the growth of the crops [7, 8].
The goal is to define a platform that allows the farmer to make decisions based on the environmental conditions of his field, optimizing returns on inputs while preserving resources [9].
It broadly includes three components:

- **Remote sensing technology:**
  Responsible for observing and sensing various field parameters such as soil moisture, temperature, crop health.
- **Intelligent decision support system (DSS):**
  Responsible for processing the field data and using analytics to provide the optimal amount of farm inputs such as water, fertilizer, etc.
- **Variable rate technology (VRT):**
  Responsible for changing the amount of farm inputs being applied to the field according to the DSS.

A study [11], conducted in the Dharmapuri district, collected data on precision and non-precision farmings and revealed that adoption of precision farming led to an increase in gross margin of 165% and 67% respectively in tomato and brinjal farming. In another case study, done by Tata Kisan

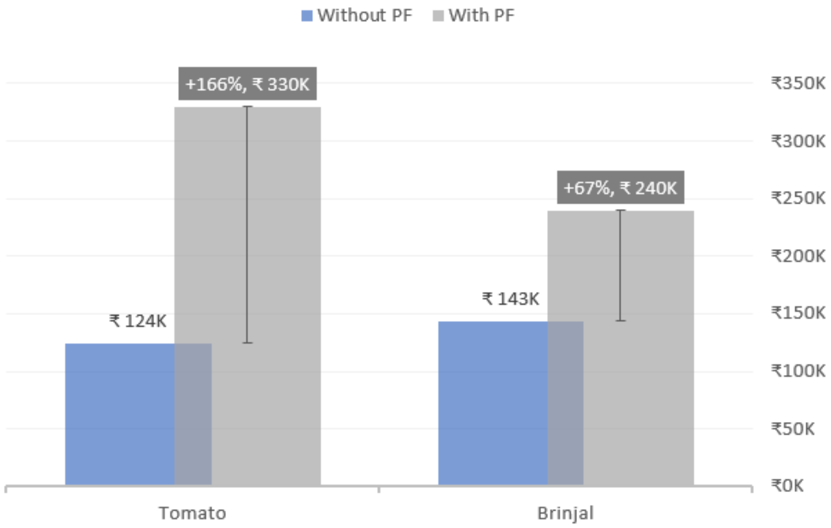

Figure 1.2: Effect of PF on Gross Margin (Rs/ha) [10, 11]

Kendra[10], they looked at the potential of PF in rural farms and successfully a implemented a customized PF system in Uttar Pradesh, Haryana and Punjab.

This clearly shows the untapped potential of Precision Farming in India. If adopted well, PF has the ability to double India's agricultural yield. The benefits include but are not limited to the following:

- Improvement in profitability, productivity and sustainability;
- Improvement in irrigation efficiency when water resources are low as well as prevent water erosion;
- Ability to forecast and mitigate problems such as water stress and nutrient deficiency; and
- Increased skilled employment in the agricultural sector.

Chapter 2

Literature Review

In [12], the authors perform a literature review and concluded that Big Data in Precision Farming is still in its nascent stage. Many of the technical challenges regarding scalability and costs can be solved if enough business opportunities for Cloud-based IoT platforms for PF can be created [13].

The advent of Cloud SaaS models such as Google Cloud Platform signifies a change in the industry. It has mitigated the high cost and risk of maintaining a reliable high availability backbone for high throughput applications such as Big Data for PF. This is implemented in [14] as a data collecting platform over distributed sensors, but the work lacks a framework for handling a large number of devices while maintaining a degree of abstraction.

A cloud-based IoT Scheme is implemented in [15] where they present a 3 layer architecture consisting of a front-end layer, gateway and back-end. This is done for load handling and device management with the use of a gateway. Likewise, [16] also presents an IoT based platform for Precision Agriculture which uses a Wireless Sensor Network(WSN) to improve scalability and range based on 6LoWPAN. In [17], the authors propose an 868Mz Mesh WSN solution to make an autonomous irrigation controller. Similar works involve IoT and WSN for Precision Agriculture such as [18–20].

