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Towards Diversification of Nigeria Economy through Adoption of IoT for Smart and Precision Agriculture

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Abstract: **Adoption of Internet of things (IoT) has been accepted across all areas of human endeavors. With the world population predicted to reach 9.2 billion by 2050 and the world suggestions on climate change, there is urgent need for the agriculture ecosystem to help the world prepare for these unavoidable realities through application of new and sustainable methods of farming. One major practice in agriculture today is precision/smart farming and IoT have been a major driver of precision/smart agriculture across the world. Many studies have been conducted on applying IoT technologies to improve agriculture; this paper just extends on them and proposes a new IoT architecture as a major driver for implementing sustainable smart/precision agriculture.**
This paper discusses on what smart/precision agriculture is and technologies that drive it. It narrates previous and current status of agriculture in Nigeria and proposes application of IoT to improve food production cycle with the aim of using agriculture to diversify Nigeria economy. It suggested a sustainable model, and uses a new IoT architecture as a standard framework for precision/smart agriculture in Nigeria taking into consideration the entire agriculture ecosystem. It also establishes the proof of solution for the concept.

Keywords: **Smart/Precision agriculture, Internet of Things, sustainable IoT model, IoT architecture, agriculture ecosystem, Big Data Analysis, agroPlatform**.

I. INTRODUCTION

The growing world population, particularly in emerging economies, and challenges associated with providing access to quality, safe, and affordable food are set to grow over time. The potential use of IoT to combat hunger and promote sustainable agricultural has received particular attention, perhaps more than any other development issue. From managing agricultural production cycles, disease threats through to automated harvesting, distribution logistics, and quality monitoring, IoT-enabled "smart agriculture" techniques are envisioned across the entire value chain to ensure improved food productivity [7] and sustainable farming. By 2050, it's expected that the world's population will reach 9.2 billion people, 34 percent higher than today. To keep up with rising populations and income growth, global food production must increase by 70 percent in order to be able to feed the world. The answer to that daunting challenge lies in almost real time data gathering and analysis. The need to research on how "precision agriculture" techniques and technologies can maximize food production, minimize environmental impact and reduce cost is of paramount importance [2].

In retrospect, agriculture in Nigeria has passed through different phases; it is worthy to briefly mention about the past and current status. As at 1978, 1$ equalled 1N (Naira-Nigeria currency). No one in Nigeria was willing to travel abroad because standard of living of Nigerian people was high and economy was booming. During this period, agriculture provided the major source of revenue to government. Agriculture provided the resources for financing economic development in Nigeria long before crude oil became the major source of revenue and foreign exchange – earnings. Before the discovery of oil in 1956, Nigeria was famous for her agrarian economy through which, cash crops like; palm produce (oil and Kernel), cocoa, rubber, timber, groundnut etc. were exported, thus making Nigeria a major exporter in

that respect. This sector offered vast opportunities and employed over seventy percent (70%) of the Nigerian labour force [10].

After independence in 1960, agriculture continued as the mainstay of the economy. In spite of fluctuations in world prices, agriculture contributed about 65 per cent to GDP and represented almost 70 per cent of total exports. Agriculture provided the foreign exchange that was utilized in importing raw materials and capital goods. The peasant farmers produced enough to feed the entire population. The various Marketing Boards generated much revenue, the surplus of which was used by government to develop the basic infrastructure needed for long term development. The main thrust of policy was to maximize the benefits of the export-led development strategy. Raw materials, comprising agricultural produce and minerals were exported to the industrialized nations [11].

Upon the discovery of crude oil and its subsequent exportation, there was a boom in the economy of Nigeria as it accounted for over eighty percent (80%) of the country's foreign exchange earnings. The discovery to some extent assisted the country's economic prosperity, but has now become the bane of Nigeria's economic growth. The fact being that, the money earned by a country with less or little effort; through petroleum, resulted in the abandoning of the agricultural sector and over dependent on oil. Over time the country's situation is persistently risky, with fluctuations in Oil prices. The economy remains in dire need of reflection to boost consumer aggregate demand and overall productivity. The labour market remains a serious threat [10].

Although Nigeria depends heavily on the oil industry for its budgetary revenue; it is believed that if the agricultural sector is properly managed and enhanced, it would greatly boost the country's gross domestic product and even replace oil on the top of the list, considering the vast area of land that is unused in Nigeria. In 1990, it was observed that about 82 million hectares out of Nigeria's total land area of 91 million hectares were found to be arable, and merely 42 percent of this cultivable area was farmed. Much of this land was farmed under the bush fallow system, a process whereby land is left idle for a period of time to allow natural regeneration of soil fertility and replacement of soil nutrient. Livestock farming is a very important aspect of agriculture in Nigeria; the Nigerian community depends mostly on meat from cows and chicken. Meat is an important part of the foods in Nigeria. The kind of animals reared in Nigeria includes - Cow, Goat, Sheep, Cattle, Pig, Horse and several others while poultry birds includes chicken, turkey, duck, pigeons and others [3]. It is glaring to all that the agricultural sector is one of Nigeria's potential sources of revenue that is yet underdeveloped and unexplored.

1.1 Problems of agriculture in Nigeria:

Despite all the opportunities mentioned earlier, there are lots of problem hampering the production of food crops in Nigeria and rearing of animals, chiefly among them is electricity. Over 40 percent of Nigeria perishable goods get spoilt after harvest due to the lack of electricity needed for the storage and processing. Electricity is needed for the running of large farm equipment; most Nigerian farmer simply chose to stick with manual labor as the cost of running machines with alternative source of power is often steep. Average Nigerian farmers still make use of out-dated manual farm tools - like cutlass and hoe. The use of these kinds of Archaic and out-dated tools and techniques, constitutes a great set-back in the country's food and agricultural outputs. This lack of modern machine and techniques due to lack of sustainable funding and policy is having serious drawbacks on agriculture development in Nigeria [3,12].

