Smart Farming in Emerging Economies

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

Institute of Informatics
Faculty of mathematics and natural sciences

UNIVERSITY OF OSLO

Autumn 2019

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

Printed: Reprosentralen, University of Oslo

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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 requiremnts of smart farming in resource constrained regions is given in subsection 2.4. We also give introduction to different technolgies that are used in this thesis to meet the requirements of smart farming in subsection 2.5 - 2.8. In the third section, we give a brief overview of the related work. Section 4 builds on the technolgies discussed on subsection 2.5 - 2.8 and presents the architecture and implementation of smart farming in developing countries. Sections 5 gives an evalaution 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 [1]. These demographic, climatic and environmental changes encourage 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.

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 [2]. The effects of climate change affects food production and it is felt mostly by the people in the developing world since agriculture is the main source of livelihood. Farmers in these areas are resource limited and vulnerable to the effects of 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 [3]. Yet, according to the UN Food and Agriculture Organization (FAO), 821 million (one person out of every nine in the world) are currently undernourished [4] and it is estimated that the food production in Africa has to increase by 260 % by 2050 to provide food for the expected population [5]. 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 [6]. To address food security problem and at the same time reducing ecological footprint associated with food production, agriculture has to be transformed.

Figure 1: Food demand vs ecological foot print (Source: [6]) .

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 [2]. In addition, 40 % of the rural population live in river basin areas that are classified as water scarce [7]. 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 [8]. 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[9].

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 [10, 11]. 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 [12] and in many cases even the existing knowledge and technologies have not reached farmers in developing countries [13].

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 [14]. 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 [15].]. 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 [16]. 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 [17]. 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 [18].

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 [14]. The Eropean Union has allocated euro 95 billion to the European Rural Development Fund for modernisation of agricultural industry between 2007 and 2013 [19].

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" [20]. 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 [21]. 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 [22]

According to [23], 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. 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[6]. It differs from traditional farming by accurtely identifying variations and relating spatial data to management activities [24].

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 [25]. It overlaps with technologies like precision farming and management information systems that have been derived from farm management information systems (FMIS) [25]. 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 [6]. Figure 2 shows different technologies that are used smart farming.

Figure 2: A smart farming technologies (Source: [19]).

In Smart Farming, the emphasizes is on the use of information and communication technology in the cyber-physical farm management cycle [26]. The advancement of nanotechnology in the last decade enable production of small and inexpensive sensors [27]. Moreover, cloud computing and internet of things will enhance the development of smart farming [6].

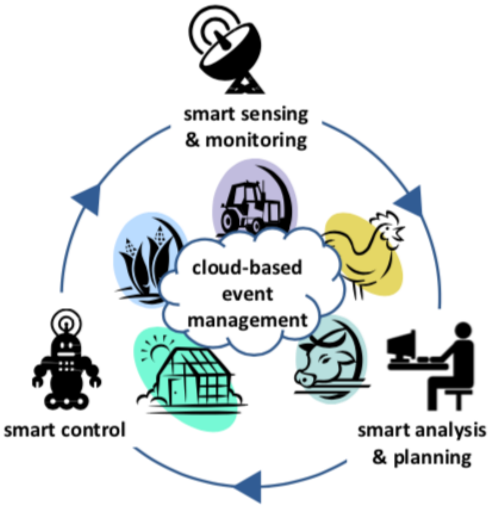


Figure 3: An ideal cycle of smart farming (Source: [23]).

Figure 3 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 [28]. 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.

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 [29]. 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" [29].

Hydroponics farming is classified as either open (nutrient solution is not reused) or closed (where solution is recovered, replenished and recycled)[30]. 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 [31]. 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 [32]. 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 [29] 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 [32]. The major limitation of adoption of in hydroponics is the initial capital required [31] especially for the small holder farmers in developing countries. However, the cost can be reduced by low cost devices/construction material [32].

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 chemical 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 [16].

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 [33]. Also a cost-efficient communication is required for sending data to the cloud. Since bandwidth is limited, data mitigation techniques [24] 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 reaserchers to replicate the design and customize it to meet specific needs of the context [16]. 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 [34, 16].

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 [6].

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 [35] 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 [36]. 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 [37].

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" [38].

A user centric definition is given by [37]. 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"

IoT has many applications areas and [39] has given a comprehensive taxonomy of different applications including health-care, environmental, smart city, commercial, industrial and general aspects. 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 [40], hydroponic greenhouse [41], monitoring and control of irrigation system in rural communities [42], smart irrigation in tunnel farming [43], smart animal farm [44].

