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Leveraging Low Power Wide Area Networks for Precision Farming

Limabora: A Smart Farming Case Using LoRa modules, Gateway, TTN and Firebase in Kenya

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Abstract - Over the last couple of years, the Internet of Things (IoT) technology has dominated the headlines globally. A number of forums, conferences and seminars have been organised locally to inform and educate people, specifically the C-suite, about IoT and the opportunities it brings concerning digital transformation for better business. In this regard, @iLabAfrica, an ICT and Innovation Research Centre based in Strathmore University, Nairobi, Kenya, set up a Lab in 2016 to foster industry-led research and innovation in the area of IoT. The Lab has implemented a number of IoT projects that address various sectors including Agriculture. A noteworthy project is the Limabora-A Remote Farm Monitoring system project, an ongoing collaborative effort between @iLabAfrica, IBM Kenya, Oregon State University and Trans-African Hydro-Meteorological Observatory (TAHMO), which leverages on IoT technology and Data Analytics to facilitate Precision Farming. This is meant to address the fear of food insecurity that has been raised by the interchanging flood and drought plagues that have subsequently affected the remote regions in Kenya. 'Lima' and 'Bora' are both Swahili words that mean 'to farm' and 'well/good/better' in English respectively. The real value of IoT lies in the data and the insights that can be derived from it through various analytics algorithms. The Big Data Revolution has provided novel ways that large amounts of data can be analysed to derive meaningful insights in various fields, including Agriculture. This paper provides a detailed account of Smart Farming- A Remote Farm Monitoring system project, which has proven reproducible outcomes towards ensuring food security and the realisation of development goals in Africa.

Keywords - Precision Farming; Agriculture; Internet of Things (IoT); LoRa; Machine to Machince (M2M); Low Power Wide Area Networks (LPWAN); Big Data

I. Introduction

The 3rd Green Revolution has transformed Agriculture, often seen as very traditional, into a technology reliant venture to provide for efficient, innovative, dynamic and eco-friendly farms. Farmers are now embracing Information Communication Technology (ICT) solutions to monitor and manage their farms remotely. Specifically, farmers are looking to monitor and manage resources such as water and energy usage and supply in their farms, in addition to parameters concerning the weather (humidity, temperature) and soil (soil moisture). However, in the rural regions of Africa, specifically Kenya, the benefits of smart farming are not accessible to farmers. The IoT lab of @iLabAfrica has embarked on a research project that seeks to provide an innovative solution for remote farm monitoring, which is built on IoT and Big Data Analytics technologies. The goal of this project is to build a usable solution for farmers in rural Kenya and to inform on the implementation and sustainability approaches of similar systems in other developing countries towards the realization of national and global development goals, especially the Sustainable Development Goals (SGDs).

II. Implementation approach

The Remote Farm Monitoring system leverages on Internet of Things (IoT) architecture, through remote sensing and low power wide area networks, and Big Data Analytics to provide Precision Farming to farmers located in rural areas. The data collected so far includes temperature, humidity, water level (rate of water evaporation also monitored through the use of evaporimeters), battery level and the signal strength of the data transmitting devices. Due to poor signal strength experienced in rural areas, GSM/GPRS and Long Range (LoRa) connectivity has been used extensively to achieve the desired Machine-to-Machine data exchange between the farms and the cloud. The data is transmitted in real-time to an Android mobile application through Google's Firebase – a mobile application development platform.

The infrastructural setup implemented for the Remote Farm Monitoring system constitutes usage of open source electronics and software. The edge devices encompass an 8-bit AVR microcontroller (MCU). In this case, an ATmega328P MCU which operates at a power voltage of 5V and packages a 16MHz crystal oscillator to handle the processing of the sensor data is used. The soil moisture and the water level sensors use the analogue interface while the humidity and temperature sensors utilise the digital interface of the MCU. An RN2483 LoRa module is also integrated to the MCU through the Receiver-Transmitter (UART) interface for the transmission of the data on one set of the nodes while a GSM/GPRS module from Adafruit is connected to the other set of the nodes using the same UART interface.

