Smart Farming For Emerging Economies

Stephen Simei Kimogol

Thesis submitted for the degree of
Master in Informatics: Programming and System Architecture
(Distributed Systems and Networks)
60 credits

Institute of Informatics
Faculty of mathematics and natural sciences

UNIVERSITY OF OSLO

Autumn 2019

Smart Farming For Emerging Economies

Stephen Simei Kimogol

Smart Farming For Emerging Economies

http://www.duo.uio.no/

Printed: Reprosentralen, University of Oslo

Summary

summary

Acknowledgement

Acknowledgement part

Contents

List of Figures

List of Tables

List of Abbreviations

abbreviations

1 Introduction

1.1 Motivation

The use of technology, especially the implementation of IoT in agriculture hasn't found significant space in developing countries. Need for efficient food production, food security, need to levarage the technology advancement

1.2 Problem statement

Efficient food production, climate change, use of technology. Limited network coverage -key areas that will be addressed.

Monitoring, decision making, information - data, low cost and power , ease of use.

1.3 Thesis outline

This thesis is organized is organized as follows. Section 2 gives a background information on population, food security and adoption of technology in agriculture. In subsection 2.2 we present digital dimensions of agriculture. In subsection 2.3 a use case used in this thesis is presented. An outline of the requirements of smart farming in resource constrained regions is given in subsection 2.4. We also give introduction to different technologies that are used in this thesis to meet the requirements of smart farming in subsection 2.5 - 2.8. In the section 3.5 we give a brief overview of the related work. Section 4 builds on the technologies discussed on subsection 2.5 - 2.8 and presents the architecture and implementation of smart farming in developing countries. Sections 5 gives an evaluation and directions of future work. The final section we give our conclusion.

2 Background

The continuous growth of the world population and climate change poses a great threat to food security. Population growth will have an effect on the capacity of the environment on food production due to changes and availability of arable land and increased fluctuations of weather patterns have an impact on food production. In spite of this, food production globally has to increase by 70 % by 2050 in order to feed the growing population [16]. This is a global challenge and United Nation's 2030 agenda, defines 17 Sustainable Development Goals [1], among them eradication of hunger and responsible production and consumption. The demographic, climatic and environmental changes call for the use of innovative technologies to address food security problems. There is a need to use technology to regulate the consumption of depleting resources, increase productivity and enhance resilience. As Tjoa and Tjoa puts it that information and communication technologies (ICTs) has had the most impact on development, particularly on innovation, efficiency and effectiveness in all sectors[17].

Figure 1: Sustainable Development Goals.

2.1 Agriculture and Technology in developing countries

2.1.1 Population, climate change and agriculture

Besides providing food, agriculture is a source of livelihood for 36 % of the world's task force with 40-50 % of Asia and the Pacific population and two-thirds of people in sub-Saharan Africa relying on it to make a living [18]. The effects of climate change affects food production and it is felt mostly by the people in the developing world since agriculture is the main source of livelihood. Farmers in these areas are resource limited and vulnerable to the effects of

---

[1] `https://www.un.org/sustainabledevelopment/sustainable-development-goals/`

climate change. Since most people depend on agriculture, which is sensitive to rainfall variability and temperature change, hunger is a significant threat in the face of climate change.

The United Nations (UN) projected in 2017 that the world population will reach 9.8 billion in 2050 and over half of this population growth (1.3 billion) and 750 million will occur in Africa and Asia respectively [19]. Yet, according to the UN Food and Agriculture Organization (FAO), 821 million (one person out of every nine in the world) are currently undernourished [20] and it is estimated that food production in Africa has to increase by 260 % by 2050 to provide food for the expected population [21]. The demand to increase in food production to feed the growing population will have an effect on the ecological footprint and the current agricultural production have already created a large ecological footprint [1]. To address food security problem and at the same time reducing ecological footprint associated with food production, agriculture has to be transformed.

Figure 2: Food demand vs ecological footprint (Source: [1]) .

Climate change will only exacerbate water scarcity and unpredictability of water supply due to changes in weather patterns. Currently, 70 % of freshwater in the world is used for agriculture and there will be growing competition for water between agriculture, industries, and consumption in the cities [18]. In addition, 40 % of the rural population lives in river basin areas that are classified as water scarce [22]. Water scarcity in the face of climate change will affect most rural communities in sub-Saharan Africa and South Asia where water problem is already a challenge and have low capacities to adopt changes in climate.

2.1.2 Uptake of agricultural technologies

In these section we will discuss the uptake of agricultural technologies in developing countries, causes of low uptake and opportunities technological developments offer.

Agricultural engineering and mechanization contributed to rise of large-scale farming and increased production and transformation of countries from agriculture to industry-based economies [23]. With the use of modern agricultural approaches like irrigation and fertilizers, the cereal production in East Asia increased by 2.8 % a year between 1961 and 2004 while there was stagnation of yields in sub-saharan African countries that didn't adopt those approaches[24].

The importance of technology couldn't be stressed more. Nonetheless, the uptake of advanced agricultural technologies has been restricted to the developing countries. They are many factors leading to this.

2.1.2.1 Socio-economic Factors The social-demographic and socio-economic factors affect the adoption of new technologies [25, 26]. Farmer's education level, age and computer confidence are among the factors that hinder farmers choice of technology. The knowledge to existence of technology is also an important factor in the adoption of technology [27] and in many cases even the existing knowledge and technologies have not reached farmers in developing countries [28].

2.1.2.2 Infrastructure Adoption of smart farming in developing economies is mostly hindered by insufficient or lack of infrastructure. Access to communication infrastructure and the Internet are key enablers in the adoption of technology in agriculture. Information and communication technologies keep farms informed about the recent technologies in agriculture, weather conditions, financial services and enable connection with buyers [29]. However, according to the International Telecommunication Union (ITU), 53 % of the world's population are still unconnected to the Internet and they could not benefit from the aforementioned benefits [30]. Internet connection is not given in the most developing economies – of the 6000 gateways that are operation in the world, only 100 are in Africa inhibiting access to open and free network [31]. The UN has acknowledged the indispensability of access to information and the critical role played by communication technology. In the recently launched Sustainable development goals, one of the targets of the goal 9 seeks to 'increase access to information and communications technology and strive to provide universal and affordable access to the Internet in least developed countries by 2020 [32]. Several mobile services are already offered to farmers, but uptake and use of more advanced devices and services e.g cloud-based services are influenced by battery life of devices and access to fast internet [33].

2.1.2.3 Cost and ownership of technology Further, there is a disparity in the research, development and ownership of new technologies since public and private investment in such technologies is concentrated in high- income countries thus limiting access to emerging countries [29]. The European Union has allocated euro 95 billion to the European Rural Development Fund for modernisation of agricultural industry between 2007 and 2013 [2].

2.2 Digital Dimension of Agriculture

The use of advanced technologies has been integrated to farming and new concepts like precision farming/agriculture and smart farming concepts have emerged. While these concepts all revolve around modernization and use technology in agriculture, they have some differences.

2.2.1 Precision Farming

According to a report by European Parliament on Precision agriculture and the future of farming in Europe, precision agriculture is defined as: "a modern farming management concept using digital techniques to monitor and optimise agricultural production processes" [34]. The focus is optimization of farm inputs. It ranges from application of correct amount of fertilizers to the specific part of the field based on soil properties, precise water use and to giving the correct amount feed to specific animal. Sensor, satellite navigation and positioning technology are an indispensable part of Precision Agriculture. Precision farming commenced when GPS signals were made available for the general public [35]. Precision farming has successfully been implemented in large-scale farms in Central and Northern Europe, the USA and Australia with use of Controlled Traffic Farming (CTF) and auto-guiding systems showing clear benefits [36]

According to Wolfert et al., the development of precision agriculture is as a result of growth of farm enterprises and move from scaling of farm assets to optimization of assets[3]. With the increase of cost of the farm inputs and regulations e.g. use of fertilizers and unpredictability due to climate and market prices, different systems that collect and manage data were developed to help farmers in making right decisions. Precise monitoring and control are done to manage spatial and temporal variability of crops, animals and soil factors[1]. It differs from traditional farming by accurately identifying variations and relating spatial data to management activities [37].

2.2.2 Smart Farming

Smart Farming is a recent phenomenon that came into being with inclusion of computing technologies and transmission of data in agriculture [38]. It overlaps with technologies like precision farming and management information systems that have been derived from farm management information systems (FMIS) [38]. It is an extension of precision agriculture where management is based not only on the location but also on data that is triggered by real-time events [1]. Figure 3 shows different technologies that are used smart farming.

Figure 3: A smart farming technologies (Source: [2]).

In Smart Farming, the emphasis is on the use of information and communication technology in the cyber-physical farm management cycle [39]. The advancement of nanotechnology in the last decade enable production of small and inexpensive sensors [7]. Moreover, cloud computing and internet of things enhance the development of smart farming [1].

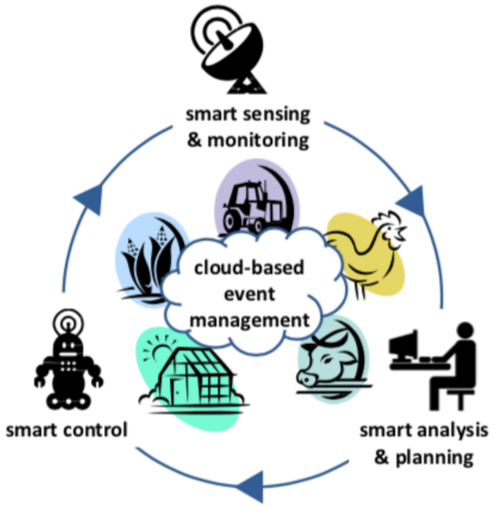


Figure 4: An ideal cycle of smart farming (Source: [3]).

Figure 4 shows a smart farming as cycle of sensing, monitoring, analyses and cloud based control of farm events. The harvesting of data from sensors deployed in the fields aid decision making process on animal health, remote monitoring and accurate diagnosis of the soil and crop conditions and timely interventions. Farmers will also have access to historical data of weather and other inputs and they can make informed decisions. This will result in less waste, efficient use of resources and effective food production thus reduction of the ecological footprint [4].

ICT is viewed as an enabler of climate-smart farming which is “agriculture that sustainably increases productivity, resilience (adaptation), reduces/removes GreenHouse Gases(GHGs) (mitigation), and enhances achievement of national food security and development goals.”[28]. But the adoption of technology by smallholder farmers in developing countries, especially in Africa mostly revolve around the use of mobile phones and services provided through it. This include sharing of agriculture related information, provision of financial services, weather and market price information[33]. To further improve practise of climate-smart farming, we can leverage technological advancement and help farmers diversify farming practises. However this requires holistic approach and involvement of different agents to achieve it. Indeed, as Walter et al. points out that "only if aspects of technology, diversity of crop and livestock systems, and networking and institutions (i.e. markets and policies), are considered jointly in the dialogue, should farming in the digital era be termed 'smart farming'"[4].Figure 5 shows depicts these four factors. We endorse their opinion and this approach is necessary in developing countries where planning and implementations of policies is mostly disjointed due to lack of resources and poor governance. Inspired by this view of smart farming and taking into consideration the complexity around adoption of technology in developing countries as discussed in section, this thesis, we focus on following technological aspects of smart farming:

- The integration of information and communication technology into farming management systems and leverage (advancement in technology) low-cost sensors to monitor farm systems for efficient use of resources and sustainable food production.

- Making sensor data and information on smart farming accessible to farmers and sharing of data among different stakeholders. This entails storage of data in local servers and periodic transmission to cloud for remote access for extension officers and other agents. In developing countries, farmers rely on agricultural extension officers on issues related to farming and this is usually done through field visits. Use of online platforms that store data from farms will give new interaction between farms and extension officers. This will enable timely response from agricultural officers and save on cost related to fieldwork for data collection. Early warning and timely information about farm conditions and advice from extension officers can foster effective response and measures by farmers. Augment data collected from the farms with information like weather forecast to help farmers and extension officers in decision making and generation of actionable information.

- Use technology to diversify farming systems and introduce practises that aren't possible or required skills to do e.g. hydroponic farming (monitoring nutrient solutions) or precise irrigation to reduce water consumption(time for water and site specific needs) thus, reconciling the need for increased food production and sustainability.

.

This will create an ecosystem that will enable data collection, analysis and intelligence sharing between farmers and other stakeholders.I

%picture smaller

obstacles:
- knowledge
- hierachy
- “system”: creativity, entrepreneurship

Smart Cities
- Europe (smart xx, efficiency)
- India (waste, transport, …)

=> Europe: environmental issues

Smart Farming as entry point for “system change”

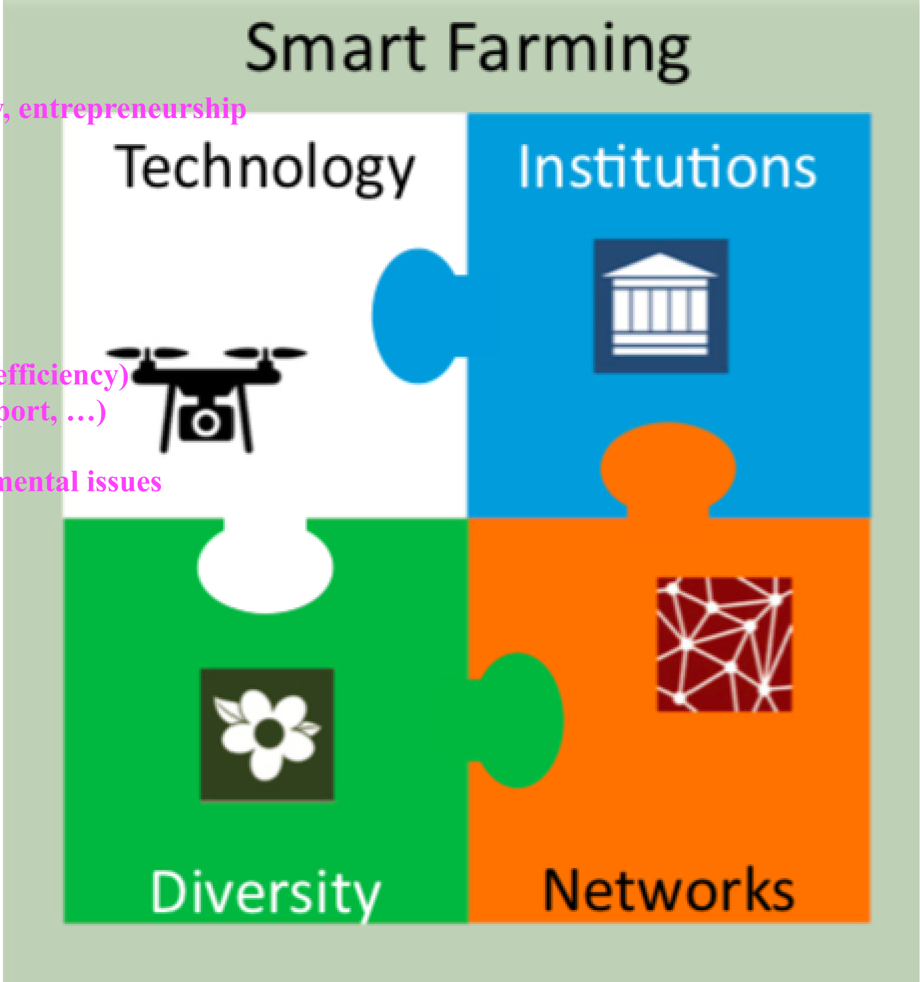


Figure 5: Smart farming in digital era source [4]

2.3 Use Case Scenario: Hydroponic farming

The objectives of using hydroponic farming as use case scenarios are two fold. 1) extract the functional requirements of smart farming in resource constrained setting (technologies) and 2) the need of using technology for efficient food production in the face of climate change and population growth (shortage of water and arable land).

Growing plants without soil has been practiced for a long time. This method of food production has been practiced earlier e.g hanging gardens of Babylon, the floating gardens of the Aztecs of Mexico. The term Hydroponics, however, is recent and was first used by W.F. Gericke of the University of California in early 1930s [40]. Hydroponics can be defined "as the science of growing plants without the use of soil, but by the use of an inert medium, such as gravel, sand, peat, vermiculite, pumice, perlite, coco coir, sawdust, rice hulls, or other substrates, to which is added a nutrient solution containing all the essential elements needed by a plant for its normal growth and development" [40]. In hydroponic systems plants can either grow in an aqueous media or substrate[5]. In substrate approach plants grow in pots filled with growing medium e.g. sawdust while in aqueous approach they are three designs used: nutrient film technique(nutrient solutions flow through the plastic pipes with holes on which plants are placed), deep water culture(plants roots are in the nutrient solution which is aerated) and aeroponics(roots of the plants are suspended in air and are sprayed with nutrient solution continuously)[5]. Figure 6 shows nutrient film technique and deep water culture.

Hydroponics farming is classified as either open (nutrient solution is not reused) or closed (where solution is recovered, replenished and recycled)[41]. Hydroponics has several advantages over the traditional farming: it can be used in areas where in-ground farming is not possible e.g due to climate (cold and desert), areas with water scarcity and conditions where complete control of nutrient content is required and there is a need for increased productivity/crop yields [42]. Table 1 compares soil less culture(hydroponic) and soil(traditional).

Hydroponics, if adopted can address challenges faced by smallholder farmers in developing countries like scarcity of water, limited arable land, labour cost and reduced long growth periods [43]. In optimal growing conditions hydroponic greenhouse far out-yield varieties produced on the field e.g Tomatoes production increased in yields by 4- 10 times [40] and for the production of fodder 50 sq. m. area could produce 600 kg maize fodder in seven days compared to 1 ha of land needed to produce the same amount of fodder [43]. The major limitation of adoption of in hydroponics is the initial capital required [42] especially for smallholder farmers in developing countries. However, the cost can be reduced by low cost devices/construction material [43]. Floating hydroponic system used South East Asia is an example of low cost approach[5].

Hydroponic farming is a relatively new practice in most of the countries in developing countries with smallholder farmers barely having knowledge about it. Most smallholder farmers practice mixed farming: farmers grow crops and keep animals. Hydroponic farming is, as such, an approach that can be used to produce food crops and fodder for farm animals. Closed hydroponic could address problems faced currently due to scarcity of water and rainfall variability. The recycling of water could affect production and necessary measurements and monitoring need to be done for the farm to be economically viable. Moreover as stated in table 1 hydroponic system needs higher knowledge on technology as compared to traditional farming. IoT could solve these problem. Farmers do need to rely on experts as the information they need to make decisions is made available to them by data from sensors. Sensors can collect data of the ingredients of the solutions and this can help farmers make informed decisions at the right time. Nutrient imbalance can easily be identified and necessary action taken at the right time.

(a) deep water culture

(b) Nutrient Film Technique

Figure 6: IHydroponic Systems ([5])

	Soil	Soilless
Farming in new areas	Not always possible. Depends on the type of soil, fertility, salinity	Agriculture possible in any condition
Cultivation	Constant preparation of soil, need of machines, fuel intensive	No needed, substrates preparation or positioning on troughs/ground
Intensification of production	Limited. Monoculture brings “soil tiredness” and already decreases yields after two successive crops Soil tiredness requires crop rotation, fallow or soil sterilization, which is time consuming and interrupts crop cycles for 2–3 weeks	Monoculture is possible with no decadence of performances Substrates could be sterilized with simple means and no crop interruptions Inert media or water do not face risk of any fertility losses due to their characteristics
Plant nutrition	Variable delivery. The release depends on soil characteristics. Some deficiencies are possible. The precise delivery of nutrients according to the plant growth stage is not possible	Real time distribution of nutrients and pH according to the growth stage of the plants. Real-time control of the levels of nutrients required by plants
Nutrient use efficiency	Fertilizers broadcasted broadly, High dispersal through leaching and runoff in outdoor conditions	Minimal amount required due to microirrigation and containment of media. Water and nutrients monitoring avoid the loss of nutrients
Water use efficiency	Efficiency affected by soil texture and irrigation system	Optimal delivery trough microirrigation supported by sensors
Weed control	Need continuous control	No need of any control
Diseases and pests	Affected by soil-borne diseases and pests. Needs sterilization, crop rotation	Not affected because of no use of soil
Quality	Product characteristics depends on of the type of soil and management	Standardized production with full control of nutrients. Optimized growth
Production costs	Normal, but use of machinery necessary for soil cultivation and higher use of inputs (water). Higher costs if greenhouses/nethouses are used	Higher costs due to more expensive setting in greenhouses/nethouses and the presence of a monitoring system,
Farm management	Standard level	Expert level. Needs higher knowledge for the higher technology used

Table 1: Soil versus soilless production (Source: [5]).

2.4 Requirements of smart farming in resource constrained regions

As explained in section 2.1.2 infrastructural, economical and knowledge divide are some of the factors that contribute to low uptake of the technologies in developing economies. As such, the technical requirements suggested for the smart farming countries have to put these factors into consideration. For the sustainability and enhanced use of the technologies the solutions should be easy for the local communities and give new meanings in their own context. In addition, they should foster local digital capacity and innovations.

2.4.1 Low cost device

The computing and sensors devices in such settings with limited resources have to be low cost and low power consuming. Computing platform like single board computer e.g. Raspberry Pi are inexpensive and could easily be installed.

2.4.2 Low power device

Power connectivity is not given in most of these regions and if it is available, power outage is frequent. Rechargeable batteries and the solar panels should thus be used power the system or act as back-up in case of outage. Furthermore use of solar panels is a cheap, clean and sustainable source of energy. The gateways that continuously receive power from the sensors should be power frugal especially in the receiving mode [31].

2.4.3 Cost-efficient communication

Internet connectivity is unavailable, intermittent, slow or costly in most of the developing countries. Connectivity is an essential part of the smart farming. In most IoT applications where connectivity is given, devices connect to the internet through Internet Protocol (IP) and send data directly to the edge and cloud. This is not the case in this context and connectivity is viewed as two parts: first sending of data to the edge/gateway and the second part is sending of data from edge to the cloud. Consequently, the solutions needed include use of unlicensed bands and non-IP network that connect to the Internet through a gateway in the first layer and the second layer mobile/cellular to connect to the internet. Communication between devices and particularly wireless communication is power consuming, thus solutions that offer efficient communication, low power consumption and routing protocols with low memory requirement are required [44]. Also a cost-efficient communication is required for sending data to the cloud. Since bandwidth is limited, data mitigation techniques [37] are required in such areas to reduce the amount of bandwidth needed to send data to the cloud.

2.4.4 Software

Software acts as a bridge between things and the applications and for interoperability between devices. There are many commercial and open source software for IoT with respective strengths and weaknesses. Cost is a limiting factor when considering proprietary software. Open software enables the researchers to replicate the design and customize it to meet specific needs of the context [31]. Most IoT devices are resource constrained and battery powered therefore, software used should be low memory consuming. In this thesis we consider only open source software.