A generic three-layer IoT architecture consisting of sensing, transport and application layer is depicted in Figure 4 and this can also be extended to five layers with inclusion of network and processing layers between the second and third layer [45, 33]

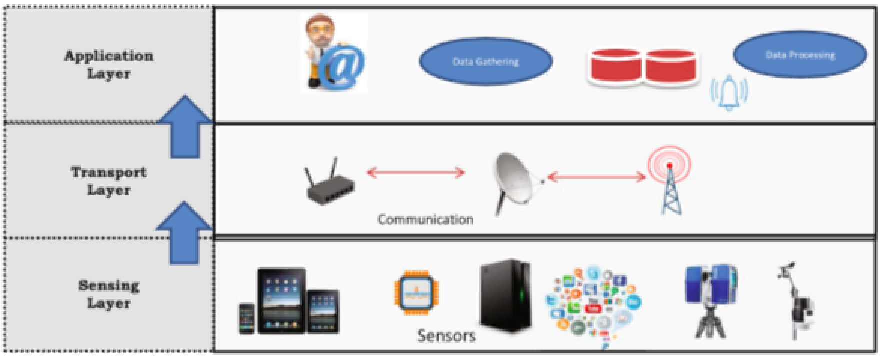


Figure 4: IoT based agricultural framework (Source: [45]).

IoT in agriculture consists of several layers interconnected things and interfaces. [27] provides a six layer framework for a fully fledged agricultural solutions based on IoT. Figure 5 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.

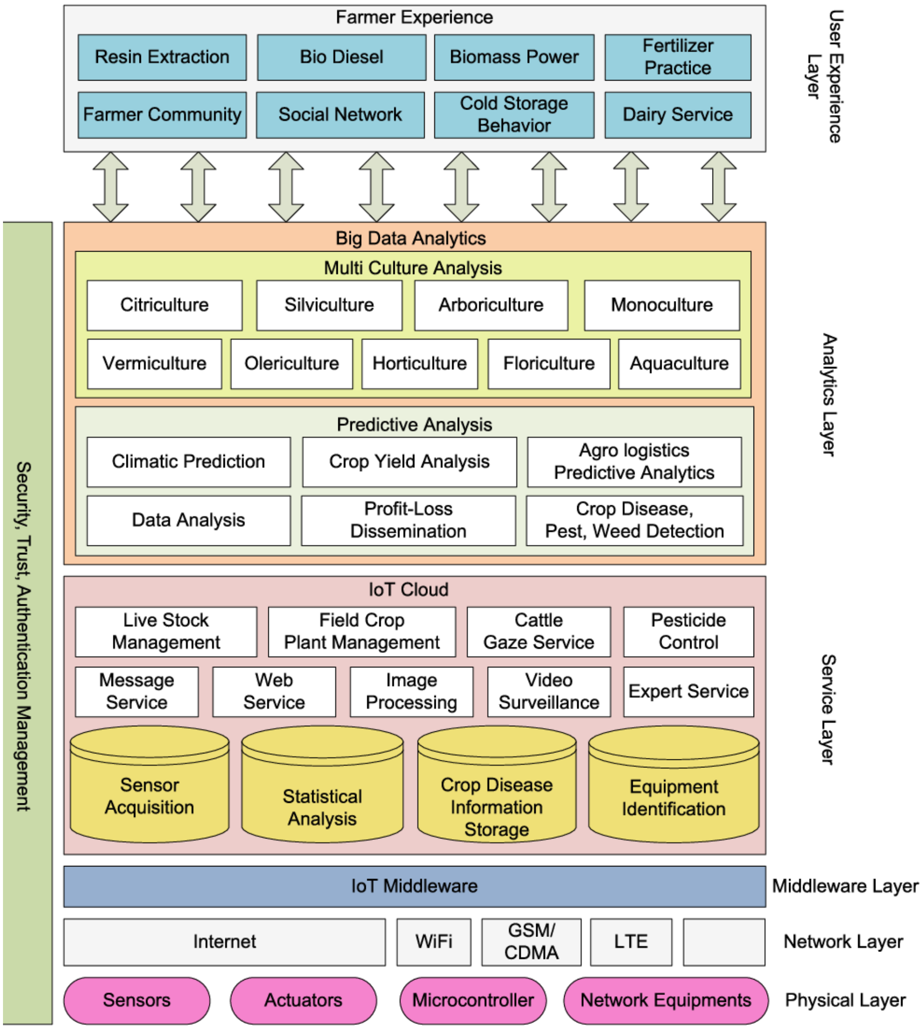


Figure 5: IoT based agricultural framework (Source: [27]).

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 [46]. Figure 6 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 [46]), Websockets and HTTP (designed for WEB and not optimal for IoT as it is heavy weight protocol [47]). In this section we will only consider MQTT and CoAP, which are the most common protocols in IoT systems.

