Smart Farming For Emerging Economies

Stephen Simei Kimogol

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Summary

summary

Acknowledgement

Acknowledgement part

Contents

3. Technologies and related work

as enabler

low cost communication?

Applicability for use case

“eval”

2.8 Applicability for use case
2.8.1 Selection of wireless communication technology
2.8.2 Cloud vs edge
2.8.3 Deep-dive into selected technologies
- LoRa
- Platform/Front-End (?) - low cost, low bandwidth demand, local decision making

= here “evaluation” and reasoning for your decision

4.3 From data collection to user empowerment
Discussion:
- type of decision making
- Cloud (when? what? knowledge… sharing)
- user empowerment (information spots)

4.2.3.5 to 4.3

Focus (and what not: semantic knowledge base, cloud, monitoring of equipment)
- Need to do/evaluate
- Nice to do (not system critical), but will enhance the solution

a) enhancements of the current solution
b) additional aspects to be considered (helicopter perspective)

Numbers & Facts
- starting point: challenge
- what have you achieved
- what are the lessons learned

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 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 [14]. 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[15].

Figure 1: Sustainable Development Goals.

2.1 Agriculture and Technology in developing countries-Setting the Scene

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 [16]. The effects of climate change affects food production and it is felt mostly by the

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

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 the 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 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 [17]. Yet, according to the UN Food and Agriculture Organization (FAO), 821 million (one person out of every nine in the world) are currently undernourished [18] and it is estimated that the food production in Africa has to increase by 260 % by 2050 to provide food for the expected population [19]. The demand to increase in food production to feed the growing population will have 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 foot print (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 [16]. In addition, 40 % of the rural population live in river basin areas that are classified as water scarce [20]. Water scarcity in the face of climate change will affect most the 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 [21]. 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[22].

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 social-economic factors affect the adoption of new technologies [23, 24]. 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 important factor in the adoption of technology [25] and in many cases even the existing knowledge and technologies have not reached farmers in developing countries [26].

2.1.2.2 Infrastructure Adaption 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 adaption 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 [27]. However, according to 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 [28]. 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 [29]. 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 [30]. Several mobile service 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 [31].

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 [27]. 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 concept all revolve around modernization and use technology in agriculture, they have some difference.

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" [32]. 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 [33]. 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 [34]

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 accurtely identifying variations and relating spatial data to management activities [35].

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 [36]. It overlaps with technologies like precision farming and management information systems that have been derived from farm management information systems (FMIS) [36]. 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 emphasizes is on the use of information and communication technology in the cyber-physical farm management cycle [37]. The advancement of nanotechnology in the last decade enable production of small and inexpensive sensors [6]. Moreover, cloud computing and internet of things will enhance the development of smart farming [1].

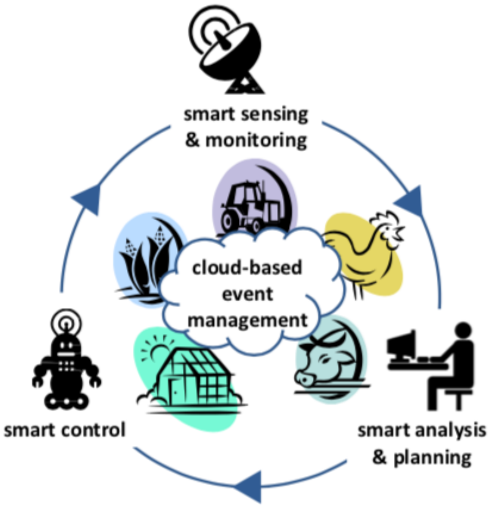


Figure 4: An ideal cycle of smart farming (Source: [3]).

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 or 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 profuction thus reduction of the ecological footprint [4]. cloud based event management, remote access, different stakeholders, use of historical data. The integration of information and communication technology into farming management systems and availability of low-cost sensors can be used in developing countries to enhance efficient food production. This will create an ecosystem that will enable data collection, analysis and intelligence sharing between farmers and other stakeholders. In developing countries, farmers rely on agricultural extension officers on issues related to farming and this are 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. In this thesis, we consider smart farming as a cycle that involves collection of data by sensors, transmission to data to cloud and edge servers and generation of actionable information for farmers and extension officers. As Walter et al. points out that farming in digital era can only be considered as smart if it there is a continuous interaction between technology, different farming practises, networking and institutions. 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 also poor governance. Holistic approach is needed for smart farming to be achieved.

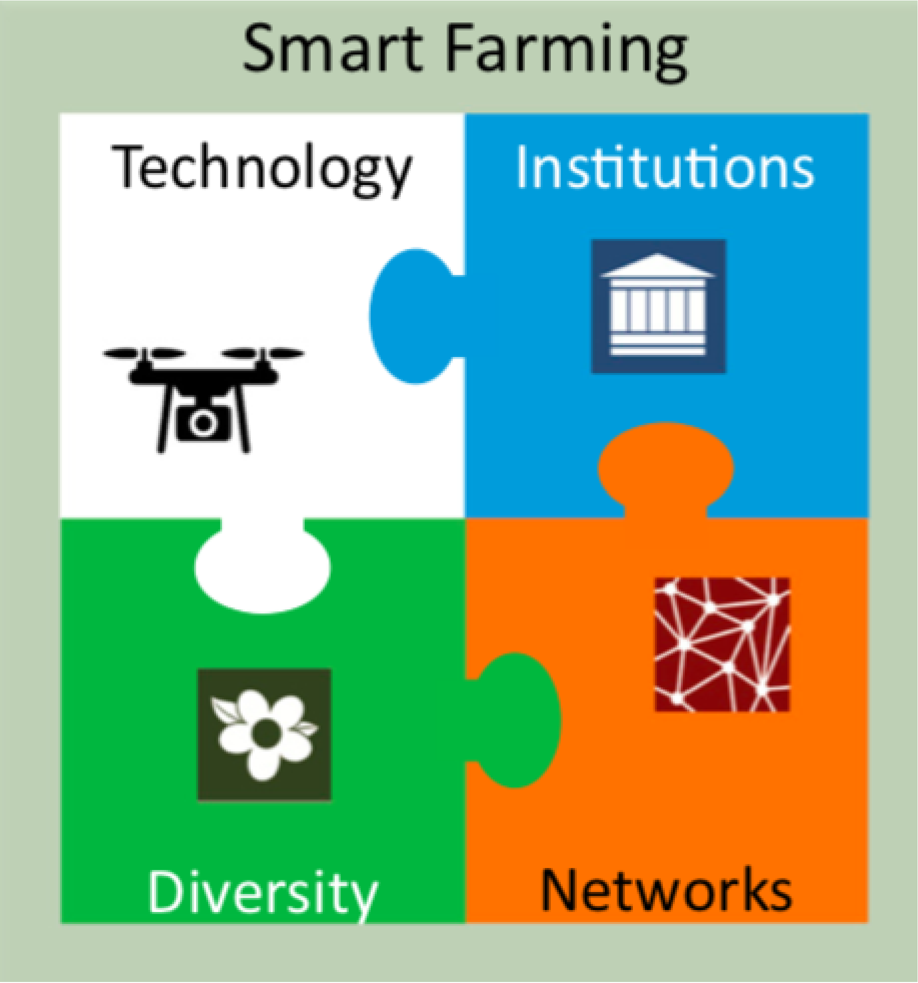


Figure 5: Smart farming in digital era source [4]

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 of 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 [38]. 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" [38].

Hydroponics farming is classified as either open (nutrient solution is not reused) or closed (where solution is recovered, replenished and recycled)[39]. 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 [40]. Hydroponics, if adopted can address challenges faced by small holders farmers in developing countries like scarcity of water, limited arable land, labour cost and reduced long growth periods [41]. 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 [38] and for 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 same amount of fodder [41]. The major limitation of adoption of in hydroponics is the initial capital required [40] especially for the small holder farmers in developing countries. However, the cost can be reduced by low cost devices/construction material [41].

Hydroponic farming is relatively new practice in most of the countries in developing countries with smallholder farmers barely having knowledge about it. Most smallholder farmers practice mix 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 in order fo the farm to be economically viable. IoT could solve this problem. Sensors can collect data of the ingredients of the solutions and this can help farmer make informed decisions at the right time. Disease outbreak or nutrient imbalance can easily be noticed and necessary action taken at the right time.

2.4 Requirements of hyrdoponic 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 this 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 continuosly receive power from the sensors should be power frugal especially in the receiving mode [29].