2.4.5 Computation and storage

The data collected by the sensors need to be stored for the decision making and to develop a knowledge base for the farmers to make necessary adjustments to the system. Cloud computing offers limitless on-demand storage and computation capacity. A key problem with the use of cloud computing is need for connectivity to the internet which is not realistic in most of the developing countries due to cost and limited network coverage. Edge computing can substitute in areas with no coverage and complement cloud computing in areas with limited network coverage. Edge enables storage and processing of data locally and make it accessible to the users [45, 31].

2.4.6 Scalability

Scalability involves ability of system to adapt to changes and adapting to increase in number of devices connected while giving optimal performance. In this case, system should be able to accommodate connection of new hydroponic farms, efficient transmission of data to gateways and dispense information to farmers effectively.

2.4.7 Ease of use and sustainability

Given that most small scale farmers are not tech savvy, a system that is easy to operate without continuous technical support is needed. System should also be adaptable to different farm sizes and low learning curve for farmers [1]. In addition, the system should equip farmers with skills and build capacity of the communities through provision of access to information about smart farming.

Based on the above requirements, we consider the following technologies in the design of the smart hydroponic farming.

3 Enabling Technologies and Related Work

In this section we will discuss the technologies that enable smart farming. In section 3.1 we discuss the IoT and how it promotes connection of things and data collection. In section 3.2 we introduce different IoT protocols and how they perform in IoT and applicability in smart farming. Section 3.3 discusses the different wireless technologies and evaluate their feasibility in IoT driven farming. We discuss the trend on Low Power Wide Area Networks and the opportunities they offer when it comes to IoT. Section 3.4 discusses the role of cloud and edge computing and how they can be used to enable share information and at the same time reduce cost. In the last section we discuss a selection of related work on smart farming and how they make use of the technologies discussed in the previous section.

3.1 Internet of Things

The term 'Internet of Things' was coined in 1999 by Kevin Ashton and is generally viewed as interconnected devices, objects, people and software. Internet of Things is rapidly developing and it continues to receive much attention due many possible market and applications scenario it offers. CISCO estimates that there will be 50 billion devices connected by 2020 [46] and McKinsey Global

Institute estimated in 2015 that IoT will have economic impact of between $3.9 trillion to $11.1 trillion per year in 2025 [47]. Internet of Things is a combination of technological push, human pull for connectivity between the immediate and wider environment and it emerged from development in identification technologies e.g. RFID and barcodes and from development of networked sensors and actuators [48].

There is no agreed on definition for the Internet of things. According to European Research Cluster on the Internet of Things (IERC), Internet of Things is

“A dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols where physical and virtual “things” have identities, physical attributes, and virtual personalities and use intelligent interfaces, and are seamlessly integrated into the information network, often communicate data associated with users and their environments” [49].

A user centric definition is given by Gubbi et al.. IoT is “Interconnection of sensing and actuating devices providing the ability to share information across platforms through a unified framework, developing a common operating picture for enabling innovative applications. This is achieved by seamless large scale sensing, data analytics and information representation using cutting edge ubiquitous sensing and cloud computing” [48].

IoT has many applications areas and Asghari et al. have given a comprehensive taxonomy of different applications including health-care, environmental, smart city, commercial, industrial and general aspects[50]. Smart farming/agriculture is a subsection of environmental application scenario. IoT platforms is used different agricultural sectors and the following are some of the examples: a henhouse to monitor and control environmental factors (temperature, humidity, carbon dioxide, ammonia levels [51], hydroponic greenhouse [52], monitoring and control of irrigation system in rural communities [53], smart irrigation in tunnel farming [54], smart animal farm [55].

A generic three-layer IoT architecture consisting of sensing, transport and application layer is depicted in Figure 7 and this can also be extended to five layers with inclusion of network and processing layers between the second and third layer [6, 44]

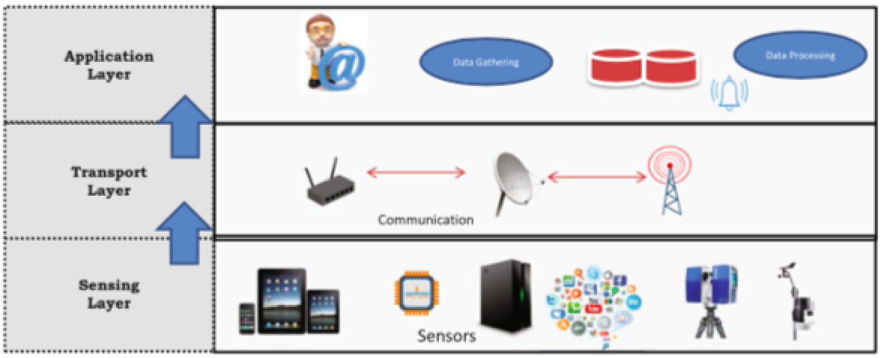


Figure 7: IoT based agricultural framework (Source: [6]).

IoT in agriculture consists of several layers interconnected things and interfaces. Ray provides a six layer framework for a fully fledged agricultural solutions based on IoT[7]. Figure 8 shows these six layers and interconnection between them. However, the service layer in this framework doesn't include edge plane and data is directly sent to the cloud and no analysis of data is done either at this stage.

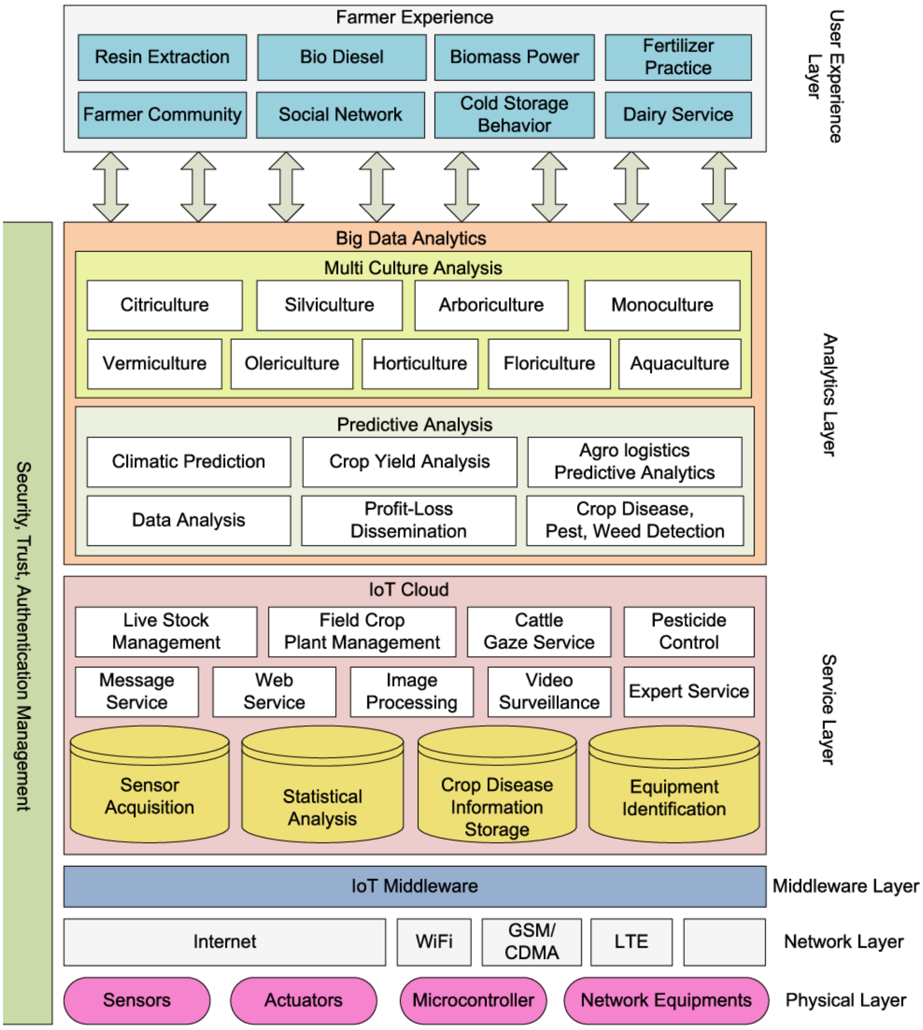


Figure 8: IoT based agricultural framework (Source: [7]).

Even though 20 years since IoT was first introduced, there is no unified IoT architecture and different protocols and standards are used to connect IoT parts depending on the requirements of the IoT use case. In the next section we will discuss existing IoT application layer protocols that are currently used by developers and researchers.

3.2 IoT application layer protocols

Application layer protocols are used to update the online servers with the current readings of the sensor nodes and also carry commands from applications to the sensor nodes [8]. Figure 9 illustrates the communication between end devices, online servers and applications. Several application layer protocols have been suggested and these include Constrained Application Protoco (CoAP), Message Queuing Telemetry Transport (MQTT), Extensible Messaging and Presence Protocol (XMPP), RESTFUL Services (Representational State Transfer), AMQP (Advanced Message Queuing Protocol - a corporate messaging protocol that emerged from financial industry [8]), Websockets and HTTP (designed for WEB and not optimal for IoT as it is heavy weight protocol [56]). In this section we will only consider MQTT and CoAP, which are the most common protocols in IoT systems.

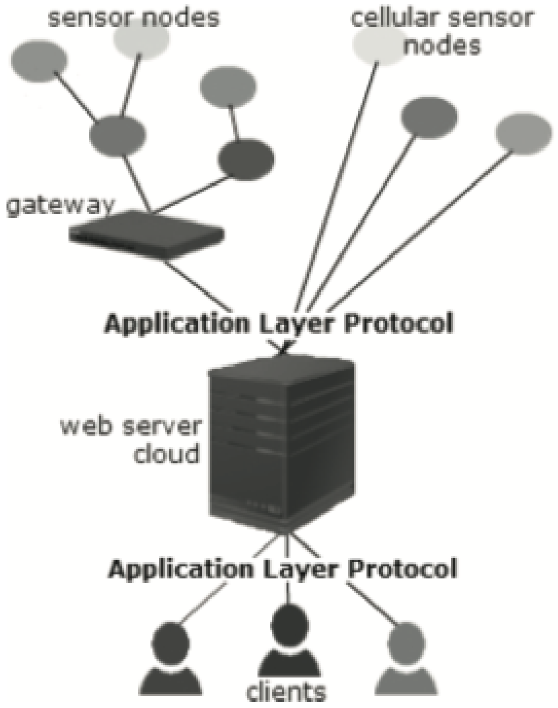
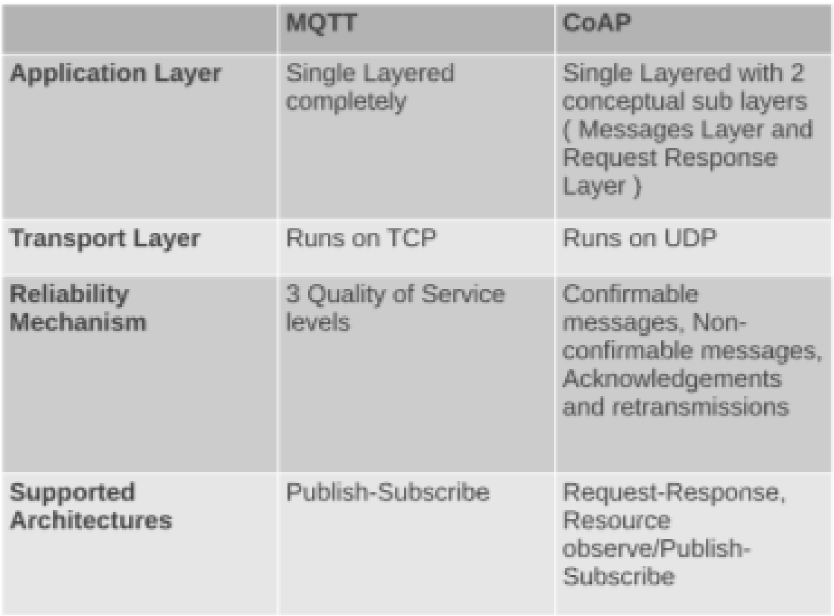


Figure 9: Application layer protocols source ([8]).

3.2.1 CoAP

The Constrained Application Protocol (CoAP) was designed by Internet Engineering Task Force (IETF) to address the requirements of resource constrained devices[8]. It uses request/response and resource/observe (variant of publish/subscribe) architecture making it interoperable with HTTP [56]. It is uses Universal

Resource Identifier (URI) rather than topics thus publishing and subscription are done to a specific URI. It is a UDP based protocol, Datagram Transport Layer Security (DTLS) is used for security and to achieve reliability and Quality of Service(QoS), it utilizes four message types: Confirmable(message needs acknowledgement by the receiver), Non-Confirmable(message doesn't need acknowledgment), Acknowledgment(reception of confirmable message confirmed) and Reset (message received but couldn't be processed) [8]. Authors in [8] argue that even though CoAP is designed for IoT, its use of DTLS for security increases network traffic as DTLS handshakes require add packets and computation resources thus affecting the battery lifespan on the end devices.



	MQTT	CoAP
Application Layer	Single Layered completely	Single Layered with 2 conceptual sub layers (Messages Layer and Request Response Layer)
Transport Layer	Runs on TCP	Runs on UDP
Reliability Mechanism	3 Quality of Service levels	Confirmable messages, Non-confirmable messages, Acknowledgements and retransmissions
Supported Architectures	Publish-Subscribe	Request-Response, Resource observe/Publish-Subscribe

Figure 10: Difference between CoAP and MQTT. source ([9]).

3.2.2 MQTT

Message Queuing Telemetry Transport Protocol is a lightweight publish/subscribe protocol that uses topics as the addresses where the messages are published to and subscribed to by the clients [56]. Topics are contained in a broker [8] - these are servers that publishers send messages to and where clients automatically receive updates on the topic they subscribed to. They are many open source brokers e.g. mosquitto. MQTT runs on TCP and uses TLS/SSL for security [56].

3.2.3 Suitability in smart farming

Naik did an in-depth comparative study of four (HTTP, AMQP, MQTT and CoAP) application layer protocols have been done[56]. According to the author [56] CoAP requires lowest power and lower bandwidth than MQTT in transferring same payload under same network conditions. However, MQTT does better in terms of Quality of Services and reliability. In addition, MQTT is used by large number of organizations in the world but not yet global standard as HTTP. In [9] performance analysis between MQTT and CoAP shows that performance of the protocols depend on the network condition: MQTT packets have low delays for lower packet loss but CoAP performs better if the value of packet loss increase due to smaller UDP headers as compared to TCP headers required in retransmission of message. They also suggest that difference in performance can be exploited at the gateway by detecting network condition and using the protocol that gives best performance depending on prevailing network conditions. Whereas smart gateway has the above mentioned advantages, we have not implemented it in this thesis. However, the choice of this protocol depends on the conditions and requirements of the IoT system (consider end devices- communication between local server and user devices).

3.3 Wireless Communication Standards

Traditionally, connectivity in IoT has mainly been provided by short-range multi-hop technologies based on unlicensed spectrum or long-range cellular networks. A new promising solution for IoT wireless connectivity is Low Power Wide Area Network (LPWAN), which offers long-range [57]. IoT can connect directly to the Internet or through a gateway. For devices to connect to Internet directly they must use Internet Protocol (IP) and on the other hand non-IP connectivity is done through an internet gateway. However, devices can communicate through non-IP protocols within a local network. This section will look at these three approaches and discuss their feasibility in smart agriculture in developing countries.

3.3.1 Short-range communication

The most common short-range wireless technologies include Bluetooth, ZigBee, near field communications (NFC), radio frequency Identification (RFID), ZigBee, 6LoWPAN,Thread, Wi-Fi and Z- wave which is a proprietary systems [57]. These technologies are from different vendors and one of the biggest challenges is interoperability. As shown in figure different some standards one or few network layers and others define entire network layers in Open Systems Interconnection (OSI) model. This problem is addressed by different organization that defines standardization procedures and testing to guarantee interoperability between devices [58].

Short-range technologies have the advantage of low power consumption- a requirement in IoT but they have a limited coverage, which hinders its application in some IoT scenarios. As such, these technologies are primarily used in personal area network or local area network. In the following section we will discuss the different features of four of the common short-range protocols that are applicable in our use case scenario.

3.3.1.1 Bluetooth Bluetooth is a wireless communication technology operating on 2.4Ghz and was previously standardized as IEEE 802.15.1 but currently maintained by Bluetooth SIG [58]. It is mainly used in personal area network with range of upto 10 meters and it uses star network topology. It is a low power technology and devices are mostly battery powered. It has a throughput of upto 2MBps. Bluetooth Low Energy (BLE) is a new standard aimed at reducing power consumption and increasing the life-time of the coin cell batteries while the downside of this is low data throughput [58].

3.3.1.2 ZigBee ZigBee is based on IEEE 802.15.4 link layer standard and is managed by ZigBee Alliance. It is low power, low cost and low throughput (up to 250KBps) with a mesh network topology making it possible to connect with thousands of nodes [58]. ZigBee network requires an application-level gateway to connect to the Internet. ZigBee has low-duty cycle and are suitable for agricultural applications where periodic information update is needed such as irrigation management, pesticide and fertilizer control and water quality management [59].

3.3.1.3 6LoWPAN 6LoWPAN 6LowPAN (IPv6 over Low power Wireless Personal Area Networks) is standard by 6LoWPAN working group of the Internet Engineering Task Force (IETF). Compared to the other standards above, 6LoWPAN enables devices to directly communicate over the Internet [58]. It operates on 2.4-GHz and the 868MHz/915MHz ISM bands and it uses mesh network topology. It only supports IP version 6 (IPv6) thus it requires a IPv6-to-IP version 4 (IPv4) conversion protocol in the gateway [58]. (range and throughput)

3.3.1.4 Wi-Fi Wi-Fi is based on the IEEE 802.11 standard. It operates on 2.4 GHz and 5 GHz with star topology and access point (AP) as gateway. It has a range of 100m and throughput of upto 72Mbps [60]. Most of the new devices come with Wi-Fi software and the TCP/IP software making integration easier. The downside of this standard is that it has high power consumption mainly due to high data rate and coverage. However, advanced sleep protocols and power management design mechanism to increase the lifetime of battery powered devices [58]. In agricultural applications, WiFi enables connection of multiple types of devices through heterogeneous architectures over an ad-hoc network [59].

3.3.2 Low-Power Wide Area Networks (LPWANs)

Low-Power Wide Area Networks utilize unlicensed frequency bands (2.4 GHz, 868/915 MHz, 433 MHz, and 169 MHz depending on region) and it has star network topology [61]. They are known for low power consumption and wide area coverage hence they are termed as Low Power Wide Area (LPWA) technology. The new physical layer design aimed at very high receiver sensitivity enables short-range devices to have coverage of about 10-15 and 2–5 km in rural and urban areas respectively [58]. According to [57] the use paradigm for IoT connectivity with long-range and low data rate is encouraged by the sporadic transmissions of very small packets by the IoT services. The end devices connect to the Internet through a gateway. Some of the LPWAN solutions include LoRa, Sigfox, Ingenu-RPMA, DASH7, Weightless [57, 61]. DASH7 and Weightless are open source while the rest are proprietary systems. In the following sections we look at three of the most common LPWANs.

3.3.2.1 Long Range Radio (LoRa) LoRa is a spread spectrum modulation technique developed by Semtec [2], which is based on chirp spread spectrum (CSS) technology [62]. LoRa physical layer enables long-range communication and it operates on different frequencies depending on the region: 902–928 MHz band (United States), 863– 870 MHz band (Europe), however it can also work on lower ISM bands at 433 MHz and 169 MHz [57]. LoRa is a proprietary product and one of the mostly used communication protocols built above the LoRa is LoRaWAN. LoRaWAN is an open communication protocol and network system architecture [12] by LoRa Alliance[3], a nonprofit association. LoRaWAN network architecture consist of the end nodes, gateway, and network server. The network server handles all the complexities related to packets de-duplication and decoding [62]. The end devices communicate with gateway using LoRa and from gateway packets are forwarded to network server through backhaul interfaces like 3G or Ethernet [37].

3.3.2.2 SigFox SigFox is based on ultra-narrowband technology (UNB) and it uses 915MHz ISM band (United States) and the 868MHz (Europe) [60]. It was first released in 2009 and IoT service provider as its business model thus no documentation is publically available [57]. The communication range is upto 30 km and this is achieved by transmitting at very low data rates (up to 100bps) [60].

3.3.2.3 Ingenu-RPMA Ingenu-RPMA is a proprietary technology by On-Ramp Wireless which developed 802.15.4k standard and owns right to Random Phase Multiple Access technology [57]. According to [61] Ingenu-RPMA achieves higher throughput and capacity compared to other technologies that operate on sub-GHz band due to its flexibility in the use of spectrum across different regions. It has a typical uplink data rate of 50 kbps [11].

---

[2] `https://www.semtech.com/lora/what-is-lora`

[3] `https://lora-alliance.org`

3.3.3 Cellular Network

Cellular network is an established world-wide system with potential of providing ubiquitous access. These include GSM, UMTS and LTE networks. It is considered as a prominent candidate in the provision connectivity to IoT due to its capillary geographical coverage, technological maturity and cost effectiveness due to high revenue it generates from other services like video, voice and data [63]. However, due the expected growth of IoT devices and sporadic nature of traffic generated by them, the current cellular network could collapse due to signalling traffic from these devices [63, 57]. To address these shortcomings, revamping of second generation/ Global System for Mobile Communications (2G/ GSM) [57] and LPWA solutions have been introduced to cope with the requirements of IoT. The solutions introduced by Third Generation Partnership Project (3GPP) include EC-GSM-IoT, eMTC, LTE and NB-IoT [61]. Fifth generation (5G) standards have been released in 2018 and the earliest deployment are expected in the second quarter of 2019 whereas sixth generation (6G) is just on its start in terms of research and artificial intelligence (AI) is seen as the driver for 6G [64].

3.3.4 Connectivity with alternative low cost networks

Bringing Internet connectivity to remote regions does not make a good business case for the mainstream network providers. Alternative Networks have emerged and deployed in areas where that traditional network couldn't cover due to high cost,privacy concerns and limited power resources [67]. Alternative networks are mostly small scale, individuals and other interested stakeholders share the cost of setting up and maintenance expenses. In LoRaWAN based IoT applications, alternative networks deployment have also emarged. They are two deployment models: big providers build core network components and platforms just like the traditional network and public community networks such as The Things Network (TTN)[4], where individuals can set up their own gateways and the shared infrastructure is used by community enabling them to build their own IoT applications[68].