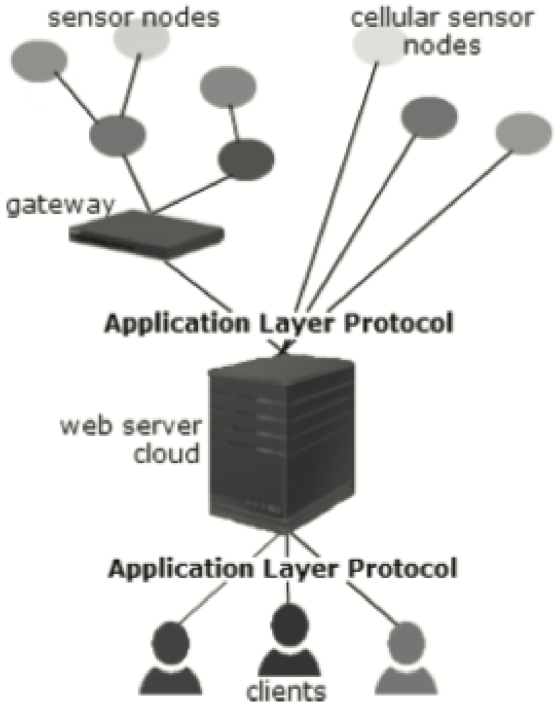
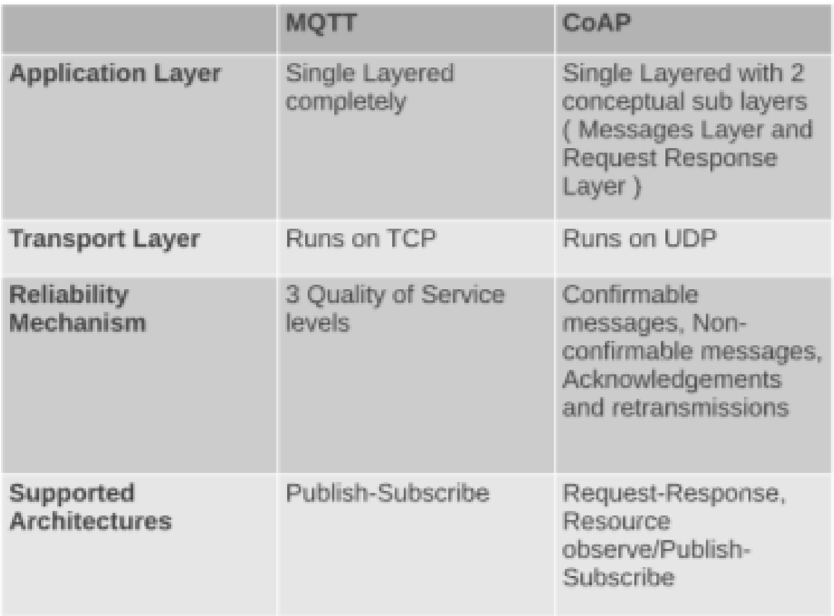


Figure 6: Application layer protocols source ([46]).

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[46]. It uses request/response and resource/observe (variant of publish/subscribe) architecturemaking it interoperable with HTTP [47]. 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) [46]. Authors in [46] 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 7: Difference between CoAP and MQTT. source ([48]).

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 [47]. Topics are contained in a broker [46] - 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 [47].

2.6.3 Suitability in smart farming

In [47] an in-dpeth comparative study of four (HTTP, AMQP, MQTT and CoAP) application layer protocols have been done. According to the authors [47] 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 [48] 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 [49]. 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 [49]. 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 [50].

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 [50]. 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 [50].

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 [50]. 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 [51].

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 [50]. 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 [50]. (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 [52]. 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 [50]. In agricultural applications, WiFi enables connection of multiple types of devices through heterogeneous architectures over an ad-hoc network [51].

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 [53]. 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 [50]. According to [49] 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 [49, 53]. 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 [1], which is based on chirp spread spectrum (CSS) technology [54]. 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 [49]. 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 [55] by LoRa Alliance[2], 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 [54]. The end devices communicate with gateway using LoRa and from gateway packets are forwarded to network server through backhaul interfaces like 3G or Ethernet [24].

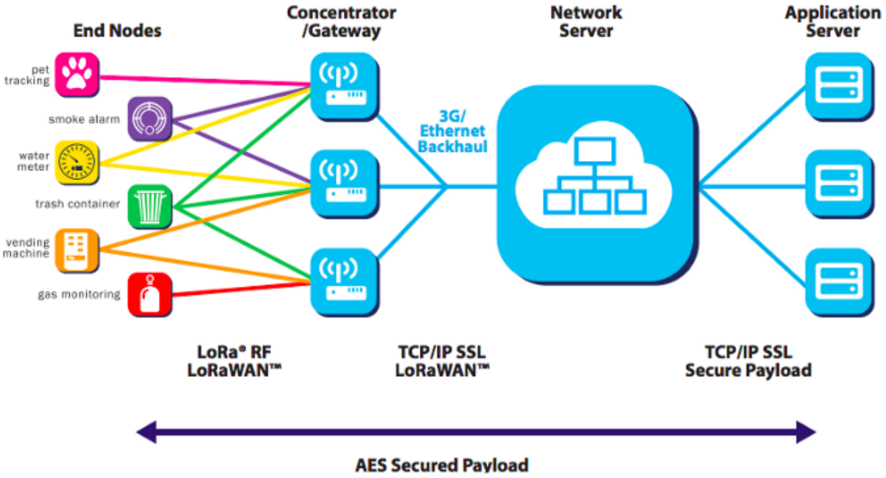


Figure 8: LoRaWAN network architecture (Source: [55]).