The LoRa module transmits data through a LoRa-based gateway which has been implemented with a Raspberry Pi 3, an open source system-on-chip. It hence utilises the LoRaWAN protocol as described in [1]. The gateway leverages the Wi-Fi interface of the raspberry Pi to relay the sensor data to the Firebase cloud through The Things Network (TTN). TTN is an open-source LoRa-based platform. The data currently streams from all the nodes in real-time since the nodes are still under study. This implementation also makes use of mini solar panels which power the sensor nodes. The gateway is currently located indoors and is hence connected to the main power supply backed up with an Uninterruptible Power Supply (UPS) unit.

A. Overview of Low Power Wide Area Networks (LPWAN)

Low Power Wide Area Networks (LPWAN) have become a popular low-rate long-range radio communication technology for adoption globally. Sigfox, LoRa, and NB-IoT are the three leading LPWAN technologies that compete for large-scale IoT deployment. This paper focuses on the usage of the LoRa technology within the domain of agriculture. A brief comparative study of these technologies, which serve as efficient solutions to connect smart, autonomous, and heterogeneous devices is also discussed here. We show that Sigfox and LoRa are advantageous in terms of battery lifetime, capacity, and cost. Meanwhile, Narrow-band IoT (NB-IoT) offers benefits in terms of latency and quality of service [2].

LPWAN is increasingly gaining popularity in industrial and research communities because of its low power, long range, and low-cost communication characteristics. It provides long range communication up to 10–40 km in rural zones and 1–5 km in urban zones [3]. In addition, it is highly energy efficient (i.e. 10+ years of battery lifetime) and inexpensive, with the cost of a radio chipset being less than two dollars and an operating cost of one dollar per device per year. These promising aspects of LPWAN have prompted recent experimental studies on the performance of LPWAN in outdoor and indoor environments [4].

LoRa

LoRa is a spread spectrum modulation scheme that uses wideband linear frequency modulated pulses whose frequency increases or decreases over a certain amount of time to encode information. The main advantages of this approach are twofold: a substantial increase in receiver sensitivity due to the processing gain of the spread spectrum technique and a high tolerance to frequency misalignment between receiver and transmitter. Just Like Sigfox, LoRa uses unlicensed ISM bands, i.e., 868 MHz in Europe, 915 MHz in North America, and 433 MHz in Asia. The bidirectional communication is provided by the chirp spread spectrum (CSS) modulation that spreads a narrow-band signal over a wider channel bandwidth. The resulting signal has low noise levels, enabling high interference resilience, and is difficult to detect or jam.

LoRa uses six spreading factors (SF7 to SF12) to adapt the data rate and range tradeoff. Higher spreading factor allows longer range at the expense of lower data rate, and vice versa. The LoRa data rate is between 300 bps and 50 kbps depending on spreading factor and channel bandwidth. Further, messages transmitted using different spreading factors can be received simultaneously by LoRa base stations. The maximum payload length is 243 bytes. A LoRa-based communication protocol called LoRaWAN was standardized by LoRa-Alliance (first version in 2015). Using LoRaWAN, each message transmitted by an end device is received by all the base stations in the range. By exploiting this redundant reception, LoRaWAN improves the successfully received messages ratio [5].

Sigfox

Sigfox is an LPWAN network operator that offers an end-to-end IoT connectivity solution based on its patented technologies. Sigfox deploys its proprietary base stations equipped with cognitive software-defined radios and connect them to the back end servers using an IP-based network. The end devices connected to these base stations using binary phase-shift keying (BPSK) modulation in an ultra-narrow band (100 Hz) subGHZ ISM band carrier. Sigfox uses unlicensed ISM bands, for example, 868 MHz in Europe, 915 MHz in North America, and 433 MHz in Asia. By employing the ultra-narrow band, Sigfox uses the frequency bandwidth efficiently and experiences very low noise levels, leading to very low power consumption, high receiver sensitivity, and low-cost antenna design at the expense of maximum throughput of only 100 bps. Sigfox initially supported only uplink communication, but later evolved to bidirectional technology with a significant link asymmetry. The downlink communication, i.e., data from the base stations to the end devices can only occur following an uplink communication. The number of messages over the uplink is limited to 140 messages per day. The maximum payload length for each uplink message is 12 bytes. However, the number of messages over the downlink is limited to four messages per day, which means that the acknowledgment of every uplink message is not supported. The maximum payload length for each downlink message is eight bytes.