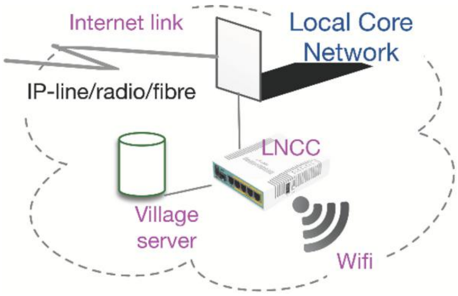
Internet Lite is a concept by Basic Internet Foundation aimed at addressing

---

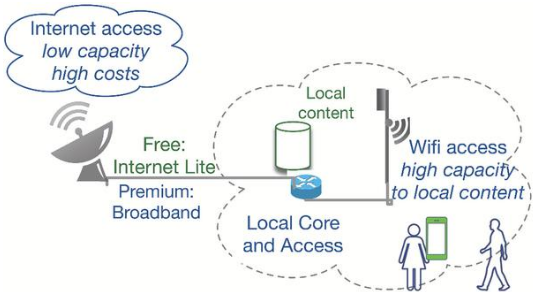
[4] `https://www.thethingsnetwork.org`

the digital dive challenge [10]. It aims at providing affordable internet access to the residents of the developing countries and there by bridging the digital divide and at the same time working towards achievement of the UN sustainable development goals(SDG) where internet is set as an enabler in attaining these goals. The broadband service provided by traditional mobile service providers continues to be expensive and limited thus limiting the opportunities offered by internet to attain SDG. To achieve this, the Basic Internet Foundation used low-cost network infrastructure that includes local core network, a local network, a centralized core, and backhaul network [65, 66]. Sudhir and Noll have defined InfoInternet standard that is aimed at making access to information free (text, pictures) [66]. This is implemented in the Local Network Control Centre (LNCC). In one of their pilot projects, the Basic Internet Foundation compressed pictures and text in order to fit the content into bandwidth-limited link.

Internet Lite solution complies with net neutrality requirement by restricting the content type, not the content. Contents are filtered depending on the number of bits consumed. This approach accommodates both the users of basic Internet and users with paid subscriptions. For the users of basic Internet, the dynamic content e.g. video is filtered out while the text and pictures are allowed while if a user has a voucher, then all content is allowed.



(a) Local core network

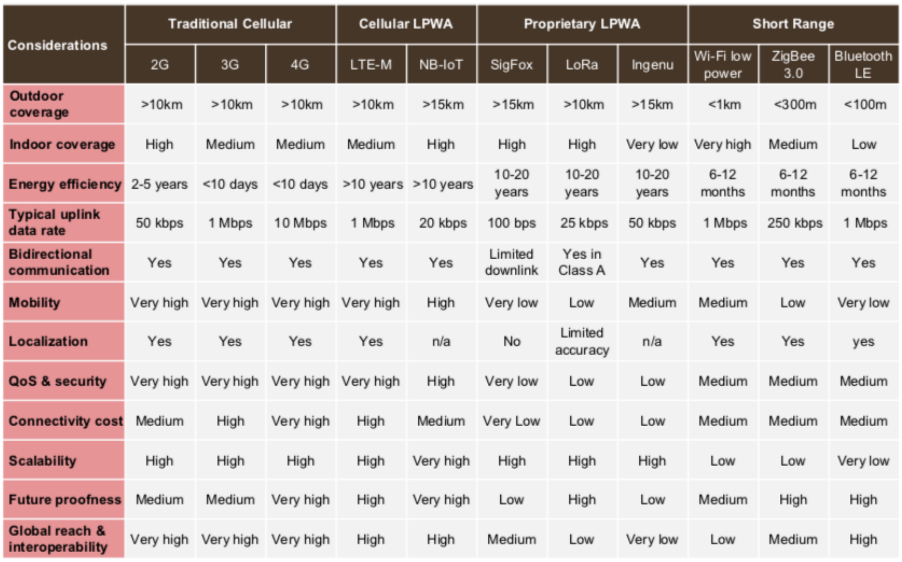


(b) WiFi access point

Figure 11: Internet Lite source ([10])

3.3.5 Applicability in Smart farming

Figure 12 depicts a comparison of the main wireless communication technologies and parameters such as transmission range, data rate, energy consumption and cost. All these technologies have their own strengths and weaknesses and therefore a choice depends on the application scenario. In this thesis we are considering a smart hydroponic farm in resource-constrained region(poor network coverage, lack of power connectivity). Hydroponic farm require monitoring of water quality, nutrient solutions and other factors within the greenhouse for efficient food production. In addition, farmers cannot afford to install a complete monitoring system due to cost. We therefore consider a scenario where farmers have shared infrastructure such that the sensors deployed in individual farms transmit data to a centralized local server. In such scenario range of the wireless technology becomes a vital factor to consider as hydroponic farms owned by smallholder farmers are located in different parts of a village. Moreover high energy efficiency and low cost is a requirement is such a scenario.



Considerations	Traditional Cellular			Cellular LPWA		Proprietary LPWA			Short Range		
	2G	3G	4G	LTE-M	NB-IoT	SigFox	LoRa	Ingenu	Wi-Fi low power	ZigBee 3.0	Bluetooth LE
Outdoor coverage	>10km	>10km	>10km	>10km	>15km	>15km	>10km	>15km	<1km	<300m	<100m
Indoor coverage	High	Medium	Medium	Medium	High	High	High	Very low	Very high	Medium	Low
Energy efficiency	2-5 years	<10 days	<10 days	>10 years	>10 years	10-20 years	10-20 years	10-20 years	6-12 months	6-12 months	6-12 months
Typical uplink data rate	50 kbps	1 Mbps	10 Mbps	1 Mbps	20 kbps	100 bps	25 kbps	50 kbps	1 Mbps	250 kbps	1 Mbps
Bidirectional communication	Yes	Yes	Yes	Yes	Yes	Limited downlink	Yes in Class A	Yes	Yes	Yes	Yes
Mobility	Very high	Very high	Very high	Very high	High	Very low	Low	Medium	Medium	Low	Very low
Localization	Yes	Yes	Yes	Yes	n/a	No	Limited accuracy	n/a	Yes	Yes	yes
QoS & security	Very high	Very high	Very high	Very high	High	Very low	Low	Low	Medium	Medium	Medium
Connectivity cost	Medium	High	Very high	High	Medium	Very Low	Low	Low	Medium	Medium	Medium
Scalability	High	High	High	High	Very high	High	High	High	Low	Low	Very low
Future proofness	Medium	Medium	Very high	High	Very high	Low	High	Low	Medium	High	High
Global reach & interoperability	Very high	Very high	Very high	High	High	Medium	Low	Very low	Low	Medium	High

Figure 12: A comparison of different wireless technologies (Source: [11]).

With this in mind, we first consider the feasible wireless technology to connect the devices to edge and then backhaul connectivity between the edge layer and cloud. Whereas Bluetooth, ZigBee and WiFi offer better throughput they have a short communication range. This will require high node density to cover a small area which also adds complexity and reduce battery lifetime. As such, they are not suitable to farming that require a share infrastructure to reduce cost and long range is needed. BLE and ZigBee, 6LoWPAN and Wi-FI throughput values.

A comparative study of LWPAN technologies is given [14, 69]. Mekki et al. compare large-scale deployment of LoRa, SigFox and NB-IoT [14]. From this comparison Lora and SigFox are considered as cost-effective as spectrum and deployment cost for NB-IoT is high. SigFox end devices are cheaper but the deployment cost is high and on the other hand LoRa end devices are slightly expensive but its deployment cost is lower. Table 2 shows this comparison. Low cost single board computers and microcontrollers like Raspberry Pi and Arduino are used to construct gateways and end devices to reduce cost even further [70]. The proliferation of low cost hardware, availability of open software and initiatives like Sparkfun[5] and Adafruit [6] has led to the third wave

---

[5] `https://www.sparkfun.com/categories/23`

[6] `https://www.adafruit.com`

	Spectrum cost	Deployment cost	End-device cost
Sigfox	Free	>4000€/base station	<2 €
LoRa	Free	>100€/gateway >1000€/base station	3-5€
NB-IoT	>500 M€/MHz	>15000€/base station	>20 €

Table 2: A cost comparison of LoRa, SigFox and NB-IoT (Source: [14]).

of Do-It-Yourself(DIY) which is seen as revolutionary, enabling anybody anywhere to create innovative solutions and this suits well regions where industrial manufacturing infrastructure is lacking [71].

Even though LoRa is proprietary product, its upper layer, LoRaWAN is open, operator and subscription free making it simple to deploy and manage infrastructure whereas in SigFox, user purchase end devices and subscription for the devices from the network operators [69]. The flexibility offered by LoRa ecosystem makes it suitable for local deployment[14] and is as such ideal for deployment in rural areas. In terms of cost, openness and availability SigFox is currently not feasible in most developing countries.

Ingenu-RPMA?

LWPANs generally offer longer range and a limited throughput. LoRa offers long range and low bandwidth and it compliments and fill the gap cellular and short-range technologies to meet the requirements of IoT use case scenarios. Figure 13 shows this comparison. This makes it suitable for scenarios like smart farming in rural areas with farms are spread in a large area and the data from sensors in farms are short and sporadic. Transmission of data can also be limited to when certain threshold is met.

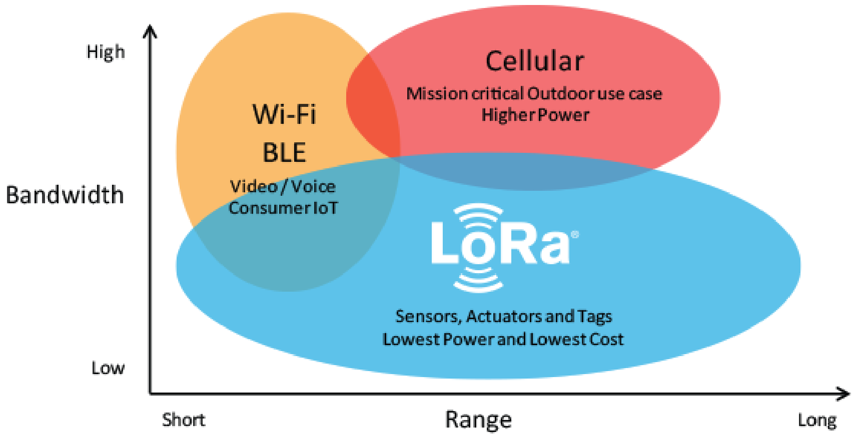


Figure 13: A range comparison of short range technologies, cellular and LoRa.

Cellular is widely available in most of the developing countries and the technology is mature, secure with high quality of service. The disadvantage is that devices need sim cards to connect to the network and data plans offered in developing countries are very expensive. Cellular LWPANs are not yet deployed in most of these countries are thus not feasible for smart farming in near future. In addition they are not cost effective e.g NB-IoT as shown table 2. Cellular, however, is suitable for backhaul connectivity. From the edge server the data can be consolidated and sent to the cloud regularly depending on the needs of the smart farm ecosystem. Despite wide coverage and its presence in almost every part of the world, it continues to be expensive especially in developing countries. Thus low cost connectivity provided by Basic Internet is suitable.

Table 3 shows a comparison of different wireless technologies that are applicable in IoT. We considered three main factors based on the application scenario: cost, power efficiency and range.

Table 3: Cost, Energy efficiency and range

Legends: + favourable, ++ more favourable, - less favourable, –least favourable and 0 reasonable.

Wireless technology	Cost	Energy efficiency	Range	Availability and openness
Bluetooth	++	++	−	++
ZigBee	++	++	−	++
6LoWPAN	++	++	−	++
Wi-Fi	++	−	−	++
LoRa	++	++	++	++
SigFox	+	++	++	−
Ingenu-RPMA	++	++	++	−
Cellular-LWPN	−	++	++	−

From this brief analysis, we consider LoRa as the suitable solution for the connectivity between the devices and the gateway and cellular or Internet Lite as the backhaul solution. Solutions offered by Internet Lite architecture suits well for accessing the sensor data stored at the local server through WiFi access points. In this case data analysis can be locally as this information is mainly consumed locally. In addition, it offers backhaul connectivity that can be utilized if pushing of data to cloud is necessary. Local server can host the LoRa network server and act as the edge layer and do data analysis. Solution suggested in this thesis can be integrated into Basic Internet solution making use of local storage and local access. Furthermore, farmers can access agricultural and information related to the system can be accessed at the WiFi access points. This will help build capacity of the local communities to foster further innovations. However, the solution we propose can also be implemented as a stand-alone system where LoRa is used for connectivity between sensors and gateway and cellular network is for backhaul.

3.3.6 Fundamentals of LoRa

As described in section 3.3.2.1, LoRa , a technology by Semtech, uses chirp spread spectrum(CSS) modulation to achieve long range while maintaining low power usage. The carrier signals in LoRa have chirps that enable signals to travel long range and still be demodulated even if the signal power is 20dB below the noise floor[15]. LoRa offers configuration parameters that can be modified to achieve different power consumptions, transmission distance and data rate. According to Bor and Roedig, LoRa device configuration involves a combination of different bandwidth, spreading factors, coding rate and transmission power resulting to over 6720 settings[72]. In the following section we look at these four parameters, what they mean in LoRa and the inevitable trade-off as a result of different combination of these factors. Table 4 gives a summary of this parameters. LoRaWANspecs

Spreading Factor (SF): SF refers to how spread a chirp is and the *spreadness* is depedent on the numbers of bits in a chirp[73]. LoRa offers spread factor of between SF6 and SF12. An increase in SF reduces the transmission rate by half and doubles the airtime of the packet, thus increase in power consumption [72]. However, increase of transmission time gives receiver enough chances to sample the signal which results in higher signal-to-noise ratio(SNR) increasing probability of decoding correctly[73]. SF6 is used when the receiver is close to the transmitter and spreading factor of 12 is used when the distance is higher or obstacles in the path making it possible to decode/demodulate signals down to -136 dBm [74].

Coding Rate(CR): CR is a forward error correction code aimed at increasing resilience against interference [73]. These are 4/5, 4/6, 4/7 or 4/8. In LoRa 4/5 CR means that for four bits of data 1 bit is added. Higher CR leads to higher transmission time due to increased number of bits but offers improved protection from interference[72].

Bandwidth (BW): BW is a range of frequencies between the upper and lower frequencies of the transmission band. High bandwidth gives higher rate thus shorter air time but with a lower sensitity[72]. 125kHz, 250kHz and 500kHz are mostly used in LoRa.

Transmission Power (TX): LoRa permits adjustment of transmission power like other wireless radios. Transmission power directly affects the amount of power required to transmit a packet. Therefore higher Tx pow increases the SNR thus improving chances of packet being received and survival against attenuation caused by environment at the cost of increased energy usage at the transmitting end.

LoRaWAN: While LoRa defines the physical layer which responsible for

Settings	Values	Effect
Bandwidth	125 . . . 500 kHz	Higher bandwidths allow for transmitting packets at higher data rates (1 kHz = 1 kcps), but reduce receiver sensitivity and communication range.
Spreading Factor	2^6 . . . 2^{12} $\frac{chips}{symbol}$	Bigger spreading factors increase the signal-to-noise ratio and hence radio sensitivity, augmenting the communication range at the cost of longer packets and hence a higher energy expenditure.
Coding Rate	4/5 . . . 4/8	Larger coding rates increase the resilience to interference bursts and decoding errors at the cost of longer packets and a higher energy expenditure.
Transmission Power	4, . . . , 20 dBm	Higher transmission powers reduce the signal-to-noise ratio at the cost of an increase in the energy consumption of the transmitter.

Table 4: LoRa configurations and effects on communication perfomance (Source: [15]).

long range communication, the LoRaWAN is defines for system architecture for network and the communication protocol. Figure 15 shows the LoRa and LoRaWAN protocol stack. According to LoRaWAN specifications, the network architecture comprises of the end nodes, gateways, network server and the application. Figure 14 shows the network architecture. To avoid the complexity and battery effect of mesh network architecture, LoRaWAN employs a star topology[12]. The end nodes are agnostic of the gateways thus they are not associated with any gateway. Because of this, data from end nodes can be received by different multiple gateways. The network server has the purpose of de-duplicating the packets sent by end devices, data authentication and sending acknowledgement.

The LoRaWAN network server optimizes data rates and battery lifetime using adaptive data rates (ADR)[12]. The ADR is determined by maximum SNR of the last 20 received uplink messages and from this the network server optimizes the airtime to ensure as lowest TX power is used [75]. ADR also enhances the overall capacity of the network and scalability. With ADR the network is scalable i.e. increased number of nodes supported as compared to default LoRaWAN settings[69]. The scalability is also affected by the regulatory constraints on the use of physical medium since LoRa is using ISM bands. The imposed duty cycle for LoRa is 1%.

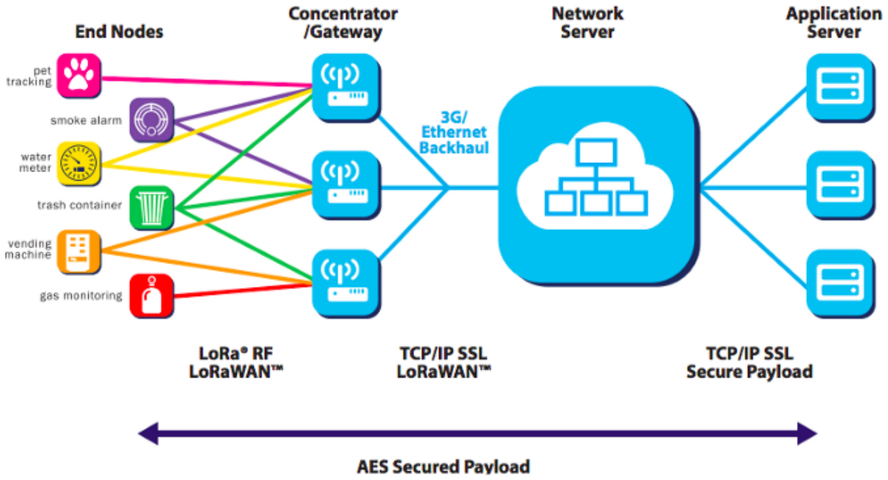


Figure 14: LoRaWAN network architecture (Source: [12]).

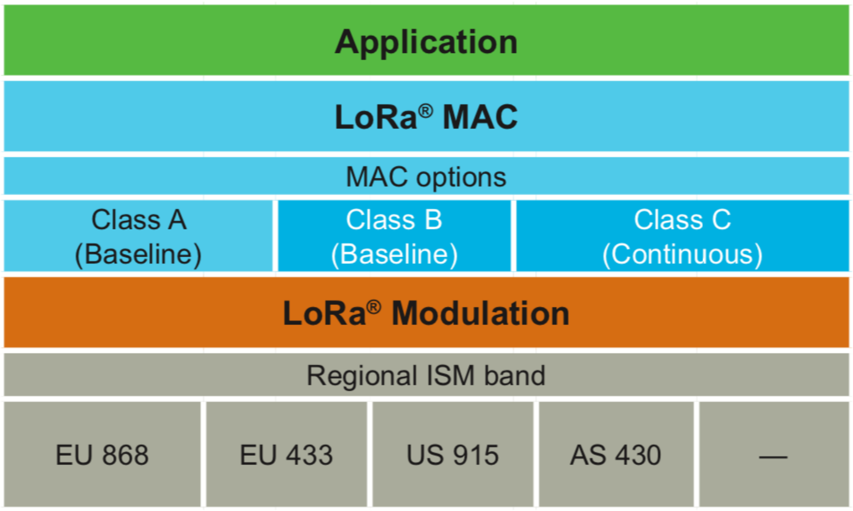


Figure 15: LoRaWAN protocol stack (Source: [12]).

Semtech packet forwarder **Network Server**

device type LoRa also offer better energy efficiency and are suitable for this areas as connection to power grid is not guaranteed. LoRa has three end device classifications (Fig 16): class A(end device transmission followed by two short download windows), B(scheduled receive slots through synchronization by gateway beacon), and C (continuously listening: open windows to receive data) [12]. According to a predictive model by Liando et al. on the lifetime of end nodes, battery efficiency and longevity can be increased by choosing carefully the micro controllers unit used in end nodes and using the right combination of spreading factor, transmission power and duty cycle[73]. Choosing the right combination of hardware and settings is particularly important in rural areas where connection to power is not guaranteed and also reduce the cost of replacing batteries often.

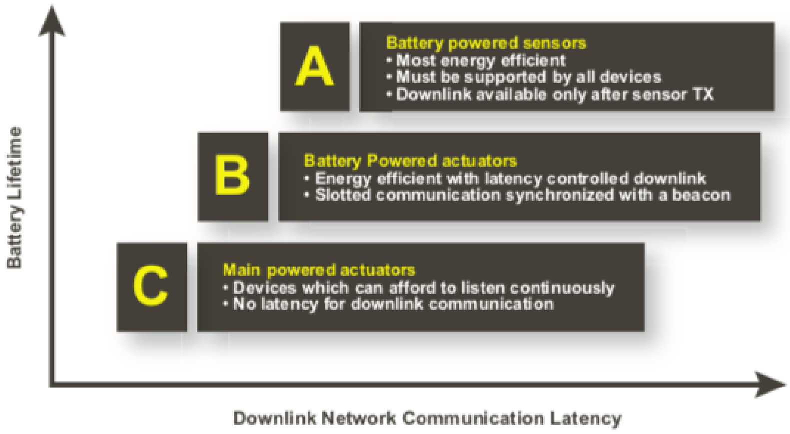


Figure 16: LoRa device classes and power consumption [12].

In this section, we have introduced different wireless technologies. We have discussed the short range technologies and cellular. The new incomers in the LPWANs the opportunities and challenges they offer. We have also introduced alternative low cost communications for remote unconnected areas. From the general requirement of the use case, LoRa was identified to fulfil the requirement and alternative networks for backhaul where cellular is unavailable. In the last section we have introduced the basics of LoRa and LoRaWAN.

3.4 Cloud vs Edge Computing

Cloud computing was seen as one of the computing paradigms that could deliver utility computing vision, namely, computing to be commoditized and offered like other utilities such as water, electricity, gas, and telephony [76]. Vaquero et al. have analysed over 20 definitions of cloud computing and they have proposed the following definition:

"Clouds are a large pool of easily usable and accessible virtualized resources (such as hardware, development platforms and/or services). These resources can be dynamically reconfigured to adjust to a variable load (scale), allowing also for an optimum resource utilization. This pool of resources is typically exploited by a pay- per-use model in which guarantees are offered by the Infrastructure Provider by means of customized (Service-Level Agreements) SLAs" [77].

The National Institute of Standards and Technology (NIST) of the U.S. Department of Commerce has defined cloud computing as "a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction " [78].

This ubiquitous and on-demand access to storage and computational resources has made cloud computing gain copious usage in different sectors. In addition, cloud centralized architecture offers effective economies of scale [79]. In the agricultural sector, the usage of cloud computing has grown due to usage of ICT and sensor technologies. This has enabled data to be collected and pushed to the cloud for storage and analysis. Production of big data from farms and storage in cloud give insights to farm operations and facilitate real-time decision making [39]. This also enables the sharing of data between different stakeholders and remote control of farming operations.

Cloud computing has enabled users to obtain computing and storage resources provided by data centres at anytime and from anywhere [80]. Cisco Internet Business Solutions Group predicted that there would be 50 billion devices connected to the Internet by 2020 [46]. The data produced by these devices at the edge of the network pose a challenge to networks and central cloud computing. The increase in number of devices and rapid advancement of Internet technologies comes with its own unique set of challenges such as latency issues for time critical applications, storage of sensitive data at external service providers raises privacy issues and limited bandwidth to transmit large amounts of data produced by the devices [81].