However, most of these works either lack actual implementations or are too expensive to be viable. Moreover, none of them combines the power of an established Cloud Service, with the scalability of a consumer-grade WSN, controlled and coordinated by a 3 layer architecture.

Chapter 3

Preliminaries

3.1 Internet of Things

Internet of Things (IoT) [21] is an ecosystem of devices that are connected to the internet. The 'thing' can be anything from a heart monitor, an automobile, temperature sensor to a refrigerator. It includes any object that can transmit or receive data either directly or indirectly to the internet without manual assistance. The advent of wireless technology has lead to a rapid decrease in costs of such a system and increased the viability of a large deployment of IoT devices exponentially.

The devices are managed using an IoT platform which is a multi-layer technology that enables straightforward provisioning and management of connected devices. This has lead to IoT being widely used in connecting devices and collecting data information. The system is used to register their sensors, manage streams of data and handle configuration updates. Using a cloud-based service for the same greatly speeds up the development of applications and takes care of scalability and cross-device compatibility as well [22].

This connects your diverse hardware using a range of enterprise-grade connectivity options to huge data processing solutions, opening up a plethora of applications ranging from data collection to drone delivery networks to precision farming [23].

3.2 Wireless Sensor Network

A Wireless sensor network (WSN) refers to a group of spatially dispersed connected sensors that can be used for monitoring and recording the environmental conditions and creating a network to route that data to a central location. WSNs in precision farming increase efficiency and profitability by reducing networking costs and deployment complexity [24]. This gives real-time access to environmental information remotely which can be used for storage, data analytics, and make resource decisions. This contrasts with the traditional agricultural methods in which decisions were taken based on tradition and habit.

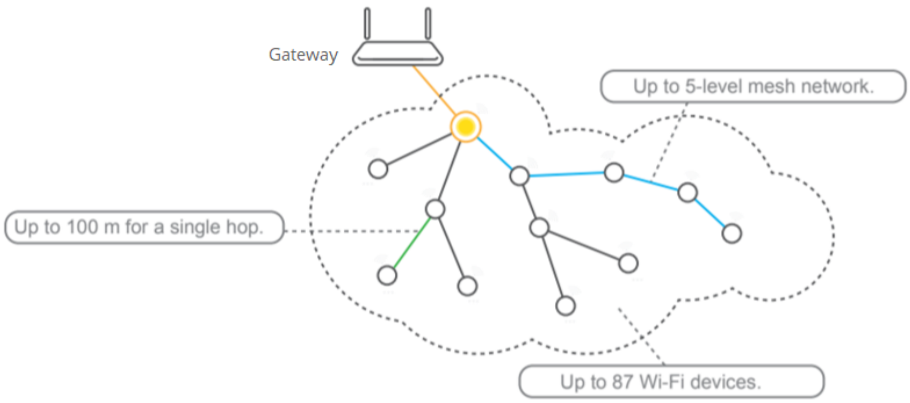

Figure 3.1: ESP8266 Mesh Network

WSNs make a large scale deployment of sensors economically viable for the farming domain [25]. It supports many operations such as irrigation, fertilizer use, soil monitoring and intruder detection [16]. Its integration has resulted in a plethora of applications such as remote healthcare, water control, precision agriculture, smart cities, and wildlife monitoring [15].

3.3 Gateway

An IoT gateway is a device/software that serves as the bridge between the WSN and the cloud side. It is responsible for device management, data processing, and routing [26].
In a cloud-based network architecture, these gateways act as edge nodes, reducing the amount of processing power required on the cloud end. As seen in Figure 3.2, this reduces both the cost and the complexity of the network.
It performs several tasks on their behalf, such as: [26]

- Communicating with IoT Platform;
- Connecting to the internet when the device can't directly connect itself, such as a ZigBee or Bluetooth device;
- Providing secure authentication when the device can't send its credentials, or when you want to add a layer of security by using the credentials of both the device and the gateway;