Narrowband-IoT (NB-IoT)

NB-IoT is a Narrow Band IoT technology specified in Release 13 of the 3GPP in June 2016. NB-IoT can coexist with GSM (global system for mobile communications) and LTE (long-term evolution) under licensed frequency bands (e.g., 700 MHz, 800 MHz, and 900 MHz). NB-IoT occupies a frequency band width of 200 KHz, which corresponds to one resource block in GSM and LTE transmission [6]. In fact, the 3GPP recommends the integration of NB-IoT in conjunction with the LTE cellular networks. NB-IoT can be supported with only a software upgrade in addition to the existing LTE infrastructure. The NB-IoT communication protocol is based on the LTE protocol. In fact, NB-IoT reduces LTE protocol functionalities to the minimum and enhances them as required for IoT applications. For example, the LTE backend system is used to broadcast information that is valid for all end devices within a cell. As the broadcasting back end system obtains resources and consumes battery power from each end device, it is kept to a minimum, in size as well as in its occurrence. It was optimized to small and infrequent data messages and avoids the features not required for the IoT purpose, e.g., measurements to monitor the channel quality, carrier aggregation, and dual connectivity. Therefore, the end devices require only a small amount of battery, thus making it cost-efficient[12].

B. Development of the Sensor Node Environment

The devices used in the development of the prototype to collect data from their farms under this study include:

1. ATmega328P MCU
2. Soil moisture sensor from Sparkfun
3. DHT11 sensor module for temperature and humidity sensing
4. An RN2483 LoRa Module

The soil moisture sensor connects to the ATmega328P [2] microcontroller unit (MCU) using one of the analog pins of this MCU chip while the DHT11 uses any of the digital pins. In this case, pins A5 and D2 were used. The RN2483 module uses the Universal Asynchronous Rec (Wang , Grovlen, Sui, & Bergman , 2016)eiver Transmitter (UART) interface to connect to the MCU [7]. One can use hardware serial or software serial to make this connection. In this case, software serial has been used. The diagram of the connection is as shown below. Both sensors use 5V power input while the RN2483 communication module uses 3.3V. Since the ATmega 328P MCU used is the 16MHz, 5V input, the LD1117 regulator is used to get the 3.3V for the RN2483 LoRa module.

The ATmega328P was programmed with platformio as described in the platformio documentation using the C++ language. Platformio is added as a plugin to your preferred text editor such as vim, visual studio code, eclipse or atom. Visual studio code is the preferred environment in this case although the code is uploaded on the terminal interface. The diagram of this connection is as shown in figure 1. The soil moisture and the RN2483 connections have only been described on how they could be interacted to the circuit.