Edge computing has been emerging approach in distributed computing in the last few years. It extends traditional cloud computing to the edge of the network. It is worth noting that fog computing and edge computing are used interchangeably in literature. However, they are some that make distinction between these two paradigms. OpenFog consortium defines fog computing as a "system-level horizontal architecture that distributes resources and services of computing, storage, control and networking anywhere along the continuum from the cloud to things. Fog computing is different from edge computing and provides tools for distributing, orchestrating, managing, and securing resources and services across networks and between devices that reside at the edge. Edge architecture places servers, applications, and small clouds at the edge. Fog jointly works with the cloud, while edge is defined by the exclusion of cloud " [82]. Yousefpour et al. made in-depth comparison of edge and fog computing and other related paradigms. From this, edge viewed as one of the immediate first hop from IoT devices like WiFi access points or gateways[83].

Edge computing sits at the peak of Gartners Hype Cycle for Cloud Computing, 2018 [13] and disillusionment and false starts are to be expected before standardization and wide adoption. However, it has the potential to complement and decentralize the current centralized cloud architecture and legacy data centres [84].

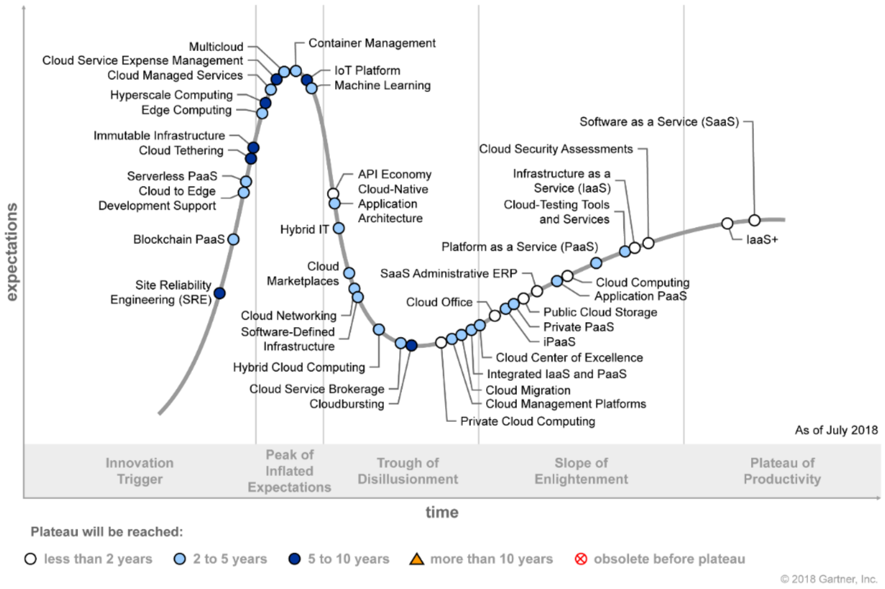


Figure 17: Gartner's Hype Cycle (Source: [13]).

Edge computing architecture is built on edge servers that offer storage, computing and networking services and enable communication and cooperation between decentralized devices without supervision by a third party [85]. This new paradigm extends the cloud services and has the potential to address the aforementioned challenges related to latency and privacy.

Traditionally IoT applications have stringent requirement of low latency, but this is not the case in smart and precision farming as network performance requirements are less stringent [52]. Furthermore, in most areas in developed countries where small-scale farmers reside is associated with insufficient infrastructure and limited bandwidth. The benefit edge computing offers in this context is filtering, pre-processing, analysing and aggregation of raw data before forwarding to cloud thus reducing bandwidth used and local caching for retrieval robustness and reducing the need for communication with cloud [86]. This also saves the user bandwidth if they depend on carriers data plan and also it gives the possibility of users to evaluate which connection and speed they can use at the edge [81]. Analysis can also be done at the edge. Edge analysis is "any data analysis task performed within an edge device (or leaf node) can be identified as edge analytics [45] e.g. smart plug instead of sending data to cloud every second can analyse data and only send when there is fluctuation in the energy consumed. In addition parameters like sampling frequency and communication frequency can be optimized to reduce bandwidth and storage cost and elongate the lifetime of the device. Knowledge inferring can also be done at the edge by comparing data collected from faulty sensor to the nearby sensor [87].

So far we have discussed how edge computing can reduce the cost of communication by reducing the amount of data transmitted to the cloud and reduce power consumption. But one of the fundamental elements that edge offers is putting humans in the control loop giving them control over their system and network links [79]. Such user centric design are important in smart farm as they put humans in loop making them part of the decision making process relating to the farm [88]. Since smart farming is data driven and decisions are based on analysis made on this, socially aware system with humans in control loop and local access to data will encourage adoption of such technologies. Adoption of technological innovations is influenced by farmers perceptions on the effectiveness and accrued benefits [89]. From this, the perception that farmers get from being in control due to benefits offered by computation done at the edge and being in the control loop and decision making could help adoption- same couldn't be said if computation is done at cloud and especially if farmers technological understanding is limited. However, the benefits offered by cloud computing in the general smart farming ecosystem shouldn't be overlooked- as it offers storage and remote access to important data to other stakeholders i.e agricultural extension officers and other experts for analysis and contribute decision making process. Whereas the advantages of edge computing are many, in this thesis we intend to use this to solve issues related to bandwidth consumption and storage usage. Also governance policies related to transmission of data to cloud and frequency of transmission can be set depending on the needs of the farmers and other stakeholders that consume the data produced at the farms. In addition simple analysis will be performed on the edge on the data received before notifications are sent to the farms. In this thesis, we therefore harness the benefits offered by edge and cloud solutions to meet the requirements of smart farming in developing countries. In deed, in most IoT applications scenario one size rarely fits all.

3.5 Related Work

The earlier applications of technology in precision and smart farming focused mostly on automating farm systems based on the data collected by sensors. Zamora-Izquierdo et al. argue that control area in agriculture have developed gradually and significant improvement has been achieved after integration of information and communication system into farm management system[52]. As such, there is a vast amount of literature on greenhouse and hydroponic smart farming and different approaches to monitoring of plants using sensors have been proposed. In [90], the authors have presented a current smart system that monitors the state of water that provides nutrient solution to the plants in hydroponic farming. It also presents auto calibrated pH sensors and use of wireless networks to monitor their functioning. Crisnapati et al. presents a hydroponic monitoring and automation system with a responsive web framework[91]. Different wireless technologies are used in depending on the requirements of the agricultural applications scenario. In [92] a wireless control system for Tomato hydroponic farm using the 400 MHz band and IEEE 802.15.6 standard is described. The authors used 400MHz band as it less affected by plants than 2.4GHz band.

The inclusion of intermediary processing layers (edge or fog) has been recently introduced to smart farming implementations. Caria et al. have proposed a smart farming for animal welfare monitoring with fog layer that enables farmers to locally access the system, manually control parameters and actuators[93]. Authors in [94] present edge computing and IoT paradigms in agriculture and they implemented the system in a real hydroponic farm. A more advanced approach with edge computing and virtualization is presented by Zamora-Izquierdo et al. [52]. In their approach edge computing layer is enabled by Network Function Virtualization(NFV) technology so as to increases flexibility in deployment of control modules. Truong have propose a software component to enable edge analytics on LoRaWAN[68]. The author argues that this is suitable for monitoring of environment and farmers in developing countries where network connectivity and cost are the key constraints and that data is consumed locally reducing the need for pushing data to cloud. Pham et al. have presented a low cost IoT solution based on LoRa gateway with local storage and access for rural African villages [70]. The solution suggested is part of European Union-Africa project[7] and is applied in monitoring of storage and farming facilities and it targets small and medium scale deployment scenarios in sub-Saharan Africa.

Above solutions show different implementation of different smart farming components such as IoT, edge and cloud computing and low cost approach to farming in resource constrained regions. A wide range of factors ranging from lack of infrastructure, high cost, limited access to technology to lack of technical know-how hinders the adoption of technologies in agriculture in developing countries. As such, smart farming solutions for such environments should consider the above factors for effective use of technology in food production and for sustainability of the said system. In this thesis we propose a low cost smart farming solution. Since smallholder farms are usually located in villages, it is cost effective for them to share infrastructure. Consequently, LoRa communication link is used between individual farms hosting the hydroponic farms and the gateway and cellular network for backhaul. In addition, InfoInternet architecture can be integrated and used for access and local storage of sensor data. To encourage further DIY innovations and build the capacity of the local communities, a knowledge bank that includes instructions on related to system and information related farming can be stored and accessed locally. Intermediary processing layer at the edge offers pre-processing and consolidation of data, optimize communication to cloud resulting in reduced cost of pushing data to the cloud. Extensions officer can also access data remotely and give timely response to farmers.

In section two and three we have given a holistic view of the application of technology in agriculture, challenges related to the adoption of new technologies in the context of developing countries. We have suggested a smart hydroponic farming that aims at leveraging technological advancement to enable efficient food production for smallholder farmers. We have described requirements for smart hydroponic farming and suggested different technologies that can facilitate this.

---

[7] `https://www.waziup.eu`

4 Implementation

In this section we will discuss the implementation of the system. Section 4.1 describes the architecture of the system used in this thesis. We will also discuss the various components of the system and their implementation in section 4.2. This section will also explain the experimental set-up used. In section 4.3 we discuss the results and the importance of building capacity of the farmers and their communities.

4.1 System architecture

The smart farming solution proposed here is aimed at helping small scale farmers in rural areas to better monitor their hydroponics system in their farms. LoRaWAN network architecture is generally distributed with centralized cloud-based data aggregation centers which does not promote edge analytics making it unsuitable for developing countries due to high cost of internet connectivity limiting pushing of data to cloud[68]. The solution proposed here incorporates edge layer and the system essentially comprises of three layers:

- IoT end devices layer,
- LoRa gateway and local server, also called edge layer and
- Cloud layer

.

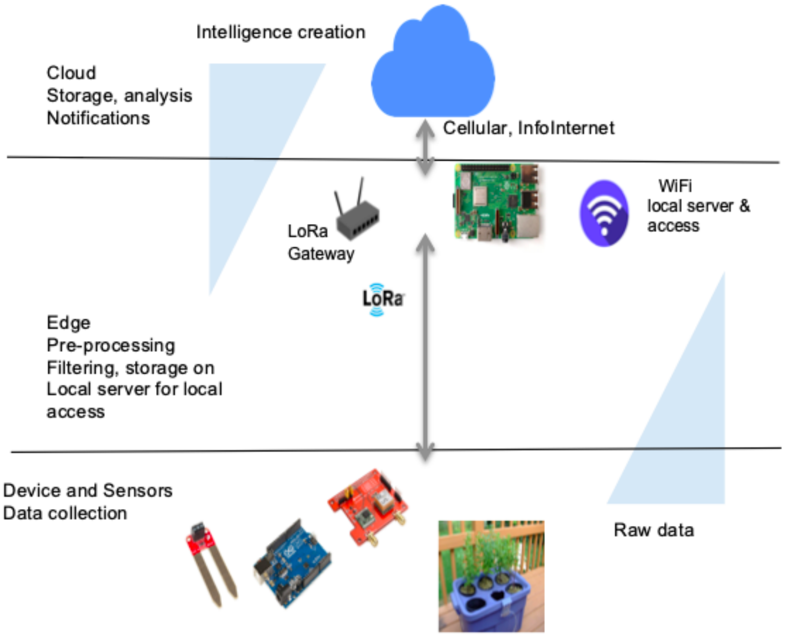


Figure 18: A three layer architecture

Figure 18 shows the three layers (Three-layer IoT architecture). The IoT end devices are located in the Hydroponic farm in the proposed solution. The edge layer consists of the LoRa gateway and local server. The local server hosts LoRaWAN network server for processing of LoRa packets and links end nodes to the applications consumsing the data. This layer is responsible for processing of data so as to reduce the amount of raw data transmitted to the cloud. The amount of raw data collected is huge in the end devices level and intelligence created increases in the upper layers as data is processed to get meaningful information [82]. The local server therefore process data to give meaningful information to the farmers and send notifications when necessary. The data is also processed at the layer because we do not push live data to cloud so as to overcome challenges related to the bandwidth usage and cost.

Due to minimal infrastructure and limited information on smart farming, solutions designed for developing countries do not only include collection of data and integration of communication and information to farm management system, but it also requires the provision of and access to information on smart farming. To this end we have included WiFi access points, referred here as 'information spots' from Basic Internet Foundation so as to empower the local farmers. In addition, their back-haul connectivity option is suitable in rural area scenarios as discussed in section 3.3.4. Figure 19 shows an overview of the whole system.

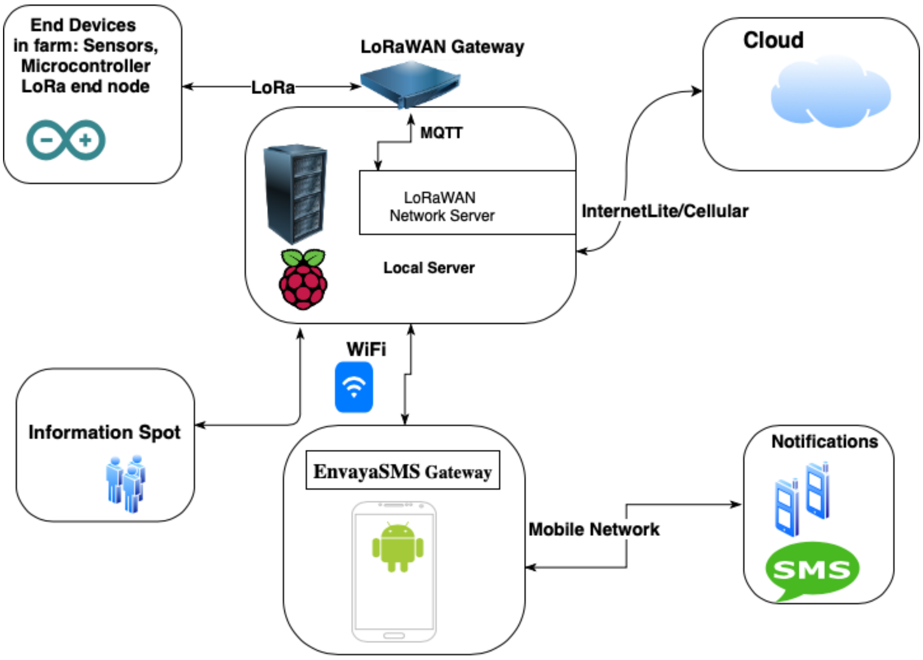
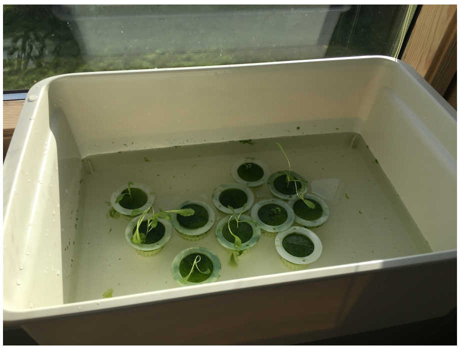


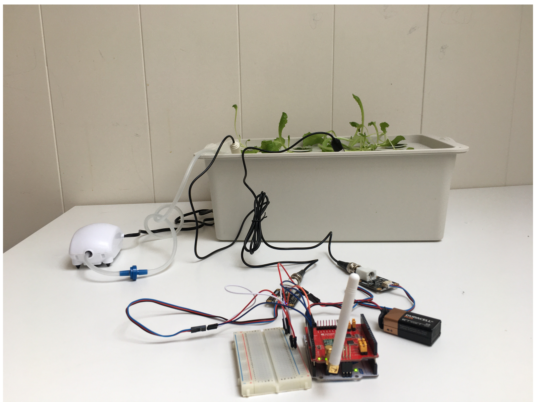
Figure 19: An overview of the system.

4.2 System implementation

Experiment set-up: In order to get data for our implementation, we have used a simple hydroponic system and planted lettuce. This is deep water culture system and the nutrient does not flow in our set-up. We have included an air pump to provide aeration and prevent the roots from suffocating in the water.



(a) nursery



(b) After four weeks

Figure 20: Hydroponic experiment set-up

4.2.1 End devices

The end devices comprise of:

- Sensors: pH and electrical conductivity (EC)
- Micro-controller unit to facilitate data acquisition
- LoRa end nodes for transmission of data to gateway sparingly through LoRa

4.2.1.1 Sensors In hydroponic farming monitoring the nutrient solution is crucial in plant health and necessary for efficient use of resources. pH and EC sensors are used to monitor the nutrients in this thesis. Electrical Conductivity(EC) is measured in siemens and it indicates the amount of dissolved material in a solution. Alternative to EC sensor is Total dissolved solids (TDS) sensor, which indicates the total dissolved parts which is measured in parts per million

Sensor	Manufacturer	Model	Data Interface	Voltage Input
pH sensor	DFRobot	Version 2	Analog	3.0 - 5.0V
EC sensor	DFRobot	Version 2	Analog	3.0 - 5.0V

Table 5: Sensors used in the experiment set-up

(ppm). However, this has disadvantages because TDS value is derived from EC readings and this can give different results depending on the conversion factors used [40]. In addition different TDS sensor manufactures different conversion factors thus different readings. As such we have decided to use EC sensor.

Sensor calibration

The pH, EC sensors and two standard calibration solutions are from DFRobot[8]. The EC sensor was calibrated using Arduino, two standard buffer solutions and manufactures software library [9] that uses two point calibration method. Two point calibration is used when readings from sensor are known to be fairly linear. The buffer solutions have different concentration levels: 12.88ms/cm is used to set the high end and 1413us/cm is used to set the low end of the measurement range. The software library automatically identifies the buffer solutions once the calibration procedure is initiated.

Figure 21: EC, pH probes and standard buffer calibration solutions

---

[8] https://www.dfrobot.com/product-1123.html

[9] https://github.com/DFRobot/DFRobot_EC

Specifications[11]	Arduino Information
RAM	1GB
CPU	Broadcom BCM2837B0 quad-core, 64-bit @1.4GHz
GPU	GPU: Broadcom Videocore-IV
Ethernet	Gigabit Ethernet (via USB channel)
WiFi	2.4GHz and 5GHz 802.11b/g/n/ac Wi-Fi,
Bluetooth	Bluetooth 4.2, Bluetooth Low Energy (BLE)
Storage	MicroSD
Power consumption	5V

Table 6: Arduino

4.2.1.2 Micro Controller Unit The current trend of IoT end devices development is open source/open hardware providing a baseline architecture enabling users to develop their own custom end devices [95]. However, this raises compatibility problem as different sensors are developed by different vendors and might not be compatible with some boards. Arduino microcontroller development boards have inbuilt analog to digital converter making it suitable for sensing analog signals and it offers ease of programming [96]. In addition, it is widely used in education and has a huge on-line community. They are a variety of sensors that are compatible with it and many well documented open source programs. As such, we chose Arduino Uno microcontroller board [10], with an open source IDE and libraries that have been developed by community of users. The MCU will facilitate data acquisition.

4.2.1.3 LoRa Module Since farming is not time critical, data can be sent from the end node hourly or can be configured according to the needs of the farm. From device categories offered by LoRa, device A fits the needs of this system and is thus used in the end nodes. This also suits the power consumption requirements as transmission is initiated by the end device and done asynchronously. Device A by default has two short download receive windows. For communication with the gateway, a Dragino shield that is compatible with Arduino is used [12]. It is based on Semtech SX1276/SX1278 chip. More details

---

[10] `https://store.arduino.cc/arduino-uno-rev3`

[12] `https://www.dragino.com/products/module/item/102-lora-shield.html`

on this lora module is shown in table below.

Dragino LoRa Shield for Arduino	
Specifications	Information
Chip	Semtech SX1276
Frequency	ISM 868(Pre-configured)
Bit rate	Programmable up to 300 kbps
Sensitivity	-148dBm
Compatibility	3.3V or 5.5v Arduino board

Table 7: LoRa

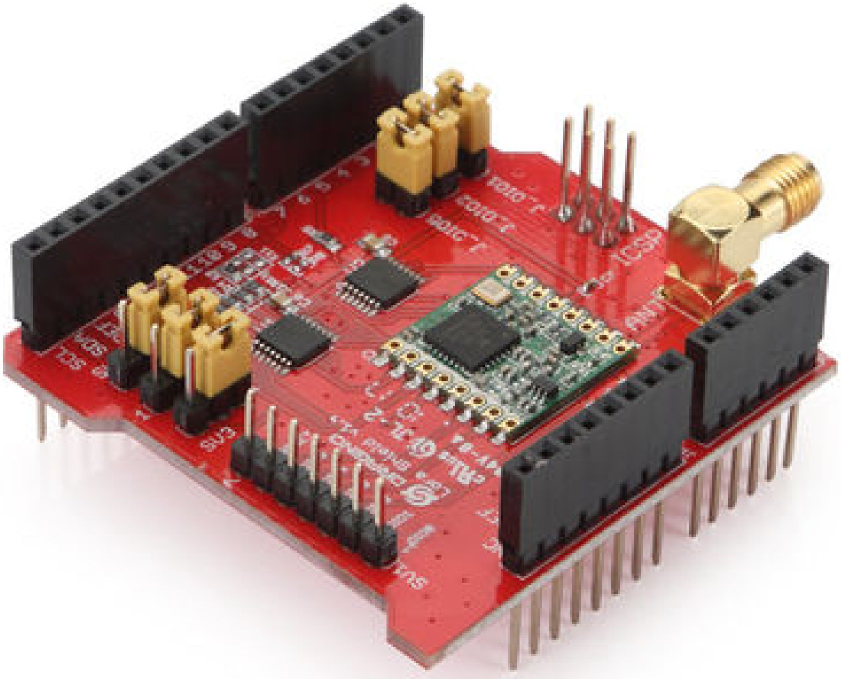


Figure 22: Dragino LoRa shield

RAK7249 Specifications[14]	Information
RAM	128MB DDR2
Flash	16MB
LoRa chip	SX1301 Mini PCIe card
Channels	8
TX Power:	27dBm (Max)
RX Sensitivity:	-142dBm (Min)
Cellular:	EG95: LTE CAT 4
GPS	L70 GPS Module
Wireless	2.4GHz 802.11b/g/n
Power consumption	12W
Power supply	Power over Ethernet(PoE)

Table 8: RAK7249

4.2.2 LoRa gateway and Local Server

4.2.2.1 LoRa Gateway The gateway forms the link between the end devices and the LoRaWAN network server.It receives RF packets and runs packet forwarder that sends packets to the network server through IP/UDP. The requirements of proposed system is a gateway that can give a wide coverage and supports connection from many end devices. We used RAK7249 DIY outdoor gateway [13]. RAK7249 is based SX1301 LoRa chip. This is an enterprise grade outdoor gate and it comes with LoRa, two LTE and GPS antennas. The cellular connectivity option it offers is suitable where InternetLite connectivity is not available. RAK7249 offers three configuration options. It can be configured as integrated system which uses that inbuilt network server, act as LoRa gateway MQTT bridge and communicate with network server through MQTT or use Semtech UDP packet forwarder. This implementation uses an external network server which offers gateway MQTT bridge functionality as such we used Semtech Packet Forwarder. Semtech developed Gateway Message Protocol(GWMS) which is the first gateway protocol for LoRaWAN. This protocol uses User Datagram Protocol (UDP) and JSON format for the frames transported. In the gateway web interface figure 24, we configured the packet forwarder to communicate with the server as shown in figure 25. Table belows shows the specifications of the gateway.