2.4.3 Cost-efficient communication

Internet connectivity is unavailable, intermittent, slow or costly in most of the developing countries. Connectivity is essential part of the smart farming. In most IoT applications where connectivity is given, devices connect to internet through Internet Protocol (IP) and send data direclty 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 unlincensed bands and non-IP network that connect to internet through a gateway in the first layer and in 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 [42]. Also a cost-efficient communication is required for sending data to the cloud. Since bandwidth is limited, data mitigation techniques [35] are required in such areas to reduce 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 the interoperability between devices. They are many commercial and open source software for IoT with respective strengths and weaknesses. Cost is a limiting factor when considering proprietery software. Open software enables the reasearchers to replicate the design and customize it to meet specific needs of the context [29]. 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 adjustment to the system. Cloud computing offers limitless on-demand storage and computation capacity. A key problem with 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 [43, 29].

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

Give that most small scale farmers are not tech savvy, a system that is easy to operate without continous 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 access to information about smart farming.

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

2.5 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 [44] 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 [45]. Internet of Things is a combination of technological push and human pull for connectivity between the immediate and wider environment and it emerged from development in identification technologies e.g. RFID and bar codes and from development of networked sensors and actuators [46].

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 associate with users and their environments” [47].

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” [46].

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[48]. 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 [49], hydroponic greenhouse [50], monitoring and control of irrigation system in rural communities [51], smart irrigation in tunnel farming [52], smart animal farm [53].

A generic three-layer IoT architecture consisting of sensing, transport and application layer is depicted in Figure 6 and this can also be extended to five layers with inclusion of network and processing layers between the second and third layer [5, 42]

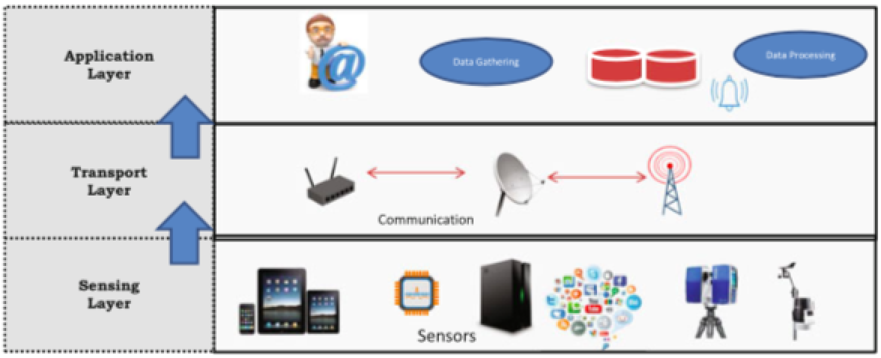


Figure 6: IoT based agricultural framework (Source: [5]).

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[6]. Figure 7 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.

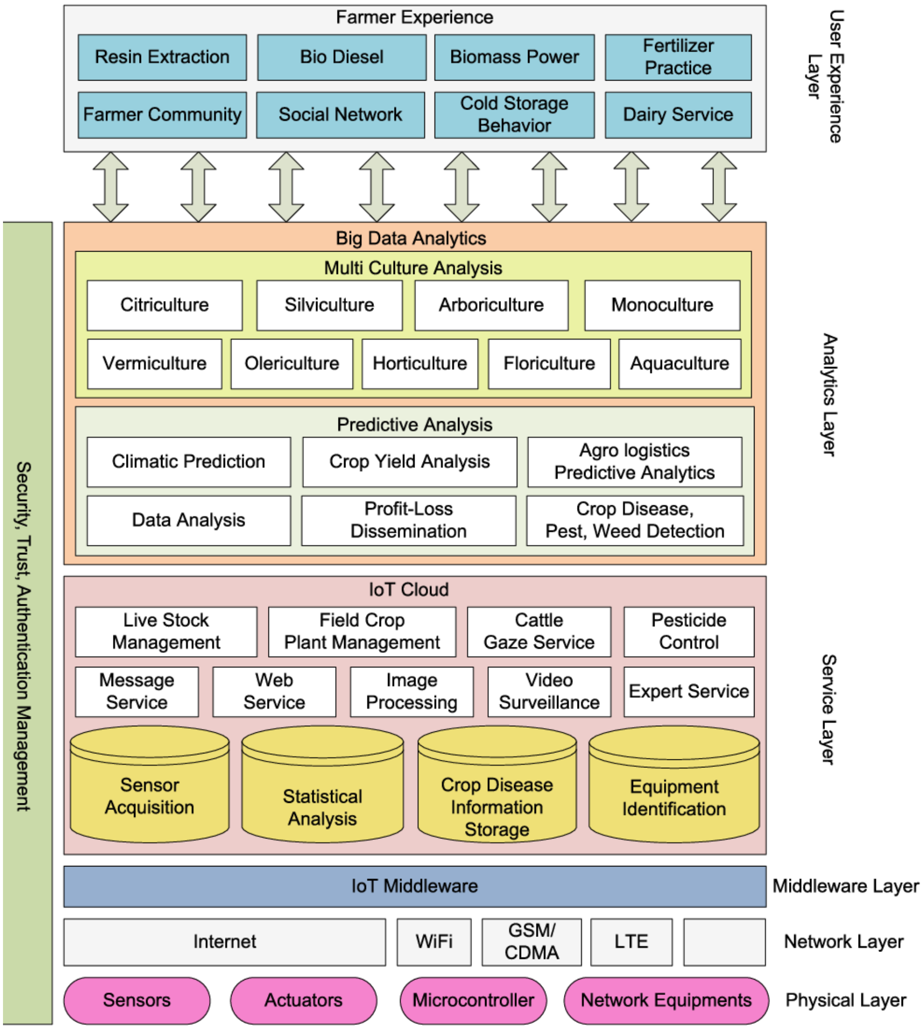


Figure 7: IoT based agricultural framework (Source: [6]).

Even though 20 years since IoT was first introduced, there is no a 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.

2.6 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 [7]. Figure 8 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 [7]), Websockets and HTTP (designed for WEB and not optimal for IoT as it is heavy weight protocol [54]). In this section we will only consider MQTT and CoAP, which are the most common protocols in IoT systems.

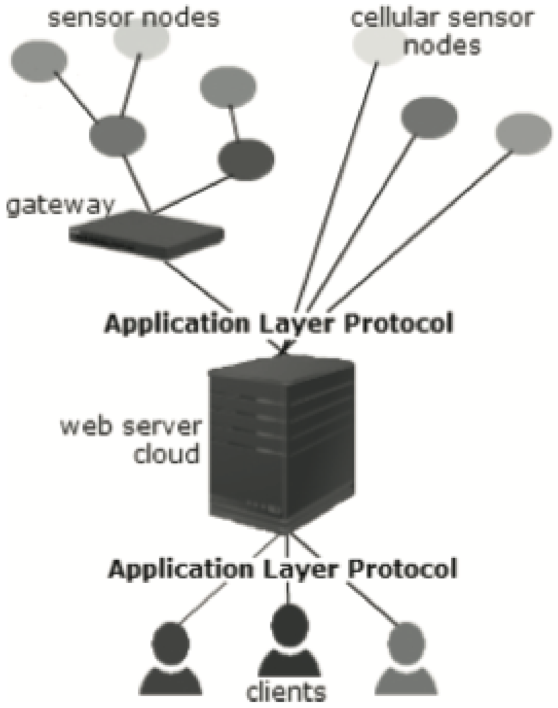
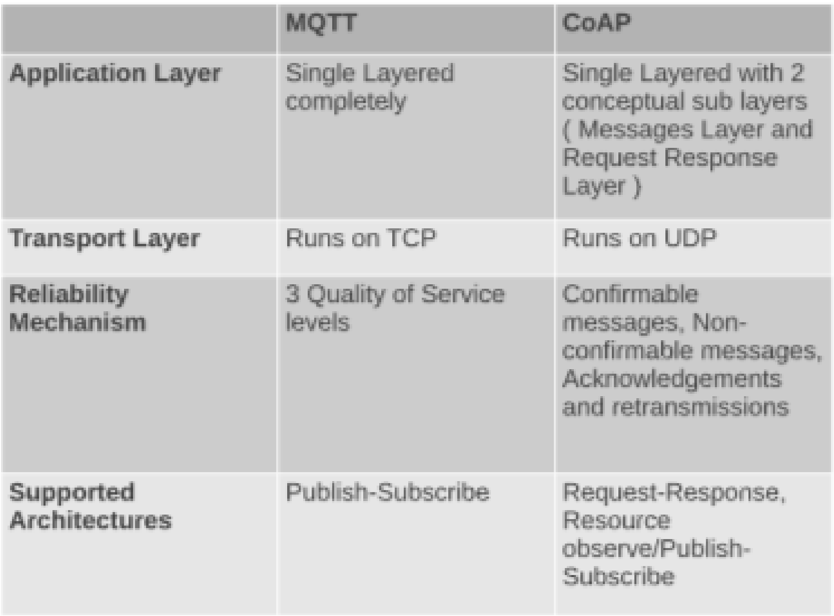


Figure 8: Application layer protocols source ([7]).