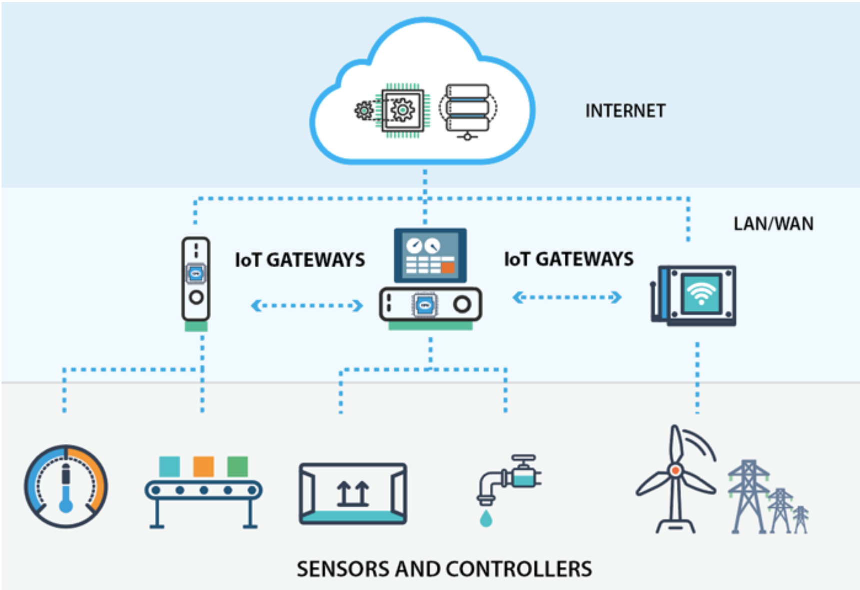

Figure 3.2: Role of an IoT Gateway [27]

- Publishing telemetry events, device management, getting configuration data, or setting device state;
- Storing and processing data, logs and telemetry; and
- Translating between different protocols.

Chapter 4

Proposed Solution

4.1 Requirements and Design Consideration

The requirements for this project are clear and fixed. The functional requirements are as follows:

1. The platform should scale easily with the number of devices and sensing parameters;
2. WSN should be inexpensive and easy to deploy;
3. The platform should have archival cloud storage with data analytics capability;
4. The cloud service must be reliable and always on;
5. Devices must be authenticated before sending telemetry data;
6. Devices should be managed and reconfigured via over-the-air (OTA) updates;
7. Data should be accessible in real-time by the user via MQTT; and
8. The telemetry parameters required for each sensing node are given in Table 4.1.

Based on the functional requirement, the proposed Software Design Considerations are given in Table 4.2.

Service Type	Telemetry Parameters
Publish	Soil Temperature
	Soil Moisture
	Timestamp
	NodeID
	FarmID
Subscribe	Configuration State
	Commands

Table 4.1: Device Telemetry Parameters

	Requirement	Design Consideration
1	Scalable with the number of devices and sensing parameters	An easily scalable WSN to be used.
2	WSN should be inexpensive and easy to deploy	WSN shouldn't be based on proprietary software/hardware; preferably consumer hardware
3	Cloud Platform must have archival cloud storage with data analytics capability	Utilizing Google BigQuery for its high throughput and big data analytics capability
4	Cloud service must be reliable and always on	Google Cloud Platform is reliable and has high availability
5	Devices must be authenticated before sending telemetry data	Sensing nodes will be authenticated using an intermediary device keeping the cost down
6	Devices should be managed and reconfigured via over-the-air (OTA) updates	GCP IoT Core provides device management and configuration over the air
7	Data should be accessible in real-time by the user via MQTT	Real-time data will be made available through an MQTT broker hosted by Google Cloud Pub/Sub

Table 4.2: Functional Requirements and Design Considerations

4.2 Network Architecture

The proposed network architecture (depicted in Figure 4.1) is composed of 3 layers: sensor, gateway, and cloud back-end. In this section, we will discuss these three layers and their implementation.

