An Overview of Internet of Things (IoT) and Data Analytics in Agriculture: Benefits and Challenges

Olakunle Elijah, *Student Member, IEEE*, Tharek Abdul Rahman, *Member, IEEE*, Igbafe Orikumhi, *Member, IEEE*, Chee Yen Leow, *Member, IEEE*, and MHD Nour Hindia, *Member, IEEE*

***Abstract*—The surge in global population is compelling a shift toward smart agriculture practices. This coupled with the diminishing natural resources, limited availability of arable land, increase in unpredictable weather conditions makes food security a major concern for most countries. As a result, the use of Internet of Things (IoT) and data analytics (DA) are employed to enhance the operational efficiency and productivity in the agriculture sector. There is a paradigm shift from use of wireless sensor network (WSN) as a major driver of smart agriculture to the use of IoT and DA. The IoT integrates several existing technologies, such as WSN, radio frequency identification, cloud computing, middleware systems, and end-user applications. In this paper, several benefits and challenges of IoT have been identified. We present the IoT ecosystem and how the combination of IoT and DA is enabling smart agriculture. Furthermore, we provide future trends and opportunities which are categorized into technological innovations, application scenarios, business, and marketability.**

***Index Terms*—Agriculture, data analytics (DA), Internet of Things (IoT), IoT ecosystems, IoT in agriculture, IoT sensors, smart agriculture.**

I. Introduction

THE INTERNET of Things (IoT) has found its application in several areas, such as connected industry, smart-city [1], [2], smart-home [3] smart-energy, connected car [4], smart-agriculture [5], connected building and campus [6], health care [7], logistics [8], among other domains. IoT aims to integrate the physical world with the virtual world by using the Internet as the medium to communicate and exchange information [9]. IoT has been defined as a system of interrelated computing devices, mechanical and digital machines, objects, animals, or people that are provided with unique identifiers and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction. A key area of interest in this paper is the application of IoT in agriculture. The world population is estimated to be about 9.7 billion in 2050, as such there will be great demand for food. This coupled with the diminishing natural resources, arable land, unpredictable weather conditions make food security a major concern for most countries. The world is turning to the use of IoT combined with data analytics (DA) to meet the world's food demands in the coming years [10]. It is predicted that IoT device installations in the agriculture sector will increase from 30 million in 2015 to 75 million by 2020. The use of IoT and DA will enable smart agriculture which is expected to deliver high operational efficiency and high yield [11], [12].

Over the years, wireless sensor networks (WSNs) has been deployed for smart agriculture and food production with a focus on environmental monitoring, precision agriculture, machine and process control automation and traceability [13]–[18]. The capability of WSN to self-organize, self-configure, self-diagnosis, and self-heal has made it a good choice for smart agriculture and the food industry. The WSN is a system that comprise of radio frequency (RF) transceivers, sensors, microcontrollers and power sources [13]. However, with the emergency of IoT there has been a paradigm shift from the use of WSN for smart agriculture to IoT as the major driver of smart agriculture. The IoT integrates several technologies that already exist, such as WSN, RF identification, cloud computing, middleware systems and end-user applications [19].

The application of IoT in agriculture is about empowering farmers with the decision tools and automation technologies that seamlessly integrate products, knowledge and services for better productivity, quality, and profit. Recent surveys on the IoT in agriculture have focused on the challenges and constraints for large-scale pilots in entire supply chain in the agrifood sector [5], [20]. Some of the key issues addressed are the need for new business models, security and privacy, and data governance and ownership solution. Other related survey on smart agriculture have largely focused on the use of WSNs [21]. While these survey papers deal with the application of sensor technology and challenges in the application of IoT to the food supply chain, the communication technology were limited to conventional methods which employs low range communication technologies.

Manuscript received October 23, 2017; revised May 13, 2018; accepted May 31, 2018. Date of publication June 5, 2018; date of current version November 14, 2018. This work was supported by the Ministry of Education and Universiti Teknologi Malaysia (UTM) through Grant Q.J130000.2509, 19H38, 4F818, 19H58. This work was supported in part by H2020-MSCA-RISE-2015 under the grant (690750). *(Corresponding author: Olakunle Elijah.)*

O. Elijah, T. A. Rahman, and C. Y. Leow are with the Wireless Communication Center, Universiti Teknologi Malaysia, Johor Bahru 81310, Malaysia (e-mail: elij_olak@yahoo.com; tharek@fke.utm.my; bruceleow@fke.utm.my).

I. Orikumhi is with the Department of Electronics Engineering, 5G/Unmanned Vehicle Research Center, Hanyang University, Seoul 04673, South Korea (e-mail: johnorikumhi@yahoo.com).

MHD N. Hindia is with the Department of Electrical Engineering, Faculty of Engineering, University of Malaya, Kuala Lumpur 50603, Malaysia (e-mail: nourhindia@hotmail.com).

Digital Object Identifier 10.1109/JIOT.2018.2844296

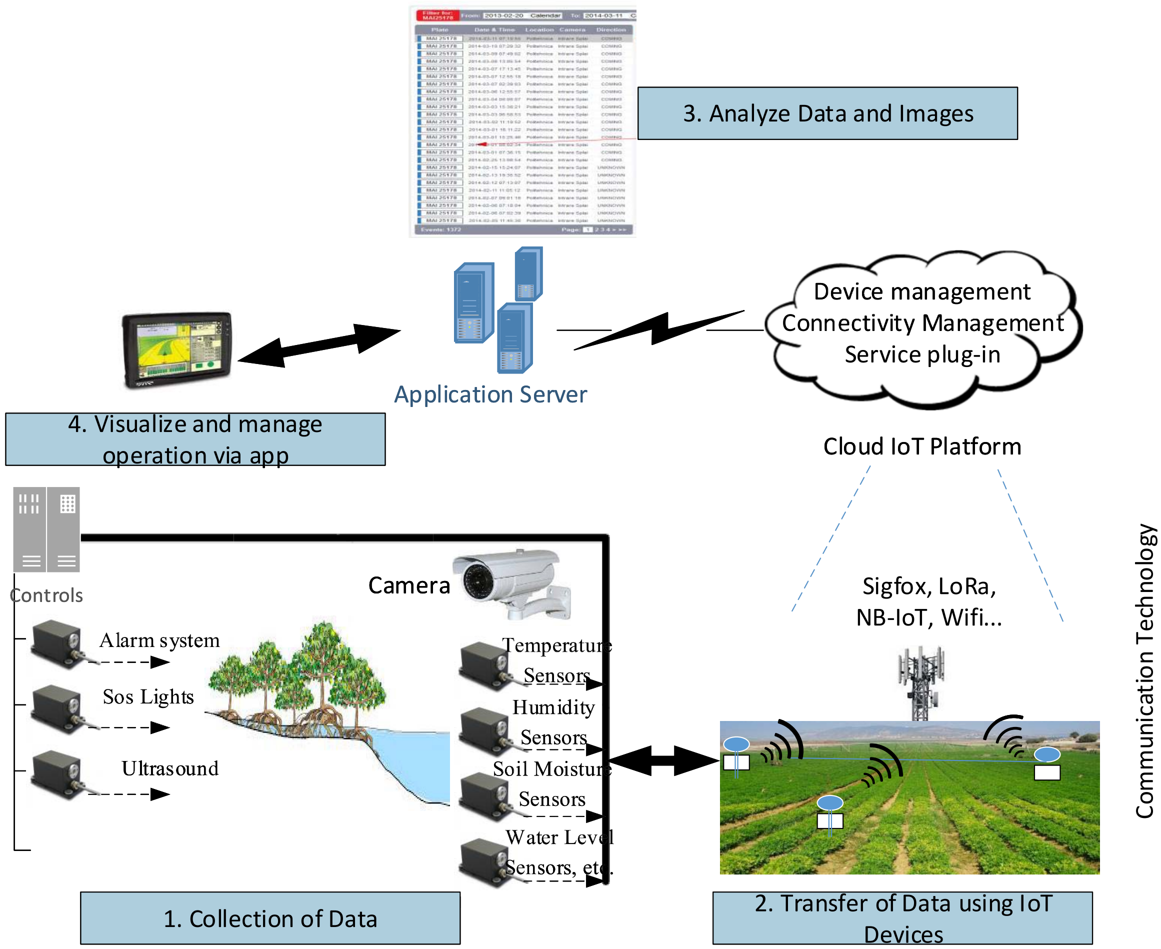


Fig. 1. Illustration of IoT ecosystem for agriculture.

In this paper, an extensive review of IoT in agriculture is carried out. The review includes a survey of published articles, white paper and existing solutions. The IoT ecosystem for agriculture is discussed in detail based on four major components which are IoT devices, communication technology, Internet, data storage, and processing. The application of IoT and DA and how it is enabling smart agriculture is presented. Furthermore, the benefits, challenges, open issues, future trends and opportunities are discussed.

The organization of this paper is presented as follows.

1) In Section II, the IoT ecosystem for agriculture, which consist of four major components: a) IoT devices; b) communication technology; c) Internet; and d) data are presented.
2) Section III covers the classification of IoT application in agriculture. Key areas are considered: a) monitoring; b) tracking and tracing; c) agricultural machinery; d) precision agriculture; and e) greenhouse production.
3) Section IV discusses the importance of IoT and DA. Six key areas are considered which are: a) prediction; b) storage management; c) decision making; d) farm management; e) precision farming; and f) insurance.
4) In Section V, the benefits are highlighted. These include the use of IoT to promote community farming, safety and fraud prevention, competitive advantages, wealth creation, cost reduction, operational efficiency, awareness, and asset management.
5) Section VI discusses several open issues and key challenges in the adoption of IoT in agriculture. The issues are identified and discussed under three main categories: a) business; b) technical; and c) sectoral.
6) Section VII takes a look at the future trends and opportunities.
7) Section VIII finally concludes this paper.

II. IoT Ecosystem

In this section, an overview of the IoT ecosystem for agriculture is presented. It consists of four major components which are: 1) IoT devices; 2) communication technology; 3) Internet; and 4) data storage and processing. Fig. 1 illustrates the IoT ecosystem. The four major components are essential for any IoT application. The description of the IoT components as it relates to agriculture is provided as follows.

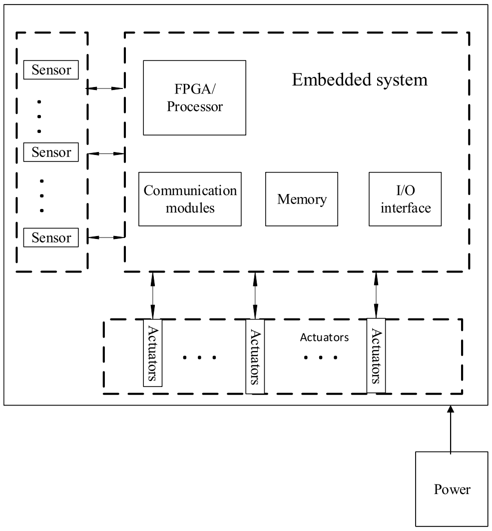


Fig. 2. Architecture of IoT device.

A. IoT Devices

The IoT devices consist of embedded systems which interacts with sensors and actuators and requires wireless connectivity. These IoT devices are sometimes referred to as IoT sensors. Throughout this paper it is referred to as IoT device. The architecture of a typical IoT device for agriculture is shown in Fig. 2. The embedded system consists of field programmable gate arrays or microprocessor, communication modules, memory and input/output interfaces.