2.6.1 CoAP

The Constrained Application Protocol (CoAP) was designed by Internet Engineering Task Force (IETF) to address the requirements of resource constrained devices[7]. It uses request/response and resource/observe (variant of publish/subscribe) architecturemaking it interoperable with HTTP [54]. 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) [7]. Authors in [7] 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 9: Difference between CoAP and MQTT. source ([8]).

2.6.2 MQTT

Message Queuing Telemetry Transport Protocol is a lightweight publish/subscribe protocol that uses topics as the addresses where messages are published to and subscribed to by the clients [54]. Topics are contained in a broker [7] - 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 [54].

2.6.3 Suitability in smart farming

Naik did an in-dpeth comparative study of four (HTTP, AMQP, MQTT and CoAP) application layer protocols have been done[54]. According to the author [54] 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 [8] 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).

2.7 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 [55]. 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 a 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.

2.7.1 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 [55]. These technologies are from different vendors and one of the biggest challenges is interoperability. As show in fig 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 [56].

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.

2.7.1.1 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 [56]. 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 [56].

2.7.1.2 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 [56]. 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 [57].

2.7.1.3 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 [56]. 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 [56]. (range and throughput)

2.7.1.4 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 [58]. 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 lifetime of battery powered devices [56]. In agricultural applications, WiFi enables connection of multiple types of devices through heterogeneous architectures over an ad-hoc network [57].

2.7.2 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 [59]. 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 [56]. According to [55] 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 [55, 59]. 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.

2.7.2.1 Long Range Radio (LoRa) LoRa is a spread spectrum modulation technique developed by Semtec [2], which is based on chirp spread spectrum (CSS) technology [60]. 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 [55]. LoRa is a proprietary product and one of the mostly used communication protocol built above the LoRa is LoRaWAN. LoRaWAN is an open communication protocol and network system architecture [9] 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 [60]. The end devices communicate with gateway using LoRa and from gateway packets are forwarded to network server through backhaul interfaces like 3G or Ethernet [35].

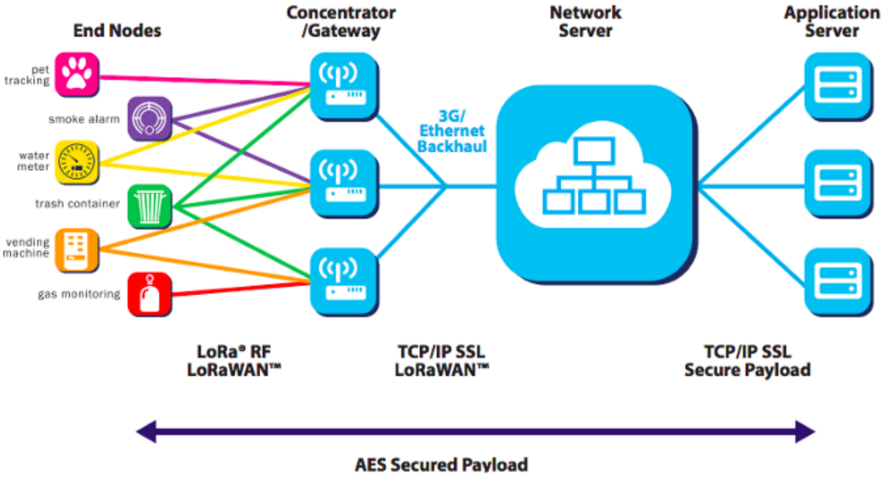


Figure 10: LoRaWAN network architecture (Source: [9]).

2.7.2.2 SigFox SigFox is based on ultra-narrowband technology (UNB) and it uses 915MHz ISM band (United States) and the 868MHz (Europe) [58]. It was first released in 2009 and IoT service provider as its business model thus

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

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

no documentation is publically available [55]. The communication range is upto 30 km and this is achieved by transmiting at very low data rates (up to 100bps) [58].

2.7.2.3 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 [55]. According to [59] Ingenu-RPMA achieves higher throughput and capacity compared to other technologies that operate on sub-GHz band due to its flexibility in use of spectrum across different regions. It has a typical uplink data rate of 50 kbps [11].

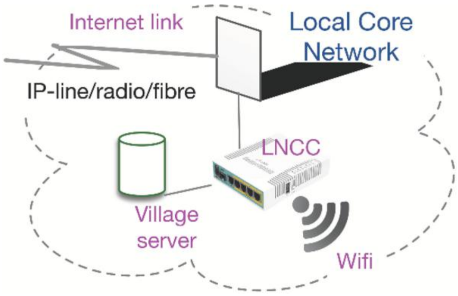
2.7.3 Cellular Network

Cellular network is a 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 [61]. 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 [61, 55]. To address these shortcomings, revamping of second generation/ Global System for Mobile Communications (2G/ GSM) [55] 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 [59]. Fifth generation (5G) standards have been released in 2018 and the earliest deployment are expected in 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 [62].

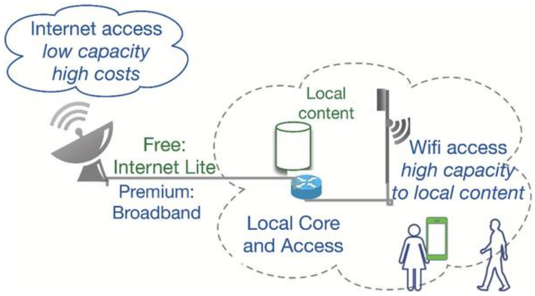
2.7.4 Connectivity with Internet Lite

Internet Lite is a concept by Basic Internet Foundation aimed at addressing 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 goals 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. 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 [63, 64]. Sudhir and Noll have defined InfoInternet standard that is aimed at making access to information free (text, pictures) [64]. 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])

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 [65]. In the IoT sector, alternative networks have also emarged -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 buld their own applications[66].

2.7.5 Feasibility

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 strength 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.

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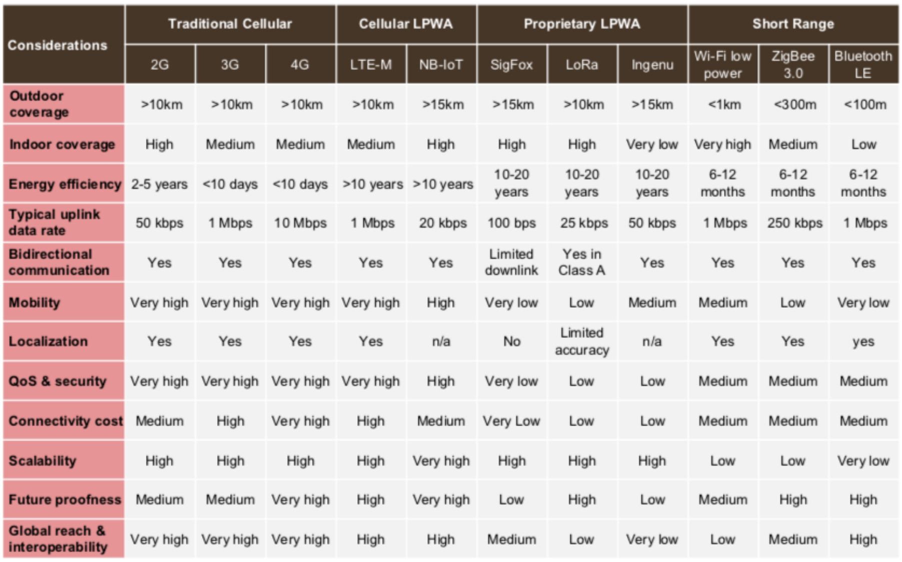
[4] `https://www.thethingsnetwork.org`



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 range. This will require high node density to cover a small area. As such, they are not suitable to such scenario. A comparative study of LWPAN technologies is given [13, 67]. Mekki et al. compare large-scale deployment of LoRa, SigFox and NB-IoT [13]. 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 **??** 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 [68]. The proliferation of low cost hardware, availability of open software and initiatives like Sparkfun[5] and Adafruit [6] has led to the third wave 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 [69].

Even though LoRa is proprietary product, its upper layer, LoRaWAN is

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[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 1: A cost comparison of LoRa, SigFox and NB-IoT (Source: [13]).

open, operator and subscription free making it simple to deploy and manage infrastructure whereas in SigFox, user purchase end devices and subsription for the devices from the network operators [67]. In terms of cost, openness and availability SigFox is currently not feasible in most developing countries.

LWPANs generally offer longer range and a limited throughput. LoRa offers long range and low bandwidth and it fills the gap the gap between cellular and short-range technologies as depicted in figure 13. This is achieved through modification of four key parameters in the Chirp Spread Spectrum modulation: channel, bandwidth,spreading factor (SF) and transmission power [70]. The data rate is controlled by spread factor which can between SF6 and SF12. With a low spreading factor, a high data rate is achieved but a higher singal-to-noise ratio(SNR) is required and for SF12 low SNR is required to achieve low data rates for the same transmitted power [70]. 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 signals down to -136 dBm [71]. The LoRaWAN network server handles this by optimizing data rates using adaptive data rates(ADR) for the static end devices [72]. 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.