Another problem facing agriculture in Nigeria is lack of good roads needed for the transportation of harvested crops from the farm land to the main roads, most farms in Nigeria are located about a mile away from the main road and the only entrance to these farms are mostly a path beaten by the foot of men. A lot of food waste happens during distribution, so it's important to transport the food at the right temperature and not hold it for longer than needed. Even the weather can affect this; in Nigeria, many of the roads are dirt, and heavy rain can cause trucks to get stuck in mud. By knowing where it will rain and which routes may be affected, companies can make better decisions on which routes will be the fastest to transport their food [6].

The other issue is that farming has been rainfall-dependent. However, in most parts of the North, droughts and other climate change issues have deteriorated the environment over the last two decades. As a result, it is becoming quite difficult to predict the rainfall pattern. This is affecting farming because not many farmers have the capacity to irrigate their land and produce on large scale. Therefore, they are victims to the unpredictable rain for their crops. Commodities are harvested from fields with different exposures [9].

The result of these problems is a Nigeria with high deficit of food stuff and animals. Nigeria became a dumping ground for all sorts of food stuffs. Nigeria is the highest importer of rice in Africa despite all the arable lands she is blessed with. The cost of running government is becoming unsustainable. Recurrent budget has been on the high side, highly more than capital budget. External debt service remained high and unsustainable. Infrastructures at all levels are in sorry states. All these have emerged as a result of negligence to agricultural sector because of the advent of oil. To worsen the situation, in mid-2015, there was drastic drop in the price of oil in the international market thus resulted in serious economic threat. Now, Nigeria is in dire need to embark on sustainable diversification of the economy. Agriculture in Nigeria contributes merely about 30 percent of the Nigeria total GDP, trailing behind petroleum which is the major Nigerian domestic produce. Solving these problems requires good leadership and readiness by all stakeholders in agriculture industry to come together to champion ways of doing things differently than now.

1.2 Way forward:

Despite these challenges, agriculture in Nigeria can still be considerably developed to contribute largest percentage of the revenue to governments at all levels in the nearest future if there are orchestrated strategic planning and policy directions that support smart and precision farming practice through the use of emerging technologies in a sustainable way. The strategy and policy should also see to the need for the education of farmers; most farmers in Nigeria who engage in subsistence agriculture have very little knowledge of the new operational and production methods of farming. If farmers in Nigeria are provided with the necessary tool and adequate resources, there would be gross improvement in Nigerian agricultural sector; the land would be properly utilized and this would greatly reduce high cost of production.

Even if heavy amount of investment could not be made in modern agriculture equipment considering the state of the economy, Nigeria can start by introducing smart and precision farming using IoT technologies described in the previous section. The technology solution proposed in this paper takes into consideration Nigeria peculiarity by adopting a sustainable model based on a particular IoT architecture.

Specifically, this paper is set out to achieve the following:

•To use IoT to provide a central point for collecting and disseminating information (data) necessary for higher crop yield, improving quality of farm produce and cost reduction of farm management.

•To develop a dynamic and sustainable model using an IoT architecture that provides real time data processing and analysis for farmers with mapping of crop production to soil properties as well as providing advice on next crop to be cultivated based on specific farm locations

•To bring together all agriculture stakeholders/entities, also through the use of an IoT architecture that serves as a driver for connecting agriculture value chain and ensure a revival and diversification of Nigeria economy.

This paper is organized as follows. Section II presents literature while section III presents sustainable model based on application of IoT for smart agriculture in Nigeria. Section IV and V presents the solution and proof of concept respectively. The last section concludes the paper.

II. LITERATURE REVIEW

In Nigeria and around the world, traditionally, agriculture is practiced by performing a particular task, such as planting or harvesting, against a predetermined schedule. But by collecting real-time data on weather, soil and air quality, crop maturity; predictive analytics can be used to make smarter decisions. This is known as precision agriculture [6]. This is new trend in farming today, that is, the practice of sensing and responding to variable soil, moisture, weather and other conditions across different plots. Farmers are deploying wireless sensors and weather stations to gather real-time data about things such as how much water different plants need and whether they require pest management or fertilizer. Using this data, growers can customize growing processes. Indeed, one of the biggest benefits IoT offers farmers is the ability to gather much more granular data about smaller parcels of land. With site-specific data, growers can then optimize growing conditions on a plot-by-plot basis, boosting yields, improving quality and cutting costs in the process [2].

With precision agriculture, control centres collect and process data in real time to help farmers make the best decisions with regard to planting, fertilizing and harvesting crops. Sensors placed throughout the fields are used to measure temperature and humidity of the soil and surrounding air. In order to grow crops optimally farmers need to understand how to cultivate those crops in a particular area, taking into account a seed's resistance to weather and local diseases, and

considering the environmental impact of planting that seed. For example, when planting in a field near a river, it's best to use a seed that requires less fertilizer to help reduce pollution. Once the seeds have been planted, the decisions made around fertilizing and maintaining the crops are time-sensitive and heavily influenced by the weather. If farmers know they will have heavy rain the next day, they may decide not to put down fertilizer since it would get washed away. Knowing whether it's going to rain or not can also influence when to irrigate fields. With 70 percent of fresh water worldwide used for agriculture, being able to better manage how it's used will have a huge impact on the world's fresh water supply. By understanding what the weather will be over several days and what fields will be affected, better decisions can be made in advance. Once the food has been harvested the logistics of harvesting and transporting food to the distribution centers is crucial. A lot of food waste happens during distribution, so it's important to transport the food at the right temperature and not hold it for longer than needed which is a major issue in Nigeria [6].