The sensors are used to monitor and to measure different farm variables (example soil nutrients, weather data) and factors that affect production. The sensors can be classified into location sensors, optical sensors, mechanical sensors, electrochemical sensors, and airflow sensors [22]. These sensors are used to gather information, such as air temperature, soil temperature at various depths, rainfall, leaf wetness, chlorophyll, wind speed, dew point temperature, wind direction, relative humidity, solar radiation, and atmospheric pressure. Table I provides a summary of some of the sensors and their applications. There are key characteristics of IoT device that makes them suitable for agriculture purposes. They are: 1) power efficiency; 2) memory; 3) computational efficiency; 4) portability; 5) durability; 6) coverage; 7) reliability; and 8) cost.

B. Communication Technology

The communication technology plays a key role in the successful deployment of IoT systems. The existing communication technology can be classified based on standards, spectrum, and application scenarios. The communication standard can be grouped into short-range communication standard and long-range communication standard. The communication spectrum can be grouped into licensed and unlicensed spectrum. The IoT devices application scenarios can be based on sensors or backhaul network, and deployment scenarios [23].

1) Spectrum: The unlicensed spectrum makes use of industrial scientific and medical RF band known as ISM band. The drawback to the use of the unlicensed spectrum are security issues, cost of infrastructure, and interference. Electromagnetic interference is generated by ISM IoT devices that interrupts radio communications that use the same frequency. On the other hand, the licensed spectrum which are allocated to the cellular network offers more efficient traffic management, less interference, better reliability, increased quality of service (QoS), high level of security, wider coverage and lesser cost of infrastructure to the users. The drawback to the use of licensed spectrum is cost of subscription for data transmission and transmit power consumption on the IoT devices.

2) Standard: There are so many existing standards for wireless communications, some of which have been listed in Table II. They can be classified into short-range and long-range communication standards. Examples of the short-range standards are near field communications-enabled devices, Bluetooth, ZigBee, Z-Wave, passive and active radio frequency identification (RFID) systems. The short-range standards can cover distances within 100 m. The long-range communication standards can cover distances up to 10 s of kilometers. The long-range communication standards are classified as the low power wide area (LPWA) (examples are LoRa, Sigfox, NB-IoT). The LPWA makes use of low power and can cover wide area [24], [25].

3) Application Scenario: The choice of communication technology also depends on applications of the IoT device. The communication technology can either be used for IoT devices that acts as nodes or as backhaul networks. The nodes transmit low data and cover very short distances with low power consumption. The backhaul network supports high data rates and can be used for very long distances. Some of the communication technologies support bi-directional link. The bi-directional link allows for forward error correction, handshaking for data reliability, encryption of data, over-the-air firmware updates, and communication between devices. In [26], the comparison of LoRa and NB-IoT shows that each technology has its advantages and disadvantages hence the most appropriate technology depends on the application.

Furthermore, the choice of communication technology for the IoT device also depends on the type of topology to be deployed. There are different types of topology, such as peer-to-peer (P2P) or line, star, mesh, ring, tree, and bus topology. In each of these topologies, an IoT device plays different roles and different functions.[1] The role can either be a personal area coordinator (PAN) or as an end device. The functions can be full function device (FFD) or a reduced function device (RFD). Fig. 3 illustrates two types of topologies and roles played. In the P2P topology, the PAN functions as FFD and starts the communication while the end devices can either function as an FFD or RFD. The end device which acts as FFD can have multiple connections while the end device that acts as

[1] If an IoT device is configured as PAN, it functions as an FFD and the device starts first and waits for a connection. On the other hand, if it is configured as the end device, it can either function as FFD or RFD. In this case the device starts after the PAN coordinator has started to establish a connection.

TABLE I
SUMMARY OF AGRICULTURE SENSORS

Type of Sensors	Functions	Examples of Applications
Optical	Use of light to measure soil properties	Photodiodes and photodectors to determine clay, organic matter and moisture content of the soil
Mechanical	Use of probes to measure soil compaction or mechanical resistance	Tensiometers to detect the force used by the roots in water absorption and useful for irrigation interventions
Electrochemical	Use of electrodes to detect specific ions in the soil	Use of ion-selective electrodes (ISE) and ion-selective field effect transistor sensors (ISEFT) for detecting nitrogen phosphorus potassium (NPK) in soils
Dielectric soil Moisture	Use of electrodes to assess moisture levels by measuring the dielectric constant in the soil	Frequency domain reflectometry (FDR) or time domain reflectometry (TDR) to sense soil water content
Airflow	Measure soil air permeability	Properties such as compaction, structure, soil type, and moisture level of the soil can be measured
Location	Use of Global positioning system (GPS) satellites to determines the latitude, longitude and altitude	The GPS provides precise positioning for which is a corner stone for precision agriculture

RFD can only connect to one FFD and cannot connect to another RFD. The star topology consists of PAN that initiates the communication and accepts connection from other devices. The end devices can only establish connections with the PAN coordinator.

C. Internet

The advancement in the field of wireless communication systems, mobile devices, and ubiquitous services has paved way for massive connectivity to the Internet. According to Machina research report, the number of connected agricultural devices is expected to grow from 13 million at the end of 2014 to 225 million by 2024 [27]. The Internet forms the core network layer, where paths are provided to carry and exchange data and network information between multiple subnetworks. The connection of IoT devices to the Internet enables data to be available anywhere and anytime. However, the transfer of data via the Internet requires adequate security, support of real time data and ease of accessibility. The Internet has paved way for cloud computing, where large data are gathered for storage and processing. Cloud computing involves the management of user interface, services, organizing and coordinating of network nodes, computing, and processing data [28]. To achieve the connectivity of heterogeneous systems and devices over the Internet, IoT middleware and connectivity protocols are being developed. Examples of the IoT middleware is the service-oriented architecture (SOA), cloud-based IoT middleware and actor-based IoT middleware which have been applied to support IoT [29], [30]. The SOA for IoT consist of multilayer architecture. Some of the proposed IoT architecture consist of the following layers: sensing, accessing, networking, middleware, and application layers. We refer readers to [29], [31], and [32] and the references therein for more details on the IoT architecture and technology.

D. Data Storage and Processing Units

Data driven agriculture involves the collection of enormous, dynamic, complex, and spatial data, which requires storage and processing [33]. The complexity of the data can range from structured to nonstructured data [11], [34] which can be in the form of text, images, audio, and video. The data can range from historical data, sensor data, live streamed data, business, and market related data. The use of cloud IoT platforms allow for big data collected from sensors to be stored in the cloud. This includes hosting of application that are critical in providing services and to manage end-to-end IoT architecture. Recently, edge or fog computing is advocated, where IoT devices and gateways carry out computation and analysis in order to reduce latency for critical applications, reduce cost and promote QoS [35], [36].

There are several agriculture management information systems that have been developed to manage the various forms of data [33]. Examples of some of the commercially available platforms are Onfarm systems, Farmobile, the silent herdsman platform, Cropx [37], Farmx [38], Easyfarm [39], KAA [40], and Farmlogs [41]. This platforms provide data storage, data management, and DA. Table III provides a summary of IoT solutions for agriculture.

E. Summary

In the deployment of IoT device, there are key technical parameters that needs to be considered. For wireless connectivity, the following parameters should be considered: the range of communication distance, data rate, battery life, mobility, latency, security and resilience, and cost of gateway modems. Among the communication technology, the LPWA is attracting so much interest [47] especially with the emergence of NB-IoT. The NB-IoT promises interesting features which include low device power consumption, ultralow device cost, simpler to implement, support of a massive number of low-throughput devices, long distance coverage and can support upload and download of data [48], [49]. There are several use cases of IoT in agriculture which have adopted the use of the IoT ecosystems discussed in this section. Some of these applications are discussed in Section III.

TABLE II
COMMUNICATION TECHNOLOGY

Type	Spectrum	Transmission Distance	Type of Network	Frequency Bands	Bi-directional link	Data Rate
802.11a/b/g/n/ac	Unlicensed	6 - 50 m	WLAN	2.4/5 GHz	✓	2 Mbps - 7 Gbps
802.11ah	✓	1000 m	✓	various, sub -1 GHz	✓	78 Mbps
802.11p	Licensed	<1 km	✓	5.9 GHz	✓	
802.11af (white space)	✓	1 km	✓	54-790	✓	26.7 - 568.9 Mbit/s
SigFox	✓	Rural: 30-50 km Urban: 3-10 km	LPWA	868 or 902 MHz	✓	100 bps(UL), 600 bps(DL)
LoRaWAN	✓	<20 km	✓	various, sub-GHz	✓	0.3-37.5 kbps
Ingenu/OnRamp	✓	15	✓	2.4 GHz	χ	78 kbps (UL), 19.5 kbps (DL)
Telensa	✓	1 km (Urban)	✓	60 MHz, 200 MHz, 433 Mhz, 470 MHz, 868 MHz, 915 MHz	✓	62.5 bps(UL), 500 bps(DL)
3GPP NB-IoT	Licensed (cellular)	<35 km	✓	450 MHz - 3.5 GHz	✓	250 kbps
3GPP LTE-MTC (Cat-M1)	✓	<5 km	WWAN	1.4 MHz	✓	200 kbps
EC-GPRS	✓	✓	✓	GSM licensed bands	✓	240 kbps
WiMAX	Licensed and Unlicensed	up to 50-80 km	✓	2 - 11 Ghz, 10 - 66 Ghz	✓	70 Mbps
Bluetooth	Unlicensed	< 100 m	WPAN	2.4 GHz	✓	2 Mbps - 26 Mbps
ANT+	✓	<30 m	✓	2.4 GHz	✓	
MiWi	✓	<50 m	✓	Sub-GHz, 2.4 GHz	✓	256
ZigBee	✓	< 1 km	WHAN	2.4 GHz	✓	250 kbps
Z-Wave	✓	< 100 m	✓	900 MHz	✓	100 kbps
Thread (6LoWPAN)	✓	< 30 m	✓	868/915/2450 MHz	✓	250 kbps
Enocean/ (ISO/IEC 14543-3-10)	✓	< 30 m	✓	900 MHz	✓	125 kbps
WirelessHART	✓	< 228 m	WFAN	2.4 GHz	✓	250 kbps
NFC	✓	< 20 cm	P2P	13.56 MHz	χ	424 kbit/s

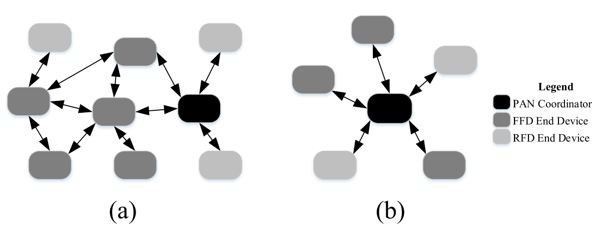


Fig. 3. Topology. (a) Peer-to-peer. (b) Star.

III. APPLICATION OF IOT IN AGRICULTURE

There are several examples of application of IoT in agriculture. Examples of such use case are crop and livestock [50], [51], machinery [52], irrigation and water quality monitoring [53]–[60], weather monitoring [61], soil monitoring [61], [62], disease and pest control [63], [64], automation and precision [65]. The application of IoT is discussed based on the following functions: monitoring, tracking and tracing, agriculture machinery, precision agriculture, and greenhouse production.

A. Monitoring

In agriculture several factors can be monitored, these factors depend on the sector of agriculture under considerations. The key factors to be monitored are highlighted and discussed as follows.