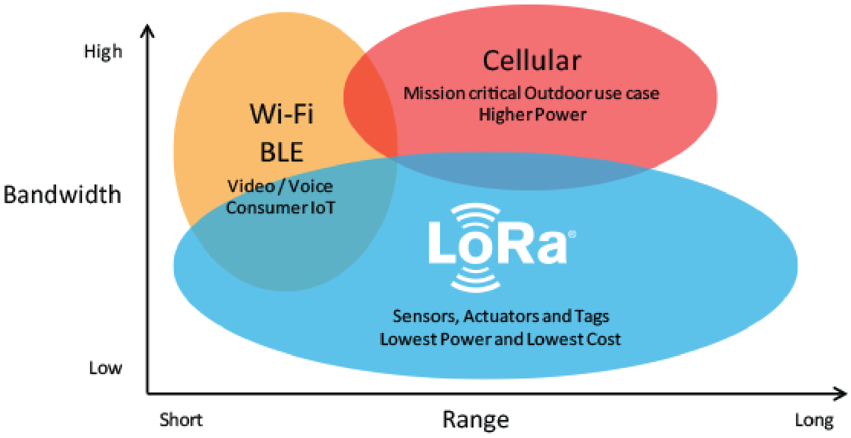

Figure 13: A range comparison of short range technologies, cellular and LoRa.

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 14): class A(end device transimission followed by two short download windows), B(scheduled receive slots through synchronization by gateway beacon), and C (continuously listening: open windows to receive data) [9]. According to a predictive model by Liando et al. on the lifetime of end nodes, battery efficiency and longevity can 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[70]. 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.

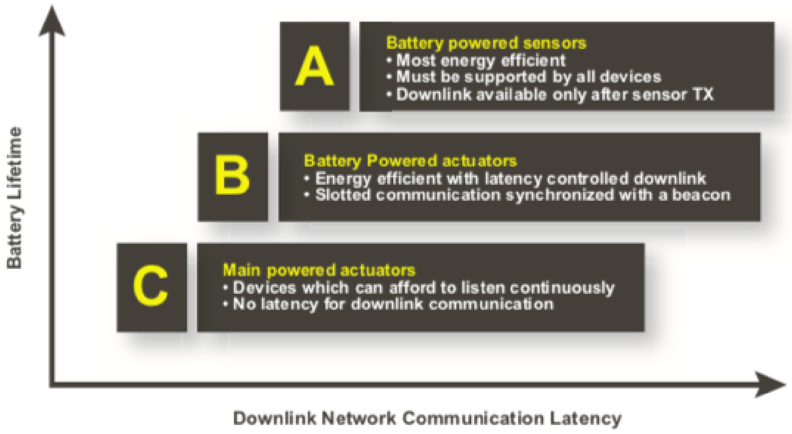

Figure 14: LoRa device classes and power consumption [9].

Cellular is widely available in most of developing countries and the technology is mature, secure with high quality of service. The disadvantage is that devices need simcards 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. 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.

Table below to be edited...

Wireless technology	Cost	Power consumption	Range	Availability
Bluetooth	-	0	-	+
ZigBee	0	+	-	-
6LoWPAN	0	+	-	-
Wi-Fi	0	0	-	0
LoRa	+	++	++	0
SigFox	-	++	++	-
Ingenu-RPMA	+	0	+	-
Cellular	-	-	++	++

From this brief analysis, we consider LoRa as the best 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 in LoRa network will act as the edge and do data analysis and it can also connect to the WiFi to transmit data to local content server. Solution suggested in this thesis can be integrated into Basic Internet solution making use of local storage and access. Furthermore, we will use low cost hardware and DIY approach. As such, instructions on how to set-up the system and information related to the system will be stored at the local server. 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.

2.8 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 [73]. 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 re- configured 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" [74].

The National Institute of Standards and Technology (NIST) of 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 " [75].

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 [76]. In the agricultural sector, the usage of cloud computing has grown due to usage of information, communication 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 [37]. This also enables 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 [77]. Cisco Internet Business Solutions Group predicted that there would be 50 billion devices connected to the Internet by 2020 [44]. 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 [78].

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 " [79]. 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[80].

Edge computing sits at the peak of Gartners Hype Cycle for Cloud Computing, 2018 [12] and disillusionment and false starts are to be expected before standardization and wide adoption. However, it has a potential to complement and decentralize the current centralized cloud architecture and legacy data centres [81].

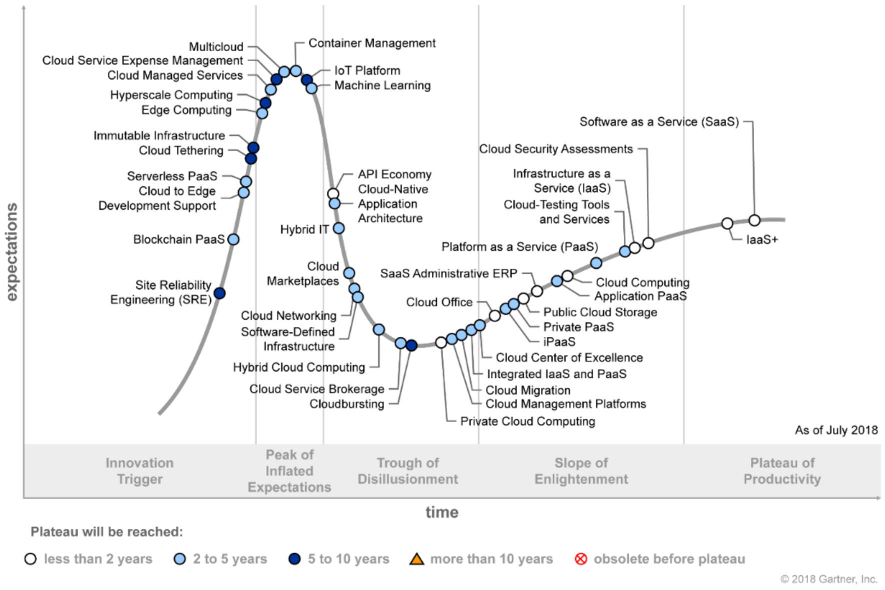

Figure 15: Gartner's Hype Cycle (Source: [12]).

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 [82]. This new paradigm extends the cloud services and has the potential to address afforementioned 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 [50]. 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 need for communication with cloud [83]. 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 [78]. 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 [43] 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 edge by comparing data collected from faulty sensor to the nearby sensor [84].

So far we have disucssed how edge computing can reduce cost of communication 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 [76]. Such user centric design are important in smart farm as they put human in loop making them part of the decision making process relating to the farm [85]. Since smart farming is data driven and decisions are based on analysis made on this, socially aware system with human in control loop and local access to data will encourages to adapt of such technologies. Adaption of technological innovations is influenced by farmers perceptions on the effectiveness and accrued benefits [86]. From this, the perception that farmers get from being in control due to benefits offered computation done at the edge (physically and logically close) 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. As such we intend to define the governance policies related to transmission of data to cloud and frequency of transmission. In addition simple analysis will be performed on the edge on the data received before notifications are sent to the farms (since it is logically and physically closed to the end users). 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 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[50]. 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 [87], 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[88]. Different wireless technologies are used in depending on the requirements of the agricultural applications scenario. In [89] 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[90]. Authors in [91] 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. [50]. 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[66]. The author argue that this is suitable for monitoring of environment and farmers in developing countries where network connectivity and cost are the key constrains 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 [68]. 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 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 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.

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[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. The system comprises of three layers:

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

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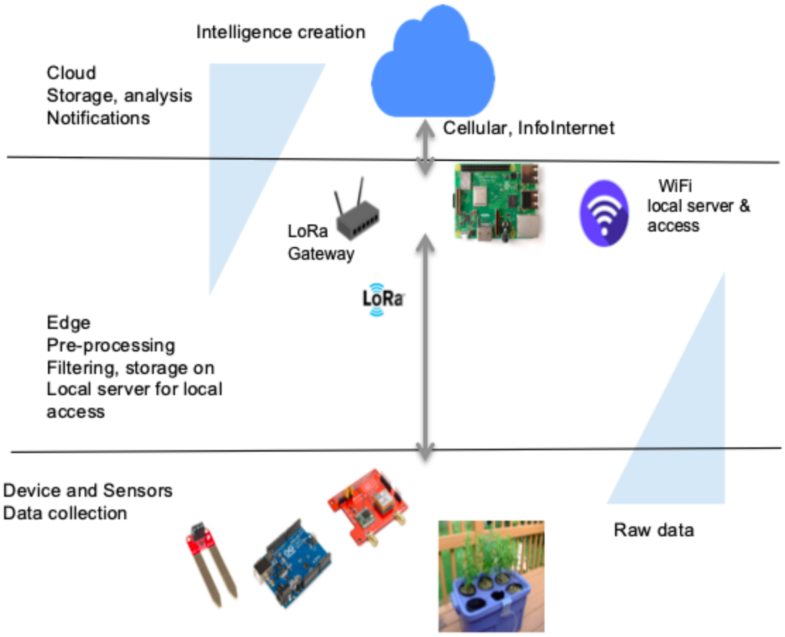


Figure 16: A three layer architecture

Figure 16 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 [79]. 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 harvesting of data and integration of communication and information to farm management system, but it also requires provision of and access to information on smart farming. To this end we have included 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. Figure 17 shows overview of the whole system.