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) [52]. It was first released in 2009 and IoT service provider as its business model thus

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

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

no documentation is publically available [49]. The communication range is upto 30 km and this is achieved by transmiting at very low data rates (up to 100bps) [52].

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 [49]. According to [53] 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 [56].

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 [57]. 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 [57, 49]. To address these shortcomings, revamping of second generation/ Global System for Mobile Communications (2G/ GSM) [49] 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 [53]. 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 [58].

2.7.4 Connectivity with Internet Lite

Internet Lite is a concept by Basic Internet Foundation aimed at addressing the digital dive challenge [59]. 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. 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 [60].

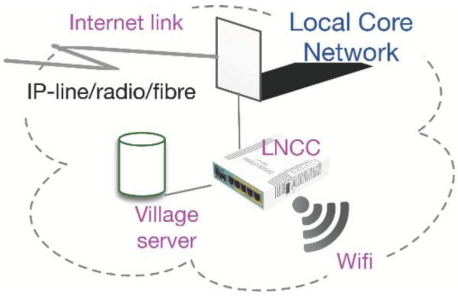
To achieve this, the Basic Internet Foundation used low-cost network infrastructure that includes local core network, a local network, a centralized core, and backhaul network [61, 62]. They defined InfoInternet standard that is aimed at making access to information free (text, pictures) [62]. This is 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.

InfoInternet 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.

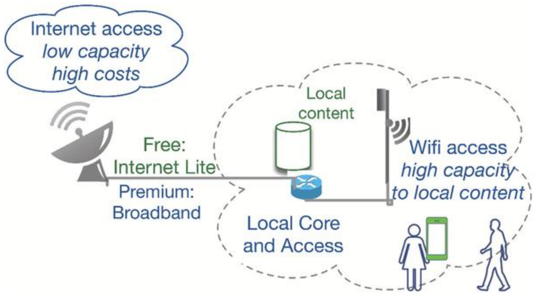
community gateways (TTN), as a form of alternative networks- integrating this to the basic internet architecture. LoRaWAN- 1). Bg dedicated deployment 29) community, public deployment thus a share infrastructure [63].

2.7.5 Feasibility

Table 11 depicts a comparison of the main wireless communication technologies and parameters such as transmission range, data rate, energy consumption and cost. All this 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



(a) label 1

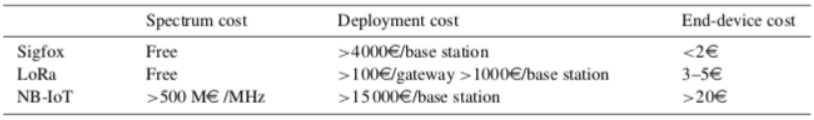


(b) label 2

Figure 9: Internet Lite source ([59])

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 parts within a village.

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 [64, 65]. In [64] LoRa, SigFox and NB-IoT are compared. From this 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 10 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 [66]. The proliferation of low cost hardware, availability of open software and initiatives like Sparkfun[3] and Adafruit [4] 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 [67].



	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	>15 000€/base station	>20€

Figure 10: A cost comparison of LoRa, SigFox and NB-IoT (Source: [64]).

Even though LoRa is proprietary product, its upper layer, LoRaWAN is open, operator and subscription free making it simple to deploy and manage infrastructure whereas in SigFox, user purchase end devices and subsription for the devices from the network operators [65]. 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. However, the data from sensors farms are short and sporadic. Transmission of data can also be limited to when certain threshold is met. They also offer better energy efficiency and are suitable for this areas as connection to power grid is not guaranteed.

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.