---

[13] `https://store.rakwireless.com/products/rak7249-diy-outdoor-gateway`

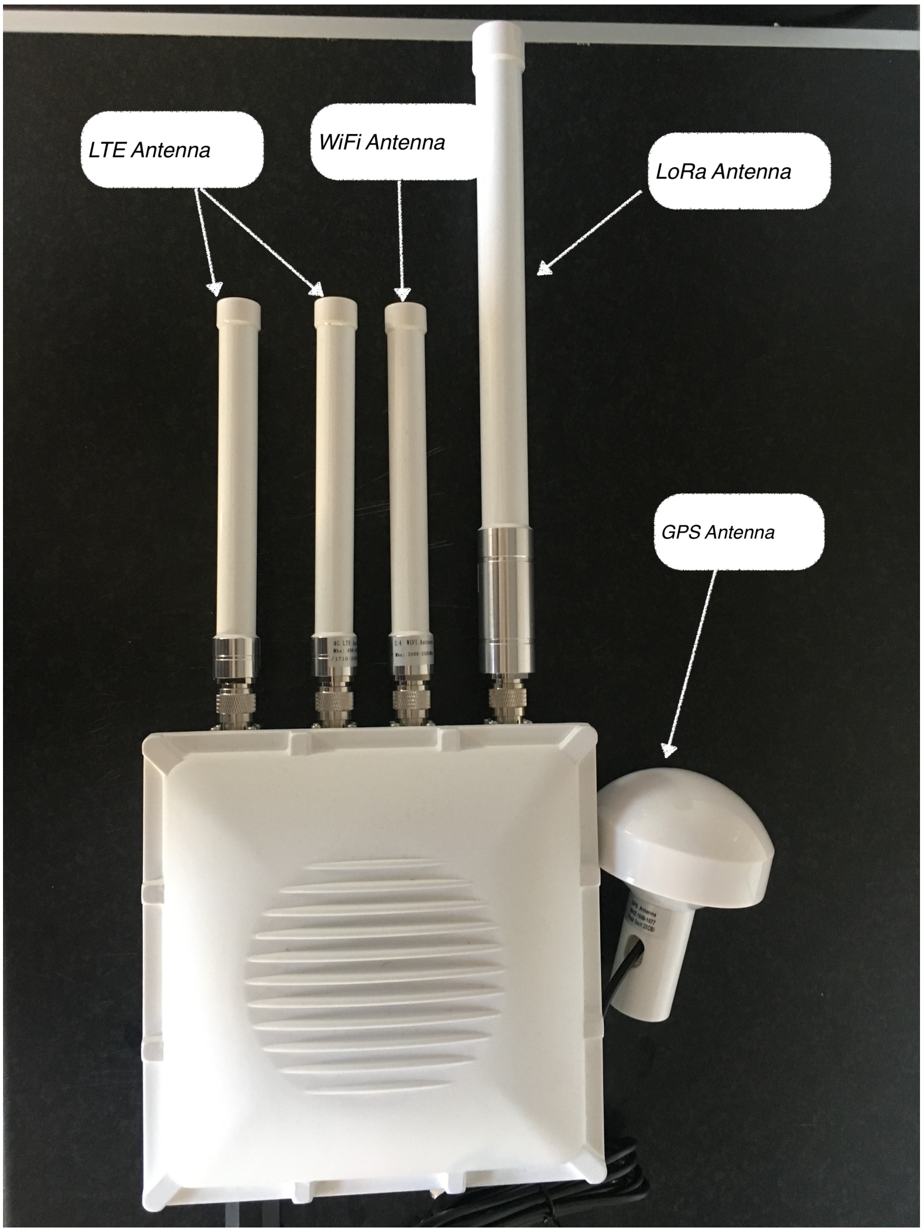
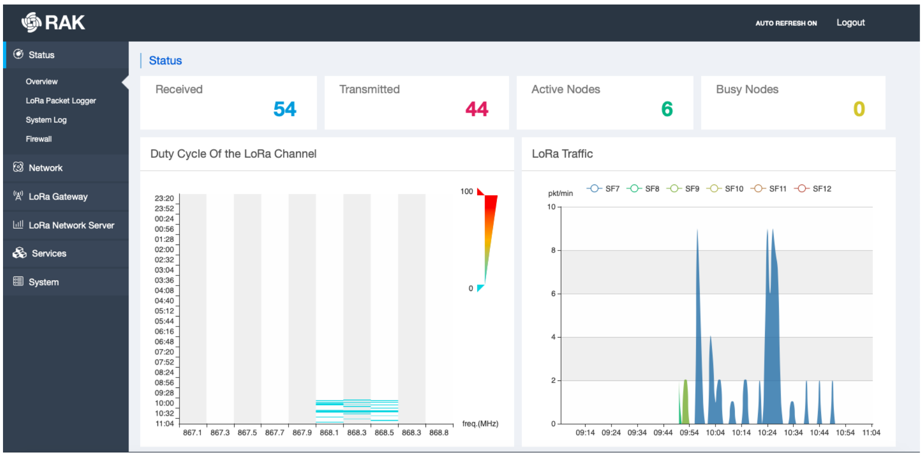


Figure 23: RAK7249 outdoor gateway



Status

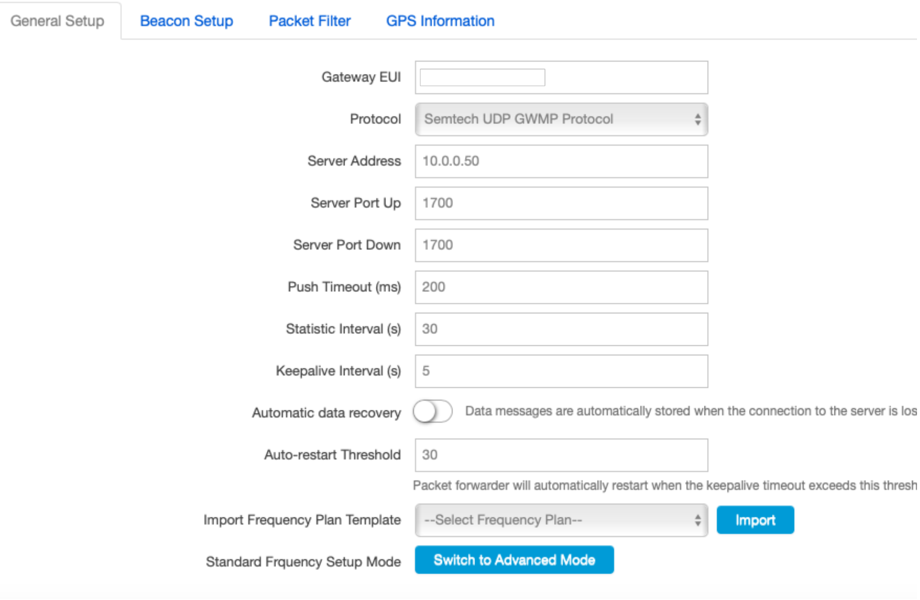
Received 54

Transmitted 44

Active Nodes 6

Busy Nodes 0

Figure 24: RAK7249 web interface



Gateway EUI

Protocol: Semtech UDP GWMP Protocol

Server Address: 10.0.0.50

Server Port Up: 1700

Server Port Down: 1700

Push Timeout (ms): 200

Statistic Interval (s): 30

Keepalive Interval (s): 5

Automatic data recovery: Data messages are automatically stored when the connection to the server is los

Auto-restart Threshold: 30

Packet forwarder will automatically restart when the keepalive timeout exceeds this thresh

Import Frequency Plan Template: --Select Frequency Plan--

Standard Frquency Setup Mode

Figure 25: Semtech UDP configuration on the gateway

4.2.2.2 Local server Raspberry Pi 3+ [15] was used as the local server hosting the LoRaWAN network server. Raspberry Pi is a low cost and powerful single board computer. It has been used in several smart farming approaches e.g [93] in a low cost smart farming for monitoring animal health. In our implementation the local server hosts the LoRaWAN network server, LoRa App

---

[15] `https://www.raspberrypi.org/products/raspberry-pi-3-model-b-plus/`

Specifications[16]	Raspberry Pi Model 3B+ Information
RAM	1GB
CPU	Broadcom BCM2837B0 quad-core, 64-bit @1.4GHz
GPU	GPU: Broadcom Videocore-IV
Ethernet	Gigabit Ethernet
WiFi	2.4GHz and 5GHz 802.11b/g/n/ac Wi-Fi,
Bluetooth	Bluetooth 4.2, Bluetooth Low Energy (BLE)
Storage	MicroSD
Power consumption	5V

Table 9: Raspberry Pi

server and gateway bridge and it also plays the role of local server in the Basic internet architecture. These two entities can physically be separated since they perform different functions, but in this case they are both hosted in a Raspberry Pi. The local server also acts as an intermediary processing layer that performs the storage of sensor data, send notifications to farmer based on data analysis and also pushes data periodically to the cloud where further analysis is done. Since the suggested solution is integrated into the Basic Internet infrastructure, agriculture related information and other local content are stored and accessed by farmers.

Configuration architectures

In experimental set-up, the gateway and the Raspberry Pi are in the same local network. The LoRaWAN components used in this thesis are from an open source LoRaServer project[17] that offers applications that can be implemented flexibly. While a common alternative is the The Things Network(TTN) a crowd sourced community network, it doesn't not offer the flexibility needed in the developing world scenario. Because TTN's network server is hosted in Cloud it would be expensive to transmit data. LoRa Server components include LoRa Gateway bridge, LoRa Server and LoRa App Server. All of these three components are installed in the same server. The LoRa Server project offers two main architecture as shown in 26. The difference in these two approaches is where the LoRa Gateway bridge is installed. It can either be installed in the gateway or on another server that may or may not host the other components.

---

[17] `https://www.loraserver.io`

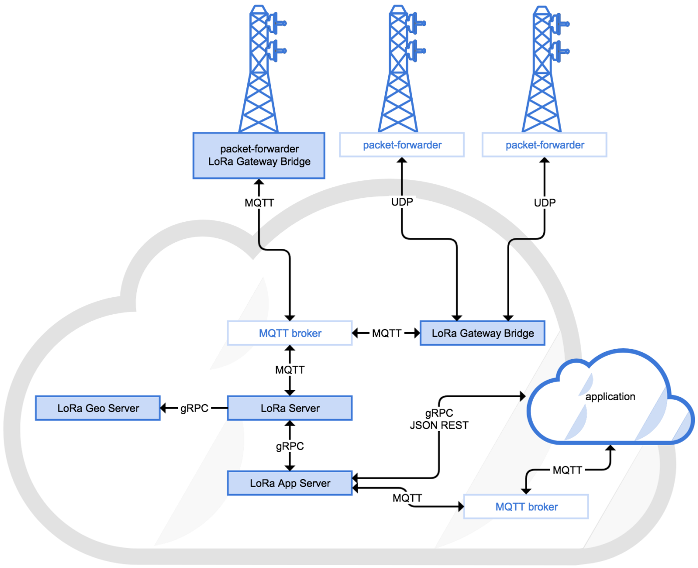


Figure 26: General LoRaWAN configuration architectures.

The configuration used in this thesis is shown in 27. The gateway bridge is installed in the same server together with other components. We chose this configuration because it enables other gateways to be installed and only a single gateway bridge can handle the conversion of packets. As mentioned earlier RAK7249, also has inbuilt LoRa gateway bridge, but we have not used it because the message formats on gateway is not compatible with the LoRa server project message formats at the time of this writing.

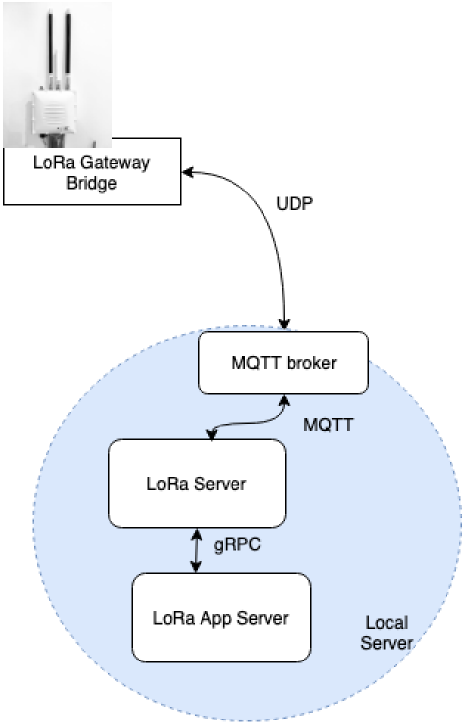


Figure 27: Gateway bridge, LoRa server and LoRa app server are installed in the same server instance.

LoRa Gateway bridge. LoRa gateway bridge abstracts LoRa packets to messages that can be sent over MQTT.

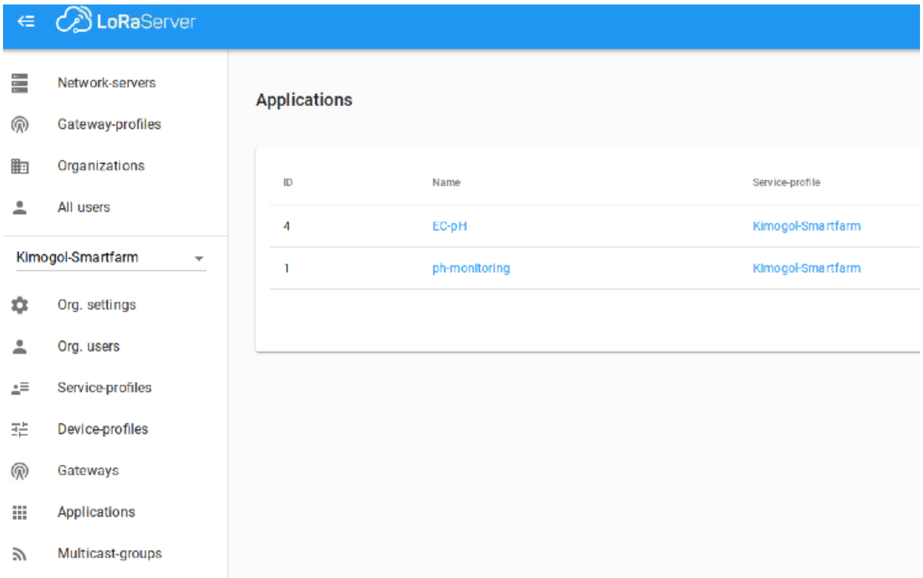
LoRa Server LoRa server is the LoRaWAN network server component that handles the general state of the network, processing of uplink and scheduling of downlink communication. It is also responsible for deduplication of packets if the packets are sent from different gateways such that messages are sent to the applications once. It also serves the function of scheduling downlink transmissions.

LoRa App Server It provides a web-interface to enable management of users and is also an inventory for applications and devices. Live LoRaWAN frames can also be inspected through this interface. It also encrypts and decrypts application payloads thus network server can't access them. It also generates application key and manages join-request of network and end device activation. It also provides integration like HTTP, integration

Software	
LoRa Server	LoRa Server LoRa App Server LoRa Gateway bridge PostgreSQL - to persist gateway data
Broker	Mosquitto[18]
Node-red	Node-red[19] server
Database	InfluxDb[20]
Visualization	Grafana[21]
Notification	EnvayaSMS[22] server

Table 10: Software

with InfluxDB and it also offers MQTT, gRPC and RESTful API for integration with other applications.



Applications

ID	Name	Service-profile
4	EC-pH	Kimogol-Smartfarm
1	ph-monitoring	Kimogol-Smartfarm

Figure 28: LoRa App Server web-interface

LoRa Server components and their dependencies were installed in Raspberry Pi. Because the LoRa gateway bridge uses publish-subscribe communication, Mosquitto, a lightweight broker that implements MQTT protocols was also installed. The Semtech UDP packet forwarder that runs on the gateway forwards the data to the LoRa Gateway Bridge which converts the LoRa packets to MQTT and transmits to LoRa Server.

4.2.3 Data collection, transmission and processing

4.2.3.1 End Device Activation LoRaWAN offers two methods for activating end nodes: Over the air activation(OTAA) and Activation By Personalization (ABP). Device activation is handle by the LoRa App Server and this can be done through the web-interface- see figure 28. When applications and devices are created they are assigned 64 bit end device identifier (**DevEUI**) and application identifier(**AppEUI**) (EUI - Extended Unique Identifier). The devices are dynamically also assigned 32-bit address(**DevAddr**) and is used to identify the device after it joins the network. LoRaWAN also has further three more security keys network session key (**NwkSKey**),Application session key (**AppSKey**) and Application key (**AppKey**). End devices and the network use (**NwkSKey**) to calculate message integrity code(MIC) for the purpose of data integrity while AppSKey is used to encrypt and decrypt payload. In ABP (**DevAddr**), (**NwkSKey**) and (**AppSKey**) are preprogrammed in the end device and also stored in the network thus device is only attached to a specific network. Activation process therefore does not go through the join request and accept procedure. On the other hand OTAA uses (**DevEUI**), (**AppEUI**) and (**AppKey**) which must be stored both in the network and the end device for the join procedure. (**AppKey**) is used to generate the (**NwkSKey**) and (**AppSKey**). The (**DevAddr**) is also dynamically assigned in the process. In our case OTAA was used to connect the end device to the network. To facilitate this we used Arduino LoRaWAN-MAC-in-C(LMIC) library [23] that was developed by International Business Machines(IBM). Dragino LoRa shield was connected to the Arduino and since shield is based on Arduino form factor no jumper cables were required for connection. See figure. Then (**DevEUI**), (**AppEUI**) and (**AppKey**) generated in the LoRa App Server were added to sketch. Once the sketch is uploaded to the Arduino, the end device activation process starts automatically.

4.2.3.2 Reading sensor values and transmitting After the activation the end device starts to transmit data. The EC and PH codes were adapted from

---

[23] `https://github.com/matthijskooijman/arduino-lmic`

the DFRobot product libraries [24] and LMIC library. This code can be found in appendix A. The data mitigation techniques used here is data compression which involves encoding data at end nodes and decoding them at the application server. This technique reduces size of information transmitted and reduce power consumption thus improving battery life[37]. Because the EC and pH do not change significantly within an hour, values are then transmitted to the gateway once every hour through the LoRa end node. Before the transmission the sensor readings are encoded show in the following code.

```
void do_send(osjob_t* j) {

  struct sensorValues ss = ecread();
  float structec = ss.ec;
  float structph = ss.ph;
  byte payload1[4];
  uint32_t ecValue = structec*100;
  uint32_t phValue = structph*100;
  payload1[0] =highByte(ecValue);
  payload1[1] =lowByte(ecValue);
  payload1[2] =highByte(phValue);
  payload1[3] =lowByte(phValue);


  if (LMIC.opmode & OP_TXRXPEND) {
    Serial.println(F("OP_TXRXPEND,␣not␣sending"));
  } else {
     LMIC_setTxData2(1, payload1, sizeof(payload1), 0);
    Serial.println(F("Packet␣queued"));
    Serial.println(LMIC.freq);
  }}
```

---

[24] `https://wiki.dfrobot.com/Gravity__Analog_Electrical_Conductivity_Sensor___Meter_V2__K=1__SKU_DFR0300`

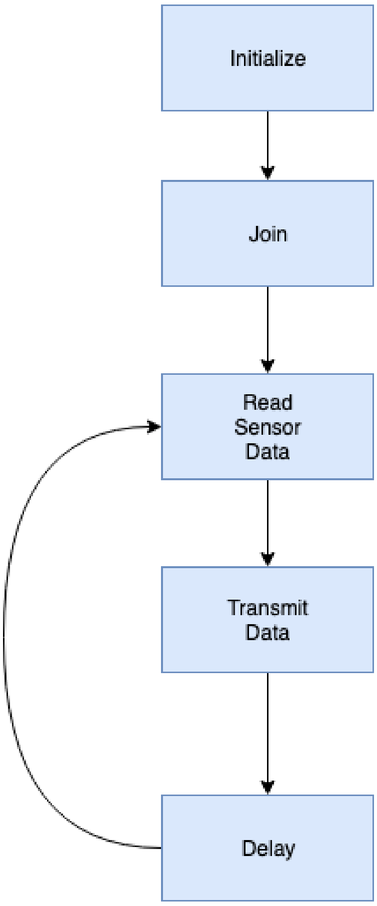


Figure 29: State machine end device

4.2.3.3 Data processing Figure shows the flow of the data from the end devices to the applications. The UDP Semtec software running in gateway forwards the data to LoRa-Gateway- bridge. LoRa Gateway bridge publishes messages to the mosquito broker and which LoRa server subscribes to. LoRa server sends the data to the LoRa App Server through gRPC api. Here the data is decoded and is published to mosquitto broker for application using MQTT can access them. In the LoRa App server we used the following custom JavaScript codec to decode the payload.

```
function Decode(fPort, bytes) {
    var ec = (bytes[0] << 8) | bytes[1];
```

```
    var ph = (bytes[2] << 8) | bytes[3];

    var dataout = {
        "sensorvalues": {
            'ec': ec / 100,
            'ph': ph / 100
        },
    };
    return dataout;
}
```

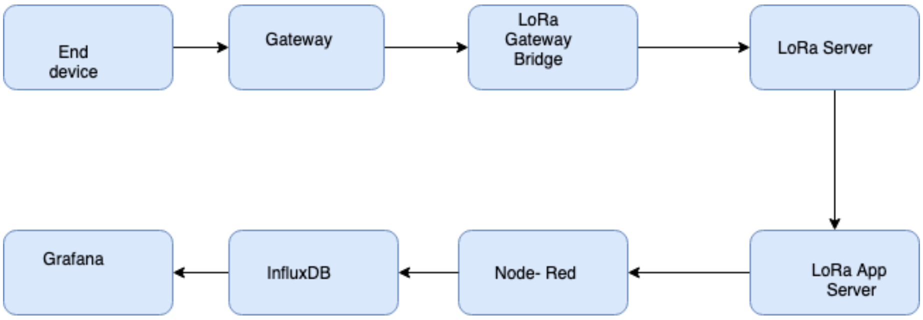


Figure 30: Data flow.