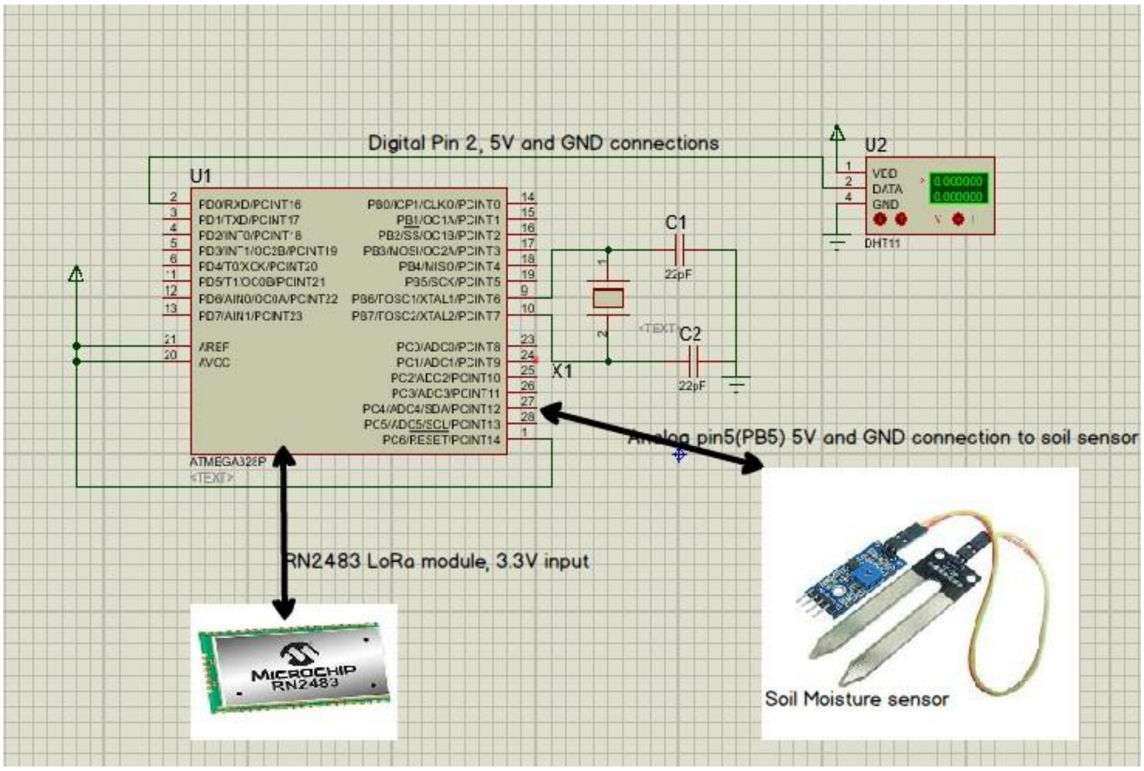

Figure 1: Connection Diagram on ISIS Proteus

Figure 2 shows a serial image of the windows cmd on transmission of data from the sensors to the things network (TTN) platform. The diagram shows how the data gets to be transmitted on the LoRa network both on fail and successful transmission.

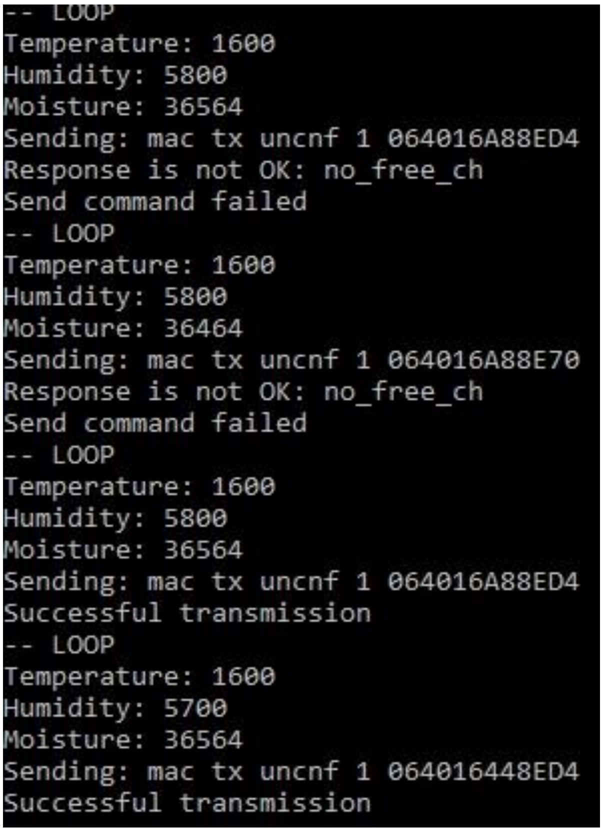

Figure 2: CMD screenshot on transmission of data over the LoRa network

C. The Communication Architecture

Obtaining sensor data to an interface of use by the farmers is a major challenge within the context of this study since the farmers targeted in our development live in the rural areas of Kenya. Most of these areas occasionally experience poor signal strength on the cellular band. Internet connectivity has not penetrated in these places as it has done in the major cities and towns in Kenya. Hence most farmers only rely on the use of feature phones through Unstructured Supplementary Service Data (USSD) and Short Message Services (SMS) or mobile data for the ones using the smart phone [11]. With this picture in mind, our approach of implementation focused on the use of the GSM/GPRS infrastructure which has also had its cons overriding the pros to deliver a precision farming test case in terms of signal stability, power consumption and management of data. We therefore opted to combine that with Long Range (LoRa) technology in our development to deliver a cheaper, reliable and energy efficient solution. The implementation of the LoRa Communication Architecture leverages the low power wide area network technology that taps into an unlicensed band of 868 MHz in the ITU region 1. Based on the LoRa radio modulation technology, invented in 2010 by the French startup Cycleo and then acquired by Semtech, a Media Access Control (MAC) layer has been added to standardise and extend the LoRa physical layer onto Internet networks[7]. Its low power performance capability provides a longer battery life enhancing the ability of monitoring farms that are not closely linked to grid power. Our implementation elucidated our agreement to the following advantages coming from a number of signal strength and power tests we carried within our University on five floors as shown in table 1.