Soil physical and mechanical properties are highly variable and to a large extent depend on soil moisture content at field capacity (FC) and at permanent wilting point (PWP). Data on these important soil properties could be obtained through on-the-go soil sensors (many of which are commercially available) and the map indicating differences in soil from one location to another can be prepared. This map is used in modeling the environment and establishing requisite data base for decisions concerning farm inputs. Strategically applying precision agriculture management principles will lead to many economic and environmental benefits such as: optimized tillage operations and energy efficiency, increased agricultural profitability and sustainability, environmental protection, enhanced crop quality, optimized use of fertilizers, pesticides, seeds, water, and other crop amendments [8].

Most of the agricultural produce is directly driven by the weather and soil nutrients. For farmers, their interest is being able to reduce economic impact of weather-good or bad. Ultimately, it is about crops being produced more efficiently; being able to distribute this crop to market more efficiently and still retain greater quality amount of nutrient after distribution. Also, there is need to ensure not being run off of fertilizers or pesticides. It is believed that precision farming driven by weather forecast could have strong improvement on farm efficiency and therefore have positive economic impact. But it's not just getting better weather forecast but also connecting it to farm processes. Getting better weather forecast is definitely not sufficient but perquisite. It really has to be connected to agriculture business. The sustainable and productive solution is to start with better weather forecast and coupling that to the analytic and visualization that connects to the agriculture business processes [6].

2.1 Technologies for Smart and Precision Agriculture:

The development of smart based systems for the farming sector has to be focused on Internet of Things which includes geomatics or 3S (RS, GIS and GPS), sensor technology, WSN, RFID, Big Data Analytics and Cloud Computing. Advances in image sensors and Wireless Sensor Networks (WSN) help to identify and delineate landscape to manageable field level food production zones more quickly and effectively than before and at much higher resolutions. Image processing software supports these sensors providing greater analytical capabilities and improved knowledge than was previously possible. RFID technology is fairly mature and food traceability is now more common in the developed world [4].

Sensors will automatically monitor irrigation activity and aggregate data at the block level to allow for accurate reporting. It makes seeding, irrigation and the application of fertilizers and pesticides more accurate. It monitors livestock for location and movement, so injury, illness or theft can be instantly detected. And it brings new levels of automation to crop harvesting. More broadly, IoT will help promote the efficient use of resources and will result in high-quality products while preserving the Earth. Agriculture IoT solution can be designed to gain insights and provide actionable intelligence at a block level. On a multi-acre farm, block level is defined as adjacent acres with unified conditions. Growers can collect sensor data for each block and then calibrate watering or the spraying of herbicides or fungicides for each block. A new generation of technology-savvy farmers is embracing digital agriculture. As a result, big data analytics and data visualization are expected to play an expanded role in food production [2].

III. SUSTAINABLE MODEL BASED ON APPLICATION OF IOT FOR SMART AGRICULTURE IN NIGERIA

The need to strategize on the sustainable model for smart and precision agriculture in Nigeria is long overdue considering the drop in price of oil in the international market and the reality of diversifying Nigeria economy. Application of Internet of things in critical sectors of the economy is strategic to diversification of the economy. One such application of IoT is in

smart and precision agriculture with the aim of generating more employment, improving standard of living of farmers, ensuring food security and eventually contributing to diversification of the economy.

Although researchers have proposed few models in agriculture domain using one or more of the technologies mentioned. There is need for dynamic and sustainable model considering the peculiarity of Nigerian state. It requires an integrated and collaborative approach to:

1. Monitor various soil properties and environmental conditions periodically from multi-acre farmland in block levels through portable cost effective IoT device and usable by multiple users, enquires about crop production details to the farmers after crop harvesting and stores these details at the central place (cloud). This will result into Big-data over the time and will be analyzed for fertilizer requirements for current crop, mapping of crop production to soil properties at that time, next crop to be cultivated, weather information like rainfall in specific area, block and multi-acre etc. All this information will be disseminated to farmers which will be helpful for boosting food production. Growers can collect this information for each block and then calibrate watering or the spraying of herbicides or fungicides for each block.

2. Connect all agricultural entities together including farmers, agro marketing agencies; agro product vendors; agencies of government in charge of agriculture; telecommunication companies or Internet Service Provider (ISP) or other IT infrastructure service providers; agro software developers; IT agencies of government; weather agencies and AgroBanks etc. These are the agro stakeholders that form agro ecosystem to ensure IoT application for precision farming is sustainable. Each stakeholder has important role to play. For instance, through the Ministry of agriculture farmers will be able to get notifications about new schemes, capacity building programmes, policies announced by the government for agriculture sector.

3. Adopt new IoT architecture for smart and precision agriculture. This architecture is the most unique aspect of this paper in implementing precision agriculture.

In the Nigeria context, there are two categories of farming based on mode of operation, farming method and financial capability. The categories are:

1. Commercial Farming: These are big organizations that are operating on a large scale. They have financial capability and human resources to use the proposed IoT platform and encourage others having seen the benefits of IoT application in smart and precision agriculture. There are number of them in Nigeria already applying modern farming tools and equipment for their operations. However, the use of IoT technologies for precision agriculture is lacking. They can take advantage of the proposed solution in this paper to better improve their business operations, increase efficiency and profitability, improve quality of farm produce, comply with international food regulations and compete in international markets.

The commercial farmers have a big role to play because their adoption and demonstration of success in using IoT platform for smart farming has huge implications on the success of this idea and its adoption by SME.