1) Crop Farming: In crop farming, there are several environmental factors that affect farm produce. Acquiring such data help to understand the patterns and process of the farm. Such data includes, the amount of rainfall, leaf wetness, temperature, humidity, soil moisture, salinity, climate, dry circle, solar radiation, pest movement, human activities, etc. [66]. The acquisition of such detailed record enables optimal decision making to improve the quality of the farm produce, minimize

TABLE III
EXAMPLES OF IOT SOLUTIONS FOR AGRICULTURE

IoT solutions	Services	Remarks
OnFarm [42]	A farm management tool that displays and analyses data from many different sources	Provides three levels of subscriptions which are free, standard and enterprise. Each subscription comes with different levels of functionalities
Phytech [43]	Provides Plant IoT platform for direct sensing, data analytics, plant status and recommendations	Provides growers with decision support service to increase yield and optimize irrigation
Semios [44]	Focuses on network coverage, pests, frost, diseases and irrigation for orchards.	Real time monitoring services event notifications are provided
EZfarm [45]	An IBM project that focuses on water management, monitoring of soil and health of plant.	A trial project in Nairobi Kenya
KAA [40]	Provides remote crop monitoring, resource mapping, predictive analytics for crop and livestock, livestock tracking, stats on livestock feeding and produce, smart logistics and warehousing	An open IoT cloud platform that addresses a large IoT use cases and rapid IoT product development
MbeguChoice [46]	Is an application that helps farmers to access better seeds, drought tolerant and variety of seeds from various suppliers	Targeted towards Kenya farmers
Farmlogs [41]	Farm management software for automatic activity recording and crop health imagery	Provides three levels of subscriptions which are free, essentials and premium.
Cropx [37]	Provides adaptive irrigation software services that delivers crop yield increase, water and energy cost saving services.	Involves cost of sensors and annual subscriptions for cloud services which allows you to monitor your soil anywhere and anytime

risk, and maximize profits. For instance, the solar radiation data gives information about the plants exposure to sunlight from, where the farmer can identify if the plants are properly exposed or over exposed. The soil moisture content gives information on the dampness of the soil which can help in controlling soil conditions and reduce the risk of plant diseases. Furthermore, timely and accurate weather forecasting data, such as, climatic changes and rainfall, can improve the productivity level. In addition, such data can help farmers in the planning stage and reduce the cost of labor. The farmers can also take corrective and preventive measures in advance based on the data provided. The pest movement data can be collected and remotely fed live to the farmers for pest control or used to provide advice to the farmers based on record tracking of pest attacks [67].

2) Aquaponics: Aquaponics is the combination of aquaculture and hydroponics, where fish wastes are fed into plant farms to provide the essential nutrients required by the plants. In such farms, it is important to constantly monitor the water quality, water level, temperature levels, health of the fishes, salinity, pH level, humidity, and sunlight [68]. The accurate data can improve the fish and plants yield as it allows nutrients transfer between the plants and fish. The data can also be used for automation purposes with less human intervention.

3) Forestry: Forestry plays an important role in the carbon cycle, and also harbor over two-thirds of world known species. The factors to be monitored in a forest includes; soil and air temperatures and humidity, and the different levels of gases, such as carbon monoxide, carbon dioxide, toluene, oxygen, hydrogen, methane, isobutane, ammonia, ethanol, hydrogen sulphide, and nitrogen dioxide [69]. These parameters can provide early warning and alert systems against veld fire in the forest and also help to monitor against diseases.

4) Livestock Farming: The factors to be monitored in livestock depends on the types of animals under consideration [70]. For example, the conductivity of milk from buffaloes and cows can give information about the health state of the animals. Other factors are temperature, humidity, yield, pest attack, and water quality. The deployment and implementation solution also allow farmers to track and query the location of their livestock by tagging individual animal with RFID device, thereby preventing animal theft.

Other areas, such as storage monitoring which includes water, fuel, and animals feeds can also be monitored, and the data can help the farmers to plan ahead and save cost. While several solutions have been provided in the area of monitoring, the adoption in small and medium scale farms are very much limited especially in developing countries due to lack of awareness and deployment cost. The potential to develop cost effective agricultural base IoT solutions is still a very open area.

B. Tracking and Tracing

IoT can also be applied in asset tracking to improve companies supply chain and logistics. IoT can provide data to enable agricultural companies to make better decisions, planning, intelligently connect with business partners, and save time and money. Information, such as location, asset identification can be tracked using RFID and cloud-based global positioning system (GPS) [8].

Tracking and tracing of agricultural product chain allows the consumer to know the complete history of the product, thereby improving the consumer's trust on the product safety and health related issues. While tracking is the ability to capture, collect, and store data related to the supply chain from upstream to downstream, tracing allows the product to be distinguished from downstream to upstream. Tracking and tracing allows several data to be collected along the supply chain such that the consumer and other stakeholders are guaranteed on the origin, location, and life history of a product [71], [72].

There are several factors that can be tracked which include the growing environment, production conditions, pest factors, management factors, storage conditions, transportation, and time to market. These factors can also pose direct or potential health risk to consumers. The significant factors which affects the growing environment are the soil, air, and water. The production conditions are influenced by the application of herbicides, fertilizers, pesticides. In addition, the type of feeds and vaccines administered to livestock can be tracked since they could directly cause health safety issues. Agricultural products can generally be affected by pest along the entire process, which could affect the quantity and quality of the product, tracking the products can help the farmers to improve the production and supply chain.

A tracking and tracing systems should basically include: information input, storage, transfer, process, and output. The input information includes the data of the entire life cycle of the product, the geographical origin, the current position, destination, and the stakeholders involved in the entire supply chain [73]. The systems should also include memory to store the information over a period of time for research and development purposes. The information transfer refers to the process of unifying and standardizing the entire information. The tracking and tracing system should also be able to process the data collected and finally output it to everyone involved along the supply chain. The use of RFID in tracking from the production stage, processing, transportation, storage, distribution, sales and after sales services is highlighted in [74]. It provides the ability to collect, store, and analyze data over a long distance at a quick speed.

C. Agricultural Machinery

IoT-based agricultural machinery can help improve crop productivity and reduce grain losses. By proper mapping, use of GPS and global navigation satellite systems (GNSSs) the machinery can be operated in autopilot mode [52], [75]. The machines which include vehicles, unmanned aerial vehicles (UAVs) and robots can be remotely controlled based on the available information collected via the IoT system for precise and efficient application of resources to required farm areas [76]. The machinery can also collect data and such data can help farmers in mapping their field for planning programs, such as fertilizing, irrigation, nutrition [77]. For example, CLAAS, an agricultural machinery manufacturer has implemented IoT on their equipment, enabling their machinery to be operated in auto pilot mode [78]. Another solution is the Precisionhawk's UAV sensors, which can provide farmers information, such as wind speed, air pressure, among other parameters [79]. The solution can also be used for imagery and mapping of agricultural plots.

D. Precision Agriculture

Precision agriculture can simply be defined as the collection of real-time data from farm variables[2] and use of predictive analytics for smart decisions in order to maximize yields, minimize environmental impact, and reduce cost [80]. Precision agriculture relies on various technology, which include sensor nodes [81], [82], GPS and big DA to achieve improved crop yield. The smart decision achieved from the DA also results in less waste of resources, such as water in irrigation systems, fertilizer, pesticides, etc. Precision agriculture presents new challenges for researchers in the area of robotics, image processing, meteorological data sensing, etc. With the GPS and GNSS, farmers are able to locate precise location and map sites with several data variables, which are then used by variable rate technology to optimally distribute farm resources, such as seeding, spraying, and other services. Although precision agriculture technology can improve yield, it is essential to provide solutions that are easy to use by the farmers and also provide training to enable small and medium scale farmers benefit from the systems.

[2]Examples of farm variables are weather, soil and air quality, crop maturity and even equipment, and labor costs and availability.

E. Greenhouse Production

Greenhouse also known as glasshouse technology is a technique, where plants are grown under controlled environment. It offers the benefit of growing any plant in any place at any time by providing suitable environmental conditions. Several studies have been carried out on the application of WSNs in greenhouse to monitor environmental conditions [83]–[85]. Recent works have shown how IoT can be applied to greenhouse in order to reduce human resource, save energy, increase efficiency in greenhouse-site monitoring, and direct connection of greenhouse farmers to customers [61], [66], [86].

IV. IoT and Data Analytics in Agriculture

Accurate data analysis in farming plays a major role in improving the operational efficiency and increasing productivity. DA has been categorized into types based on requirement of IoT applications [87]. This includes real-time analytics, off-line analytics, memory-level analytics, business intelligence level analytics, and massive analytics [87]–[89]. The data consist of sensor data, audio, images, and video. Image processing has been extensively used in agriculture for various purposes ranging from detection of disease in leaf, stem, and fruit [90], quality of fruits [91], and weed detection and irrigation [76], [90], [92]–[94]. Recently, the combination of image processing and IoT in agriculture is being carried out to achieve higher quality produce and reduce crop failure. This involves the use of drones to capture aerial images at regular interval as well as monitoring of environmental factors using the IoT devices [76], [92], [94]. There are several DA methods which has been discussed in detail in [95]. The methods are categorized into classification, clustering, prediction, and association rule. The discussion of these methods is outside the scope of this paper. We discuss the importance of DA in agriculture and how DA can help in insurance, prediction, storage management, decision making, farm management, and precision farming.

A. Prediction

IoT provides big data that can be studied over time to estimate the present environmental conditions. The data collected across different types of networks sensors can be studied using DA and smart algorithm can be developed to predict the environmental changes and provide data driven solutions. Although IoT data can help in controlling various aspects of a farm, such as the irrigation systems, the data can also be used to predict and warn farmers against disease or extreme weather conditions, such as flood or drought [64]. For instance, in forestry, the sensors can be used to monitor fire outbreak or predict the region in a forest that provides high risk of fire outbreak. This information can help the firefighters to take preventive measures on the exact location. Other area of prediction includes early warning against natural disasters to improve emergency response [96].

B. Storage Management

A large number of agricultural products are usually lost due to poor storage management system. While temperature, moisture and other environmental factors greatly affect the contamination of food products, insects, microorganism, rodent, etc. can affect the quality and quantity of the food products [97]. The use of IoT and DA in storage management systems can help to improve agricultural product storage [98]. Sensors can be deployed to monitor the storage facilities and environmental conditions. The data are sent to the cloud and analyzed. A self-automated decision system, which relies on the analyzed data can be deployed to adjust the environmental conditions. Moreover, a warning alert can be initiated to farmers when extreme conditions are reached or if pest are reported in the storage facility. In India, it is reported that about 35% to 40% of the fresh product are lost after harvesting due to several factors which includes spoilage or pest [97]. In [99], a cold storage management system is designed based on IoT technology, where the storage facility is operated at a controlled temperature. Although IoT can improve the agricultural storage facility, security should be embedded into such system to avoid product theft in case of power outages.

C. Decision

Decision making requires reliable information which can be obtained from sensors data. The large data obtained from sensor offers learning opportunities to improve decision making in constantly changing environmental conditions, such decision making can be over a short, medium, or long term. Automated decisions can be made from the IoT system when certain conditions are reached, therefore requiring less or no human interventions. Such automated decision could range from regulating the temperatures to the control of water supply from an irrigation system. For instance, in greenhouses the use of machine learning can help determine optimal conditions under which to grow a certain crop by observing the data acquired from sensors relating to nutrients, yield, growth, transpiration, color, taste, and retransplantation, light temperature pest levels and air quality.