The advantages of the LoRa technology include:

1. It uses 868 MHz/ 915 MHz Industrial, Scientific and Medical (ISM) bands which is available worldwide.
2. It has very wide coverage range about 5 km in urban areas and 15 km in suburban areas.
3. It consumes less power and hence battery will last for longer duration.
4. Single Lomg Range (LoRa) Gateway device is designed to take care of 1000s of end devices or nodes.
5. It is easy to deploy due to its simple architecture.
6. It uses Adaptive Data Rate technique to vary output data rate/Radio Frequency (R.F.) output of end devices. This helps in maximizing battery life as well as overall capacity of the LoRaWAN network. The data rate can be varied from 0.3 kbps to 27 Kbps for 125 KHz bandwidth.
7. The physical layer uses robust CSS modulation. CSS stands for Chirp Spread Spectrum. It uses 6 Spreading Factor (S.F.) from SF 7 to 12. This delivers orthogonal transmissions at different data rates. Additionaly, it provides processing gain and hence transmitter output power can be reduced with same RF link budget and hence will increase battery life.
8. It uses LoRa modulation which has constant envelope modulation similar to Frequency Shift Keying (FSK) modulation type and hence available PA (power amplifier) stages having low cost and low power with high efficiency can be used.

In the development of Limabora, a LoRa Gateway was constructed using a Raspberry Pi 3 and the iC880a (purchased from IMST) concentrator. The iC880a is able to receive packets of different end devices send with different spreading factors on up to 8 channels in parallel. The LoRa nodes with larger distances from the concentrator must use higher spreading factors while the nodes closer to the concentrator must use lower spreading factors eliciting the concept of dynamic data rate. The larger the distance, the lower the data rate and vice versa. The usage of this technology in this study is to help bridge the IoT connectivity gap and present a case of LPWAN that is well suited to support services which need long range communication (dozens of kilometres) to reach devices which must have a low power consumption budget in order to operate several years on a battery pack. The trade-off is a low data rate delivered by the low power wide area network technologies, from 300bps up to 5kbps (with 125kHz bandwidth) in LoRa modulation as outlined in [8].

The LoRa node connected to the ATmega328P MCU packages the payload of the two sensors and transmits them to the Internet through the iC880a concentrator sitting on the raspberry Pi 3 to the Things Network (TTN) platform. The TTN platform has also been used to decode the payload from hexadecimal to float. The payload is packaged as bytes in the microcontroller code.

Figure 3 shows how the communication architecture is developed in trying to transmit the data to the cloud. The RN2483 packages the data and sends to the iC880a concentrator on the raspberry pi. This is what is called uplink transmission. The concentrator has LoRa on one end and Internet on the other end through the Raspberry Pi. In this, an Ethernet cable has been used on the Pi although Wi-Fi has also been implemented on the other Raspberry Pi devices used in the project.

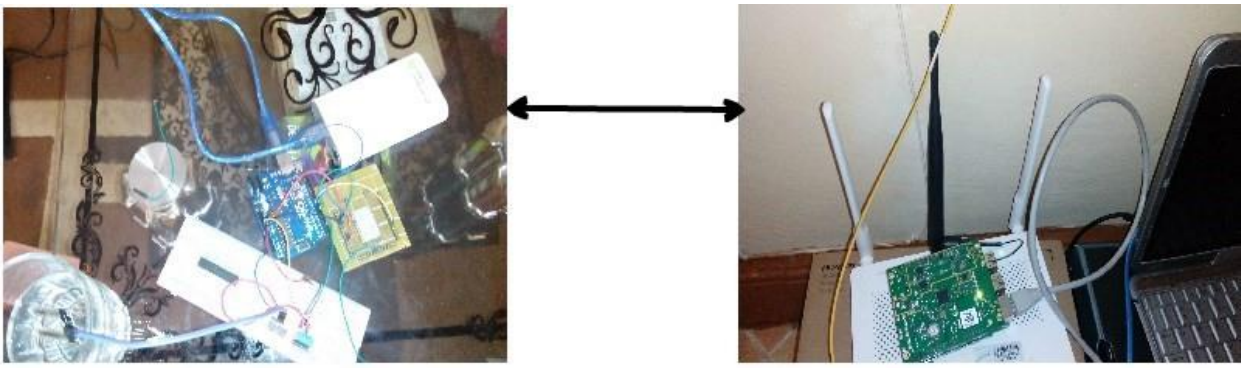

Figure 3: Transmission of data from the nodes to the Gateway with an Internet backhaul to cloud