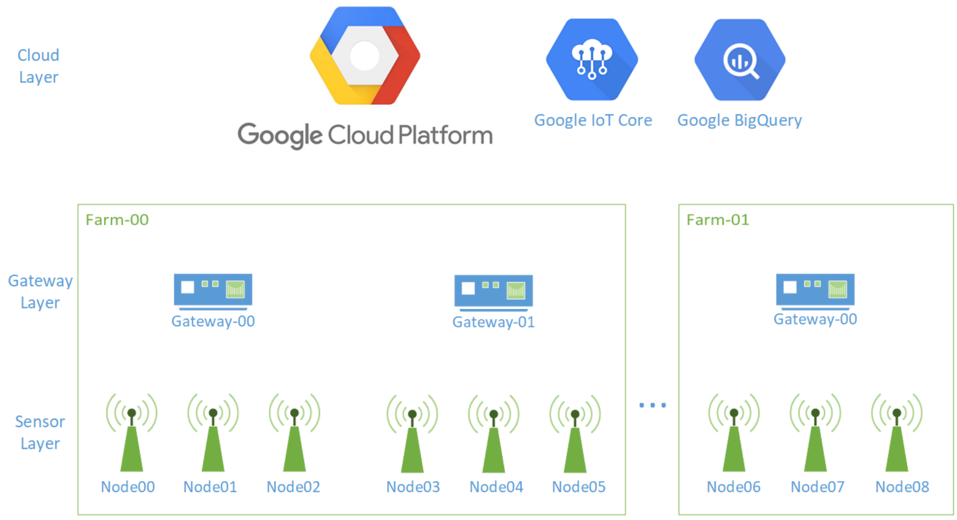

Figure 4.1: Proposed 3-layer architecture

4.2.1 Sensor Layer

The sensor layer is comprised of the actual sensing hardware. Each device or node currently comprises of just 3 modules: an IoT capable microcontroller(ESP8266), the environmental sensors (Soil Moisture and Temperature), and a 3.2v battery (LiFePo4). The functionally modular design allows for easy upgradability and repair. The node design is given in Figure 4.2.

The ESP8266 microcontroller is a low-cost, low-power microcontroller with inbuilt WiFi capability and multiple GPIOs for communication purposes (Refer to Table 4.3). The micro-controller is responsible for collecting the data from the sensors and sending it to the gateway through the mesh. The micro-controller is powered by a 3.3v power source and uses 80-90mA during load and 20µA during deep sleep. Using a 1-3 hour duty cycle, the power consumption of the micro-controller can be reduced to less than 1mA per hour. Using a 3000mah battery, this can last anywhere from 150-215 days depending on external factors.

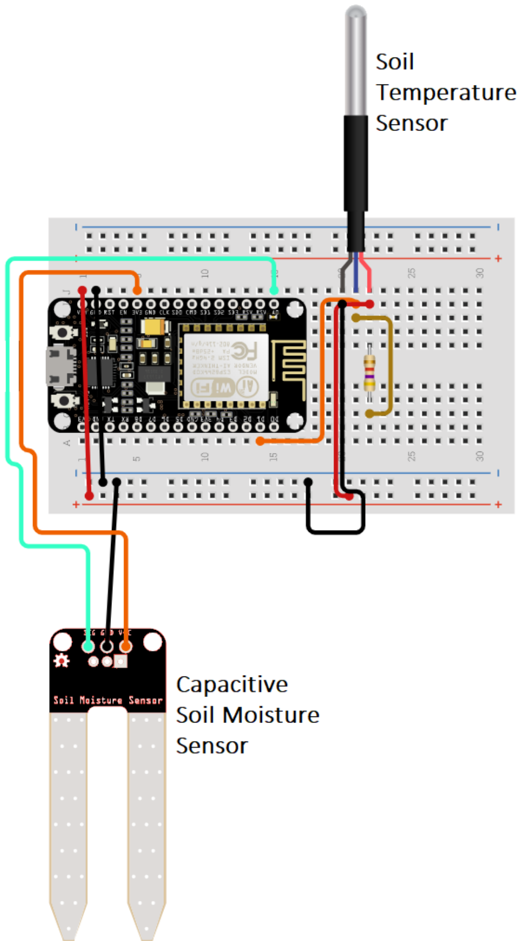

Figure 4.2: Node Design Schematics

Parameters	**Specification**
Processor	TenSilica L106 80MHz 32bit
SRAM	160 kbytes
Flash Storage	SPI Flash, up to 16 MBytes
GPIO pins	17
ADC pins	1 pin, 10 bit
WiFi	2.4GHz, 802.11 b/g/n
Operating Voltage	3-3.6 Volts