2. Small Medium Enterprise (SME) Farming: These are small to medium enterprise farmers, graduates who are willing to become farmers and rural farmers fall under this category. The future of this platform belongs to this category of farmers. A lot of them will end up operating on commercial level. They have huge role to play in domestic food supply as well as international food market as the model will ensure they meet with international food regulations. Thus, importing food to regional and international market becomes feasible.

The most sustainable way will be that multiple-acres be allocated to SME farmers or individuals in a single location but divided based on block levels to owners. An SME can obtain one or more blocks of land for farming. This will ease management, ensure shared IoT infrastructure and sustainability of the precision agriculture. Most of the state governments have started allocating farmlands to graduates or individuals who are interested in agriculture. This is a welcome development. The precision agriculture solution proposed in this paper can then be deployed on the mulita-acre or block level basis to ensure high yields, quality and safety of food production to the country and beyond.

The telecommunication providers/internet service providers/IT infrastructure providers in Nigeria are critical to the success of this model in that they are going to provide the platform and infrastructure needed for precision farming as described later in this paper. This is because they already have a number of infrastructures to support this model in a sustainable way. It however requires sustainable business model, policy and regulations for telecommunication

companies/internet service providers/IT infrastructure providers to invest their resources in anticipating for return on investment (ROI). Also, over 90% of Nigerians have mobile phones and about 20% have access to broadband internet connections.

Cellular, Low-Power Wide Area Network (LPWAN), Satellite or other wireless WAN technologies can be used to carry data from farmlands to the platform. The choice of wireless IoT network requires consideration of many factors: from coverage needs and device location to power consumption and the cost of deployment. Broadband cellular connectivity has dominated the IoT landscape for more than a decade. Key advantages include global reach, scalability, diversity, and high bandwidth capabilities. When cellular is not an option, satellite services can help provide connectivity to virtually anywhere on earth. Yet, in IoT, not all connected devices require such robust capabilities. New Low-Power Wide-Area (LPWAN) networks are entering the IoT space as alternative wide area network technologies to short-range networks like Wi-Fi. LPWAN technologies provide strong benefits including opportunities to help lower the total cost of ownership plus providing extended coverage and longer battery life [13]. In Nigerian case, this paper proposes cellular network because of the existing infrastructure by Telco and the fact that most of the potential farmers have already possess mobile and smart phones. This will ensure sustainability. However, as the platform grows, there would be need for multi-network approach for flexibility and agility purpose in order to optimize application of IoT for agriculture.

Each farmer will subscribe with a telecommunication operator or other IT infrastructure providers of his choice which will provide the infrastructure and connect him/her to the platform. Agro banks provide finance to the agriculture business stakeholders. Agro app/software companies/developers, vendor and marketing agencies, agriculture experts and Big Data analyst provide professional services.

The entire ecosystem will be working towards a common goal- diversification of Nigeria economy through application of IoT in precision/smart agriculture.