D. Transmitting the Data to Firebase

The implementation of the data store in our case is important for the development of the desired analytics and capability of A.I. to extract the farm trends in terms of the monitored parameters such as the temperature, humidity, pH and soil moisture. This should help in the development of more informative insights in terms of the future climatic changes to anticipate the best crops to grow, the best fertiliser to put to use among other relevant details. In our case, the database selected to handle both user data and the sensor data is Firebase. Although previous test developments had already been done with MySQL and MongoDB, our research approach within this context explored the use of Firebase for two reasons: The first one being the development of a new knowledge locally in regards to the use of Firebase and the second one relating to the benefit farmers can derive from a real-time implementation of a NoSQL approach of the database including real-time analytics.

Firebase is a real-time database designed to accelerate the integration of cloud-based feature into mobile and web applications. In 2014, Google completed the acquisition of a San Francisco-based company named Firbase Inc. It combined the services initially packaged with Firebase with a number of complementary features previously included as part of the Google Cloud Platform [9]. These features include functionality like analytics, databases, messaging and automatic scalability which are really useful in handling IoT-based data.

The things network under the integrations tab on the application interface has provided an easy way of integrating with Firebase. Our project leverages this on HTTP integration pointing to our Firebase url where the database is created. The payload has to be in json format.

The result is as shown in figure 4:

Figure 4: Json format of the farm sensor data

The app_id, counter, device_id and the downlink url are all fetched from the things network. The payload is received in json which is the format used by firebase. One can decode the payload_raw to obtain the sensor values for viewing it on a web interface or mobile App. The payload_raw is in base64 format as described in [9].

III. Results

This section gives an overview of the research findings that are related on the use of Long Range, a low power wide area network technology to transmit data from a sensor node on the farm to a mobile application made available to the farmer in an effort to achieve precision farming through usage of IoT technology. The capability of transmitting data from the device environment to the online LoRa platform is also presented here. Table 1 is a representation of the tests carried between two nodes to gauge the signal quality of transmitting data using the LoRa technology.

				Output Power (In Decibels)														
Floor Number		Position		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
5th		1		√														
		2		√														
		3		√														
4th		1		√														
		2		√														
		3		√														
3rd		1		X	X	X	—	—	√									
		2		X	X	X	X	X	√									
		3		X	X	X	X	X	√									
2nd		1		X	X	X	X	X	√									
		2		X	X	X	X	X	—	—	√							
		3		X	X	X	X	X	X	—	√							
1st		1									√							
		2									√							
		3									√							
GF		1		X	X	X	X	X	X	X	√	—	—	√				
		2		X	X	X	X	X	X	X	—	√		√				
		3		X	X	X	X	X	x	X	X	X	X	X	X	X	X	√

Table 1: Signal Power tests on the LoRa RN2483 modules

The two interfaces on figure 5 and 6 show how one can view the real-time data from the sensor node environment as gateway traffic and on the application registered on the things network. It is critical for one to activate the node device before adding it to the things network. The gateway traffic also indicates the frequency used, the modulation scheme used which in this case is LoRa, the spreading factor, bandwidth and the payload size.

The snippet of the programmed code for the transmission of data is shown here.

```
void loop()
{
  debugSerial.println("-- LOOP");

  // Read sensor values and multiply by 100 to effictively have 2 decimals
  uint16_t humidity = dht.readHumidity(false) * 100;

  // false: Celsius (default)
  // true: Farenheit
  uint16_t temperature = dht.readTemperature(false) * 100;

  //soilSensor reading
  uint16_t moistureValue = analogRead(soilSensor) *100 ;

  // Split both words (16 bits) into 2 bytes of 8
  byte payload[6];
  payload[0] = highByte(temperature);
  payload[1] = lowByte(temperature);
  payload[2] = highByte(humidity);
  payload[3] = lowByte(humidity);
  payload[4] = highByte(moistureValue);
```

```
  payload[5] = lowByte(moistureValue);

  debugSerial.print("Temperature: ");
  debugSerial.println(temperature);
  debugSerial.print("Humidity: ");
  debugSerial.println(humidity);
  debugSerial.print("Moisture: ");
  debugSerial.println(moistureValue);

  ttn.sendBytes(payload, sizeof(payload));

  delay(20000);
}
```