Policy making decision by government and all the stakeholders can also be enhanced by the amount of information obtained from DA, therefore it is important that the data is accurate, concise, complete, and in time. Several agricultural decision-making systems have been developed to enable farmers to make informed decision regarding their farms and livestock [100]. The DA provides decision on technical guidance to farmers, pests and diseases control and recommendation from remote expert guidance systems.

D. Farm Management

Integrated farm management system allows an entire farm to be monitored. Data are collected through a network of sensors including the on-body sensors in animals with a sole purpose of driving productivity. Three key factors which include risk management, cost, and productivity yield need to be managed with real time information and properly optimized to maximize productivity [13]. DA plays a major role to present the farmers and stake holders with large data that can be carefully studied to avoid unnecessary risk or implement preventive measures to improve productivity. DA also allow various farms to be connected and managed on a single platform, where information on scientific advances, production, marketing, farm management, recommendations and other related topics are disseminated to maximize productivity, yield, and revenue.

E. Precise Application

DA using measured data from sensors can enable precise application of chemicals and fertilizers to specific areas of the farm, this can improve the productivity while reducing the farming cost. Although precision farming systems have been deployed in farms in advanced countries, developing countries are beginning to adopt the technology especially in research farms [14]. However, the deployment cost, technology and awareness still limits the deployments of IoT-based precision farming systems in developing countries. In addition, most of the farms in developing countries are small scaled farms as such, most farmers do not see the need to apply such technology. Developing appropriate precision farming solutions for small farms still remains an open area for researcher and designers. Another advantage of DA in precision farming is its application in steering machinery using GPS and location data to precise locations in the farm thereby improving the farming efficiency when compared with human driven machines. This can save time, fuel and operational cost.

F. Insurance

Farmers are usually exposed to extreme weather conditions which could lead to poor harvest. However, with the implementation of IoT technology farmers can be insured with their crops and livestock. A network of sensors can be deployed, and monitoring can be achieved by remote unmanned stations. The data can be sent to the cloud and analyzed. The insurance policy can be embedded with a warning systems, where extreme weather conditions are predicted and the insured farmers are alerted by text messages. This can enable the farmers take precautionary approach to protect their farms. An added advantage of DA in insurance is the fact that the insurance companies have access to the data from the remote farms and can initiate an automated payout thought the IoT mobile payments systems when extreme conditions are observed.

This can eliminate the need for lengthy claim process, where the insurance company needs to ascertain the extent of damage by visiting the farms.

V. Benefits

There are several benefits that can be derived from the use of IoT in agriculture. Some of the benefits have been mentioned in the discussion of application of IoT in Sections III and IV. However, we reiterate and summarize some of the benefits as follows.

1) *Community Farming:* The use of IoT can help promote community farming especially in the rural areas. The IoT can be leveraged to promote services that allows the community to have a common data storage, share data and information, increase interaction between the farmers and agriculture experts [101]. Also, through the use of mobile apps and IoT facilities equipment can be shared within the community via free or paid services.
2) *Safety Control and Fraud Prevention:* The challenge in the agriculture sector is not just limited to sufficient production but also the ability to ensure safe and nutritious food supply. There have been several reports in food fraud which includes adulteration, counterfeit, artificial enhancement [102]. This fraud poses health challenge and can have negative economic impact [103], [104]. Some of the components of food fraud discussed in [104] are product integrity, process integrity, people integrity, and data integrity can be addressed using IoT technology. IoT can be used to provide logistics traceability and qualitative traceability of food [105].
3) *Competitive Advantages:* The increase in demand for food and the use of innovative technology is expected to make the agriculture sector very competitive. Also, the enabling of data driven agriculture using IoT will open new direction in trading, monitoring, and marketing. The ability to lower costs, reduce wastage in application of farm inputs, such as fertilizer and pesticides increase productivity. The use of real-time data for decision making will provide the competitive advantage needed for farmers who adopt the IoT ecosystem.
4) *Wealth Creation and Distributions:* The deployment of IoT will provide new business models, where the single farmers can avoid the exploitation of "middle men" and can be in direct relationship with the consumers [10] leading to higher profit.
5) *Cost Reduction and Wastage:* One of the perceived advantages of IoT is the ability to monitor remotely devices and equipment [106]. The application of IoT in agriculture will help to save time and money in inspecting large fields compared to personnel physically inspecting the field either via use of vehicles or walking. The ability to know when and where to apply pesticides or insecticides using IoT will reduce cost and wastage.
6) *Operational Efficiency:* The operational efficiency not only relates to farmers but to decision makers related to agriculture sector, such as government and non-governmental agencies. Data gathered from agriculture surveillance schemes via IoT can serve as a guide in agriculture interventions. Such interventions can be prevention of spread of diseases, veld fire outbreaks, compensation schemes and resource allocations. In addition, farmers can take advantage of IoT and DA to take accurate and timely decisions in terms of farm management and farm processes. The ability to automatically document health status of livestock or crop will provide efficient and effective diagnosis and prescription of medicine by veterinary or agriculture officer to farmers. This will help reduce loss. Also, with the use of IoT, supply chain of agri-food can be optimized. The use of the IoT in the supply chain will help to provide real time balancing between the demand and supply.
7) *Awareness:* IoT is expected to drive low cost applications and access to wireless network services in the agriculture sector. To this end, information on markets, prices, services can be accessed via mobile apps. Also, government services and regulatory standard regarding different farm produce can be made readily available. In addition, consumers who are interested in organic products and fresh products can easily locate farmers or be alerted when fresh products are available.
8) *Asset Management:* IoT will enable real time monitoring of farm assets and machinery against theft, replacement of parts, and for timely routine maintenance.

VI. Open Issues and Key Challenges

There are several challenges that are associated with deployment and application of IoT. Some of the challenges identified in the literature are security and privacy, data convergence and ownership, lack of interoperability, heterogeneity of IoT devices, uncertainty in business models [5], [107]. We discuss issues under three main headings which are business, technical, and sectoral issues.

A. Business Issues

The profit margin in the agriculture sector is very thin and as such there is the need to balance the tradeoff between the deployment of IoT enabling technology versus the potential profits. Hence, we discuss business issues related to the IoT deployment by considering cost and business models.

1) Cost: There are several cost associated with the deployment of IoT in agriculture which can be categorized into setup cost and running cost. The setup cost includes purchase of hardware (IoT devices, gateways, base station infrastructure). The running cost involves continuous subscription for use of centralized services or IoT platforms which provides data collection, management of IoT devices, sharing of information among other services. Other additional running cost are cost incurred from exchange of data between IoT devices, gateway and cloud server, energy, and maintenance. According to Turgut and Boloni [108] the success of IoT has to satisfy two conditions which are: 1) the customers are persuaded that the IoT devices provide a value that exceeds their physical and privacy costs and 2) the businesses involved in

IoT will successfully make money. The first condition can be expressed as

$$\left(V_s - C_{\text{pri}} - C_h^{\text{user}} - C_{\text{pay}}\right) > 0 \quad (1)$$

where V_s is the perceived value of the user, C_{pri} is the cost of loss of privacy, C_h^{user} cost of hardware and associated services and C_{pay} is the payment for service charge and the second condition can be expressed as

$$\left(V_{\text{info}} + R_{\text{pay}} - C_h^{\text{business}}\right) > 0 \quad (2)$$

where V_{info} is the value of information received, R_{pay} is the direct payment received, and C_h^{business} is the business's share of hardware and maintenance costs. From (2) while the value of information received is meant for provision of the services needed by the user, this can be commercially exploited by the service provider in the course of service provision. Although some of the IoT platform providers provide free subscription services with limited functionality, limited number of IoT devices that can be connected and limited amount of data that can saved. More functionality and services attract higher subscription fees.

2) Business Models: Farmers would be interested in business models that supports revenue generation from the data accumulated from their farm using IoT technologies. Most of the existing IoT platforms service providers, provide free limited services and full services with different level of subscriptions. The data provided are exploited by the IoT service providers and this remains an area of contention by farmers for control and ownership of their data.

3) Lack of Adequate Knowledge: The lack of adequate knowledge of IoT and its application especially among farmers located in rural areas is a major factor slowing the adoption of IoT in agriculture. This is common in the developing countries where majority of the farmers are often found in the rural areas and are mostly uneducated. The farmer's inability to use information could be a major barrier if human interventions are not available [12].

B. Technical Issues

1) Interference: The deployment of massive IoT devices for agricultural and other purposes will cause interference problems especially with the IoT devices using the unlicensed spectrum, such as ZigBee, Wi-Fi, Sigfox, and LoRa (see Table II). The interference caused can lead to loss of data and reduce the reliability of the IoT ecosystem. The technology to make IoT devices using the unlicensed spectrum interference proof will add to cost of the device. On the other hand, the use of IoT devices operating with licensed spectrum is expected to eliminate unnecessary interference. However, due to limited pilot assignment in the cellular band, the reuse of nonorthogonal multiple access scheme or frequency reuse can still cause interference amongst IoT devices using cellular licensed spectrum.

2) Security and Privacy: There are several security issues that needs to be addressed at different level of the IoT ecosystem. The lack of adequate security may lead to loss of data, bridge of privacy, and access to raw information about on-field parameters and other sensitive intellectual properties. This can compromise the competitive advantages of private farm owners. The IoT security and privacy issues have been discussed extensively in [106], [109], and [110]. According to the interview-based studies carried out by Asplund and Nadjm-Tehrani [106] on the attitudes and perception of IoT, security was considered a major obstacle in the deployment of IoT. There are several security issues that needs to be addressed at different level of the IoT ecosystem.

In agriculture, the IoT devices are vulnerable to physical tampering, such as theft or attacks by predators and animals, change of physical address or link [110], [111]. In addition, for the IoT devices, it is difficult to implement complex and sophisticated algorithms due to limited memory, communication capabilities, and low energy consumption. The gateway can be prone to congestion attack, denial of service (DoS), and forwarding attacks. The security and position of location information and IoT enabled location-based service which are used for precision farming are exposed to attacks, such as device capture attack [109], [110], [112]. In the device capture attack, an attacker captures the IoT device and extracts cryptographic implementations and enjoy unrestricted access to the information stored in the device's storage. Other higher communication layers can be vulnerable to DoS attacks, wireless signal jamming, and man in the middle attack [110]. In addition, the cloud servers can be prone to data tampering, unauthorized services which can affect automated processes in the farms. Other security treats that can affect the cloud infrastructure are session hijacking, cloud access control and database issues, hijacking attacks, logon abuse, and DoS [110].

3) Choice of Technology: There are several IoT technologies that have been developed recently, some of which are still going through pilot test. The right choice of IoT technology is a big challenge because a lot of investment is required for deploying new technologies. Currently, it is difficult to tell which of the new IoT technologies will dominate the market. Many factors need to be considered, such as support for roaming, suitability of technology to small-scale, medium-scale and large-scale, suitability to different geographical location, soil types and climatic conditions.

4) Reliability: The IoT devices are expected to be deployed in out-door environment. This will expose the devices to harsh environmental conditions which may lead to degradation of deployed sensors with time as well as communication failures. The physical safety of the deployed IoT sensors and systems must be ensured in order to protect the costly equipment from severe weather conditions, such as flood and hurricanes.

5) Scalability: Billions of IoT devices are expected to be deployed in the agriculture sector. Existing gateways and protocols will need to support large number of IoT devices/nodes. For example, the Sigfox gateway can support up to 10^6, Ingenu 10^4, and LoRa 10^4 nodes, respectively. This will require intelligent IoT management system for each node and identification numbers.