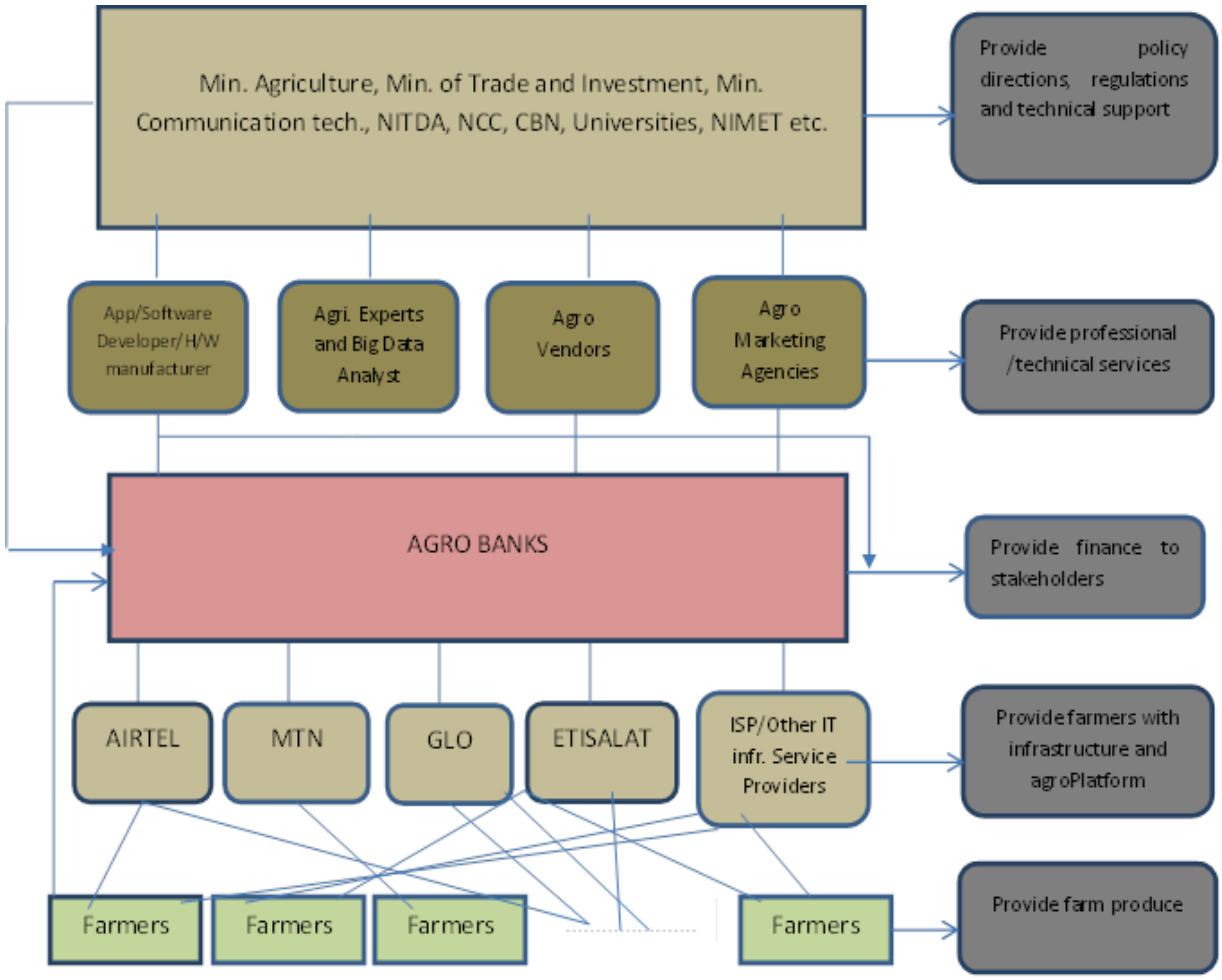


Fig 1. Nigeria Smart Agriculture Ecosystem

Ultimately, these efforts are geared towards making sure Nigeria's economy is diversified. This idea on smart and precision agriculture will contribute immensely to agriculture development in Nigeria and to a large extent diversification agenda of the country. This can be achieved by bringing all the stakeholders together on a round table to discuss on the **feasible and sustainable business model** that will best represent the interest of all and eventually build agricultural friendly society and a win-win business environment for all stakeholders.

IV. PROPOSED SOLUTION

The proposed smart/precision agriculture will utilize the new IoT architecture in [1]. The architecture and how each layer is fit into the solution is explained below.

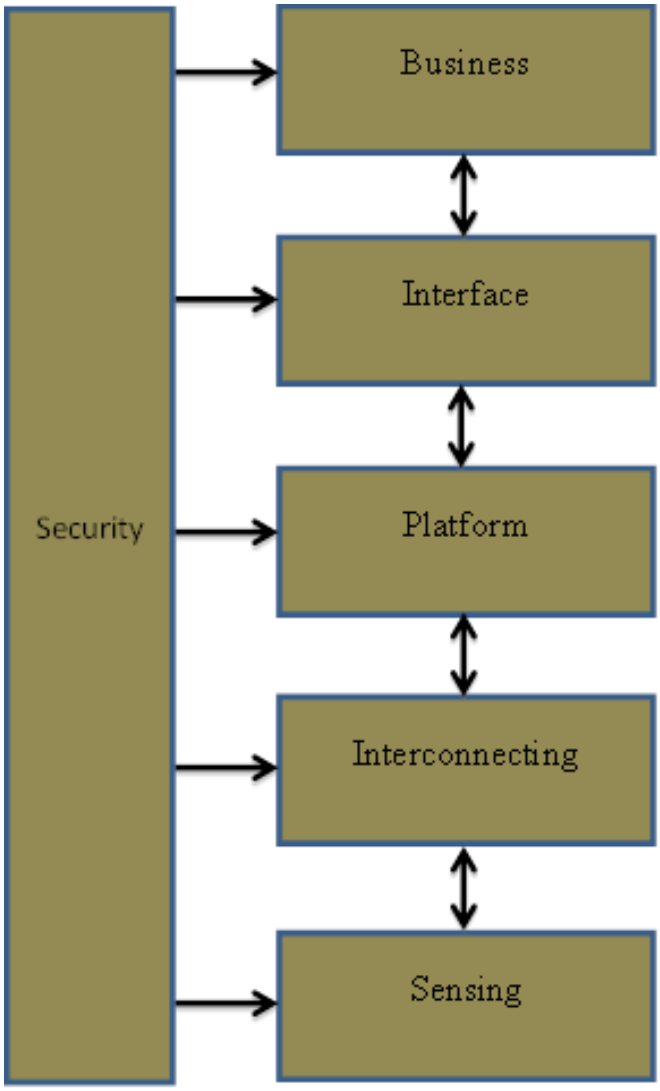


Fig 2. New IoT architecture for smart agriculture

Business Layer: Business layer is where foundation for IoT as a national infrastructure for agricultural development is canvassed. It sets policy direction for IoT and agriculture and defines the needed governance for effective implementation of the agric-IoT policy. The outcome of this layer is agriculture-IoT policy document. In the document, the necessary collaborations and specific roles of collaborators are defined. The document gives authority to the initiative and is made as national agenda for IoT-agriculture in Nigeria. It will also produce national agric-IoT business model that is enough to guarantee investors, especially the telecoms and the agro banks, of a return on investment (ROI). The following stakeholders are expected to form agro ecosystem, collaborate and ensure the success of this initiative:

- **Ministry of Agriculture:** as supervising ministry and represents the presidency. It provides agricultural information to stakeholders and the agroPlatform