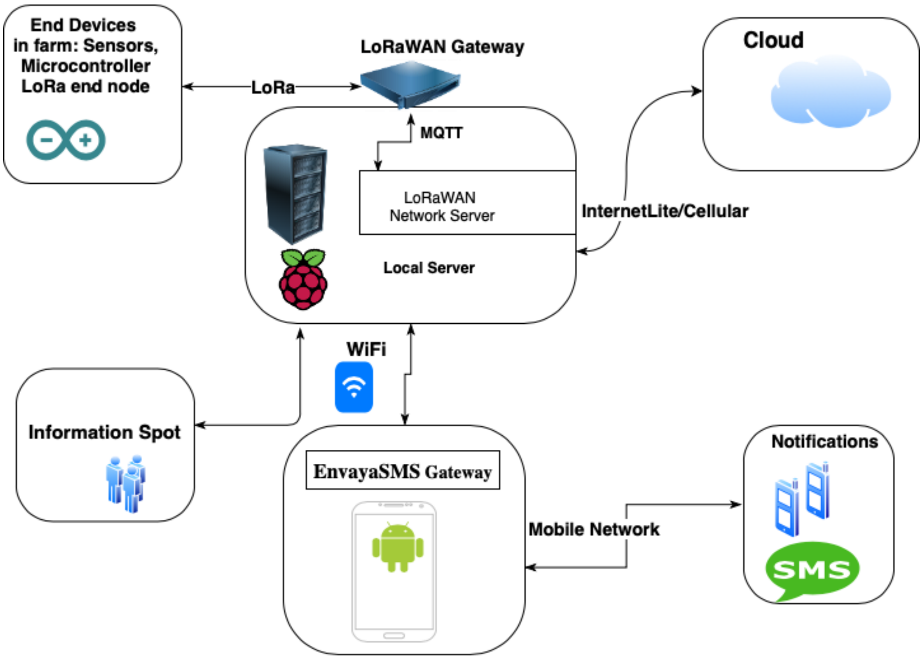
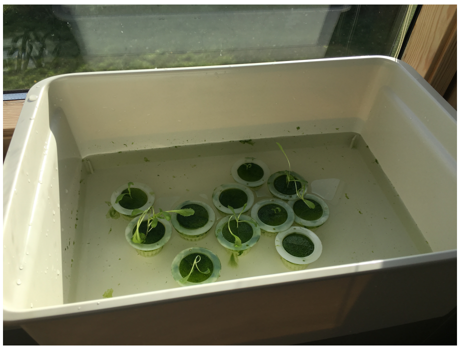


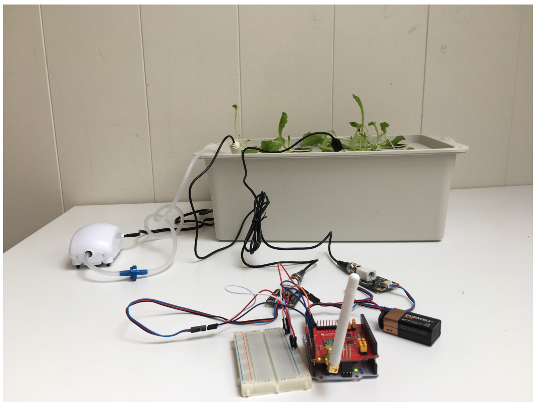
Figure 17: An overview of the system.

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. Because the nutrient doesn't 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 18: Hydroponic experiment set-up

4.2.1 End devices

The end devices comprise of:

- Sensors: pH, electrical conductivity (EC) and waterproof temperature sensors
- 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 sensor 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,

Device	Model	Power consumption
pH sensor	DFRobot Version 2	5V
EC sensor	DFRobot Version 2	5V

Table 2: Sensors used in the experiment set-up

which indicate the total dissolved parts which is measured in parts per million (ppm). However, this has disadvantage because TDS value is derived from EC readings and this can give different results depending on the conversion factors used [38]. 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.

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

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

Figure 19: EC, pH probes and standard buffer calibration solutions

4.2.1.2 Micro Controller Unit The current trend of IoT end devices development is open source/open hardware providing a baseline archicture enabling users to develop their own custom end devices [92]. However, this raises compatability problem as different sensors are developed by different vendors and might not be compatible with some boards. Ardunio microcontroller development boards have inbuilt analog to digital converter making it suitable for sensing analog signals and it offers ease of programming [93]. In addition, it is widely used in education and has a huge on-line community. They are a variety of sensors that 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 microcontroller 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

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

	Arduino
Specifications[11]	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 3: Arduino

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 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
Compatability	3.3V or 5.5v Arduino board

Table 4: LoRa

---

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

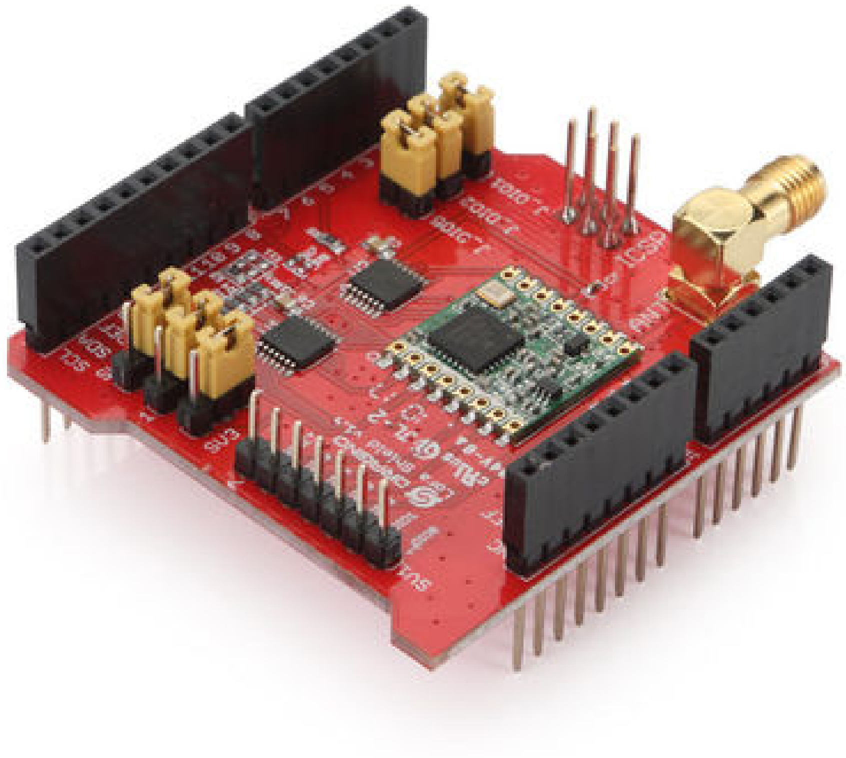

Figure 20: Dragino LoRa shield

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.The gateway receives RF packets and runs Semtech UDP protocol that forwards packets to the 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 is based SX1301 LoRa chip and it comes with LoRa, two LTE and GPS antennas.