Table 4.3: ESP8266 (Sensor Node) Specifications

Sensor	Model
Soil Temperature	DS18B20
Soil Moisture (Capacitive)	RKI-3225

Table 4.4: Used Sensor Models

4.2.2 Gateway Layer

The gateway layer comprises aggregating devices that connect to WSN networks, collect the data, authenticate the devices, and then relay the data to the cloud. During each duty cycle, the gateway will wake up and perform the following:

1. Connect to the WSN using wifi;
2. Authenticate active sensor nodes using a JSON Web Token (JWT);
3. Collect sensor reading and calculate any derived measurements;
4. Relay to Cloud MQTT broker and the BigQuery database for archival storage with proper timestamps; and
5. Receive any configuration updates and relay them to the respective node in the WSN.

The gateway is implemented using Raspberry Pi 4 (4GB) micro-controller. Being equipped with a 1.5GHz quad-core CPU and 4 GB RAM, it is more than capable enough to handle multiple data streams and adds to the scalability of the design. These devices provide sufficient edge processing, removing any requirement for cloud-based processing power. The inbuilt WiFi(2.4 GHz and 5.0 GHz), Bluetooth 5.0, and BLE modules can be used for connecting to both Wifi and BLE based WSNs. A 4G USB dongle is used to provide internet connectivity in remote areas, but an ethernet interface can also be used for the same.

4.2.3 Cloud Layer

The cloud layer is responsible for data ingestion, device management through the gateway, and providing archival storage and data analytics. The cloud architecture is described in Figure 4.3.

The Google Cloud Platform (GCP) is used for the same as Google Cloud IoT core platform has the functionality to support data ingestion from a large number of globally distributed devices. The platform also has integrated services that manage authentication and device management. Google

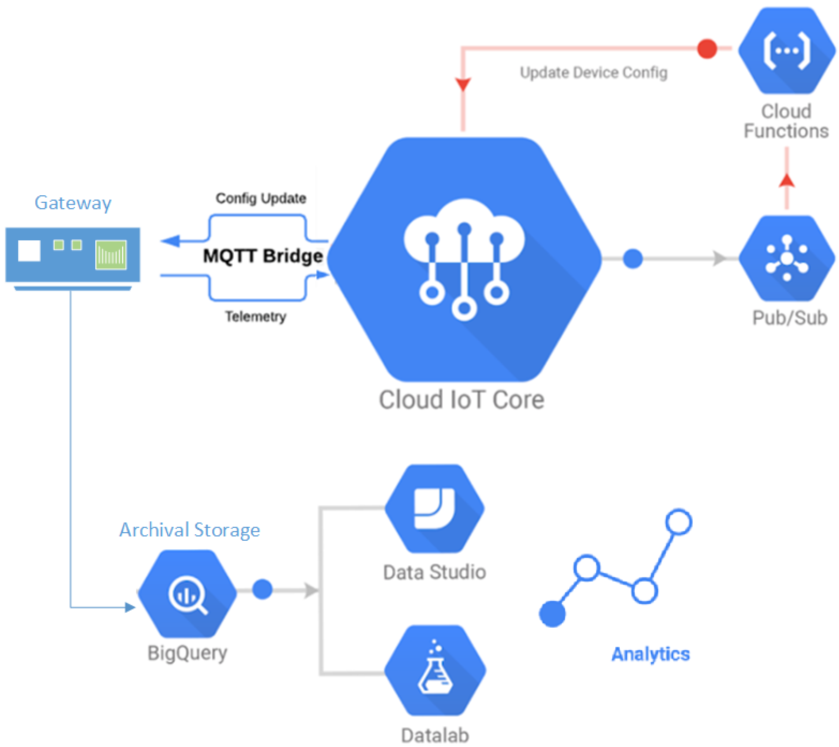

Figure 4.3: GCP Cloud Architecture

BigQuery is used for archival storage and data analytics as it supports direct streams of data and has high throughput [28, 29].