To integrate other functions to our system, we have used Node-Red, an open source web based programming tool. It is a flow-based program and can easily be used to connect things, applications and process the data they produce. It offers a broad collection of nodes in the palette that can be dragged and dropped into the flow canvas. In Node-red we use MQTT client which subscribes to topics published by the LoRa App server. The event in MQTT topics are in this format: **application/[applicationID]/device/[devEUI]/rx**. applicationID is automatically generated and can be found in the LoRa App Server web interface. In this case the node named EC-PH in figure 31 is the MQTT client and it subscribes to this topic:

application/4/device/8a90dc387df11f42/rx

Following is an example of the data received after subscribing to the above topic in Node-Red. It shows the end device details, gateway details, RSSI, SNR and it also indicates that ADR has been activated. It also contains the values of the sensor data.

```
"{"applicationID":"4","applicationName":"EC-pH",
"deviceName":"EC-pH_Hydroponic",
"devEUI":"8a90dc387df11f42","rxInfo":
[{"gatewayID":"XXXXXXXXX","name":"RAK7249",
"time":"2019-10-12T11:49:03.960173Z","rssi":-55,
"loRaSNR":10,"location":{"latitude":60.44765,
"longitude":12.05757,"altitude":349}}],
"txInfo":{"frequency":868300000,"dr":5},"adr":true
,"fCnt":34,"fPort":1,"data":"AE4CmA=="
,"object":{"sensorvalues":{"ec":0.78,"ph":6.64}}}"
```

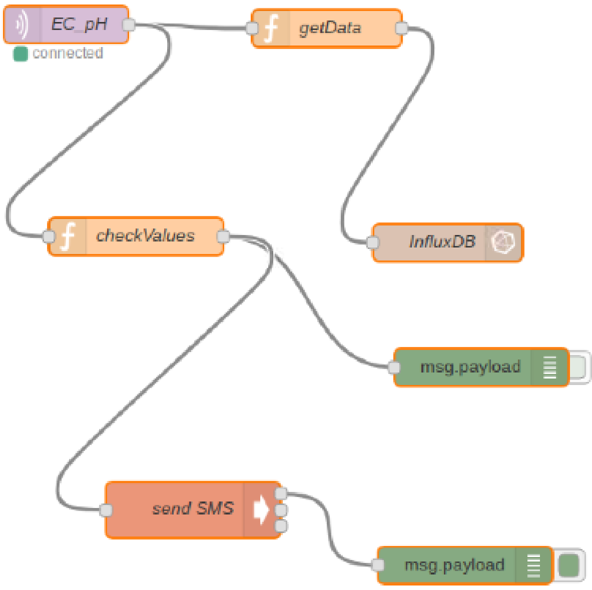


Figure 31: Node-red flow

The data received is in a string format and we used JSON.parse() function to get a JSON object so as to extract the payloads. We used InfluxDB to store the sensor data. InfluxDB is an open source time series database that enables storage of sensor data in an equally spaced time intervals. This makes it suitable for IoT application where there is a continuous flow of data. It suits the need of smart farming as data is stored with a specific time-stamp making data analysis easy. Furthermore this enables analysis with high level of granularity. Farmers or the experts helping farmers can get information on how plants absorb nutrients and they can make informed decision on when and what amount of nutrient solution to use.

In Node-Red we used a function node, named getData - see figure 31 for data extraction and posting them to the InfluxDB. Since sensors will be deployed in different sections of the hydroponic farm, knowledge inference can be done using such functions to compare data and identify faulty sensors. We have, however, not implemented this since we only have single EC and pH sensors in the experimental set-up. For data visualization we used Grafana - an open source tool for visualization which comes with data source plug-in for InfluxDB. We created dashboard on Grafana and visualized data with graphs to show the pH and EC levels. This can help system administrators to get insights from the data and valuable information which can help farmers make informed decisions. Interactive graphics help better understand underlying data and with time series representation of database, farm conditions can be compared to crop performance.

Edge Analysis With edge computation bandwidth usage can be optimized and simple data analytic can be performed. Edge layer defines the rules related to storage of data and sending of notifications. Alerts are sent to the farmers depending on the sensor readings. If the sensor readings fall below a set value then farmers are notified through SMS. For growth of lettuce a pH of 5.5 to 6.5 and EC of 0.8 to 1.2 ms is considered suitable for the growth of the plant. We have implemented a function in Node-Red that checks whether sensor data is within the above defined values. Node-red's exec node executes a command that runs a php scripts queues messages to a php server. SMSgateway applications polls for new messages periodically. We will discuss SMS gateway in 4.2.3.4. As such edge also manages the connection between the server and gateway application app running on an Android phone.

4.2.3.4 SMS gateway Notifications are important part of the IoT system as this informs users of the conditions of the things they are monitoring. The choice of notification system depends on the type of devices used by the clients. In most developing countries basic and feature phones remain the most commonly used devices and uptake of smart devices are influenced by battery life and access to fast internet [33]. Most farmers in rural areas use low-tech phones whose primary communication channels is SMS and voice. Even farmers with smartphones are restricted to use apps due to expensive data plans thus use of data connectivity orientated services are not suitable. In addition phones have limited processing capabilities might not support apps. The most suitable way to send notifications in this case is SMS. However, setting up a gateway with telecommunication operators and getting short codes that is accessible from local numbers is costly. Lightweight SMS gateway application that reside on Android phones like RapidSMS [25] and frontlineSMS [26] have already been used in health sector to send reminders to enhance postnatal care appointments [97] and SMS based alert system to monitor pregnancy, maternal and child deaths [98]. In [99], EnvayaSMS [27], an open-source SMS gateway was used to support immunization programs. We can leverage this technology by integrating into smart farming solutions suggested here. Since the phone will be using local phone number, the cost is reduced as compared to using cloud based SMS aggregator like Twilio. In this thesis we are using EnvayaSMS since it does not require subscription as frontlineSMS. It also offers expansion packs to increase messages sent per hour to 500 from the 100 per hour limit on Android phones. An example of EnvayaSMS configuration is shown in figure 32. However, in this implementation the web server is hosted locally.

---

[25] `https://www.rapidsms.org`

[26] `https://www.frontlinesms.com`

[27] `http://sms.envaya.org`

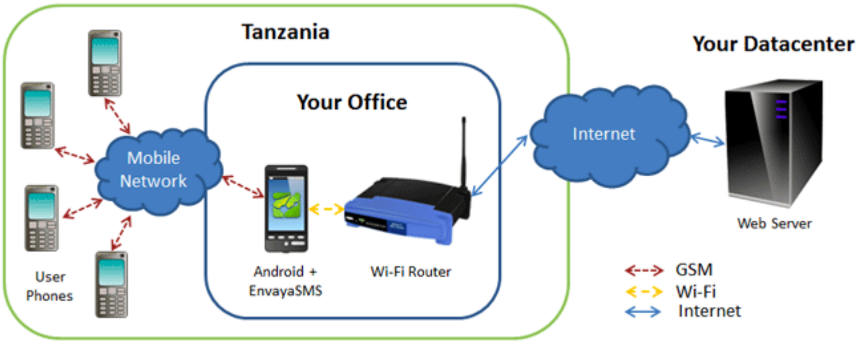


Figure 32: EnvayaSMS configuration

From EnvayaSMS webpage, it is stated that the app can run any Android phone with Android version 1.6 or higher. In this case we used MoTo G Plus [28] phone running on Android 8.1.0. The phone is connected to the same local WiFi as the Raspberry Pi. Scripts from the EnvayaSMS github repository [29] was used to handle the server functions. In these repository they are three main scripts that we used in this implementation. These are server.php, gateway.php and send_smsphp. The first scripts is a standalone HTTP server, the second script implements the EnvayaSMS API while the last one enables sending of messages from the command line. The server script was enabled to run at the Raspberry Pi on start-up. In the App settings the server Uniform Resource Locator (URL) was set to the path of the script implementing the EnvayaSMS API that is also on the Raspberry Pi as shown in Figure 33. The app was configured to poll for new messages every 5 minutes. Figure 33 shows the app configuration and the app polling for messages.

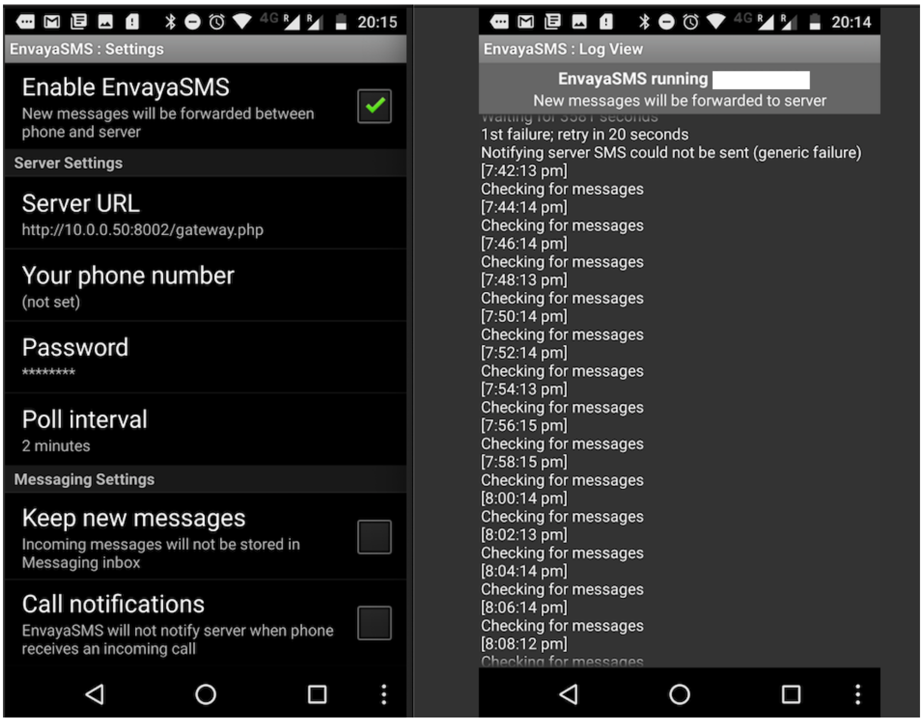
As mentioned earlier SMS alerts are triggered after the sensor values fall or go beyond a certain range. To trigger sending of messages, we analysed the sensor data in Node-red, checkValues function as shown in 31. This function analyses the data and the payload it returns contains the message and phone number of the recipient. The messages can be customized to the local language in this function. Node-red offers execute node (exec) that can be used to run scripts and programs. The payload of checkValue function are passed to the exec node. This node runs php(send_sms.php) script that queues the message to the

---

[28] `https://www.motorola.com/us/products/moto-g-plus`

[29] `http://github.com/youngj/EnvayaSMS`

local file system. This message is sent to the EnvayaSMS gateway app once it send a request to poll for outgoing sms to the server. EnvayaSMS gateway uses HTTP POST request to poll for outgoing messages and send status of the sent messages to the server.



Enable EnvayaSMS ☑
New messages will be forwarded between phone and server

Server Settings

Server URL
http://10.0.0.50:8002/gateway.php

Your phone number
(not set)

Password
****

Poll interval
2 minutes

Messaging Settings

Keep new messages ☐
Incoming messages will not be stored in Messaging inbox

Call notifications ☐
EnvayaSMS will not notify server when phone receives an incoming call

EnvayaSMS running [redacted]
New messages will be forwarded to server

```
1st failure; retry in 20 seconds
Notifying server SMS could not be sent (generic failure)
[7:42:13 pm]
Checking for messages
[7:44:14 pm]
Checking for messages
[7:46:14 pm]
Checking for messages
[7:48:13 pm]
Checking for messages
[7:50:14 pm]
Checking for messages
[7:52:14 pm]
Checking for messages
[7:54:13 pm]
Checking for messages
[7:56:15 pm]
Checking for messages
[7:58:15 pm]
Checking for messages
[8:00:14 pm]
Checking for messages
[8:02:13 pm]
Checking for messages
[8:04:14 pm]
Checking for messages
[8:06:14 pm]
Checking for messages
[8:08:12 pm]
Checking for messages
```

Figure 33: EnvayaSMS configuration and log view.

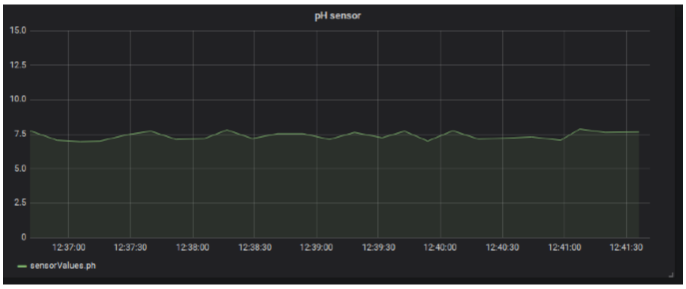
4.2.4 Cloud

As discussed in section 3.4, Cloud offers ubiquitous and on-demand access to computing resources making it suitable for storage and processing of huge data produced by IoT. It allows data consolidation, long term data analysis and effictive way to share data with stakeholders and agricultural extension officers. However, lack of or limited internet connectivity and cost is hindering the uptake of this computing paradigm in developing countries. In the proposed solution we have incorporated Basic Internet's InfoInternet and connectivity solution as a backhaul option to cellular network as depicted in figure 19. Because the InfoInternet standard allows text and pictures, sensor data can be categorised as text and be transmitted for free. With this solution sensor data can be shared with other stakeholders. Since data is consumed locally and data analysis that trigger alerts is also done locally, transmission of data to cloud needs not to be done in real-time. Moreover, IoT based smart farming in this scenario is latency tolerant as no process are automated in this implementation. Consequently data can then be pushed to the cloud at predefined time. Batch transfers to the cloud can also be enabled in the local server. subject to data ownership framework guidelines. As much as data sharing is important for smart farming, there is a need for a regulated transparency and a framework for sharing of farmers data with government(agricultural extension officers) and other stakeholders[4]. In this thesis the focus is mainly on local data processing and access but data ownership is an area that needs to be considered when this system and other smart farms are deployed in real world.

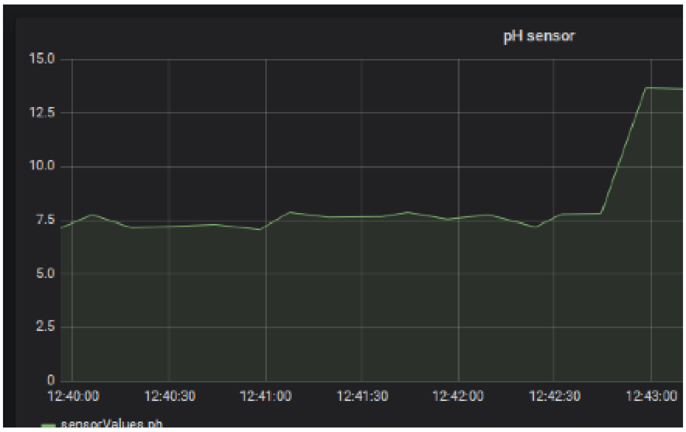
4.3 Results and Discussion

4.3.1 Results

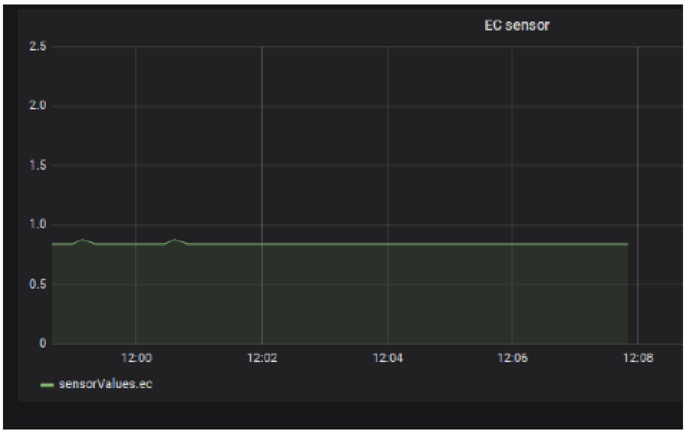
In this thesis we use IoT with LoRaWAN approach to monitor the conditions of hydroponic system. The sensor data were collected and transmitted periodically to the network server, analysed and stored in InfluxDB. We use an open source visualization tool to visualize data simplifying the understanding of the underlying data. Figure shows the dashboard the EC and pH level of the experimental set-up. From the Grafana dashboard, data can be checked as frequently as seconds to a year making it simple to identify the best conditions for growth in the hydroponic system. This information can be used to identify the best conditions to grow specific plants depending on the season.



(a) pH



(b) pH hike



(c) EC

Figure 34: pH, EC visualization on Grafana

We have also observed that the EC probe affects the values of pH. Once the EC is inserted to the nutrient solution the pH values almost doubles as shown in figure 34b. We have not investigated this far and is left as part of future work. However, from design perspective, pH and EC sensor can be place at different stages in hydroponic system.

Using Node-Red we have analysed data and sent notifications to an SMS-gateway that is running on Android phone. The SMSgateway can manage to send 500 messages per hour if the expansion packets are used. Since farming is not time critical, delayed notifications are tolerated.

As mentioned in section 3, network server handles the data rate using adaptive data rates. In this implementation LoRa Server is responsible for data rate. Since our experimental set-up is static the ADR is automatically activated and from the analysis of the meta-data from the LoRa app server, we can see that the spreading factor is used is 7 because the gateway and the end device is just a few meters from each other.

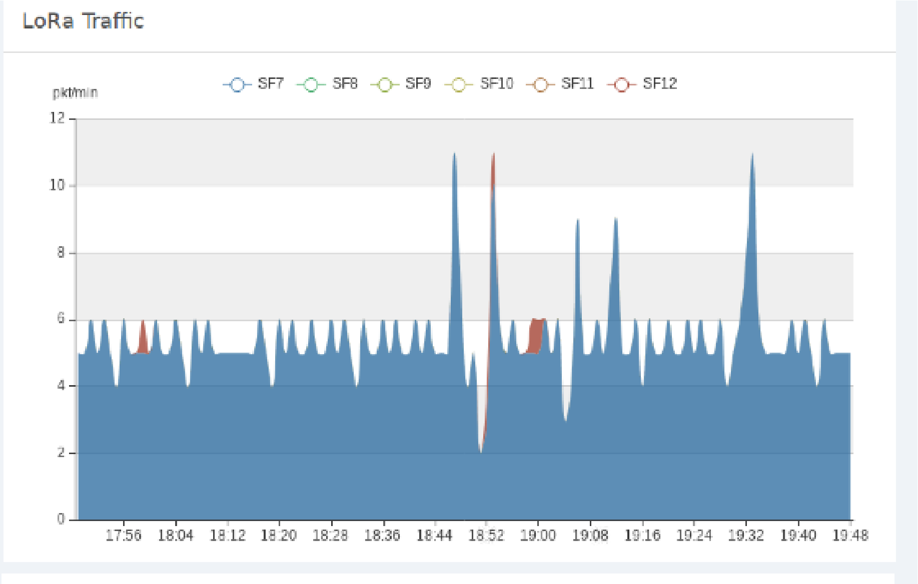


Figure 35: LoRa Traffic per minute and the spreading factor.

4.3.2 From data collection to empowerment

As stated earlier the solution proposed here is integrated into Basic Internet Foundation infrastructure which has information spots in the villages where farmers can access information freely. It is equipped with WiFi that farmers can connect to access local content. This will also act as a reference point for farmers about the hydroponic system and other agricultural information. The goal is to give farmers sufficient information about smart farming and its functioning, share data collected by the sensors for precise information on hydroponic system and the ideal conditions for crop growth. The added value from this is that farmers can get precise weather information from the local access and make necessary changes related to their plants grown in their hydroponic system and plants to grow in the open fields depending on rainfall predictions. - hydroponic system can complement the 'normal' farming(arable) when the weather conditions are unfavourable.

Basic Internet's Foundations Internet Lite is aimed at bringing connectivity to the rural areas and bridge the digital divide by providing access to information. The intention of inclusion of this approach into the solution proposed in this thesis, is to provide information about the smart farming and empower local communities by reducing information asymmetry. Since text and pictures are free in the InternetLite, farmers can access the internet without incurring additional cost and they can also access local content through the WiFi in the information spots. Similarly farmers can access information sustainable farming practises and technologies that facilitate smart farming. With this technology information driven agriculture is encouraged, increase efficient food production and reducing over-dependence on rain fed agriculture and thus helping farmers transition to sustainable farming.

For smart farming to be sustainable, capacity building must be done. Since most farmers might never have heard of this technology, it is important to give them competence required to adopt and sustain such systems. Training farmers who are the direct beneficiaries on building LoRaWAN network, sensor calibration and maintenance such that they can maintain it. As such information spot will be a reference point where farmers can access such information. As discussed in section 2 on how lack of infrastructure is impeding the adoption of new technologies, it is important to provide ways to encourage farmers to adapt new technologies and take advantage of the falling prices of devices and develop technologies that suit their needs. Thus information spot is aimed at facilitating third wave DIY innovations. - involvement of women.

Information spots will also be a point to access value added services: Here local meteorological departments can share weather information and agricultural departments can provide advisory services and information related to smart farming, disease outbreaks, information on fertilizers and nutrients for hydroponic farming.

5 Evaluation and future work

5.1 Evaluation

In this section we will analyse the proposed solution against the requirements of smart farming discussed in section 2.4. Evaluation metrics and relation to overall IoT Key Performance Indicators
What is the value of this system?

5.1.1 Cost

We will consider the capital expenditure (CAPEX) and operational expenditure (OPEX). In this cost evaluation we will only consider the cost related to *technology* part of the solution. As such the cost related to setting up a hydroponic farm has not been analysed. However, they are wide range of literature that cover this topic e.g Naik and Singh suggested cheap materials that can be used to set up a greenhouse for hydroponic farm for the cultivation of fodder [43]. Since most farmers in emerging economies are smallholder farmers, they will share the cost of setting up the system and maintenance. This is the reason of choosing a gateway that can give a wide coverage. The proposed solution uses RAK7249 outdoor gateway with a range of at least 15KM line-of-sight according to the documentation[30]. Thus the farmers within the range of this can share cost. RAK7249 goes for $599 at the time of this writing. Since LoRa is operating on ISM bands that are free, no initial and operational charges are incurred in the use of those frequencies (868MHz in Europe). For the network server Raspberry Pi 3+ at cost raspberry $35 was used. The gateway and Raspberry Pi are core components of shared infrastructure. For each specific hydroponic farm, LoRa node and MCU are need and these cost $21 and $16 respectively.

The cost of pH and EC sensor was $110. Currently the common pH and EC probes in the market are mostly hand-held and are not suitable for IoT applic-

---

[30] `https://downloads.rakwireless.com/en/LoRa/DIY-Gateway-RAK7249/Hardware-Specification/DIY_Outdoor_Gateway_RAK7249_Product_Brief_V1.2.pdf`

ation for monitoring smart farms. The cost for this varies but these are some of them: Bluelab handy EC-pen[31], cost $109 and ADWA pH-pen[32] which cost $70. The cost of the sensors used in the proposed solution are relatively cheaper as compared to other alternatives and they are also suitable and convenient for IoT applications in smart farming but they are laboratory grade and can not be immersed in nutrient solution for long. Atlas Scientific has industry grade EC [33] and pH[34] sensors that cost $162 and $40 respectively. These are suitable for smart farming and as they can be submerged to nutrient solution indefinitely. LoRa technology and IoT are still in their nascent form and with continuous decrease in the cost of electronics, cheaper sensors and MCU designed for these kind of applications will definitely be available soon.