- **Ministry of trade and Investment:** Provides international marketing platforms for farm produce and ensures international regulations on food supply are met.
- **Ministry of Communications:** Provides supervision to the success of the initiative and ensures the right collaborations and partnerships are formed.
- **National Information Technology Development Agency (NITDA):** provides technical support and regulations through the use of IoT technologies.
- **Nigeria Communication Commission (NCC):** Provides regulations on the telecommunication services provided by the telecommunication operators
- **Nigeria Meteorological Agency (NIMET):** to provide weather information across the country
- **Universities:** Provide research and development (R&D)
- **Central Bank of Nigeria:** provide financial supervision and directions to agro banks
- **Telecom operators:** provide **agroPlatform,** mobile computing services and internetworking services.
- **ISPs and other IT Infrastructure service providers:** They also provide agroPlatform, mobile computing services, networking and internetworking provided they can provide the service according to the agro-Policy and business Model.
- **Software companies and SME software developers:** develop tailored agro mobile apps and other farm management software.
- **Agriculture Experts:** Provide professional advice and consulting service based on data from the farm lands
- **Big Data Analysts:** translate insights and patterns embedded in data from agroPlatform for the agriculture experts, the farmers and the entire ecosystem
- **Agro Banks:** Provide financial services for long term investment
- **Agro marketing agencies:** Storage and sales of farm produce to local and international market
- **Registered farmers:** produce farm products
- **Agro Vendors:** Provides farm equipment, seeds etc**.**

Ultimately, this layer makes claim for the need to recognize IoT as national critical infrastructure and adoption of new IoT architecture for precision agriculture in Nigeria.

Interface Layer: This is where services and applications are defined based on requirements from stakeholders. The services and applications should be accessible, cost effective and sustainable. It's a medium through which users interact with agroPlatform to upload or download mobile apps through a special market-a gro-IoT mobile apps market, users' registration and provides a special interface for data exchange between the platform and IoT devices. It also provides access to local databases for those who prefer their data to reside on their local network. It provides information in almost real time with the aid of agroPlatform through smart devices and mobile phones or desktop if the database resides on a local network. The decision for data to reside locally is made at the business layer based on agro-business model and Agro-IoT Policy. The data can be integrated into the agroPlatform at a defined period. The essential technologies at this layer are mobile and web services.

Platform Layer: This is one of the critical layers, with huge functions, for realizing the application of IoT and Big Data analytics in agriculture. This layer will serve three purposes. First, it is Cloud Computing-based and agro-IoT is offered as a service through the telecom companies or other service providers. It will also make it easy for all developers to seamlessly integrate IoT-enabled solutions into the platform. This will facilitate employment for indigenous software and mobile apps developers and rapid deployment of agro-IoT applications and services. Second, the platform will manage and provide middleware services to those applications and services being provided at the interface layers through different telecom operators. Lastly, the platform will store lower layer data into the database and provide agro data analytics. In addition, this layer is able to retrieve, process, compute agro information, and then automatically decide based on the computational results to help farmers make decisions on multi-acre or block level basis.

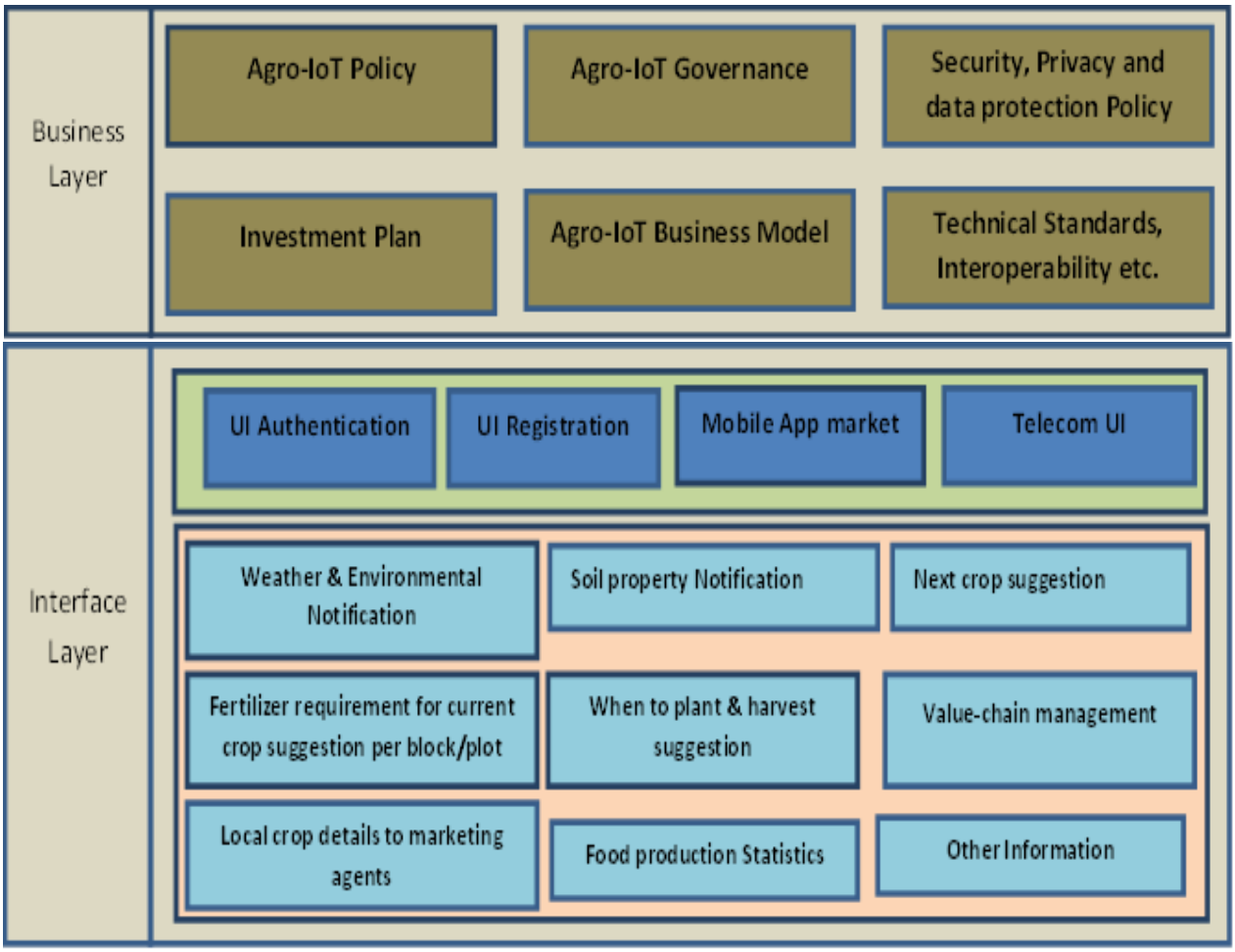
Monitoring and analytics are at the heart of agroPlatform that ensure real time monitoring of IoT devices and sensors, ensure instant analysis of specific data per stakeholder, farm location and manage those services for easy access at the interface layer. Platforms provide a one-stop shop for development tools, secure network connectivity and everything else needed to launch, scale and manage apps. These are key requirements for making precision agriculture a reality.