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

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 5: RAK7249

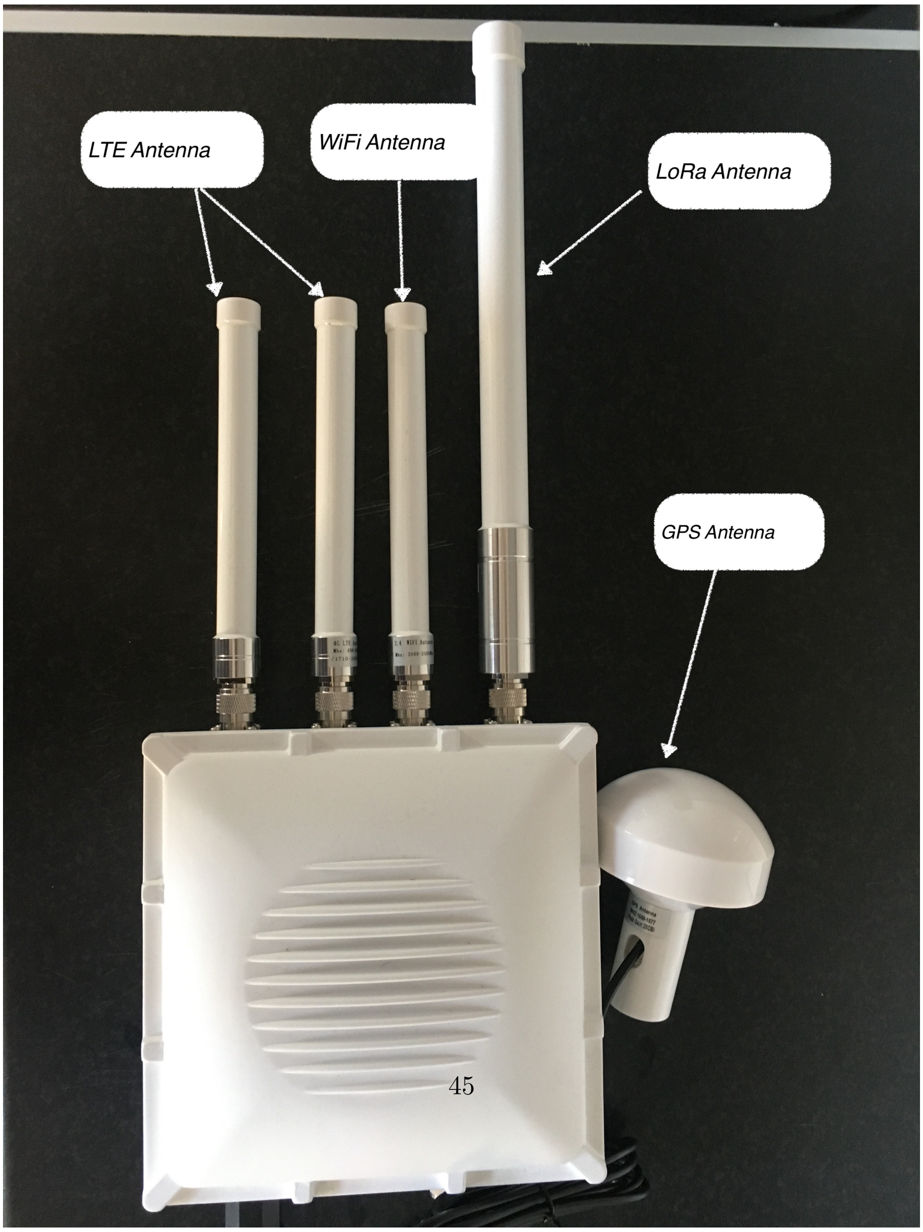
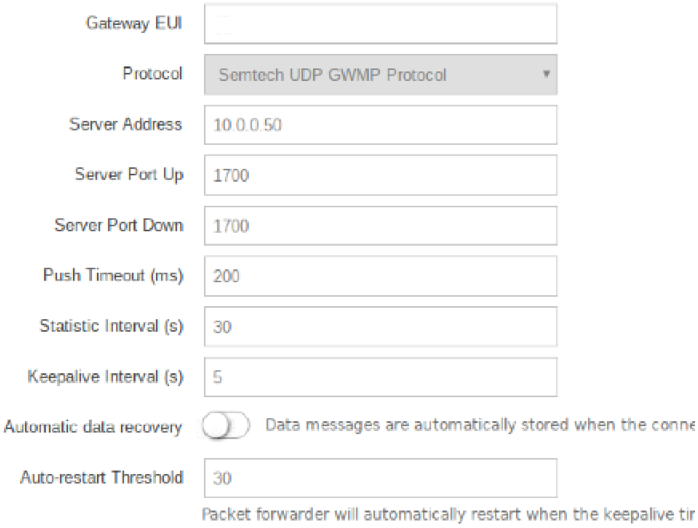


Figure 21: RAK7249 outdoor gateway

SemtechUDP



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 conne
Auto-restart Threshold	30 Packet forwarder will automatically restart when the keepalive tir

Figure 22: 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. In our implementation the local server hosts the LoRaWAN network server, LoRa App 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, agricultural 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 implemented flexibly. While a common alternative is the The Things Network(TTN) a crowd sourced

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

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

	Raspberry Pi Model 3B+
Specifications[16]	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 6: Raspberry Pi

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 23. 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.

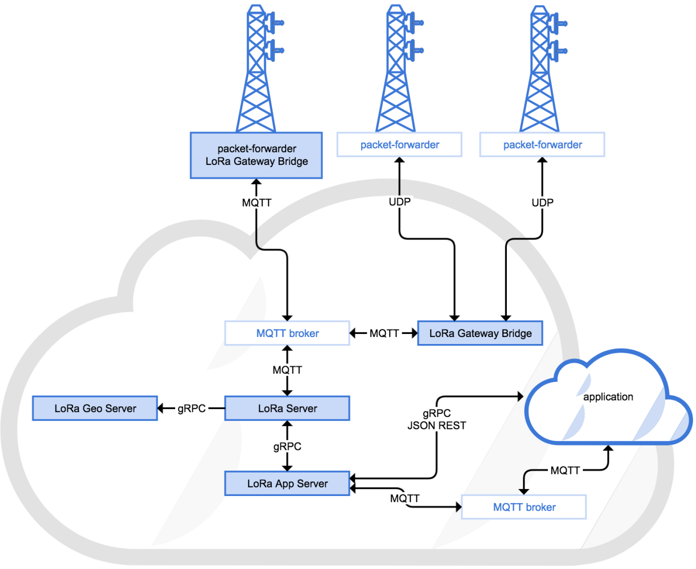


Figure 23: General LoRaWAN configuration architectures.

The configuration used in this thesis is shown in 24. 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. RAK7249, the gateway used here 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.

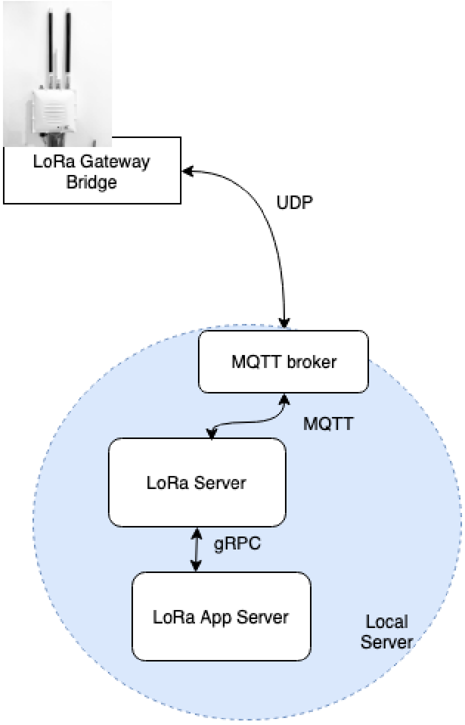
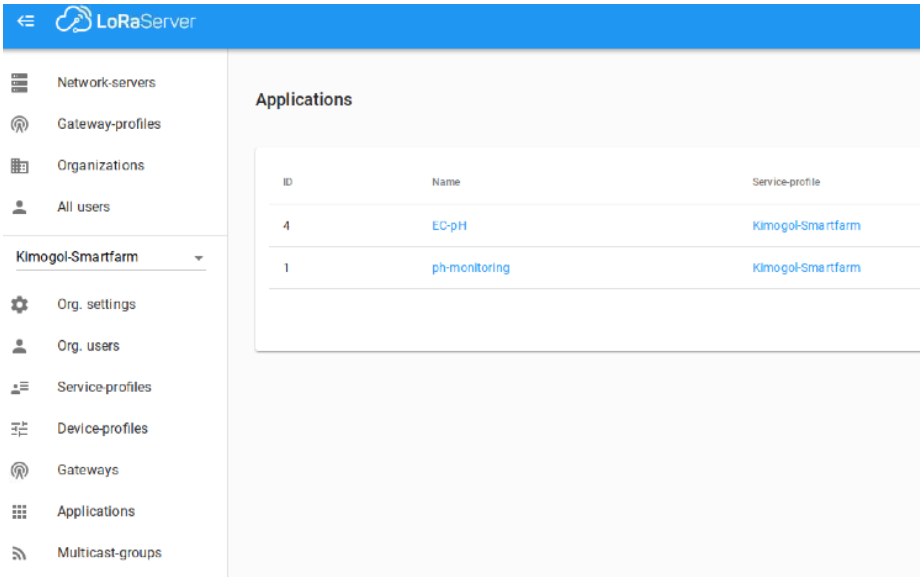


Figure 24: Gateway bridge, LoRa server and LoRa app server are installed in the same server instance.

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



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

Figure 25: 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.