6) Localization: There are several factors that needs to be considered for deployment of IoT devices. Such factors include the ability for the IoT device to support place and play functionality, i.e., be placed anywhere and connected to the rest of the world with no (or minimal configuration or deploying additional devices, such as gateways) [113]. Other factors are the best position to place the IoT device that will provide adequate information and reliability without causing interference (or minimal interference). In addition, the ability to support IoT device roaming for nomadic IoT devices and deployment of static IoT devices in location without prior knowledge of the mobile IoT technology/infrastructure needs to be considered.

7) Optimization of Resources: Farmers need resources optimization mechanism to determine how many gateways, IoT devices, amount of transmitted data, size of cloud storage are needed in order to have a breakthrough in profit margins. This is particularly challenging due to different farm sizes and different type of sensors needed to monitor farm variables for specific crops or livestock. This will require development of complex algorithm and mathematical models to be able to determine optimal resource allocation while minimizing cost and maximizing agriculture produce and profits.

C. Sectoral Issues

1) Regulatory Challenges: Regulation and legal frameworks regarding the control and ownership of farm data between farmers and data companies needs to be sorted out. The regulations may differ from countries to countries in terms of resource allocation (i.e., spectrum for cellular IoT), technical challenges, competition, data privacy, and security. Different regulations across regions or countries may affect the application of IoT in use cases, such as tracking and agri-food supply.

2) Interoperability: There are ongoing works on protocols and standards needed for billions of IoT devices to interoperate. This involves technical, syntactic, semantic, and organization interoperability [5], [9], [114]. The technical interoperability involves the development of protocols and infrastructure that enables the IoT devices to communicate [115]. It is usually associated with the hardware/software components of the IoT ecosystem. The syntactical interoperability is associated with data formats, such as extensible markup language (XML), java script object notation (JSON), comma separated variables, electronic data interchange as standard syntax for data sharing [5]. The semantic interoperability deals with the interpretation of contents exchanged between human. The organizational interoperability is the ability to effectively communicate and transfer data successfully across different infrastructure, geographic region and cultures. Thus, a key requirement here is that all systems provide export facilities or API access that return standard formats, typically XML or JSON, and where possible legacy systems are provided with appropriate interchange gateways.

According to [116], interoperability can be achieved using three methods which are: 1) partnerships among product and service developers; 2) open and close standards, and 3) adaptors and mediator services. In order to achieve interoperability, groups, such as openconnectivity [117] are promoting interoperability in IoT. In addition, the use of adapter services, such as if this then that [118] that allows users to create powerful connections and chains of simple conditional statements are currently being used. It is important to note that some of these methods may not provide widely enabled interoperability among IoT devices due to scalability. More work is expected in promotion of open standards to achieve greater operability among billions of IoT devices and services.

D. Summary

The open issues and challenges discussed in this section can serve as a factor for the slow adoption of IoT in the agriculture sector if not well addressed. More reports are needed on the monetary benefits of adopting IoT in agriculture. The issues of privacy and security will continue to remain a top priority for farmers, although this is expected to change over time as people become use to IoT and its services. Also, as the cost of IoT devices and cost of data storage, processing, and transfer reduces with time small and medium scale farmers will be able to deploy the IoT systems.

VII. Future Trends and Opportunities

From our studies and review of current trends in the application of IoT in agriculture, we present the future trends based on the following areas: 1) technological innovations; 2) application scenarios; and 3) business and marketability.

A. Technological Innovation

More and more IoT solutions will continue to emerge and this will introduce new and disruptive technologies especially in the agriculture sector. Some of the areas identified are discussed as follows.

1) Deployment of LPWA Technologies: The LPWA is expected to dominate the agriculture sector as this offers so many advantages, such as low power and long-range communication. The release of the 3GPP NB-IoT standard and adoption by many telco operators will attract many research interests in investigating the use of NB-IoT communication technologies. This will enable large-scale pilot test of IoT in agriculture [5].

2) Universal Platform: The development of IoT platform for agriculture purpose will shift from just specific crops or livestock to a universal platform (also known as generic platform) that can support any kind of crop and livestock. This will allow a system that can be easily modified to support a variety of applications ranging from managing and monitoring of crops and livestock to selling of products to local stores and consumers. Such system will be free of any geographical and regional limitations and can serve as the enabler for many IoT in agriculture.

3) Security: The security of IoT device and end-to-end data security will continue to attract more research interest. More research work is needed in the development of IoT device that can support new security schemes, such as advanced signcryption algorithm [119]. The signcryption combines digital signature and data encryption to prevent eavesdropping and unauthorized modification on sensitive information. Security measures to prevent physical attackers and intruders from the IoT devices need to be investigated and new schemes developed.

4) Spectral and Energy Efficiency: Different technologies, such as ultranarrowband channels (Sigfox and Telensa) and spread spectrum (LoRa and Ingenu) are adopted in order to achieve the LPWA requirements [120]. As more LPWA complaint solutions are being rolled out, new technologies that can support higher data, long distance coverage, high path-loss link budget, and extended battery life are required. Majority of the cellular NB-IoT systems currently support frequency bands which operates frequency division duplex modes. More work is expected in bands that operate the time division duplex modes. This will open up other research challenges, such as pilot contamination [121].

Although LPWA aims to achieve ten years battery life, energy efficient mechanism are still needed for IoT devices as the efficiency is highly dependent on the node usage [122]. There exist several algorithms that have been developed for energy efficiency in WSN, such as clustering and in-network processing algorithms [122]–[124]. Other energy efficient schemes for IoT, such as ability to predict the sleep interval of IoT devices-based upon their remaining battery level, their previous usage history, and quality of information required for a particular application as proposed in [125] can be further studied. The application of optimal wireless power transfer enabled IoT transceiver architectures, simultaneous wireless information and power transfer in IoT, energy harvesting IoT devices is expected to attract research interest.

5) Quality of Service: Existing study on the QoS of IoT shows that QoS is required in every layer of the IoT architecture [126], [127]. The ability to ensure that a device that needs to send critical data will be able to do so using IoT with any of the communication technology is still an open research area. The use of NB-IoT communication technology promises high QoS compared to LoRa [26]. More work needs to be done in providing mechanism that guarantees QoS throughout the different IoT network layers.

6) Artificial Intelligence and DA: More work is expected in the use of artificial intelligence to model crop growth and disease management based on farm data and climatic information. Example is the use of machine learning for recognition of disease from images uploaded via smartphones [128]. DA algorithms that can process large amount of data at a much faster rate compared to the IoT communication time are expected to be developed.

7) Privacy-Preservation: End-to-end privacy-preservation methods that allow the extraction of knowledge from data while preserving the privacy of individuals have been proposed to solve the issues relating to IoT data privacy violations [129]–[131]. Examples of the proposed methods designed to guarantee a certain level of privacy while maximizing the utility of the data have been classified based on data life-cycle phase at which the privacy-preservation is ensured [132]. The application of the proposed privacy-preservation methods and how it can further enhance the IoT penetration in the agriculture sector can be further researched.

8) Data Compression: As massive IoT devices are connected there will be need to develop advanced compressing and multiplexing techniques for exchange of data from hundred to thousands of sensors to a central location. This will be particularly needed for transmission of images and video data when NB-IoT cellular communication are employed. Multiplexing will also help in merging data from different farms to a single location providing backup, security and management from a single-point.

9) Real Time Monitoring: As hundreds of different types of sensors are to be deployed in the field for real time monitoring, a simple network management protocol must be devised to support communication between objects and server with less overhead possible. Current protocols are specially designed for network appliances and may cause heavy data traffic and overhead on the network as well as increase the power requirements for the IoT devices.

B. Application Scenarios

Currently, software platforms, IoT devices are being developed and research is ongoing on communication technologies that can deliver low cost IoT deployments. Most of the current work are on prototyping and testing based on small scale. Large-scale pilots are needed to evaluate the usability and usefulness of IoT technologies in agriculture [5]. Future work will see more of large-scale pilot in the entire supply chain and agri-food applications not only in the developed country but as well as developing countries in Asia and Africa.

C. Business and Marketability

1) Cost Reduction: The optimized power consumption of the IoT devices, reduction in physical size, and massive production is expected to drop the cost of IoT solutions for agriculture. Future work will see development of cheaper sensors, research on combination of different deployment scenarios, exploring the use of combined licensed and unlicensed communication technology in order to minimize setup and operating cost.

2) Policies and Regulations: More work on policy enforcement and standardization in the use of IoT in agriculture are expected to be carried out. Involvement of government level or agriculture department must be ensured when working on policies and regulation regarding IoT in agriculture which may differ from region to region as discussed in Section VI-C. This will facilitate early adoption of IoT in agriculture.

VIII. CONCLUSION

An overview of IoT and DA in agriculture has been presented in this paper. Several areas related to the deployment of IoT in agriculture have been discussed in detail. The survey of literature shows that there are lots of work ongoing in development of IoT technology that can be used to increase operational efficiency and productivity of plant and livestock. The benefits of IoT and DA, and open challenges have been identified and discussed in this paper. IoT is expected to offer several benefits to the agriculture sector. However, there are still a number of issues to be addressed to make it affordable for small and medium-scale farmers. The key issues are security and cost. It is expected that as competition increases in the agriculture sector and favorable polices are being implemented the adoption rate of IoT in agriculture will increase accordingly. One major area that is likely to draw lot of research attention is the deployment of LPWA communication technology for agriculture purposes. The NB-IoT is expected to stand out among the LPWA technologies. This is because of the 3GPP open standard and adoption by the telco companies.

APPENDIX

ACRONYMS AND TERMS

3GPP	3rd Generation Partnership Project.
AI	Artificial intelligence.
CSV	Comma separated variables.
DA	Data analytics.
DoS	Denial of service.
EDI	Electronic data interchange.
EE	Energy efficiency.
FDR	Frequency domain reflectometry.
FFD	Full function device.
FPGA	Field programmable gate arrays.
GNNS	Global navigation satellite systems.
GPS	Global positioning system.
IoT	Internet of Things.
JSON	Java script object notation.
ISM	Industrial scientific medical.
IP	Image processing.
LPWA	Low power wide area.
NB-IoT	Narrowband-IoT.
NFC	Near field communication.
P2P	Peer-to-peer.
PAN	Personal area network.
QoS	Quality of service.
RF	Radio frequency.
RFD	Reduce function device.
RFID	Radio frequency identification.
TDR	Time domain reflectometry.
UAV	Unmanned aerial vehicles.
WPAN	Wireless personal area network.
WHAN	Wireless home area network.
WLAN	Wireless local area network.
WSN	Wireless sensor network.
XML	Extensible markup language.

ACKNOWLEDGMENT

The authors would like to thank the feedback and contribution of A. D. McCole of Ericsson Malaysia, Sdn BhD, in the preparation of this paper and O. C. Obiageli of the Universiti Teknologi Malaysia, for helping to proofread this paper.

REFERENCES

[1] A. Zanella, N. Bui, A. Castellani, L. Vangelista, and M. Zorzi, “Internet of Things for smart cities,” *IEEE Internet Things J.*, vol. 1, no. 1, pp. 22–32, Feb. 2014.

[2] L. Sanchez *et al.*, “Smartsantander: IoT experimentation over a smart city testbed,” *Comput. Netw.*, vol. 61, pp. 217–238, Mar. 2014.