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

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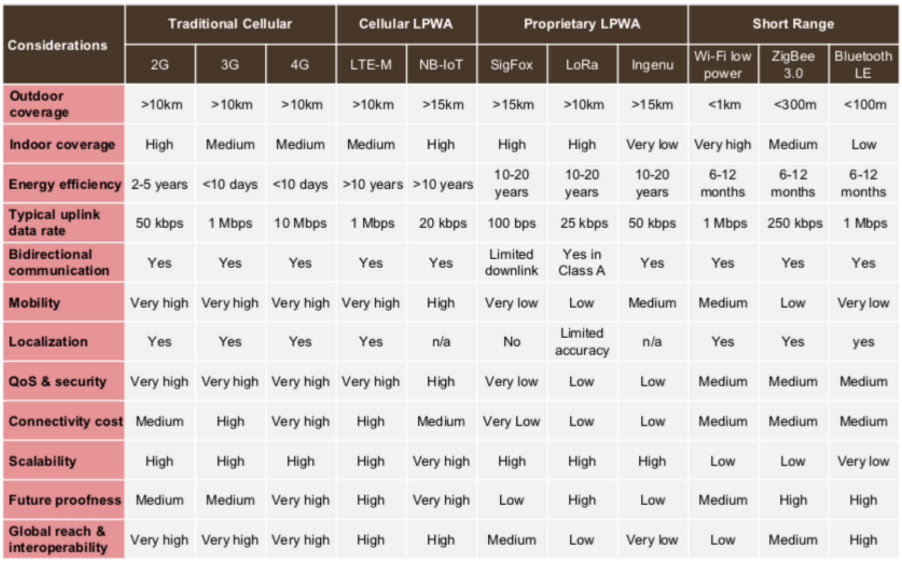
[3] `https://www.sparkfun.com/categories/23`

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

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 InfoInternet 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.



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 11: A comparison of different wireless technologies (Source: [56]).

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 [68]. In [69] over 20 definitions of cloud computing has been analysed and the following definition has been proposed:

Citation: Noll et al.~have pointed out the need for …. [76].

”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”.

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 ” [70].

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 [71]. 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 [26]. 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 [72]. Cisco Internet Business Solutions Group predicted that there would be 50 billion devices connected to the Internet by 2020 [35]. 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 [73].

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 " [74]. In [75] an in-depth comparison of edge and fog computing and other related paradigms have been made. From this, edge viewed as one of the immediate first hop from IoT devices like WiFi access points or gateways.

Edge computing sits at the peak of Gartners Hype Cycle for Cloud Computing, 2018 [76] 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 [77].

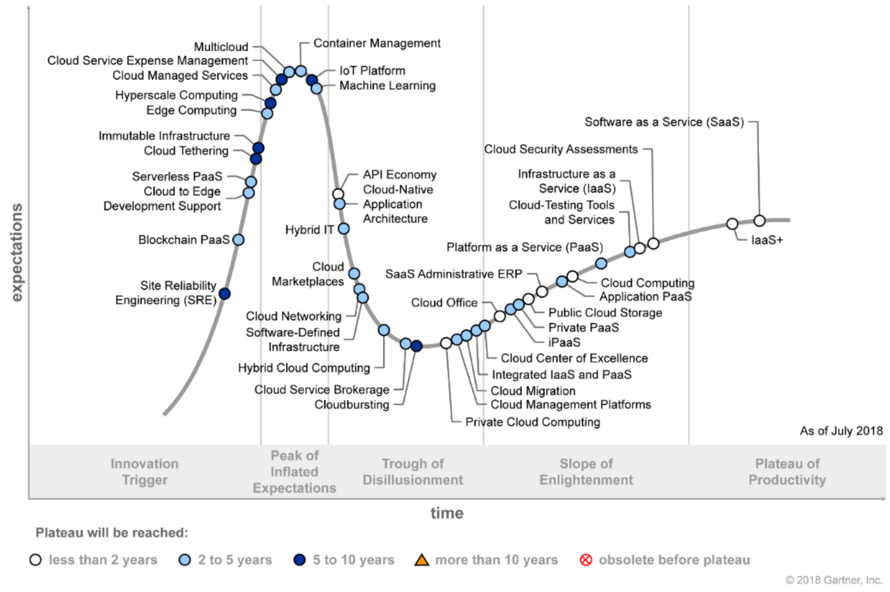


Figure 12: IoT based agricultural framework (Source: [76]).

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 [78]. 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 [41]. 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 [79]. 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 [73]. 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 [34] 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 [80].

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 [71]. 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 [81]. 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 [82]. 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. 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 and Conclusion

The earlier applications of technology in precision and smart farming focused mostly on automating farm systems based on the data collected by sensors. Authors in [41] argue that control area in agriculture have developed gradually and significant improvement has been after integration of information and communication system into farm management system. 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 [83], 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. [84] presents a hydroponic monitoring and automation system with a responsive web framework. Different wireless technologies are used in depending on the requirements of the agricultural applications scenario. In [85] 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. In [86], authors have proposed a smart farming for animal welfare monitoring with fog layer that presented by Omar and Sharif [41]

enables farmers to locally access the system, manually control parameters and actuators. Authors in [87] 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 [41]. In their approach edge computing layer is enabled by Network Function Virtualization(NFV) technology so as to increases flexibility in deployment of control modules. In [63] a software component to enable edge analytics on LoRaWAN has been proposed. They 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. In [66] a low cost IoT solution based on LoRa gateway with local storage and access for rural African villages is proposed. The solution suggested is part of European Union-Africa project[5] 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 knowhow 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,

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

Summary table: …
++, +, 0, -, —

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.