Each telecom operator or other IoT service providers can develop its agroPlatform and serve its customers but their platforms must be integrated with the national agroPlatform and this must be done based on the open standards specified in agro-IoT policy to ensure cross-platform interoperability. Cloud computing and big data analytics are the heart of this layer.

Interconnecting Layer: This layer is the connecting link between the sensing layer and platform layer. Its role is to transfer information from the sensing layer to and from the central information processing system at the platform layer. The telecom operators or other IoT service providers will facilitate internetworking services through their cellular network (2G, 3G and LTE) or Satellite or LPWAN depending on the existing infrastructure at the disposer of the providers, coverage needs and device location as well as cost of deployment.

Sensing Layer: This is the outmost layer of IoT, which is responsible for perceiving and responding to state changes. This is where all sort of devices are connected and data are generated. The primary functions of this layer include 1) perceiving the state changes of the thing itself or the environment, and transmit the information to the interconnecting layer in specific format; 2) receiving commands from the platform layer, and making responses according to commands. Example of IoT technologies and protocols at this layer are: RFID, sensor, WSN, WPAN, 802.15.4, Zigbee etc. [2]. This module is an important part of this architecture and is responsible for soil sampling at periodic intervals to get soil property values [4].

Agro-IoT Solution architecture



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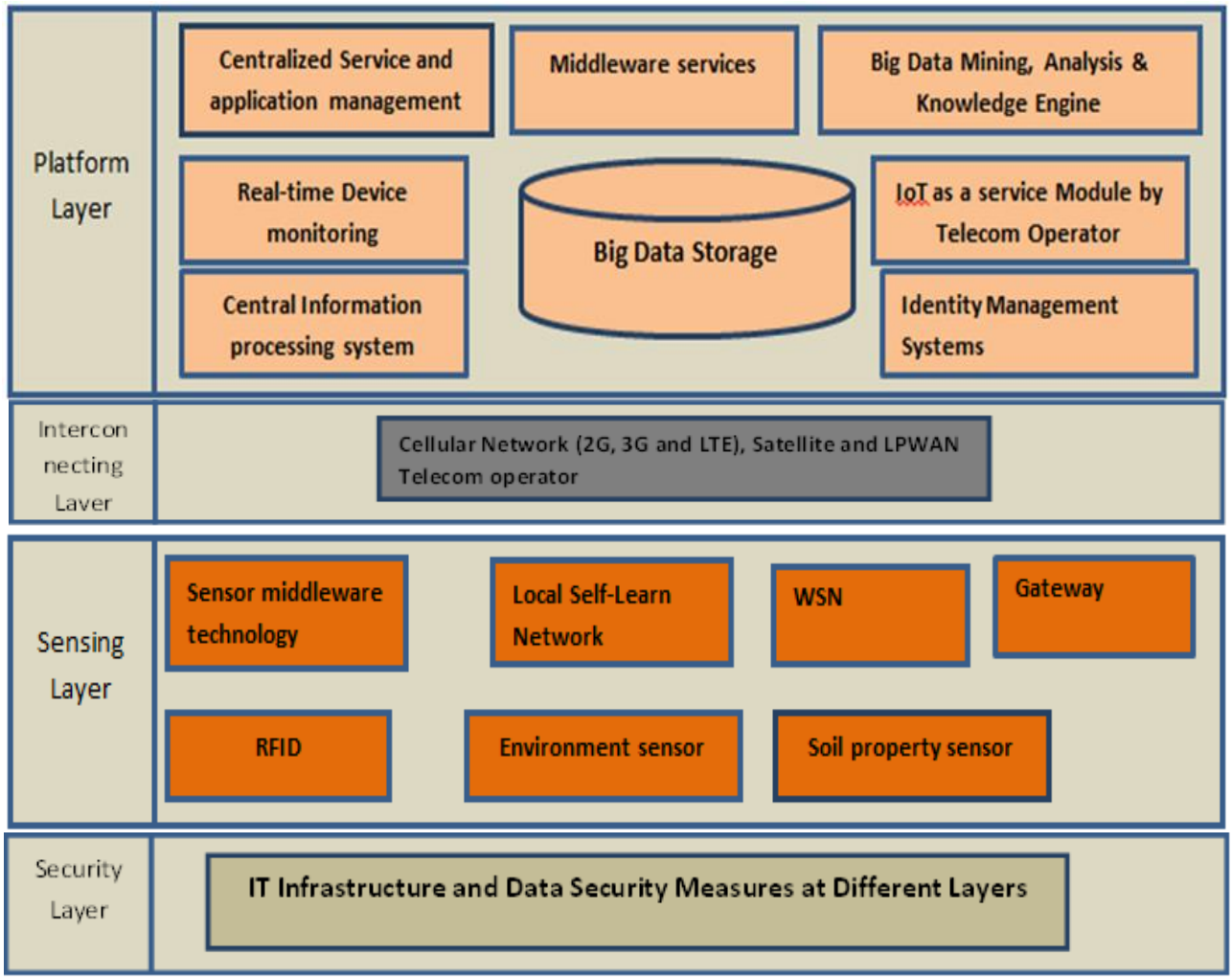