[3] E. Park, Y. Cho, J. Han, and S. J. Kwon, “Comprehensive approaches to user acceptance of Internet of Things in a smart home environment,” *IEEE Internet Things J.*, vol. 4, no. 6, pp. 2342–2350, Dec. 2017.

[4] E. Husni *et al.*, “Applied Internet of Things (IoT): Car monitoring system using IBM BlueMix,” in *Proc. Int. Seminar Intell. Technol. Appl. (ISITIA)*, Jul. 2016, pp. 417–422.

[5] C. Brewster, I. Roussaki, N. Kalatzis, K. Doolin, and K. Ellis, “IoT in agriculture: Designing a Europe-wide large-scale pilot,” *IEEE Commun. Mag.*, vol. 55, no. 9, pp. 26–33, Sep. 2017.

[6] N. P. Sastra and D. M. Wiharta, “Environmental monitoring as an IoT application in building smart campus of Universitas Udayana,” in *Proc. Int. Conf. Smart Green Technol. Elect. Inf. Syst. (ICSGTEIS)*, Oct. 2016, pp. 85–88.

[7] S. M. R. Islam, D. Kwak, M. H. Kabir, M. Hossain, and K.-S. Kwak, “The Internet of Things for health care: A comprehensive survey,” *IEEE Access*, vol. 3, pp. 678–708, 2015.

[8] L. Li, “Application of the Internet of Thing in green agricultural products supply chain management,” in *Proc. IEEE Int. Conf. Intell. Comput. Technol. Autom. (ICICTA)*, vol. 1. Shenzhen, China, 2011, pp. 1022–1025.

[9] IERC. (Mar. 2015). *European Research Cluster on the Internet of Things-Outlook of IoT Activities in Europe*. Accessed: Sep. 20, 2017. [Online]. Available: http://www.internet-of-things-research.eu/pdf/IERC_Position_Paper_IoT_Semantic_Interoperability_Final.pdf

[10] N. Dlodlo and J. Kalezhi, “The Internet of Things in agriculture for sustainable rural development,” in *Proc. Int. Conf. Emerg. Trends Netw. Comput. Commun. (ETNCC)*, May 2015, pp. 13–18.

[11] S. Wolfert, L. Ge, C. Verdouw, and M.-J. Bogaardt, “Big data in smart farming—A review,” *Agricult. Syst.*, vol. 153, pp. 69–80, May 2017.

[12] O. Elijah, I. Orikumhi, T. A. Rahman, S. A. Babale, and S. I. Orakwue, “Enabling smart agriculture in Nigeria: Application of IoT and data analytics,” in *Proc. IEEE 3rd Int. Conf. Electro Technol. Nat. Develop. (NIGERCON)*, Owerri, Nigeria, Nov. 2017, pp. 762–766.

[13] N. Wang, N. Zhang, and M. Wang, “Wireless sensors in agriculture and food industry—Recent development and future perspective,” *Comput. Electron. Agricult.*, vol. 50, no. 1, pp. 1–14, 2006.

[14] S. Ivanov, K. Bhargava, and W. Donnelly, “Precision farming: Sensor analytics,” *IEEE Intell. Syst.*, vol. 30, no. 4, pp. 76–80, Jul./Aug. 2015.

[15] G. H. E. L. de Lima, L. C. e Silva, and P. F. R. Neto, “WSN as a tool for supporting agriculture in the precision irrigation,” in *Proc. 6th Int. Conf. Netw. Services*, Cancún, Mexico, Mar. 2010, pp. 137–142.

[16] W. Merrill, “Where is the return on investment in wireless sensor networks?” *IEEE Wireless Commun.*, vol. 17, no. 1, pp. 4–6, Feb. 2010.

[17] S. E. Díaz, J. C. Pérez, A. C. Mateos, M.-C. Marinescu, and B. B. Guerra, “A novel methodology for the monitoring of the agricultural production process based on wireless sensor networks,” *Comput. Electron. Agricult.*, vol. 76, no. 2, pp. 252–265, 2011.

[18] M. S. M. Amin, W. Aimrun, S. M. Eltaib, and C. S. Chan, “Spatial soil variability mapping using electrical conductivity sensor for precision farming of rice,” *Int. J. Eng. Technol.*, vol. 1, no. 1, pp. 47–57, 2004.

[19] J. A. Manrique, J. S. Rueda-Rueda, and J. M. T. Portocarrero, “Contrasting Internet of Things and wireless sensor network from a conceptual overview,” in *Proc. IEEE Int. Conf. Internet Things (iThings) IEEE Green Comput. Commun. (GreenCom) IEEE Cyber Phys. Soc. Comput. (CPSCom) IEEE Smart Data (SmartData)*, Chengdu, China, Dec. 2016, pp. 252–257.

[20] R. Nukala *et al.*, “Internet of things: A review from ‘farm to fork,”’ in *Proc. 27th Irish Signals Syst. Conf. (ISSC)*, Jun. 2016, pp. 1–6.

[21] A. Z. Abbasi *et al.*, “A review of wireless sensors and networks’ applications in agriculture,” *Comput. Stand. Interfaces*, vol. 36, no. 2, pp. 263–270, 2014.

[22] S. Li, A. Simonian, and B. A. Chin, “Sensors for agriculture and the food industry,” *Electrochem. Soc. Interface*, vol. 19, no. 4, pp. 41–46, 2010.

[23] N. Ahmed, H. Rahman, and M. I. Hussain, “A comparison of 802.11ah and 802.15.4 for IoT,” *ICT Exp.*, vol. 2, no. 3, pp. 100–102, 2016.

[24] Y. D. Beyene *et al.*, “NB-IoT technology overview and experience from cloud-RAN implementation,” *IEEE Wireless Commun.*, vol. 24, no. 3, pp. 26–32, Jun. 2017.

[25] U. Raza, P. Kulkarni, and M. Sooriyabandara, “Low power wide area networks: An overview,” *IEEE Commun. Surveys Tuts.*, vol. 19, no. 2, pp. 855–873, 2nd Quart., 2017.

[26] R. S. Sinha, Y. Wei, and S.-H. Hwang, “A survey on LPWA technology: LoRa and NB-IoT,” *ICT Exp.*, vol. 3, no. 1, pp. 14–21, 2017.

[27] *Machina*. Accessed: Oct. 1, 2017. [Online]. Available: https://machinaresearch.com/reports/

[28] F. TongKe, “Smart agriculture based on cloud computing and IoT,” *J. Converg. Inf. Technol.*, vol. 8, no. 2, 2013.

[29] L. D. Xu, W. He, and S. Li, “Internet of Things in industries: A survey,” *IEEE Trans. Ind. Informat.*, vol. 10, no. 4, pp. 2233–2243, Nov. 2014.

[30] A. H. Ngu, M. Gutierrez, V. Metsis, S. Nepal, and Q. Z. Sheng, "IoT middleware: A survey on issues and enabling technologies," *IEEE Internet Things J.*, vol. 4, no. 1, pp. 1–20, Feb. 2017.

[31] C. H. Liu, B. Yang, and T. Liu, "Efficient naming, addressing and profile services in Internet-of-Things sensory environments," *Ad Hoc Netw.*, vol. 18, pp. 85–101, Jul. 2014.

[32] L. Atzori, A. Iera, and G. Morabito, "The Internet of Things: A survey," *Comput. Netw.*, vol. 54, no. 15, pp. 2787–2805, 2010.

[33] D. Yan-e, "Design of intelligent agriculture management information system based on IoT," in *Proc. 4th Int. Conf. Intell. Comput. Technol. Autom.*, vol. 1. Shenzhen, China, Mar. 2011, pp. 1045–1049.

[34] M. R. Bendre, R. C. Thool, and V. R. Thool, "Big data in precision agriculture: Weather forecasting for future farming," in *Proc. 1st Int. Conf. Next Gener. Comput. Technol. (NGCT)*, Sep. 2015, pp. 744–750.

[35] X. Chen, Q. Shi, L. Yang, and J. Xu, "ThriftyEdge: Resource-efficient edge computing for intelligent IoT applications," *IEEE Netw.*, vol. 32, no. 1, pp. 61–65, Jan./Feb. 2018.

[36] G. Premsankar, M. D. Francesco, and T. Taleb, "Edge computing for the Internet of Things: A case study," *IEEE Internet Things J.*, vol. 5, no. 2, pp. 1275–1284, Apr. 2018.

[37] *Cropx*. Accessed: Sep. 20, 2017. [Online]. Available: https://cropx.com/

[38] *Farmx*. Accessed: Sep. 20, 2017. [Online]. Available: http://www.farmx.co/

[39] *Easyfarm*. Accessed: Sep. 20, 2017. [Online]. Available: http://www.easyfarm.com/

[40] *KAA*. Accessed: Sep. 20, 2017. [Online]. Available: https://www.kaaproject.org/agriculture/

[41] *Farmlogs*. Accessed: Sep. 20, 2017. [Online]. Available: https://farmlogs.com/

[42] *Onfarms*. Accessed: Sep. 20, 2017. [Online]. Available: http://www.onfarm.com/

[43] *Phytec*. Accessed: Sep. 20, 2017. [Online]. Available: https://www.phytech.com/

[44] *Semios*. Accessed: Sep. 20, 2017. [Online]. Available: http://semios.com/

[45] *EZ Farm*. Accessed: Sep. 20, 2017. [Online]. Available: https://www-03.ibm.com/software/businesscasestudies/lb/en/corp?synkey=T869341Z93257N45

[46] *Mbeguchoice*. Accessed: Sep. 20, 2017. [Online]. Available: https://http://www.mbeguchoice.com/

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

[48] J. Gozalvez, "New 3GPP standard for IoT [mobile radio]," *IEEE Veh. Technol. Mag.*, vol. 11, no. 1, pp. 14–20, Mar. 2016.

[49] A. Adhikary, X. Lin, and Y.-P. E. Wang, "Performance evaluation of NB-IoT coverage," in *Proc. IEEE 84th Veh. Technol. Conf. (VTC-Fall)*, Montreal, QC, Canada, Sep. 2016, pp. 1–5.

[50] S. Benaissa *et al.*, "Internet of animals: Characterisation of LoRa sub-GHz off-body wireless channel in dairy barns," *Electron. Lett.*, vol. 53, no. 18, pp. 1281–1283, Aug. 2017.

[51] D. García-Lesta, D. Cabello, E. Ferro, P. López, and V. M. Brea, "Wireless sensor network with perpetual motes for terrestrial snail activity monitoring," *IEEE Sensors J.*, vol. 17, no. 15, pp. 5008–5015, Aug. 2017.

[52] T. Oksanen, R. Linkolehto, and I. Seilonen, "Adapting an industrial automation protocol to remote monitoring of mobile agricultural machinery: A combine harvester with IoT," *IFAC PapersOnLine*, vol. 49, no. 16, pp. 127–131, 2016.

[53] O. Chieochan, A. Saokaew, and E. Boonchieng, "IoT for smart farm: A case study of the Lingzhi mushroom farm at Maejo university," in *Proc. 14th Int. Joint Conf. Comput. Sci. Softw. Eng. (JCSSE)*, Jul. 2017, pp. 1–6.

[54] F. Viani, M. Bertolli, M. Salucci, and A. Polo, "Low-cost wireless monitoring and decision support for water saving in agriculture," *IEEE Sensors J.*, vol. 17, no. 13, pp. 4299–4309, Jul. 2017.