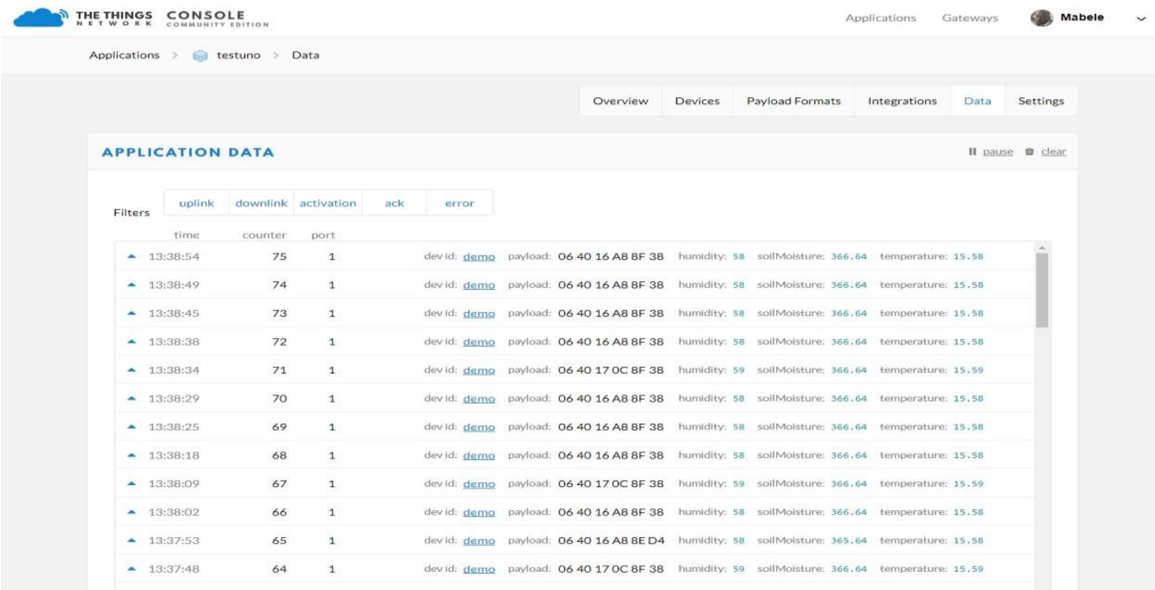

Figure 5: Application traffic of sensor data on TTN

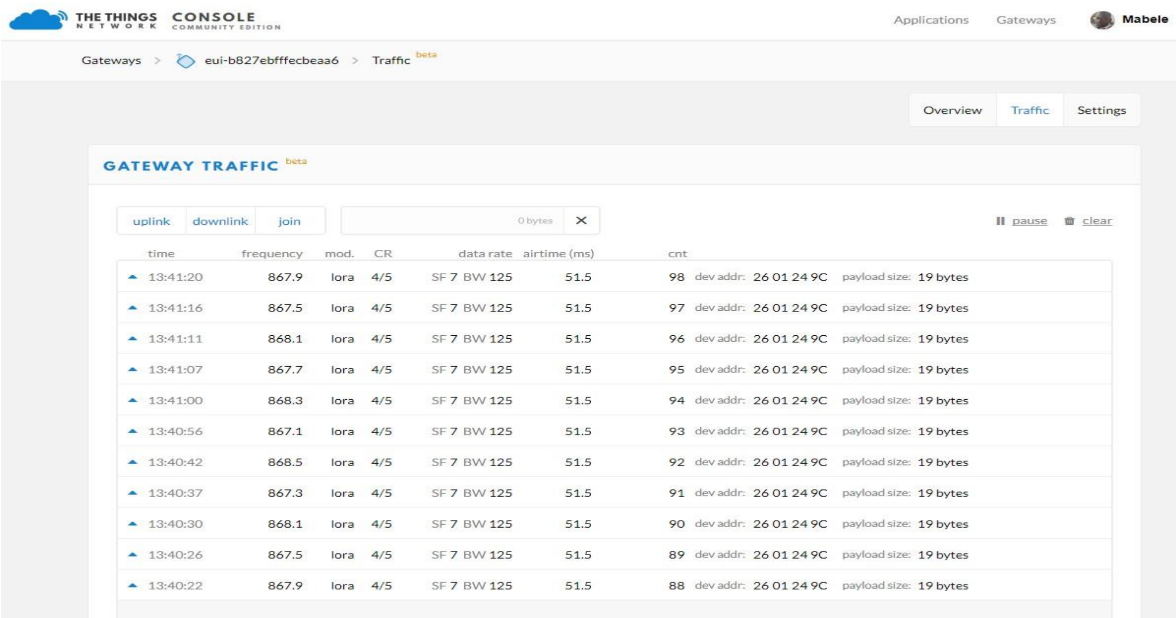

Figure 6: Gateway Traffic on TTN

A. Presenting the Data on the Android Mobile Application

In this project, we have developed an Android application that presents the data from the farm to the farmer in real-time. The application enables the farmer to view the real-time changes of soil moisture, temperature and humidity on his farm leveraging the LPWAN infrastructure. More features are currently being added to the application to improve its user interface and possibly integrate to the actuators. Historical graphs of the data and the predictive capability are also being integrated to the application to derive the value of the data analytics.

The Android interface that presents this data is shown in figure 7:

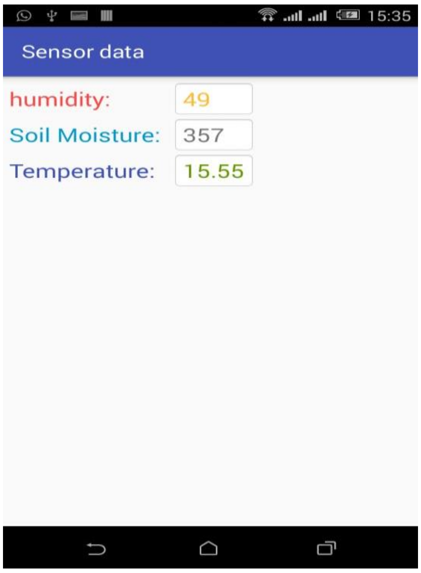

Figure 7: Android Interface for Data

IV. Anticipated outcomes

The development tests done for this project informs on the implementation of a smart farming case that leverages on LoRa Low Power Wide Area Network (LPWAN) connectivity in Kenya, with reproducible outcomes in other developing economies. The project envisions a huge break-through to overcome connectivity challenges in the rural farms by leveraging the LPWAN technology to enable thousands of farmers 'get connected' with their farms. Through the Remote Farm Monitoring System, farmers in rural Kenya will be able to view the overall state of their farm in terms of soil moisture, humidity, pH, temperature among other parameters to realise precision farming. The overall goal is to provide a data-driven approach to farming through low-cost remote sensing that can help farmers make better decisions such as when to plant, what to plant, where to plant and how to plant.

V. Conclusions and Implications