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 7: Software

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 25. 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 specified 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 that is provided 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 the DFRobot product libraries. Before the transmission the sensor readings are coded by the following code. This values are then transmitted to the gateway every 30 minutes through the LoRa end node.

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 mosquito broker for application using MQTT can access them. In the LoRa App Server we used a custom JavaScript codec to decode the payload.

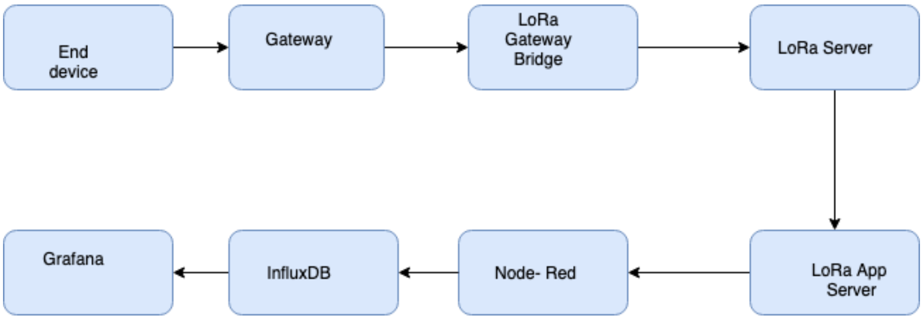


Figure 26: Data flow.

To integrate other functions to our system, we have used Node-Red, an open source web based platform. it is a flow-based program and can easily be used to connect things, applications and process the data they produce. It offers several node templates 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 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 the figure 27 is the MQTT client and it subscribes to this topic:

application/4/device/8a90dc387df11f42/rx

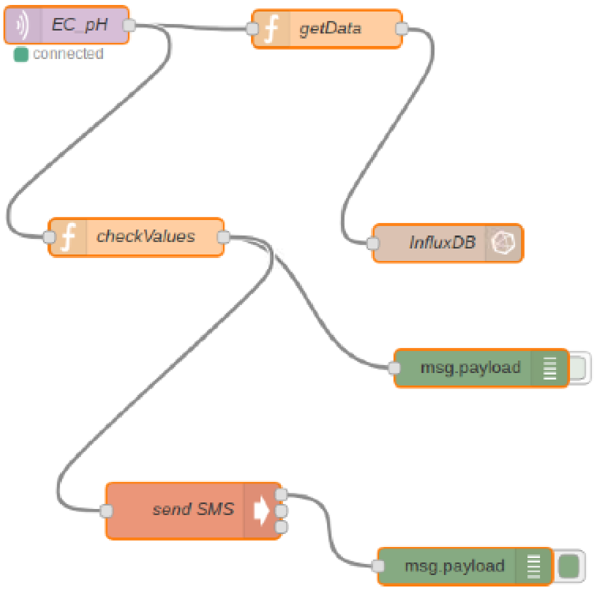


Figure 27: Node-red flow

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 continues flow of data. It suits the need of smart farming as data is stored with a specific time-stamp making data analysis easy. In Node-red we used a function node, named getData in 27 for data extraction and posting them to the InfluxDB. Since sensors will be deployed in different sections of the hydroponic farm, knowledge inferring 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 og 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 Andriod 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 [31]. Most farmers in rural areas use low-tech phones whose primary communication channels is SMS and voice. Even farmers with smart phones 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 [23] and frontlineSMS [24] have already been used in health sector to send reminders to enhance postnatal care appointments [94] and SMS based alert system to monitor pregnacy, maternal and child deaths [95]. In [96], EnvayaSMS [25], 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 aggregators 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 on figure 28. However, in this implementation the web server is hosted locally.

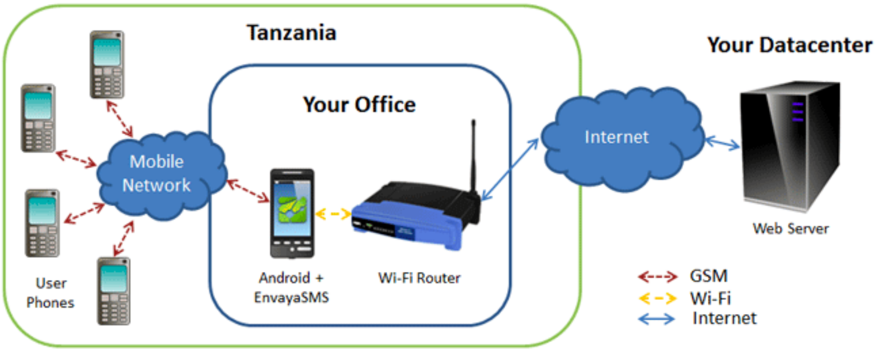


Figure 28: EnvayaSMS configuration (source)

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 [26] phone running on Android 8.1.0. The phone is connected to the same local WiFi as the Raspberry Pi. A php script from the EnvayaSMS github repository [27] was used to handle the server functions. This script was enabled to run at the

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[23] https://www.rapidsms.org

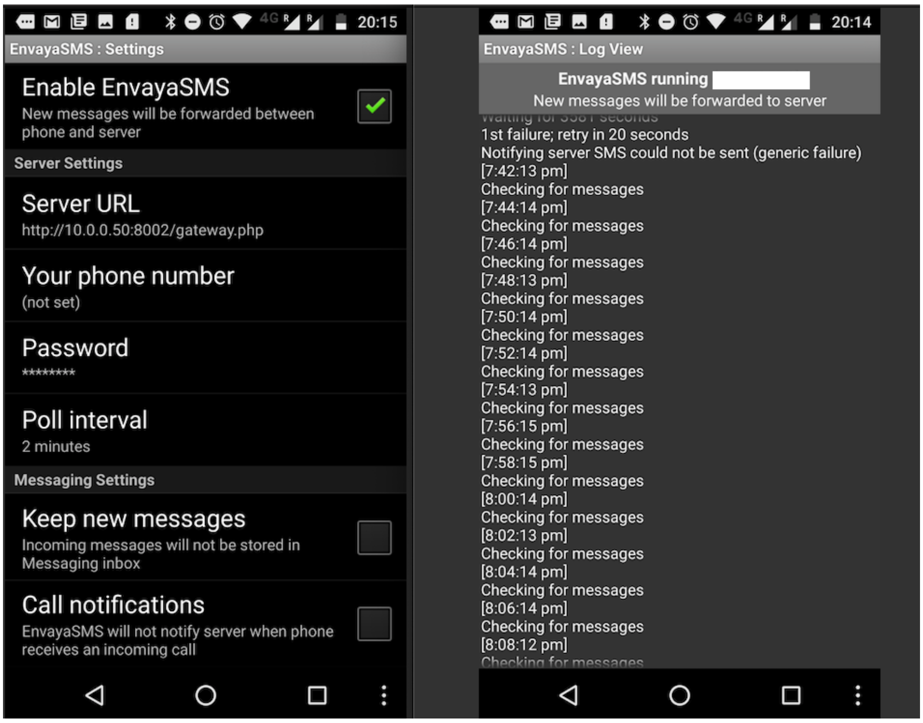
[24] https://www.frontlinesms.com

[25] http://sms.envaya.org

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

[27] http://github.com/youngj/EnvayaSMS

Raspberry Pi start-up. In the App settings the server URL was set to the path of the server script running on the Raspberry Pi. The app was configured to poll for new messages every 5 minutes. Figure 29 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 checkValues function as shown in 27. This function returns a message and phone number where notifications will be sent to. The exec node runs a php script that send a message and phone of the message recipient to the server.php script. EnvayaSMS uses HTTP POST request to poll for outgoing messages and send status of the sent messages to the server.



EnvayaSMS : Settings

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 : Log View

EnvayaSMS running
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 29: EnvayaSMS configuration and log view.

4.2.3.5 Information spots 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.

4.2.4 Cloud

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 because it is not latency sensitive. As such It can then be pushed to the cloud after predefined time. Batch transfers to the cloud can also be enabled in the local server.

- Data consolidation
- Remote access for agricultural extensional officers and other actors
- Run long term analytic on the data in the cloud.

4.3 Results and Discussion

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 check as frequent 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.