Since this is a shared infrastructure, farmers can share the cost of gateway. However, the cost of this system i.e. sensors in the farms is still beyond the reach of smallholder farmers and alternative approaches are needed. Recall section 2.2.2, holistic approach for smart farming in emerging economies is needed so as to realize the potential of technology to make food production efficient. It is therefore necessary to include other actors e.g local governments, non-governmental organizations(NGOs), academia and industry to help rural farmers set-up these system. With significant amounts of aid going into food support especially in sub-Saharan Africa, there is a need to invest such aid into farming system that leverage recently technological advancement (IoT and LPWAN) to promote efficient food production. Such cooperation with development agents can make smart farming affordable to smallholder farmers. In addition development agents can cooperate with local and international institutions to develop customized solutions that meet requirement of the smart farms for a resource constrained settings. This has already been done before and District Health Information System (DHIS)[35] - a health management information system that was developed at the University of Oslo, is an example of academia and other development agents helping in addressing the issues related to health. Similarly, smart farms solutions suggested here can be implemented in the same

---

[31] `https://www.gartnerbutikken.no/products/bluelab-handy-ec-penn2`

[32] `https://www.gartnerbutikken.no/products/adwa-ph-penn2`

[33] `https://www.atlas-scientific.com/product_pages/probes/ec_k1-0-mini.html`

[34] `https://www.atlas-scientific.com/product_pages/probes/c-ph-probe.html`

[35] `https://www.dhis2.org`

way and reduce the financial burden of setting up from the smallholder farmers and at the same time address the problems related to the food crisis in the face of climate change.

5.1.2 Power consumption

Most of the rural areas in developing countries are not connected to the power grid. All components used in this thesis can be powered by battery. The gateway can operate on 12V/10AH batteries according to the documentation[36]. The MCU, LoRa node and sensors can be powered by rechargeable Lithium batteries. In addition energy harvesting techniques such as use of solar power based on photovoltaic system. However, initial cost will increase, but a worthy investment in long term thus recurring cost will be reduced as batteries won't be changed often. The end devices are class A devices are the most energy efficient as they transmit only once. To further reduce energy consumption transmission has been set to once every hour.

5.1.3 Cost-efficient communication

As mentioned earlier, the communication between sensors and gateway is through LoRa technology that uses ISM bands and no cost is incurred in using those frequencies. Live transfer of all data sensor to cloud is costly due to bandwidth usage or might not be possible due to connectivity hence local storage is used. However, so as to share data with other stakeholders for further data analysis, Basic Internet solution offers alternative connectivity and compression and batch transfers is done at the edge layer to reduce bandwidth consumption. The Wi-Fi available in the information spots will help farmers access the information related to their farms e.g Grafana dashboards to get an insight of their farms. Since content is hosted locally, farmers will not incur additional cost compared to cloud based system.

Notifications are sent from Android based SMS gateway application that uses a local number. The app supports old versions of Android OS and can be installed on cheap and widely available Android phones. This reduces the cost of sending SMS notifications. Since it is operated locally and the sim card used

---

[36] `https://downloads.rakwireless.com/en/LoRa/DIY-Gateway-RAK7249/Hardware-Specification/DIY_Outdoor_Gateway_RAK7249_Product_Brief_V1.2.pdf`

is a local number, then local SMS tariffs are applied. This is cheaper compared to other solutions like Twilio that require a monthly subscription and limitation on the number of messages sent per data. They are other SMSgateway apps in the market e.g FrontlineSMS and Telerivet [37] - they also require subscription. Using EnvayaSMS is cheaper and satisfies the requirements of the proposed solution.

5.1.4 Software

One of limiting factor to adoption of technology in developing countries is lack of access to new technology and ownership rights of technology. Fortunately there has been increase focus on need to democratize technology and knowledge and open source software has revolutionized this. In the implementation of the proposed solution we have open source software, open and widely used standards in the implementation of the proposed solution. These software have a large community and free of licences that restrict their usage. As such no cost is incurred using them. Considering the computing capacities of the end node and local server (Raspberry Pi 3+)- we have used lightweight protocols e.g MQTT that are efficient in bandwidth and power consumption. The network server, which is an important part of the LoRaWAN, we used components of LoRaServer Project, which is also an open source and well documented. For storage and visualization, influxDB and Grafana was used. These are open source software tools. Node-red which is also open source gives the platform that is suitable for IoT implementations and easy to program system functionalities. As mentioned in the previous sections, EnvayaSMS gateway was used for to send notifications to farmers.

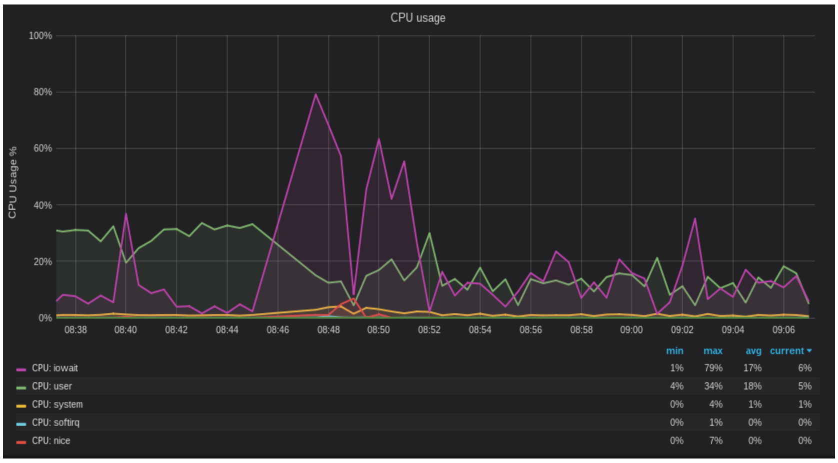
To build the capacity of the local community, platforms that hold free information on farming can be accessed from the information spots. They are platforms that provide free information in different sectors e.g in education Khan Academy, in health yeboo.com and global health media project that produce free teaching videos that for health workers in low resource setting. Similarly content that is related to farming can be hosted in the local server and accessed at the information spots.

---

[37] `https://telerivet.com`

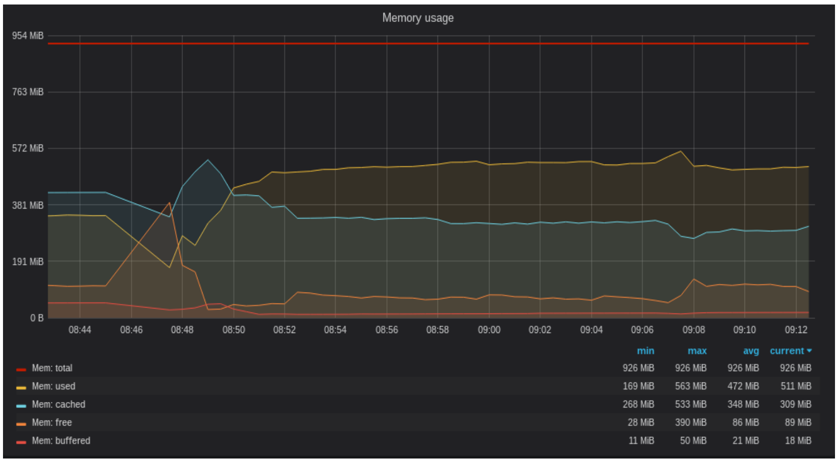
5.1.5 Computation and storage

In the proposed solution all computation is done locally. All components of LoRaServer project (Lora-gateway bridge, loraserver, lora-app-server) are running locally on the Raspberry Pi 3+. Data analysis is also done locally and activation of notification is also processed in the local server. EnvayaSMS server is also hosted in the same machine. This reduces the cost of sending data to the cloud for processing. We have however suggested inclusion of cloud layer in the system for the purpose of long-term storage, analysis and sharing information with other stakeholders. To minimize the cost, Basic Internet Foundation's solution is adopted into this solutions. We used 16 GB SD card for the experiment but the storage can be expanded if there is a need. In the current set up the sensors transmit data every hour. This is 4 bytes per hour, 96 bytes per day, 2880 bytes per month and 34 560 bytes per year. The current set-up can easily handle this amount of data.



	min	max	avg	current ▾
▬ CPU: iowait	1%	79%	17%	6%
▬ CPU: user	4%	34%	18%	5%
▬ CPU: system	0%	4%	1%	1%
▬ CPU: softirq	0%	1%	0%	0%
▬ CPU: nice	0%	7%	0%	0%

(a) CPU usage



	min	max	avg	current ▾
▬ Mem: total	926 MiB	926 MiB	926 MiB	926 MiB
▬ Mem: used	169 MiB	563 MiB	472 MiB	511 MiB
▬ Mem: cached	268 MiB	533 MiB	348 MiB	309 MiB
▬ Mem: free	28 MiB	390 MiB	86 MiB	89 MiB
▬ Mem: buffered	11 MiB	50 MiB	21 MiB	18 MiB

(b) Memory Usage

Figure 36: CPU and Memory usage visualization on Grafana

5.1.6 Scalability

The Network capacity of LoRaWAN network is determined by the frequency of data transmission, data rate, the number of channels in the gateway and duty cycle as discussed in section [12]. The regulation on duty cycle depends on the region. In Europe the duty cycle for 868 ISM band is 1 %. This equates to 36 sec/hour transmission per end device (Number of seconds in a day 86400 *1/100 = 864 seconds per day). In experimental set-up the data is transmitted once every hour which is below 36 sec/hour thus complying with duty cycle requirements. RAK7249 gateway has 8 channels and ADR has been enabled so as to optimize the performance and capacity of the network. In addition it had a light-of-sight of 15KM thus offering a coverage rural area.

The scale of data produced (amount of data: number of sensors, frequency of transmission per hydroponic farm) is small as compared to big data in other IoT sectors, but in countries with limited internet and high cost, even small data transmission is costly. The proposed solution mainly focuses on storing data at the local servers. However, use of InfoInternet standard for connectivity with cloud enables long term storage and sharing of data with other stakeholders.

5.1.7 Ease of Use and sustainability

The ease of use affects the dynamics of adoption and scaling up of the new technologies in any environment. It also affects the perceived benefits of smart farming. Farmers are generally not early adopters of technology and for farmers in emerging economies where knowledge of even existing technology is limited, new technologies should be easy to use so to encourage their adoption. In the proposed solution, the farmers share the infrastructure. Farmers only need sensors in their farms while the gateway and network server is hosted in a single place. Data will be transmitted once sensor are connected to MCU and LoRa node.

The use of smartphones is increasing gradually, but basic and feature phones remain the dominant mobile devices used in developing countries. As discussed in section 4.2.3.4 high cost of mobile and battery life affect the uptake of smart devices in emerging markets. Application based notifications require data based connection to the internet making it not suitable for smallholder farmers who can not afford to have daily data bundle subscriptions.Based on this, the suitable notification service is SMS and in text format. Text messages are format that can easily be understood and is a service that is available even in feature phones. EnvayaSMS offers a cost efficient SMS notification compared app-based notifications or other sms aggregators like Twilio.

It is important to involve farmers in the control loop and in the decision making process. The suggested solutions gives the farmers the necessary information for them changes related to their hydroponic system. For farmers, especially in rural areas where the use of technology is not common, the sense of being in control of the system gives them the confidence to use and sustain the system. In addition notifications through SMS is a simple to use and read. Since the notification system is running locally messages are written in the local language for local farmers to understand. This cost efficient approach makes this system sustainable.

The inclusion of technology can also encourage the youth into farming. With a smart hydroponic farm, young people can be motivated to go farming and create job opportunities. In most developing countries, youths migrate to towns and practise of agriculture has been left to the older generation. With digitalization of farming, like the system proposed here, the profile of farming is improved increasing chances of youth adopting this as a source of employment. The ease of use evaluated here is not only on how simple this system is for farmers to use, but also this system simplifies and modernize farming for the younger generation to practise it.

functional design: sensor - sensor comm - gateway - edge server - gateway comm - cloud functionality

costs (opex) | sensor/sensor comm | gateway | edge server | gateway comm/cloud connectivity | cloud functionality

costs (capex) | ++\footnote{use of batteries and ca be solar powered}

power |

Caption header of Tables above (figures below)

	Criteria	score	comment
Cost	gateway and local server	0	Community network-shared cost
	capex sensors	− −	Sensor per farm
Power	Gateway energy efficiency	++	Can be power by solar.
	sensor energy efficiency	++	use of batteries and can be solar powered
Communication	LoRa range	++	Long range: 15KM line-of-sight
	Notification	++	SMS cellular widely available
Software	Open source software use	++	All software used are open source including network server(LoRa server)
Computation	Local computation	++	Network server, data processing done at the local server.
	Edge analysis	++	Data analytic at local server and notification sent
	CPU and Memory	++	Reasonable performance
	Storage	++	Locally stored and accessed.
Scalability	Gateway Range	++	Upto 15KM. Sufficient for a rural area
	Scalability with increase number of end devices	++	Network capacity optimized by ADR
	Scalability with increased sensor data	++	Storage expanded with external SD card.
Ease of use	Ease of installation	+	Sensor and MCU easily be installed
	Ease of learning	0	
	Notification format	++	SMS based notifications which supported by all phones

Table 11: Evaluation of the proposed solution: Legends ++,+,Reasonable: 0, −, − −

Text describing the table: summarize the top 5 ++, challenges of - - (killer?)

Integration is not easy especially in IoT since the sector is rapidly developing - DIY approach can be a way out for countries with no industries but the challenge is integrating devices from different manufactures and software - interoperability). Following Gartner's Hype Cycle- it is going to take time before IoT goes through the five key phases of a technology's life cycle and its potential is fully achieved, especially in developing countries. Whereas the need for technology use in farming is necessary in the wake of climate change, population and food crisis, it use in emerging economies require holistic approach so as to address these global problems.

5.2 Future Works

Open issues - technical: EnvayaSMS is not optimized for IoT scenarios and is currently using HTTP. MQTT could be a better protocol in terms of
Other open issues: end-user involvement in the development of smart farming(living lab).
Sustainable business model for the local communities: Having few sensors only for hydroponic farming might not viable but with doing it together with other applications e.g monitoring irrigation system will improve the return on the investment. Help local communities identify crops that give high returns and can do well on hydroponic farming.

6 Conclusion

conclusion

Bibliography

[1] H. Sundmaeker, C. Verdouw, S. Wolfert, and L. Pérez Freire, "Internet of food and farm 2020," *Digitising the Industry-Internet of Things connecting physical, digital and virtual worlds. Ed: Vermesan, O., & Friess, P*, pp. 129–151, 2016.

[2] B. Research, " towards smart farming agriculture embracing the iot vision," http://www.beechamresearch.com/files/BRL%20Smart%20Farming%20Executive%20Summary.pdf, accessed: 2019-03-16.

[3] S. Wolfert, D. Goense, and C. A. G. Sørensen, "A future internet collaboration platform for safe and healthy food from farm to fork," in *2014 Annual SRII Global Conference.* IEEE, 2014, pp. 266–273.

[4] A. Walter, R. Finger, R. Huber, and N. Buchmann, "Opinion: Smart farming is key to developing sustainable agriculture," *Proceedings of the National Academy of Sciences*, vol. 114, no. 24, pp. 6148–6150, 2017.

[5] E. Pantanella, "Aquaponics production, practices and opportunities," in *Sustainable Aquaculture.* Springer, 2018, pp. 191–248.

[6] D. G. Kogias, E. T. Michailidis, G. Tuna, and V. C. Gungor, "Realizing the wireless technology in internet of things (iot)," in *Emerging Wireless Communication and Network Technologies.* Springer, 2018, pp. 173–192.

[7] P. P. Ray, "Internet of things for smart agriculture: Technologies, practices and future direction," *Journal of Ambient Intelligence and Smart Environments*, vol. 9, no. 4, pp. 395–420, 2017.

[8] V. Karagiannis, P. Chatzimisios, F. Vazquez-Gallego, and J. Alonso-Zarate, "A survey on application layer protocols for the internet of things," *Transaction on IoT and Cloud computing*, vol. 3, no. 1, pp. 11–17, 2015.

[9] D. Thangavel, X. Ma, A. Valera, H.-X. Tan, and C. K.-Y. Tan, "Performance evaluation of mqtt and coap via a common middleware," in *2014 IEEE Ninth International Conference on Intelligent Sensors, Sensor Networks and Information Processing (ISSNIP).* IEEE, 2014, pp. 1–6.

[10] J. Noll, W. A. Mansour, C. Holst, S. Dixit, F. Sukums, H. Ngowi, D. Radovanović, E. Mwakapeje, G. M. N. Isabwe, A. S. Winkler *et al.*, "Internet lite for sustainable development," 2018.

[11] Northstream, " connectivity technologies for iot. full report updated edition," https://www.telenor.no/binaries/Northstream%20-%20Connectivity%20Technologies%20for%20IoT%20-%20Full%20Report%202018_tcm95-353610.pdf, accessed: 2019-05-10.

[12] L. Alliance, "What is lorawan?(2018)," https://lora-alliance.org/sites/default/files/2018-04/what-is-lorawan.pdf, 2015, accessed: 2019-05-25.

[13] S. David and A. Ed, "Hype cycle for cloud computing, 2018," Available:https://irp-cdn.multiscreensite.com/33cdee1b/files/uploaded/hype_cycle_for_cloud_computi_340420.pdf, accessed: 2019-05-04.

[14] K. Mekki, E. Bajic, F. Chaxel, and F. Meyer, "A comparative study of lpwan technologies for large-scale iot deployment," *ICT Express*, vol. 5, no. 1, pp. 1–7, 2019.

[15] M. Cattani, C. Boano, and K. Römer, "An experimental evaluation of the reliability of lora long-range low-power wireless communication," *Journal of Sensor and Actuator Networks*, vol. 6, no. 2, p. 7, 2017.

[16] FAO, "How to feed the world in 2050," \http://www.fao.org/fileadmin/templates/wsfs/docs/expert_paper/How_to_Feed_the_World_in_2050.pdf, accessed: 2019-02-11.

[17] A. M. Tjoa and S. Tjoa, "The role of ict to achieve the un sustainable development goals (sdg)," in *IFIP World Information Technology Forum*. Springer, 2016, pp. 3–13.

[18] W. E. Forum, " the global risks report 2016 11th edition," http://www3.weforum.org/docs/GRR/WEF_GRR16.pdf, accessed: 2019-03-16.

[19] P. D. United Nations, D. o. E. a. SA, "World population prospects: The 2017 revision, key findings and advance tables"," 2017.

[20] W. H. Organization *et al.*, *The State of Food Security and Nutrition in the World 2018: Building climate resilience for food security and nutrition.* Food & Agriculture Org., 2018.

[21] M. Nyasimi, D. Amwata, L. Hove, J. Kinyangi, and G. Wamukoya, "Evidence of impact: climate-smart agriculture in africa," 2014.

[22] W. Al, G. ORKING, and O. CLIMA, "Climate change and food security: a framework document," 2008.

[23] J. Beddington, "Food security: contributions from science to a new and greener revolution," *Philosophical Transactions of the Royal Society B: Biological Sciences*, vol. 365, no. 1537, pp. 61–71, 2010.

[24] W. Bank, *World development report 2008: Agriculture for development.* World Bank, 2007.

[25] E. Pierpaoli, G. Carli, E. Pignatti, and M. Canavari, "Drivers of precision agriculture technologies adoption: a literature review," *Procedia Technology*, vol. 8, pp. 61–69, 2013.

[26] B. Melesse, "A review on factors affecting adoption of agricultural new technologies in ethiopia," *Journal of Agricultural Science and Food Research*, 2018.

[27] U. Deichmann, A. Goyal, and D. Mishra, *Will digital technologies transform agriculture in developing countries?* The World Bank, 2016.

[28] Food and A. O. of the United Nations., "2010b. climate-smart agriculture: policies, practice and financing for food security, adaptation and migration." 2010.

[29] FAO, "The future of food and agriculture–trends and challenges," 2017.

[30] B. Sanou, “Ict facts and figures 2016,” *International Telecommunication Union*, 2016.

[31] P. A. Barro, M. Zennaro, J. Degila, and E. Pietrosemoli, “A smart cities lorawan network based on autonomous base stations (bs) for some countries with limited internet access,” *Future Internet*, vol. 11, no. 4, p. 93, 2019.

[32] U. Nations, “ sustainable development goals: Goal 9: Industry, innovation and infrastructure,” https://www.un.org/development/desa/disabilities/envision2030-goal9.html, accessed: 2018-08-08.

[33] H. Baumüller, “Towards smart farming? mobile technology trends and their potential for developing country agriculture,” 2017.

[34] R. Schrijver, K. Poppe, and C. Daheim, “Precision agriculture and the future of farming in europe,” *Teaduslike ja tehnoloogiliste valikute hindamise üksus.[online] http://www. europarl. europa. eu/RegData/etudes/STUD/2016/581892/EPRS_STU (201 6) 581892_EN. pdf (01.05. 2018)*, 2016.

[35] R. FRESCO and G. FERRARI, “Enhancing precision agriculture by internet of things and cyber physical systems.”

[36] C. Bahr, D. Forristal, S. Fountas, E. Gil, G. Grenier, R. Hoerfarter, A. Jonsson, A. Jung, C. Kempenaar, K. Lokhorst *et al.*, “Eip-agri focus group: Precision farming,” 2015.

[37] H. Jawad, R. Nordin, S. Gharghan, A. Jawad, and M. Ismail, “Energy-efficient wireless sensor networks for precision agriculture: A review,” *Sensors*, vol. 17, no. 8, p. 1781, 2017.

[38] D. Pivoto, P. D. Waquil, E. Talamini, C. P. S. Finocchio, V. F. Dalla Corte, and G. de Vargas Mores, “Scientific development of smart farming technologies and their application in brazil,” *Information processing in agriculture*, vol. 5, no. 1, pp. 21–32, 2018.

[39] S. Wolfert, L. Ge, C. Verdouw, and M.-J. Bogaardt, “Big data in smart farming–a review,” *Agricultural Systems*, vol. 153, pp. 69–80, 2017.

[40] H. M. Resh, *Hydroponic food production: a definitive guidebook for the advanced home gardener and the commercial hydroponic grower.* CRC Press, 2016.

[41] M. H. Jensen, “Hydroponics,” *HortScience*, vol. 32, no. 6, pp. 1018–1021, 1997.

[42] A. Shrestha, B. Dunn *et al.*, “Hydroponics,” 2010.

[43] P. Naik and N. Singh, “Hydroponics fodder production: an alternative technology for sustainable livestock production against impeding climate change,” *Model Training Course on Management Strategies for Sustainable Livestock Production against Impending Climate Change*, pp. 70–75, 2013.

[44] P. Sethi and S. R. Sarangi, "Internet of things: architectures, protocols, and applications," *Journal of Electrical and Computer Engineering*, vol. 2017, 2017.

[45] C. Perera, Y. Qin, J. C. Estrella, S. Reiff-Marganiec, and A. V. Vasilakos, "Fog computing for sustainable smart cities: A survey," *ACM Computing Surveys (CSUR)*, vol. 50, no. 3, p. 32, 2017.