4 Implementation

In this section we will describe the architecture of the system used in this thesis. We will also discuss the implementation of the system.

4.1 System architecture

The smart farming solution suggested here comprises of three layers:

- IoT end devices in the Hydroponic farm,
- IoT gateway that also includes the local server for local access,
- Cloud

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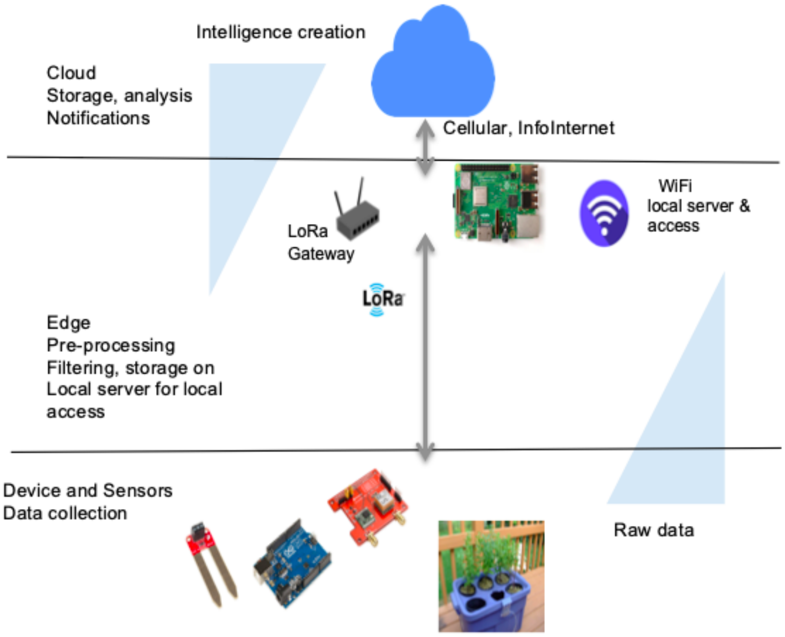

Figure 13: A three layer architecture

Figure 13 shows the three layers (Three-layer IoT architecture). The local server also hosts the edge layer that 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 and sensor level and intelligence created increases in the upper layers as data is processed to get meaningful information [74]. This is also important to overcome challenges related to the bandwidth usage.

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 and adoption of other solutions like information spots from Basic Internet Foundation so as to empower the local farmers. Figure 14 shows overview of the whole system.

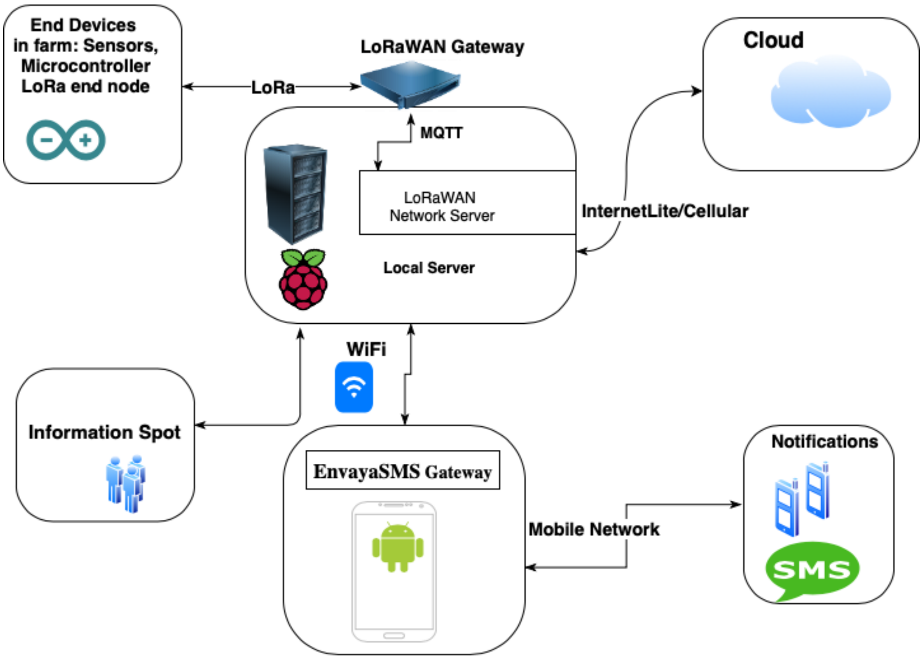

Figure 14: An overview of the system.

4.1.1 End devices

The end devices comprise of:

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

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 how much dissolved material in a solution. Alternative to EC sensor is Total dissolved solids (TDS) sensor, which measures 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 [29]. In addition different TDS manufactures different conversion factors thus different readings.