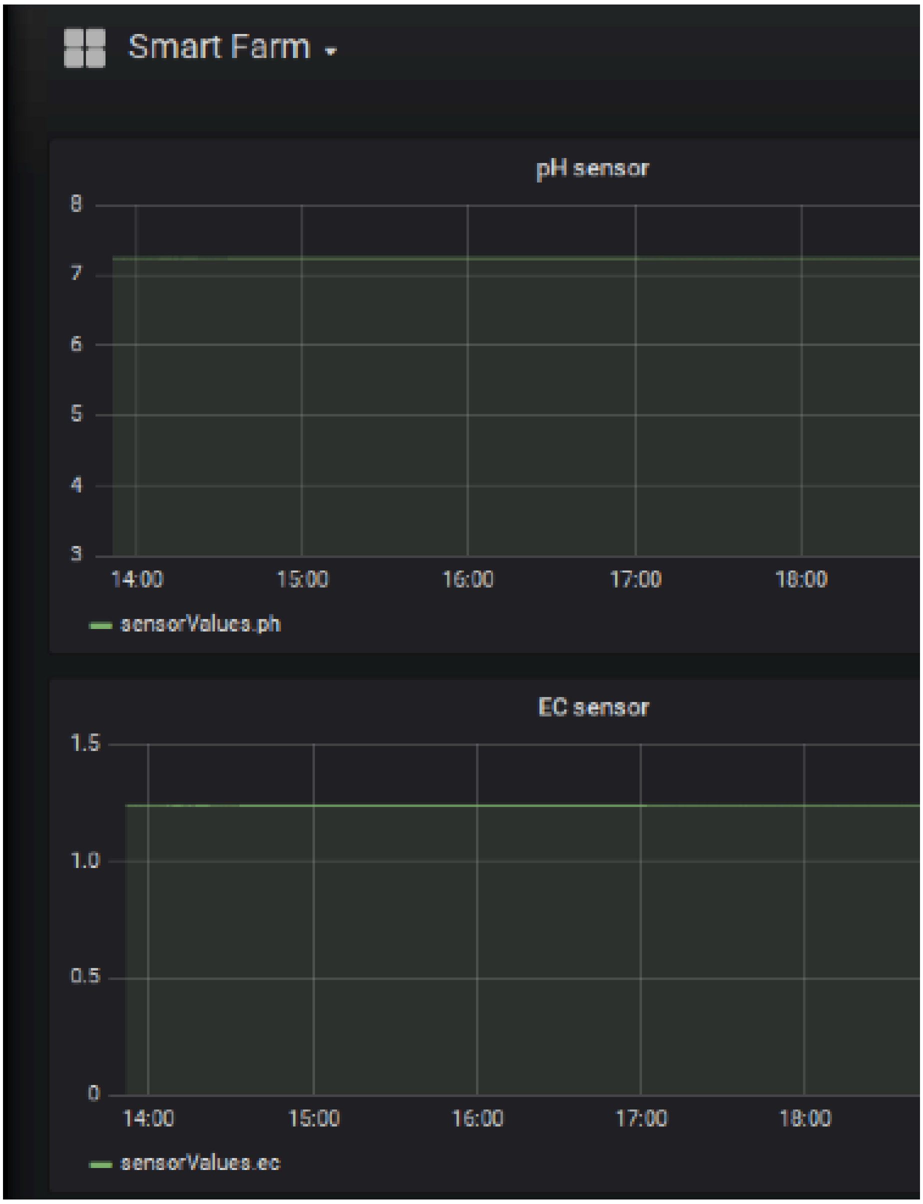


Figure 30: EC and pH levels.

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.

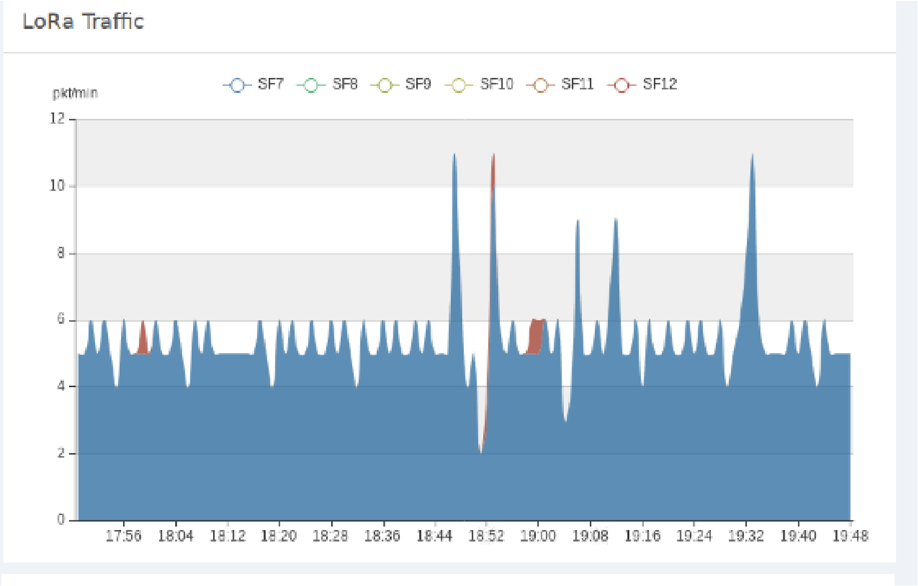


Figure 31: LoRa Traffic per minute and the spreading factor.

4.3.1 Why Information Spots?

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 analyze 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?

FIGURE (components - play)
- cost, data volume, …

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 [41]. Since most farmers in emerging economies are smallholder farmers, they table:

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 according to its documentation. [28]. Thus the farmers within the range of this can share cost. RAK7249 goes for 540 €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). The LoRa node and MCU go for 20€and 15€respectively.

868 MHz
€ 100
100 €
EC-pen^29

The cost of pH and EC sensor was 100€. Currently the common pHand EC sensors in the market are mostly hand-held and are not suitable for IoT application for monitoring smart farms. The cost for this varies but these are some of them: Bluelab handy EC-pen [29], cost 100€and ADWA pH-pen [30] which cost 64€. 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. 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.

/dev/EUR(… ~)

As discussed in section 2.2.2, smart farming especially in the emerging economies need cooperation between different actors for it be successful and fully 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. This has already been done before and District Health Information System (DHIS)[31] - a health management information system that was developed at 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 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.

Intro?

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

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

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

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

Challenge: “water quality” and how can it be measured by sensors
- Nitrat, Nitrit, Fe3, … (amount of incredients…) - pH sensor costly, limited feedback
-> your experiences => need for simplyfied sensor set-up (“only significant sensors”), other indicators

5.1.2 Power consumption

Argumentation:
- example set-up, specific on the power consumption and battery, or
- principle of power supply, and leave a detailed study to further work

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. The MCU, LoRa Node and sensors have been powered by 9v batteries in our experimental set-up. According to a predictive model by Liando et al. end node with Arduino Uno and SX1276 will last at least 2.7 years with 2AH battery [70]. Solar power can also be used to power both the end nodes, gateway and the local server. Rechargeable batteries can be used hence reducing the cost of changing batteries often. In this set-up gateway and the local server will be hosted in the same premise and a single solar power installation can power the this components.

What does it mean for our set-up?

“thin”

figure: (BasicInternet.no/Solutions)
figure with power consumption

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. In the proposed solution we have adopted the Internet Lite thus communication between local server and cloud will be free since the data transmitted fall into the category of text and pictures that are not charged in the Internet Lite approach. 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, Internet Lite approach 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.

“no numbers”?

Table:
- amount of data
- cost per kByte
- total cost
-

Alternatives:
- mobile
- LoRa

- mobile broadband
- Internet Lite

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 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 [32] - they also require subscription. Using EnvayaSMS is cheaper and satisfies the requirements of the proposed solution.

5.1.4 Software

We used open source software, open and widely used standards in the implementation of the proposed solution. The software has 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)- 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 LoRa technology, we used components of LoRaServer Project, which is 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 was used for notifications.

5.1.5 Computation and storage

In the proposed solution all computation is done locally. All components of LoRaServer project running on local server(Lora-gateway bridge, loraserver, lora-app-server) are running locally on the raspberry pi. Data analysis is also done locally and activation of alerts is also processed in the local server. EnvayaSMS server is also hosted in the same machine.

NUMBERS?
what type of RPI?
CPU/Memory usage?

5.1.6 Scalability

Scale of data produced (amount of data: number of sensors, frequency of transmission per greenhouse) is small as compared to big data in other sectors or developed world, but in countries with limited internet and high cost, even

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

5.1.4
Recommendation: Education (Khan academy…)- Health (yeboo.com, GlobalHealthMedia.org)
Agriculture: ????
High-level Panel on Digital Cooperation -> Report & Recommendations (BasicInternet.no/Publications)
(1A access - LoRa) - 1B Platform for DigitalPublicGoods.org = Candidates = “agriculture”? New requirements

small data transmission is costly. Our solution addresses this problem preprocessing at the edge reducing cost of sending data to cloud. Local server handles this functionality by enabling local storage and batch transmission to cloud. A single LoRa gateway can handle data greenhouses in a village within certain range(depending on the terrain).

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. Based on the available device(mobile phones), the farmers are notified through suitable service(SMS) and format(text)

how to judge:
“ease of use”?
[Ref: ease of use]
“how do I measure?”

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 Summar of evaluation
TABLE -CAPEX OPEX knowledge …
- cost - -, -, o, +, ++
- ease of use
- ….

5.2 Future Works

Discuss:

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

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A Program code

appendix

B RAK811 trials

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