[55] J. G. Jagüey, J. F. Villa-Medina, A. López-Guzmán, and M. A. Porta-Gándara, "Smartphone irrigation sensor," *IEEE Sensors J.*, vol. 15, no. 9, pp. 5122–5127, Sep. 2015.

[56] G. Kavianand, V. M. Nivas, R. Kiruthika, and S. Lalitha, "Smart drip irrigation system for sustainable agriculture," in *Proc. IEEE Technol. Innov. ICT Agricult. Rural Develop. (TIAR)*, Chennai, India, Jul. 2016, pp. 19–22.

[57] Z. Abedin, A. S. Chowdhury, M. S. Hossain, K. Andersson, and R. Karim, "An interoperable IP based WSN for smart irrigation system," in *Proc. 14th IEEE Annu. Consum. Commun. Netw. Conf. (CCNC)*, Las Vegas, NV, USA, Jan. 2017, pp. 1–5.

[58] R. Zaier *et al.*, "Design and implementation of smart irrigation system for groundwater use at farm scale," in *Proc. 7th Int. Conf. Model. Identification Control (ICMIC)*, Sousse, Tunisia, Dec. 2015, pp. 1–6.

[59] P. Sureephong, P. Wiangnak, and S. Wicha, "The comparison of soil sensors for integrated creation of IoT-based wetting front detector (WFD) with an efficient irrigation system to support precision farming," in *Proc. Int. Conf. Digit. Arts Media Technol. (ICDAMT)*, Mar. 2017, pp. 132–135.

[60] P. Zhang *et al.*, "The construction of the integration of water and fertilizer smart water saving irrigation system based on big data," in *Proc. IEEE Int. Conf. Comput. Sci. Eng. (CSE) IEEE Int. Conf. Embedded Ubiquitous Comput. (EUC)*, vol. 2. Guangzhou, China, Jul. 2017, pp. 392–397.

[61] R. K. Kodali, V. Jain, and S. Karagwal, "IoT based smart greenhouse," in *Proc. IEEE Region 10 Humanitarian Technol. Conf. (R10-HTC)*, Dec. 2016, pp. 1–6.

[62] A. Na, W. Isaac, S. Varshney, and E. Khan, "An IoT based system for remote monitoring of soil characteristics," in *Proc. Int. Conf. Inf. Technol. (InCITe) Next Gener. IT Summit Theme Internet Things Connect Your Worlds*, Oct. 2016, pp. 316–320.

[63] S. Zhang, X. Chen, and S. Wang, "Research on the monitoring system of wheat diseases, pests and weeds based on IoT," in *Proc. 9th Int. Conf. Comput. Sci. Educ.*, Vancouver, BC, Canada, Aug. 2014, pp. 981–985.

[64] H. Lee, A. Moon, K. Moon, and Y. Lee, "Disease and pest prediction IoT system in orchard: A preliminary study," in *Proc. 9th Int. Conf. Ubiquitous Future Netw. (ICUFN)*, Milan, Italy, Jul. 2017, pp. 525–527.

[65] A. Giri, S. Dutta, and S. Neogy, "Enabling agricultural automation to optimize utilization of water, fertilizer and insecticides by implementing Internet of Things (IoT)," in *Proc. Int. Conf. Inf. Technol. (InCITe) Next Gener. IT Summit Theme Internet Things Connect Your Worlds*, Oct. 2016, pp. 125–131.

[66] J.-C. Zhao, J.-F. Zhang, Y. Feng, and J.-X. Guo, "The study and application of the IoT technology in agriculture," in *Proc. 3rd Int. Conf. Comput. Sci. Inf. Technol.*, vol. 2. Chengdu, China, Jul. 2010, pp. 462–465.

[67] J. I. Rubala and D. Anitha, "Agriculture field monitoring using wireless sensor networks to improving crop production," *Int. J. Eng. Sci.*, vol. 5216, pp. 5216–5221, 2017.

[68] M. Odema, I. Adly, A. Wahba, and H. Ragai, "Smart aquaponics system for industrial Internet of Things (IIoT)," in *International Conference on Advanced Intelligent Systems and Informatics.* Cairo, Egypt: Springer, 2017, pp. 844–854.

[69] Z. Yu, L. Xugang, G. Xue, and L. Dan, "IoT forest environmental factors collection platform based on zigbee," *Cybern. Inf. Technol.*, vol. 14, no. 5, pp. 51–62, 2014.

[70] T. A. Shinde and J. R. Prasad, "IoT based animal health monitoring with naive Bayes classification," *Int. J. Emerg. Trends Technol.*, vol. 1, no. 2, pp. 252–257, 2017.

[71] L. Huang and P. Liu, *Key Technologies and Alogrithms' Application in Agricultural Food Supply Chain Tracking System in E-Commerce*. Beijing, China: Springer, 2014, pp. 269–281, doi: 10.1007/978-3-642-54341-8_29.

[72] L. Mainetti *et al.*, "An RFID-based tracing and tracking system for the fresh vegetables supply chain," *Int. J. Antennas Propag.*, vol. 2013, May 2013, Art. no. 531364.

[73] A. Regattieri, M. Gamberi, and R. Manzini, "Traceability of food products: General framework and experimental evidence," *J. Food Eng.*, vol. 81, no. 2, pp. 347–356, 2007.

[74] W. Gan, Y. Zhu, and T. Zhang, "On RFID application in the tracking and tracing system of agricultural product logistics," in *International Conference on Computer and Computing Technologies in Agriculture.* Nanchang, China: Springer, 2010, pp. 400–407.

[75] P. Abhishesh, B. Ryuh, Y. Oh, H. Moon, and R. Akanksha, "Multipurpose agricultural robot platform: Conceptual design of control system software for autonomous driving and agricultural operations using programmable logic controller," *World Acad. Sci. Eng. Technol. Int. J. Mech. Aerosp. Ind. Mechatronic Manuf. Eng.*, vol. 11, no. 3, pp. 496–500, 2017.

[76] P. Tripicchio, M. Satler, G. Dabisias, E. Ruffaldi, and C. A. Avizzano, "Towards smart farming and sustainable agriculture with drones," in *Proc. IEEE Int. Conf. Intell. Environ. (IE)*, Prague, Czech Republic, 2015, pp. 140–143.

[77] A. Kaloxylos *et al.*, "Farm management systems and the future Internet era," *Comput. Electron. Agricult.*, vol. 89, pp. 130–144, Nov. 2012.

[78] *CLAAS*. Accessed: Sep. 20, 2017. [Online]. Available: http://www.claasofamerica.com/

[79] *Precisionhawk*. Accessed: Sep. 20, 2017. [Online]. Available: http://www.precisionhawk.com/

[80] P. Lerdsuwan and P. Phunchongharn, "An energy-efficient transmission framework for IoT monitoring systems in precision agriculture," in *International Conference on Information Science and Applications*. Singapore: Springer, 2017, pp. 714–721.

[81] I. Mat, M. R. M. Kassim, A. N. Harun, and I. M. Yusoff, "IoT in precision agriculture applications using wireless moisture sensor network," in *Proc. IEEE Conf. Open Syst. (ICOS)*, Oct. 2016, pp. 24–29.

[82] A. Khattab, A. Abdelgawad, and K. Yelmarthi, "Design and implementation of a cloud-based IoT scheme for precision agriculture," in *Proc. 28th Int. Conf. Microelectron. (ICM)*, Dec. 2016, pp. 201–204.

[83] H. Liu, Z. Meng, and S. Cui, "A wireless sensor network prototype for environmental monitoring in greenhouses," in *Proc. Int. Conf. Wireless Commun. Netw. Mobile Comput.*, Sep. 2007, pp. 2344–2347.

[84] Q. Zhang, X.-L. Yang, Y.-M. Zhou, L.-R. Wang, and X.-S. Guo, "A wireless solution for greenhouse monitoring and control system based on Zigbee technology," *J. Zhejiang Univ. Sci. A*, vol. 8, no. 10, pp. 1584–1587, 2007.

[85] B. Pekoslawski, P. Krasinski, M. Siedlecki, and A. Napieralski, "Autonomous wireless sensor network for greenhouse environmental conditions monitoring," in *Proc. 20th Int. Conf. Mixed Design Integr. Circuits Syst. (MIXDES)* , Jun. 2013, pp. 503–507.

[86] L. Dan, C. Xin, H. Chongwei, and J. Liangliang, "Intelligent agriculture greenhouse environment monitoring system based on IoT technology," in *Proc. Int. Conf. Intell. Transport. Big Data Smart City*, Dec. 2015, pp. 487–490.

[87] C. L. P. Chen and C.-Y. Zhang, "Data-intensive applications, challenges, techniques and technologies: A survey on big data," *Inf. Sci.*, vol. 275, pp. 314–347, Aug. 2014.

[88] A. Bifet, G. Holmes, R. Kirkby, and B. Pfahringer, "MOA: Massive online analysis," *J. Mach. Learn. Res.*, vol. 11, pp. 1601–1604, May 2010.

[89] S. Hong and H. Kim, "An analytical model for a GPU architecture with memory-level and thread-level parallelism awareness," *ACM SIGARCH Comput. Archit. News*, vol. 37, no. 3, 2009, pp. 152–163.

[90] M. Jhuria, A. Kumar, and R. Borse, "Image processing for smart farming: Detection of disease and fruit grading," in *Proc. IEEE 2nd Int. Conf. Image Inf. Process. (ICIIP)*, Dec. 2013, pp. 521–526.

[91] B. Suksawat and P. Komkum, "Pineapple quality grading using image processing and fuzzy logic based on Thai agriculture standards," in *Proc. Int. Conf. Control Autom. Robot.*, May 2015, pp. 218–222.

[92] A. Kapoor, S. I. Bhat, S. Shidnal, and A. Mehra, "Implementation of IoT (Internet of Things) and image processing in smart agriculture," in *Proc. Int. Conf. Comput. Syst. Inf. Technol. Sust. Solutions (CSITSS)*, Oct. 2016, pp. 21–26.

[93] M. Roopaei, P. Rad, and K.-K. R. Choo, "Cloud of things in smart agriculture: Intelligent irrigation monitoring by thermal imaging," *IEEE Cloud Comput.*, vol. 4, no. 1, pp. 10–15, Jan./Feb. 2017.

[94] C. Cambra, S. Sendra, J. Lloret, and L. Garcia, "An IoT service-oriented system for agriculture monitoring," in *Proc. IEEE Int. Conf. Commun. (ICC)*, May 2017, pp. 1–6.

[95] M. Marjani *et al.*, "Big IoT data analytics: Architecture, opportunities, and open research challenges," *IEEE Access*, vol. 5, pp. 5247–5261, 2017.

[96] G. Xu, S. Gao, M. Daneshmand, C. Wang, and Y. Liu, "A survey for mobility big data analytics for geolocation prediction," *IEEE Wireless Commun.*, vol. 24, no. 1, pp. 111–119, Feb. 2017.

[97] H. C. J. Godfray *et al.*, "Food security: The challenge of feeding 9 billion people," *Science*, vol. 327, no. 5967, pp. 812–818, 2010.

[98] C. Nelleman *et al.*, *The Environmental Food Crisis the Environment's Role in Averting Future Food Crises. A UNEP Rapid Response Assessment*. Arendal, Norway: United Nat. Environ. Program, 2009.

[99] V. Deepak, T. Megha, G. H. Prithvi, S. A. Syed, and S. K. Sharavana, "Cold storage management system for farmers based on IoT," *Int. J. Recent Trends Eng. Res.*, vol. 3, no. 5, pp. 556–561, 2017.