A direct connection between an ESP8266-based node and Google Cloud IoT Core is possible but since many inexpensive boards lack the features required to make a secure connection, the WSN is kept isolated. The gateway layer handles the authentication process for the nodes through JSON Web Token (JWT) authentication. Each node must be authenticated via the gateway it is bound to before it can send any telemetry data.

Chapter 5

Solution Stack

5.1 Hardware Stack

The two main factors that decided the hardware stack are cost and functionality. The node needs to be as inexpensive as possible as to keep the costs down when scaling, and the gateway needs to be powerful enough to allow easy scalability and upgradability.

The 2 microcontrollers that are a great fit to serve as the brain of the node, ESP8266 and ESP32. Both are perfectly suited and the software stack is compatible with both of them. To keep the development costs down, the ESP8266 was used. The complete bill of materials is given in Table 5.1.

Device	**Components**	**Cost**	
9 x Nodes			₹ 1,050
	ESP8266	₹ 364	
	Soil Moisture Sensor	₹ 177	
	DS18B20 Soil Temperature Sensor	₹ 110	
	3000mah LiFePo4 Battery	₹ 299	
	Housing	₹ 100	
1 x Gateway			₹ 5,272
	Raspberry Pi 4 (4GB)	₹ 3,994	
	16GB Storage	₹ 279	
	4G Dongle	₹ 999	
Total:			₹ 14,722

Table 5.1: Bill of Materials

5.2 Software Stack

5.2.1 Node

The ESP8266 node is programmed using PlatformIO [30], an open-source, cross-platform IDE. This allows for fast debugging, code execution, and testing on any platform that can run python. The code is written in C++ (refer to Appendix 8.1).
The mesh is built and configured using painlessMesh [31] module, an open-source library that takes care of the particulars of creating a simple ad-hoc mesh network which required no central controller. It is compatible with both the ESP8266 and the ESP32. Each node created a wifi network with the same SSID but different BSSID. After the mesh is initialized and configured, only one SSID is publicly visible, reducing any network clutter.
The main loop logic is defined as follows:

1. Initialize the mesh and wait for the gateway to connect (until max wait time);
2. When connected, request for authentication, and sense the parameters;
3. When authenticated, send the payload with the available parameters;
4. Receive any configuration updates, or commands from the gateway and perform the necessary actions; and
5. Go to deep sleep until the next wakeup cycle.

5.2.2 Gateway

The gateway powered by the Raspberry Pi 4 hardware is programmed in python, allowing for cross-platform compatibility and support. The python script works alongside a modified version painlessMeshBoost library [32] which creates a bridge between the WSN mesh and the gateway.
The setup instructions are as simple as running the python script with the appropriate arguments. The main loop logic is defined as follows:

1. Actively looks for the WSN and connect when available;
2. When connected, using the painlessMeshBoost bridge receive the telemetry data from the Sensor nodes and act accordingly;
3. Relay the telemetry data with appropriate timestamps to Google Cloud IoT Core, and BigQuery database for archival storage;
4. Relay any configuration updates and commands to the specific nodes using the bridge; and
5. Sleep until the next wakeup cycle.

Chapter 6

Results and Discussion

A prototype of the proposed solution has been implemented for a proof of concept to evaluate the proposed IoT Mesh Framework. The three layers were fully implemented with 9 nodes in the sensors layer bound to one gateway. The setup was run for 72 hours with data collected every 3 hours.

The archived data is retried from the BigQuery database using an SQL query. The collected data contains the timestamp, nodeID, temperature and moisture information. The temperature and moisture measurements are shown in Figure 6.1, and Figure 6.2 respectively.