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 [88]. 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, ease of programming [89]. In addition, it is widely used in educational and amateur community and it has variety of sensors that compatible with and many well documented open source programs. As such, we chose Arduino Uno microcontroller board [6], with an open source IDE and libraries that have been developed by community and a wide range of sensors are compatible with it . The micro-controller will facilitate data acquisition.

For communication with the gateway, a RAK811 WisNode LoRa Module that is compatible with Arduino is used [7]. LoRa offers three end device classifications: 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) [55]. Since the model suggested is a monitoring the conditions of the hydroponic system and only data is transmitted when the threshold falls to a certain minimum, device A,is used in the end nodes. This also suits the power consumption requirements as transmission is initiated by the end device and done asynchronously and no downlink is required as no communication is expected from the gateway even though device A by default has two short download receive windows.

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

[7] `https://store.rakwireless.com/collections/lora-modules/products/rak811-wisnode-lora-module`

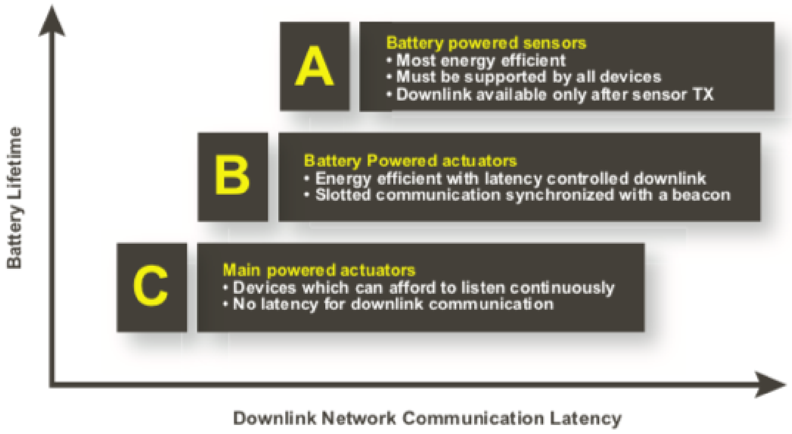

Figure 15: LoRa device classes and power consumption [55].

Schematic diagram.

Device	Model	Power consumption	Specifications
Microcontroller board	Arduino	3.3 - 5.0V	Arduino Uno.
LoRa module	LoRa shield	3.3v	RAK811 WisNode 868MHz
pH sensor	model	3.3-5v	specifications
EC sensor	model	3.3-5v	specifications

4.1.1.1 Software implementation at the end nodes

4.1.2 IoT gateway and the local server

LoRaWAN gateway forms the link between the end devices and the LoRaWAN network server. It receives LoRa packets and forwards them to the server. The components used in this thesis are from an open source LoRaServer project[8] that offers applications that can implemented flexibly. LoRaServer components include LoRa Gateway bridge, LoRa Server, LoRa App server and application. LoRa gateway bridge is installed in the LoRa gateway and it converts LoRa packets to messages that can be sent over MQTT. The LoRaServer software offers several components architecture as shown in reffig:LoRaServerConfigurations

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

and the configuration used in this thesis is shown in 17 . LoRa server and LoRa App server are installed in the local server.

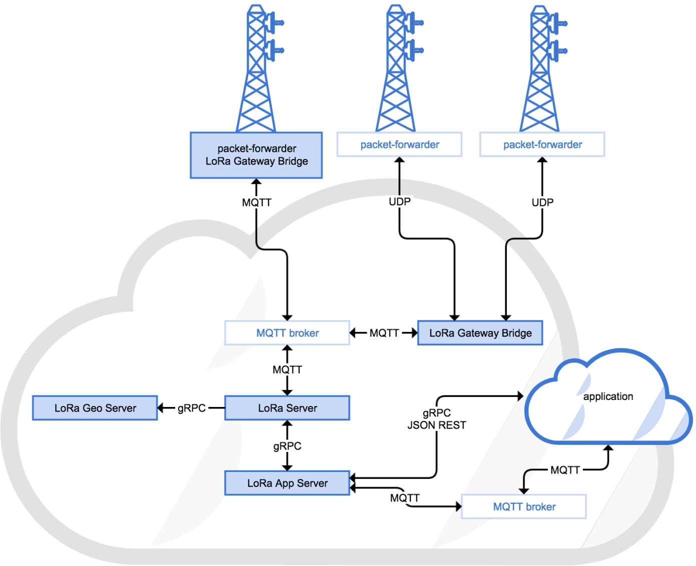

Figure 16: General LoRaWAN configuration architectures. Source()