[100] Y. Zou and L. Quan, "A new service-oriented grid-based method for AIoT application and implementation," *Mod. Phys. Lett. B*, vol. 31, nos. 19–21, 2017, Art. no. 1740064.

[101] Y. Bo and H. Wang, "The application of cloud computing and the Internet of Things in agriculture and forestry," in *Proc. Int. Joint Conf. Service Sci.*, May 2011, pp. 168–172.

[102] H. J. P. Marvin *et al.*, "A holistic approach to food safety risks: Food fraud as an example," *Food Res. Int.*, vol. 89, pp. 463–470, Nov. 2016.

[103] S. Tähkäpää, R. Maijala, H. Korkeala, and M. Nevas, "Patterns of food frauds and adulterations reported in the EU rapid alert system for food and feed and in finland," *Food Control*, vol. 47, pp. 175–184, Jan. 2015.

[104] L. Manning, "Food fraud: Policy and food chain," *Current Opinion Food Sci.*, vol. 10, pp. 16–21, Aug. 2016.

[105] D. Folinas, I. Manikas, and B. Manos, "Traceability data management for food chains," *British Food J.*, vol. 108, no. 8, pp. 622–633, 2006.

[106] M. Asplund and S. Nadjm-Tehrani, "Attitudes and perceptions of IoT security in critical societal services," *IEEE Access*, vol. 4, pp. 2130–2138, 2016.

[107] S. Chen, H. Xu, D. Liu, B. Hu, and H. Wang, "A vision of IoT: Applications, challenges, and opportunities with China perspective," *IEEE Internet Things J.*, vol. 1, no. 4, pp. 349–359, Aug. 2014.

[108] D. Turgut and L. Boloni, "Value of information and cost of privacy in the Internet of Things," *IEEE Commun. Mag.*, vol. 55, no. 9, pp. 62–66, Jan. 2017.

[109] L. Chen *et al.*, "Robustness, security and privacy in location-based services for future IoT: A survey," *IEEE Access*, vol. 5, pp. 8956–8977, 2017.

[110] P. Varga, S. Plosz, G. Soos, and C. Hegedus, "Security threats and issues in automation IoT," in *Proc. IEEE 13th Int. Workshop Factory Commun. Syst. (WFCS)*, May 2017, pp. 1–6.

[111] J. Duan, D. Gao, D. Yang, C. H. Foh, and H.-H. Chen, "An energy-aware trust derivation scheme with game theoretic approach in wireless sensor networks for IoT applications," *IEEE Internet Things J.*, vol. 1, no. 1, pp. 58–69, Feb. 2014.

[112] A. Newell, H. Yao, A. Ryker, T. Ho, and C. Nita-Rotaru, "Node-capture resilient key establishment in sensor networks: Design space and new protocols," *ACM Comput. Surveys (CSUR)*, vol. 47, no. 2, p. 24, 2015.

[113] A. Biral, M. Centenaro, A. Zanella, L. Vangelista, and M. Zorzi, "The challenges of M2M massive access in wireless cellular networks," *Digit. Commun. Netw.*, vol. 1, no. 1, pp. 1–19, 2015.

[114] V. M. Tayur and R. Suchithra, "Review of interoperability approaches in application layer of Internet of Things," in *Proc. Int. Conf. Innov. Mech. Ind. Appl. (ICIMIA)*, Feb. 2017, pp. 322–326.

[115] H. Veer and A. Wiles. (2008). *Achieving Technical Interoperability—The ETSI Approach, European Telecommunications Standards Institute*. Accessed: Sep. 20, 2017. [Online]. Available: http://www.etsi.org/images/files/ETSIWhitePapers/IOP%20whitepaper%20Edition%203%20final.pdf

[116] C. Perera, C. H. Liu, S. Jayawardena, and M. Chen, "A survey on Internet of Things from industrial market perspective," *IEEE Access*, vol. 2, pp. 1660–1679, 2014.

[117] *OpenConnectivity*. Accessed: Sep. 20, 2017. [Online]. Available: https://openconnectivity.org/

[118] *If This Then That*. Accessed: Sep. 20, 2017. [Online]. Available: https://ifttt.com/

[119] Y. Shi, J. Han, X. Wang, J. Gao, and H. Fan, "An obfuscatable aggregatable signcryption scheme for unattended devices in IoT systems," *IEEE Internet Things J.*, vol. 4, no. 4, pp. 1067–1081, Aug. 2017.

[120] Real Wireless. *A Comparison of UNB and Spread Spectrum Wireless Technologies As Used in LPWA M2M Applications*. Accessed: Sep. 20, 2017. [Online]. Available: www.thethingsnetwork.org/

[121] O. Elijah, C. Y. Leow, T. A. Rahman, S. Nunoo, and S. Z. Iliya, "A comprehensive survey of pilot contamination in massive MIMO—5G system," *IEEE Commun. Surveys Tuts.*, vol. 18, no. 2, pp. 905–923, 2nd Quart., 2016.

[122] M. I. Chidean *et al.*, "Energy efficiency and quality of data reconstruction through data-coupled clustering for self-organized large-scale WSNs," *IEEE Sensors J.*, vol. 16, no. 12, pp. 5010–5020, Jun. 2016.

[123] G. Anastasi, M. Conti, M. Di Francesco, and A. Passarella, "Energy conservation in wireless sensor networks: A survey," *Ad Hoc Netw.*, vol. 7, no. 3, pp. 537–568, 2009.

[124] S. Sarangi and S. Pappula, "Adaptive data-centric clustering with sensor networks for energy efficient IoT applications," in *Proc. IEEE 41st Conf. Local Comput. Netw. (LCN)*, Nov. 2016, pp. 398–405.

[125] N. Kaur and S. K. Sood, "An energy-efficient architecture for the Internet of Things (IoT)," *IEEE Syst. J.*, vol. 11, no. 2, pp. 796–805, Jun. 2017.

[126] R. Duan, X. Chen, and T. Xing, "A QoS architecture for IoT," in *Proc. 4th Int. Conf. Cyber Phys. Soc. Comput. Internet Things*, Oct. 2011, pp. 717–720.

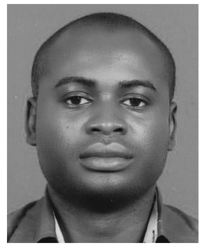
[127] Y. Huang, C. Zhou, N. Cao, and L. Zhou, "Research on application of local fruit E-commerce based on Internet of Things," in *Proc. IEEE Int. Conf. Comput. Sci. Eng. (CSE) IEEE Int. Conf. Embedded Ubiquitous Comput. (EUC)*, vol. 2, Jul. 2017, pp. 191–194.
[128] *Plantix*. Accessed: Sep. 25, 2017. [Online]. Available: https://plantix.net
[129] P. P. Jayaraman, X. Yang, A. Yavari, D. Georgakopoulos, and X. Yi, "Privacy preserving Internet of Things: From privacy techniques to a blueprint architecture and efficient implementation," *Future Gener. Comput. Syst.*, vol. 76, pp. 540–549, Nov. 2017.
[130] S. Sharma, K. Chen, and A. Sheth, "Toward practical privacy-preserving analytics for IoT and cloud-based healthcare systems," *IEEE Internet Comput.*, vol. 22, no. 2, pp. 42–51, Mar./Apr. 2018.
[131] T. Song *et al.*, "A privacy preserving communication protocol for IoT applications in smart homes," *IEEE Internet Things J.*, vol. 4, no. 6, pp. 1844–1852, Dec. 2017.
[132] R. Mendes and J. P. Vilela, "Privacy-preserving data mining: Methods, metrics, and applications," *IEEE Access*, vol. 5, pp. 10562–10582, 2017.

Olakunle Elijah (S'07) received the B.Eng. degree from the Federal University of Technology Minna, Minna, Nigeria, in 2003, the M.Sc. degree in micro-electronics and computing from Bournemouth University, Poole, U.K., in 2008, the postgraduation degree in advance microelectronics from Bolton University, Bolton, U.K., in 2010, and the Ph.D. degree from Universiti Teknologi Malaysia, Johor Bahru, Malaysia, in 2018.

He is currently conducting research in the field of wireless communications and IoT with the Wireless Communication Centre, Higher Institution Centre of Excellence, and UTM-Ericsson Innovation Centre for 5G, Kuala Lumpur, Malaysia. He was a Field Engineer with Kuyet Nigeria Ltd., Lagos, Nigeria, in 2006. From 2011 to 2013, he was the MD/CEO with Mircoscale Embedded Limited, Abuja, Nigeria. His current research interests include embedded systems, wireless communication, massive MIMO, interference mitigation, heterogeneous network, IoT with data analysis, and 5G.

Tharek Abdul Rahman (M'14) received the B.Sc. degree (Hons.) in electrical engineering from the University of Strathclyde, Glasgow, U.K., the M.Sc. degree in communication engineering from the University of Manchester Institute of Science and Technology, Manchester, U.K., and the Ph.D. degree in mobile communication from the University of Bristol, Bristol, U.K.

He is currently a Professor of wireless communication with the Faculty of Electrical Engineering, Universiti Teknologi Malaysia, Johor Bahru, Malaysia, where he is the Director of Wireless Communication Centre, Faculty of Electrical Engineering, and currently conducting research related to mobile communications, antenna, and propagation. He has been conducting various short courses related to mobile and satellite communication to the telecommunication industry and government agencies, since 1988. He is also a Consultant for many communication companies and an active member in several research academic entities. He has authored over 300 scientific papers in journals and conferences and obtained many national and international awards.



Igbafe Orikumhi (S'14–M'18) received the B.Eng. degree from the Federal University of Technology Minna, Minna, Nigeria, in 2008, and the M.Sc. degree and Ph.D. degree in electrical engineering from the Universiti of Teknologi Malaysia, Johor Bahru, Malaysia, in 2014 and 2017, respectively.

He is currently a Research Associate with Hanyang University, Seoul, South Korea. His current research interests include relay transmission, cooperative communications, wireless communication, simultaneous wireless information and power transfer, nonorthogonal multiple access, antenna propagation, IoT, 5G communications, beamtracking, and localization.

Chee Yen Leow (S'08–M'12) received the B.Eng. degree in computer engineering from Universiti Teknologi Malaysia (UTM), Johor Bahru, Malaysia, in 2007, and the Ph.D. degree from Imperial College London, London, U.K., in 2011.

Since 2007, he has been a member of academic staff with the Faculty of Electrical Engineering, UTM. He is currently a Senior Lecturer with the faculty and a Research Fellow with the Wireless Communication Centre, Higher Institution Centre of Excellence, and UTM-Ericsson Innovation Centre for 5G. His current research interests include cooperative communication, MIMO, drone communication, physical layer security, convex optimization, communications theory, wireless power transfer and communication, nonorthogonal multiple access, and 5G.

MHD N. Hindia (M'13) received the Ph.D. degree from the Faculty of Engineering in Telecommunication, University of Malaya, Kuala Lumpur, Malaysia, in 2015.

He is currently involved with research in the field of wireless communications, especially in channel sounding, network planning, converge estimation, handover, scheduling, and quality of service enhancement for 5G networks. He is currently a Post-Doctoral Fellow from the Faculty of Engineering in Telecommunication, University of Malaya. Besides that, he is involved with research with the Research Group in Modulation and Coding Scheme for Internet of Things for Future Network. He has authored or co-authored a number of science citation index journals and conference papers.

Dr. Hindia has participated as a Reviewer and a committee member of a number of ISI journals and conferences.