Farming is one of the most critical blocs of the Kenyan economy. The current government of Kenya headed by President Uhuru Kenyatta has included food security as part of its "big four" agenda which has manufacturing, universal healthcare, affordable housing alongside the food security. Usage of innovative technologies to help address some of the problems faced by farmers in our rural regions will certainly provide a boost of the yield that would strengthen our food security. Some of the problems faced include water logging, under and over use of fertilizers, and lack of understanding of soil health. There is also a dearth of accurate baseline data regarding different fields, and different soil types. This makes it impossible to understand how the yield of the land has either increased or decreased over the years. Even with the addressing of these problems, technology challenges do exist such as connectivity that can help provide data that can be used to develop more problem-solving strategies.

In this case, this work presents an interesting implementation of the LoRa technology especially with the use of the ATmega328P microcontroller. In Kenya, this implementation is unique since the LoRa technology has not gained huge recognition or technical understanding on how it can be adopted. On the other hand, the existing implementation studied on The Things Network only present usage of the already assembled LoRa chip with Arduino Uno. In this case, the usage of the ATmega328P (not on Arduino Uno) and the RN2483 LoRa module from Semtech Corporations shows that miniaturisation can be achieved on the farm through lowcost electronics and reliably transmit data to the rural farmer through the cloud services of TTN and Firebase without Internet connection on the edge. The Remote Farm Monitoring Systems demonstrates how these technologies can be put together to help address the food insecurity problem that rural Kenya faces annually. In addition, the system provides historical farm data to inform on planting seasons in relation to drought or flood trends, which in turn facilitates the achievement of Kenya's vision 2030 and the Sustainable Development Goals (SGDs).

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