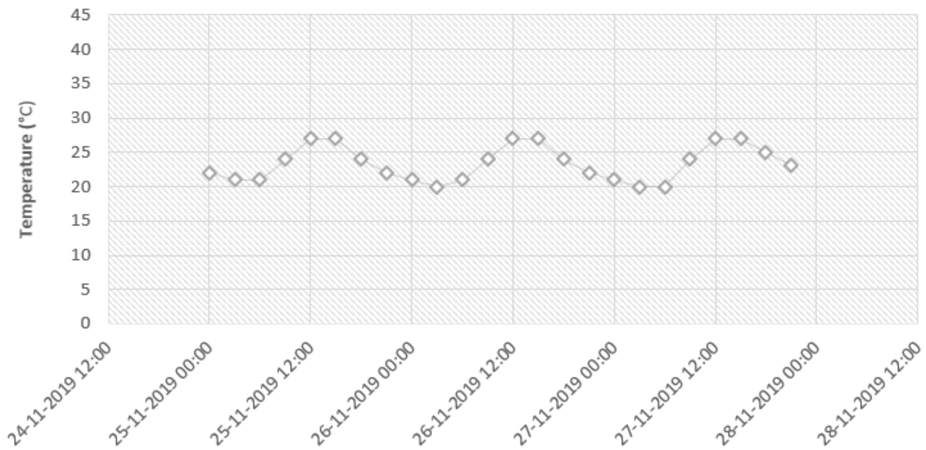

Figure 6.1: Temperature Readings

This demonstrates the ability of the proposed IoT framework to ingest, process and visualize the data needed for different precision agriculture applications.

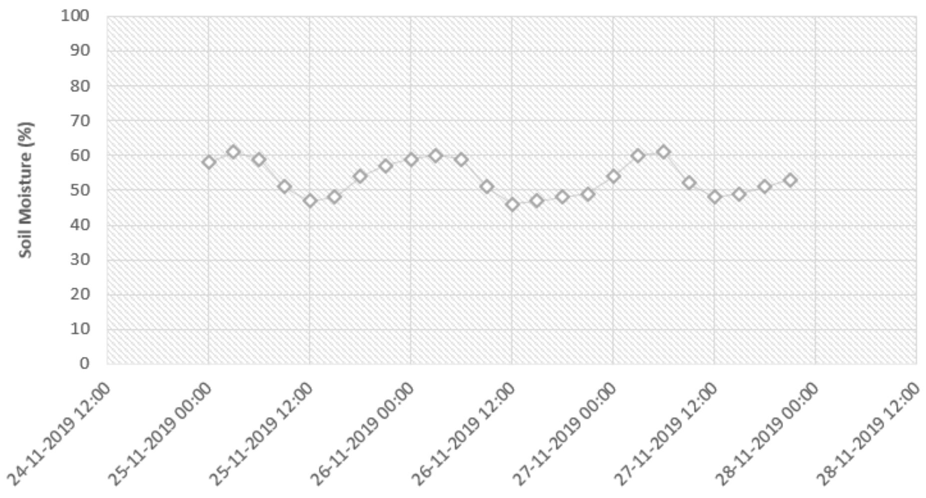

Figure 6.2: Soil Moisture Readings

6.1 Future Scope

The platform developed supports and is designed for various decision driven applications, which would include actuators and valves for controlling the amount of farm inputs. In the process of making the architecture industry ready, the following steps are needed:

- Designing a front end for platform management;
- Designing industry-ready sensors for robust hardware and more reliable measurement;
- Improving the mesh architecture for more stability; and
- Adding field imagery and drone footage as sensory input.

Chapter 7

Conclusion

The project was successful in developing a solution that cut down the costs of Precision Farming in India 10 fold while improving the functionality and scalability.

It is ultra-low-cost, more scalable, has increased modularity, and has a lower technology footprint compared to the incumbent technology.

The framework was designed in collaboration with DataCulture Farms Private Limited and will be used by them to implement their autonomous farm management solution.

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