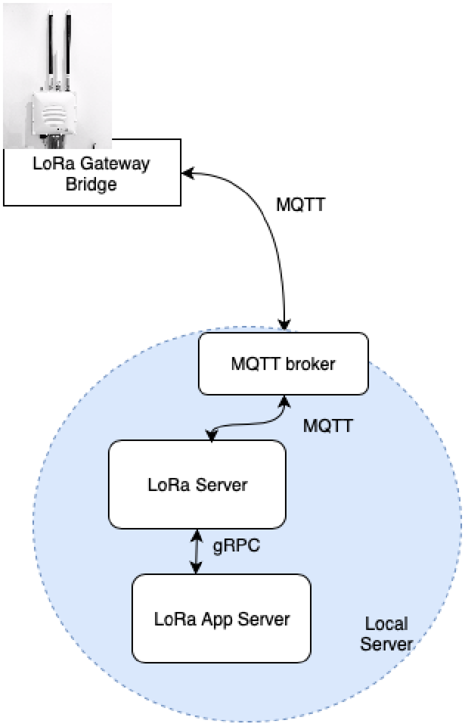

Figure 17: Components and configuration used in this thesis.

4.1.2.1 Local server It consists of the LoRaWAN network server and the 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 3 Model B+[9]. This forms the edge, an intermediary processing layer that performs the following computations:

- Pre-processing
- Data filtering
- Knowledge inferring to identify faulty sensors
- Compression
- Push data local server for storage and access or to cloud if no local server(Basic Internet)
- From data to knowledge

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

- Data locally consumed- access by locals

4.1.2.2 Software implementation

- LoRa server - open source LoRaWAN network server[10]
- Sensor data storage on influxDB[11] - open source time series database.
- Data visualization Grafana[12] - open source tool for visualization of time series database.
- Node-Red [13] - flow based programming tool that is web based.

Edge layer With edge computation bandwidth usage can be optimized and simple data analytics can be performed. Edge layer defines the rules related to storage of data and sending of notifications. Data that is not latency sensitive(that don't trigger alerts and farmers immediate action) will be stored temporarily in the local storage. It can then be pushed to the cloud after predefined time. Batch transfers to the cloud can also be enabled here.

Sending of notifications: Alerts are sent o the farmers depending on the sensor readings. If the sensor readings fall below a set value then farmers are notify through SMS. As such edge also manages the connection between the server and gateway application app running on an Andriod phone.

4.1.2.3 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 [18]. 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

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[10] `https://www.loraserver.io/loraserver/overview/`

[11] `https://www.influxdata.com`

[12] `https://grafana.com`

[13] `https://nodered.org`

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 [14] and frontlineSMS [15] have already been used in health sector to send reminders to enhance postnatal care appointments [90] and SMS based alert system to monitor pregnacy, maternal and child deaths [91]. In [92], EnvayaSMS [16], 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 has 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 18.

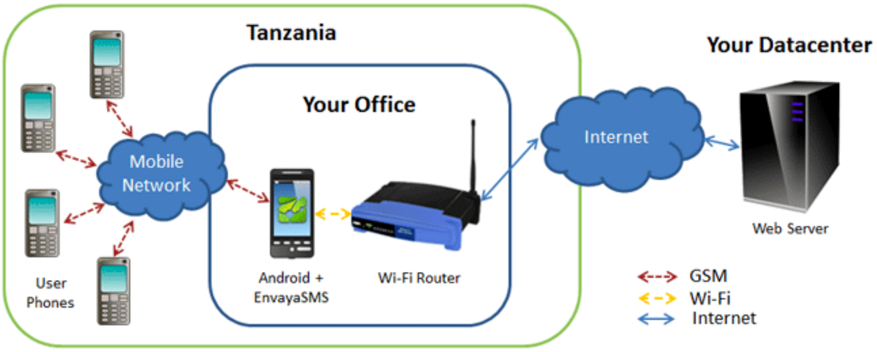

Figure 18: EnvayaSMS configuration (source)

4.1.2.4 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.

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[14] `https://www.rapidsms.org`
[15] `https://www.frontlinesms.com`
[16] `http://sms.envaya.org`

4.1.3 Cloud

Yield from traditional farming
- yield from “fertilizer” farming
- yield from Hydropont farming…

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

Argumentation: I need information in order to achieve ….
That’s why: need of information spots

4.1.4 Discussion (Capacity building and Empowerment)

The use of information centres in the basic internet infrastructure enables access to information. Since text and pictures are free in the infoInternet standard, farmers can access information regarding plants, weather forecast information. With this we believe that information driven agriculture will be practised thus building the capacity of the local communities.

Revisit table and add with “real numbers”

5 Evaluation and future work

Evaluation cost- transfer of all data sensor to cloud is costly. and also due to link capacity/speed.

Criteria (for evaluation):
- Cost
- Simplicity (DIY)
- Availability (Open Source)
- …

6 Conclusion

conclusion

Other options (what could I have done differently)
- my experiences “now”

Future work - open issues

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