[46] D. Evans, "The internet of things: How the next evolution of the internet is changing everything," *CISCO white paper*, vol. 1, no. 2011, pp. 1–11, 2011.

[47] J. Manyika, *The Internet of Things: Mapping the value beyond the hype.* McKinsey Global Institute, 2015.

[48] J. Gubbi, R. Buyya, S. Marusic, and M. Palaniswami, "Internet of things (iot): A vision, architectural elements, and future directions," *Future generation computer systems*, vol. 29, no. 7, pp. 1645–1660, 2013.

[49] I. G. Smith, *The Internet of things 2012: new horizons.* CASAGRAS2, 2012.

[50] P. Asghari, A. M. Rahmani, and H. H. S. Javadi, "Internet of things applications: A systematic review," *Computer Networks*, vol. 148, pp. 241–261, 2019.

[51] H. Li, H. Wang, W. Yin, Y. Li, Y. Qian, and F. Hu, "Development of a remote monitoring system for henhouse environment based on iot technology," *Future Internet*, vol. 7, no. 3, pp. 329–341, 2015.

[52] M. A. Zamora-Izquierdo, J. Santa, J. A. Martínez, V. Martínez, and A. F. Skarmeta, "Smart farming iot platform based on edge and cloud computing," *Biosystems Engineering*, vol. 177, pp. 4–17, 2019.

[53] R. Mulenga, J. Kalezhi, S. K. Musonda, and S. Silavwe, "Applying internet of things in monitoring and control of an irrigation system for sustainable agriculture for small-scale farmers in rural communities," in *2018 IEEE PES/IAS PowerAfrica.* IEEE, 2018, pp. 1–9.

[54] M. S. Munir, I. S. Bajwa, M. A. Naeem, and B. Ramzan, "Design and implementation of an iot system for smart energy consumption and smart irrigation in tunnel farming," *Energies*, vol. 11, no. 12, p. 3427, 2018.

[55] M. H. Memon, W. Kumar, A. Memon, B. S. Chowdhry, M. Aamir, and P. Kumar, "Internet of things (iot) enabled smart animal farm," in *2016 3rd International Conference on Computing for Sustainable Global Development (INDIACom).* IEEE, 2016, pp. 2067–2072.

[56] N. Naik, "Choice of effective messaging protocols for iot systems: Mqtt, coap, amqp and http," in *2017 IEEE international systems engineering symposium (ISSE).* IEEE, 2017, pp. 1–7.

[57] M. Centenaro, L. Vangelista, A. Zanella, and M. Zorzi, "Long-range communications in unlicensed bands: The rising stars in the iot and smart city scenarios," *IEEE Wireless Communications*, vol. 23, no. 5, pp. 60–67, 2016.

[58] G. Reiter, “Wireless connectivity for the internet of things,” *Europe*, vol. 433, p. 868MHz, 2014.

[59] T. Ojha, S. Misra, and N. S. Raghuwanshi, “Wireless sensor networks for agriculture: The state-of-the-art in practice and future challenges,” *Computers and Electronics in Agriculture*, vol. 118, pp. 66–84, 2015.

[60] N. Lethaby, “Wireless connectivity for the internet of things: One size does not fit all,” *Texas Instruments*, pp. 2–10, 2017.

[61] G. A. Akpakwu, B. J. Silva, G. P. Hancke, and A. M. Abu-Mahfouz, “A survey on 5g networks for the internet of things: Communication technologies and challenges,” *IEEE Access*, vol. 6, pp. 3619–3647, 2018.

[62] A. Augustin, J. Yi, T. Clausen, and W. Townsley, “A study of lora: Long range & low power networks for the internet of things,” *Sensors*, vol. 16, no. 9, p. 1466, 2016.

[63] A. Biral, M. Centenaro, A. Zanella, L. Vangelista, and M. Zorzi, “The challenges of m2m massive access in wireless cellular networks,” *Digital Communications and Networks*, vol. 1, no. 1, pp. 1–19, 2015.

[64] R. Stoica and G. T. F. de Abreu, “6g: the wireless communications network for collaborative and AI applications,” *CoRR*, vol. abs/1904.03413, 2019. [Online]. Available: http://arxiv.org/abs/1904.03413

[65] J. Johansen, C. Johansen, and J. Noll, “Infointernet for education in the global south: A study of applications enabled by free information-only internet access in technologically disadvantaged areas (authors’ version),” *arXiv preprint arXiv:1808.09496*, 2018.

[66] D. Sudhir and J. Noll, “ free access to information for all (a vision of the basic internet foundation),” https://its-wiki.no/images/e/e9/Basic_Internet_White_Paper.pdf, accessed: 2019-05-10.

[67] J. Saldana, A. Arcia-Moret, B. Braem, E. Pietrosemoli, A. Sathiaseelan, and M. Zennaro, “Alternative network deployments: Taxonomy, characterization, technologies, and architectures,” Tech. Rep., 2016.

[68] H.-L. Truong, “Enabling edge analytics of iot data: the case of lorawan,” in *2018 Global Internet of Things Summit (GIoTS)*. IEEE, 2018, pp. 1–6.

[69] J. Finnegan and S. Brown, “A comparative survey of lpwa networking,” *arXiv preprint arXiv:1802.04222*, 2018.

[70] C. Pham, A. Rahim, and P. Cousin, “Low-cost, long-range open iot for smarter rural african villages,” in *2016 IEEE International Smart Cities Conference (ISC2)*. IEEE, 2016, pp. 1–6.

[71] S. Fox, “Third wave do-it-yourself (diy): Potential for prosumption, innovation, and entrepreneurship by local populations in regions without industrial manufacturing infrastructure,” *Technology in Society*, vol. 39, pp. 18–30, 2014.

[72] M. Bor and U. Roedig, "Lora transmission parameter selection," in *2017 13th International Conference on Distributed Computing in Sensor Systems (DCOSS).* IEEE, 2017, pp. 27–34.

[73] J. C. Liando, A. Gamage, A. W. Tengourtius, and M. Li, "Known and unknown facts of lora: Experiences from a large-scale measurement study," *ACM Transactions on Sensor Networks (TOSN)*, vol. 15, no. 2, p. 16, 2019.

[74] M. K. N. Pinto, E. Pietrosemoli, M. Zennaro, M. Rainone, P. Manzoni *et al.*, "A lora enabled sustainable messaging system for isolated communities," in *Proceedings of the 4th EAI International Conference on Smart Objects and Technologies for Social Good.* ACM, 2018, pp. 118–123.

[75] A. Pötsch and F. Haslhofer, "Practical limitations for deployment of lora gateways," in *2017 IEEE International Workshop on Measurement and Networking (M&N).* IEEE, 2017, pp. 1–6.

[76] R. Buyya, C. S. Yeo, S. Venugopal, J. Broberg, and I. Brandic, "Cloud computing and emerging it platforms: Vision, hype, and reality for delivering computing as the 5th utility," *Future Generation computer systems*, vol. 25, no. 6, pp. 599–616, 2009.

[77] L. M. Vaquero, L. Rodero-Merino, J. Caceres, and M. Lindner, "A break in the clouds: towards a cloud definition," *ACM SIGCOMM Computer Communication Review*, vol. 39, no. 1, pp. 50–55, 2008.

[78] P. Mell, T. Grance *et al.*, "The nist definition of cloud computing," 2011.

[79] P. Garcia Lopez, A. Montresor, D. Epema, A. Datta, T. Higashino, A. Iamnitchi, M. Barcellos, P. Felber, and E. Riviere, "Edge-centric computing: Vision and challenges," *ACM SIGCOMM Computer Communication Review*, vol. 45, no. 5, pp. 37–42, 2015.

[80] Y. Ito, H. Koga, and K. Iida, "A bandwidth allocation scheme based on residual bandwidth information in mobile edge computing," in *Proceedings of the 2nd Workshop on Middleware for Edge Clouds & Cloudlets.* ACM, 2017, p. 3.

[81] W. Shi, J. Cao, Q. Zhang, Y. Li, and L. Xu, "Edge computing: Vision and challenges," *IEEE Internet of Things Journal*, vol. 3, no. 5, pp. 637–646, 2016.

[82] Y. Ai, M. Peng, and K. Zhang, "Edge computing technologies for internet of things: a primer," *Digital Communications and Networks*, vol. 4, no. 2, pp. 77–86, 2018.

[83] A. Yousefpour, C. Fung, T. Nguyen, K. Kadiyala, F. Jalali, A. Niakanlahiji, J. Kong, and J. P. Jue, "All one needs to know about fog computing and related edge computing paradigms: a complete survey," *Journal of Systems Architecture*, 2019.

[84] O. Vermesan, M. Eisenhauer, M. Serrano, P. Guillemin, H. Sundmaeker, E. Z. Tragos, J. Valino, B. Copigneaux, M. Presser, A. Aagaard *et al.*, "The

next generation internet of things–hyperconnectivity and embedded intelligence at the edge," *Next Generation Internet of Things. Distributed Intelligence at the Edge and Human Machine-to-Machine Cooperation*, 2018.

[85] S. Jingtao, L. Fuhong, Z. Xianwei, and L. Xing, "Steiner tree based optimal resource caching scheme in fog computing," *China Communications*, vol. 12, no. 8, pp. 161–168, 2015.

[86] F. A. Kraemer, A. E. Braten, N. Tamkittikhun, and D. Palma, "Fog computing in healthcare–a review and discussion," *IEEE Access*, vol. 5, pp. 9206–9222, 2017.

[87] C. Perera, P. P. Jayaraman, A. Zaslavsky, P. Christen, and D. Georgakopoulos, "Context-aware dynamic discovery and configuration of 'things' in smart environments," in *Big Data and Internet of Things: A Roadmap for Smart Environments.* Springer, 2014, pp. 215–241.

[88] M. J. O'Grady and G. M. O'Hare, "Modelling the smart farm," *Information processing in agriculture*, vol. 4, no. 3, pp. 179–187, 2017.

[89] A. Murage, J. Pittchar, C. Midega, C. Onyango, and Z. Khan, "Gender specific perceptions and adoption of the climate-smart push–pull technology in eastern africa," *Crop Protection*, vol. 76, pp. 83–91, 2015.

[90] C. Cambra, S. Sendra, J. Lloret, and R. Lacuesta, "Smart system for bicarbonate control in irrigation for hydroponic precision farming," *Sensors*, vol. 18, no. 5, p. 1333, 2018.

[91] P. N. Crisnapati, I. N. K. Wardana, I. K. A. A. Aryanto, and A. Hermawan, "Hommons: Hydroponic management and monitoring system for an iot based nft farm using web technology," in *2017 5th International Conference on Cyber and IT Service Management (CITSM).* IEEE, 2017, pp. 1–6.

[92] H. Ibayashi, Y. Kaneda, J. Imahara, N. Oishi, M. Kuroda, and H. Mineno, "A reliable wireless control system for tomato hydroponics," *Sensors*, vol. 16, no. 5, p. 644, 2016.

[93] M. Caria, J. Schudrowitz, A. Jukan, and N. Kemper, "Smart farm computing systems for animal welfare monitoring," in *2017 40th International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO).* IEEE, 2017, pp. 152–157.

[94] F. Ferrández-Pastor, J. García-Chamizo, M. Nieto-Hidalgo, J. Mora-Pascual, and J. Mora-Martínez, "Developing ubiquitous sensor network platform using internet of things: Application in precision agriculture," *Sensors*, vol. 16, no. 7, p. 1141, 2016.

[95] S. Lee, M. Bae, and H. Kim, "Future of iot networks: A survey," *Applied Sciences*, vol. 7, no. 10, p. 1072, 2017.

[96] D. R. Patnaik Patnaikuni, "A comparative study of arduino, raspberry pi and esp8266 as iot development board." *International Journal of Advanced Research in Computer Science*, vol. 8, no. 5, 2017.

[97] A. S. Kebede, I. O. Ajayi, and A. O. Arowojolu, “Effect of enhanced reminders on postnatal clinic attendance in addis ababa, ethiopia: a cluster randomized controlled trial,” *Global health action*, vol. 12, no. 1, p. 1609297, 2019.

[98] F. Ngabo, J. Nguimfack, F. Nwaigwe, C. Mugeni, D. Muhoza, D. R. Wilson, J. Kalach, R. Gakuba, C. Karema, and A. Binagwaho, “Designing and implementing an innovative sms-based alert system (rapidsms-mch) to monitor pregnancy and reduce maternal and child deaths in rwanda,” *The Pan African Medical Journal*, vol. 13, 2012.

[99] R. Anderson, T. Perrier, F. Pervaiz, N. Sisouveth, B. Kumar, S. Phongphila, A. Rahman, R. Dhiman, and S. Newland, “Supporting immunization programs with improved vaccine cold chain information systems,” in *IEEE global humanitarian technology conference (GHTC 2014)*. IEEE, 2014, pp. 215–222.

A Program code

A.1 End device activation, sensor reading and transmission code

The code below is adapted from the DFRobot library and LMIC library for LoRa activation and transmission of packets.

```
/*****************************************************************************

 *****************************************************************************

#include <lmic.h>
#include <hal/hal.h>
#include "DFRobot_EC.h"
#include "DFRobot_PH.h"
#include <EEPROM.h>

#define PH_PIN A1
#define EC_PIN A2
float voltageEC,voltagePH, phValue, ecValue,temperature = 25;
DFRobot_PH ph;
DFRobot_EC ec;
struct sensorValues {
 float ec;
 float ph;
};

// EUI little-endian format
static const u1_t PROGMEM APPEUI[8] = { 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x0
void os_getArtEui (u1_t* buf) {
  memcpy_P(buf, APPEUI, 8);
}

// little endian format
static const u1_t PROGMEM DEVEUI[8] = { 0x42, 0x1f, 0xf1, 0x7d, 0x38, 0xdc, 0x9
void os_getDevEui (u1_t* buf) {
  memcpy_P(buf, DEVEUI, 8);
}

static const u1_t PROGMEM APPKEY[16] = { 0x2c, 0xd3, 0x2e, 0x10, 0xf0, 0x2d, 0x

void os_getDevKey (u1_t* buf) {
  memcpy_P(buf, APPKEY, 16);
}

//static uint8_t mydata[] = { 0,0,0,0,0,0,0,0};
static osjob_t sendjob;

// Schedule TX every this many seconds (might become longer due to duty
```

```
// cycle limitations).
const unsigned TX_INTERVAL = 10;

// Pin mapping
const lmic_pinmap lmic_pins = {
  .nss = 10,
  .rxtx = LMIC_UNUSED_PIN,
  .rst = 9,
  .dio = {2, 6, 7},
};

void onEvent (ev_t ev) {
  Serial.print(os_getTime());
  Serial.print(":␣");
  switch (ev) {
    case EV_SCAN_TIMEOUT:
      Serial.println(F("EV_SCAN_TIMEOUT"));
      break;
    case EV_BEACON_FOUND:
      Serial.println(F("EV_BEACON_FOUND"));
      break;
    case EV_BEACON_MISSED:
      Serial.println(F("EV_BEACON_MISSED"));
      break;
    case EV_BEACON_TRACKED:
      Serial.println(F("EV_BEACON_TRACKED"));
      break;
    case EV_JOINING:
      Serial.println(F("EV_JOINING"));
      break;
    case EV_JOINED:
      Serial.println(F("EV_JOINED"));


      LMIC_setLinkCheckMode(0);
      break;
    case EV_RFU1:
      Serial.println(F("EV_RFU1"));
      break;
    case EV_JOIN_FAILED:
      Serial.println(F("EV_JOIN_FAILED"));
      break;
    case EV_REJOIN_FAILED:
      Serial.println(F("EV_REJOIN_FAILED"));
      break;
      break;
    case EV_TXCOMPLETE:
      Serial.println(F("EV_TXCOMPLETE␣(includes␣waiting␣for␣RX␣windows)"));
      if (LMIC.txrxFlags & TXRX_ACK)
        Serial.println(F("Received␣ack"));
```

```
      if (LMIC.dataLen) {
        Serial.println(F("Received␣"));
        Serial.println(LMIC.dataLen);
        Serial.println(F("␣bytes␣of␣payload"));
      }
      // Scheduling next transmission
      os_setTimedCallback(&sendjob, os_getTime() + sec2osticks(TX_INTERVAL), do
      break;
    case EV_LOST_TSYNC:
      Serial.println(F("EV_LOST_TSYNC"));
      break;
    case EV_RESET:
      Serial.println(F("EV_RESET"));
      break;
    case EV_RXCOMPLETE:
      // data received in ping slot
      Serial.println(F("EV_RXCOMPLETE"));
      break;
    case EV_LINK_DEAD:
      Serial.println(F("EV_LINK_DEAD"));
      break;
    case EV_LINK_ALIVE:
      Serial.println(F("EV_LINK_ALIVE"));
      break;
    default:
      Serial.println(F("Unknown␣event"));
      break;
  }
}

void do_send(osjob_t* j) {

  struct sensorValues ss = ecread();
  float structec = ss.ec;
  float structph = ss.ph;
  byte payload1[4];
  uint32_t ecValue = structec*100;
  uint32_t phValue = structph*100;
  payload1[0] =highByte(ecValue);
  payload1[1] =lowByte(ecValue);
  payload1[2] =highByte(phValue);
  payload1[3] =lowByte(phValue);


  if (LMIC.opmode & OP_TXRXPEND) {
    Serial.println(F("OP_TXRXPEND,␣not␣sending"));
  } else {
   LMIC_setTxData2(1, payload1, sizeof(payload1), 0); //paload1

    Serial.println(F("Packet␣queued"));
```

```
    Serial.println(LMIC.freq);
  }
  //Next transmission after TX_COMPLETE
}

void setup() {
  Serial.begin(115200);
  Serial.println(F("Starting"));
  ph.begin();
  ec.begin();

  // LMIC init
  os_init();
  // Reset the MAC state. Session and pending data transfers will be discarded.
  LMIC_reset();
  LMIC_setClockError(MAX_CLOCK_ERROR * 1 / 100);
  LMIC_disableChannel(1);
  LMIC_disableChannel(2);
  printotaainformation();

  // Start job (sending automatically starts OTAA too)
  do_send(&sendjob);
}
//print OTAA info
void printotaainformation(void)
{
  unsigned char i;
  unsigned char chartemp;
  unsigned char messagelength;

  Serial.println(F("OTAA␣mode␣to␣join␣network"));
  Serial.print("DevEui:␣");
  for (i = 0; i <= 7; i++)
  {
    chartemp = pgm_read_word_near(DEVEUI+7-i);
    covertandprint((chartemp >> 4) & 0xf);
    covertandprint(chartemp & 0xf);
  }
  Serial.println("");
  Serial.print("AppEui:␣");
  for (i = 0; i <=7; i++)
  {
    chartemp = pgm_read_word_near(APPEUI+7-i);
    covertandprint((chartemp >> 4) & 0xf);
    covertandprint(chartemp & 0xf);
  }

  Serial.println("");
  Serial.print("AppKey:␣");
  //memcpy_P(buftemp, APPKEY, 16);
```

```
  for (i = 0; i <= 15; i++)
  {
    chartemp = pgm_read_word_near(APPKEY+i);
    //Serial.print(buftemp[i],HEX);
    covertandprint((chartemp >> 4) & 0xf);
    covertandprint(chartemp & 0xf);
  }
  Serial.println("");

 /* Serial.println("In this SW will send following information to network(uplin
 // messagelength = strlen(mydata);
  //for (i = 0; i <= messagelength-1; i++)
  //{
   // Serial.print(char(mydata[i]));
  //}
  Serial.print((char*)mydata);
  Serial.println("");
  Serial.println("mydata thing"); // add one new line*/
}

void covertandprint(unsigned char value)
{
  switch (value)
  {
    case 0  : Serial.print("0"); break;
    case 1  : Serial.print("1"); break;
    case 2  : Serial.print("2"); break;
    case 3  : Serial.print("3"); break;
    case 4  : Serial.print("4"); break;
    case 5  : Serial.print("5"); break;
    case 6  : Serial.print("6"); break;
    case 7  : Serial.print("7"); break;
    case 8  : Serial.print("8"); break;
    case 9  : Serial.print("9"); break;
    case 10  : Serial.print("A"); break;
    case 11  : Serial.print("B"); break;
    case 12  : Serial.print("C"); break;
    case 13  : Serial.print("D"); break;
    case 14  : Serial.print("E"); break;
    case 15 :  Serial.print("F"); break;
    default :
      Serial.print("?");   break;
  }
}

//Read sensor Values
struct sensorValues ecread(){

  float ecValueRead;
  struct sensorValues val;
```

```
    char cmd[10];
   static unsigned long timepoint = millis();
    if(millis()-timepoint>1000U)  //time interval: 1s
    {
      timepoint = millis();
       voltagePH = analogRead(PH_PIN)/1024.0*5000;
// read the ph voltage
       phValue    = ph.readPH(voltagePH,temperature);
// convert voltage to pH with temperature compensation
       /*Serial.print("pH:");
       Serial.print(phValue,2);*/

      voltageEC = analogRead(EC_PIN)/1024.0*5000;  // read the voltage
      ecValueRead =  ec.readEC(voltageEC,temperature);  // convert voltage to E
      /*.print("temperature:");
      Serial.print(temperature,1);
      Serial.print("^C  EC:");
      Serial.print(ecValueRead,2);
      Serial.println("ms/cm");*/
      val.ec = 0.2;
      val.ph = 3.14;

     // val.ec = ecValueRead;
     // val.ph = phValue-7;
      Serial.println("transmitting␣now");
      delay(300000);
      //delay(3000);
      Serial.println("transmitting␣after␣delay");
      return val;

      //return ecValueRead;
    }

    if(readSerial(cmd)){
       strupr(cmd);
       if(strstr(cmd,"PH")){
         ph.calibration(voltagePH,temperature,cmd);
//PH calibration process by Serail CMD
        }
        if(strstr(cmd,"EC")){
         ec.calibration(voltageEC,temperature,cmd);
//EC calibration process by Serail CMD
        }
    }
    //ec.calibration(voltageEC,temperature);  // calibration process by Serail
}

int i = 0;
bool readSerial(char result[]){
    while(Serial.available() > 0){
```

```
        char inChar = Serial.read();
        if(inChar == '\n'){
            result[i] = '\0';
            Serial.flush();
            i=0;
            return true;
        }
        if(inChar != '\r'){
            result[i] = inChar;
            i++;
        }
        delay(1);
    }
    return false;
}


void loop() {
  os_runloop_once();

}
```

A.2 Custom decode function in LoRa App Server

Custom JavaScript decode function was used in the LoRa App Server

```
function Decode(fPort, bytes) {
    var ec = (bytes[0] << 8) | bytes[1];
    var ph = (bytes[2] << 8) | bytes[3];

    var dataout = {
        "sensorvalues": {
            'ec': ec / 100,
            'ph': ph / 100
        },
    };
    return dataout;
}
```

B RAK811 trials

Rak811 lora node issues and action taken trying to fix it.