Fig.3 Agro-IoT Solution architecture

Security Layer: This layer is an integral part of all the layers described above. Security and privacy has been a major issue in IoT world. Because of huge amount of data that will be generated from sensing layer into the agroPlatform, security of data and privacy of individual entity in the platform is of paramount importance as well as protection of devices and the platform itself. The security policy that specifies protection of all the layers is defined at the business layer. This is Nigeria agro-IoT security policy. It defines various security standards, solutions and response measures in case of attacks.

V. PROOF OF CONCEPT

The different sensors that measure soil moisture, temperature, pH, Nitrate, Phosphorus, Potassium and environmental temperature and humidity are connected to each other by Wireless Sensor Network through Xbee/ZigBee protocol or any other feasible protocols. The sense data may be sent to the gateway through Xbee/Zigbee protocols and further send to the agroPlatform/telecom platform using mobile network (2G/3G), satellite or LPWAN etc. as shown in the figure 4 below. There are standards WSN solutions that are cost effective. Example of such solution is Wireless Sensor Networks with Waspmote and Meshlium. It supports standard protocols such as WiFi, XBee/LoRa, Bluetooth and 3G/GPRS. There are different RF/XBee models which can be configured as well [5].

It is important to note that this paper does not support any vendor for wireless sensor network but only use this product as an example to prove the proposed solution, since it supports most of the protocols that provide the needed solutions. This solution is one of those solutions that is fully integrated into the third party platform like the proposed agroPlatform for Nigeria. All decisions regarding technical expertise and standards can be jointly made by all the stakeholders. The telecom operators/other IoT service providers might suggest which solution will best work with their network.

The bulk of the work lies on the telecom operators/other IoT service providers whose technical know-how will be highly valuable in operating Cloud Computing platform and other experts like Big Data analysts and agriculture experts. Each operator/provider will fully support their customers (farmers) to ensure data generated from each farm location is integrated into the agroPlatform for processing and necessary actions.

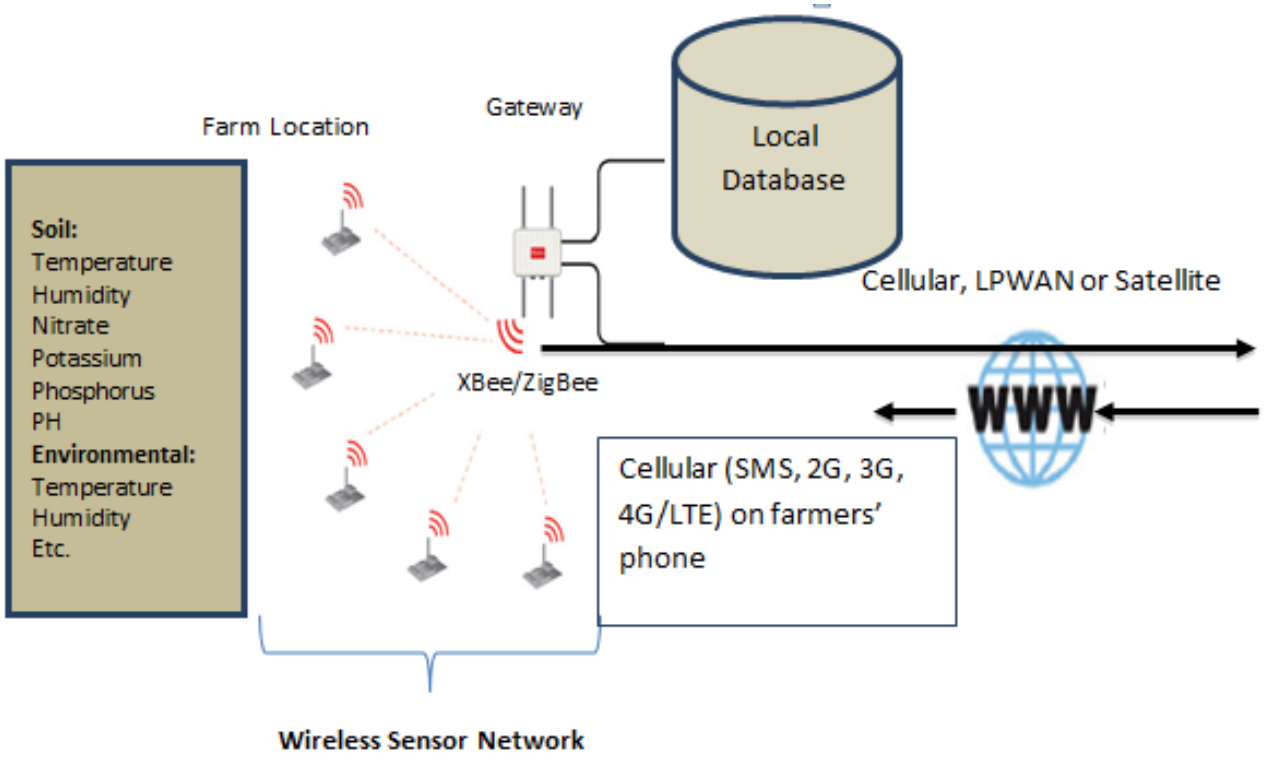
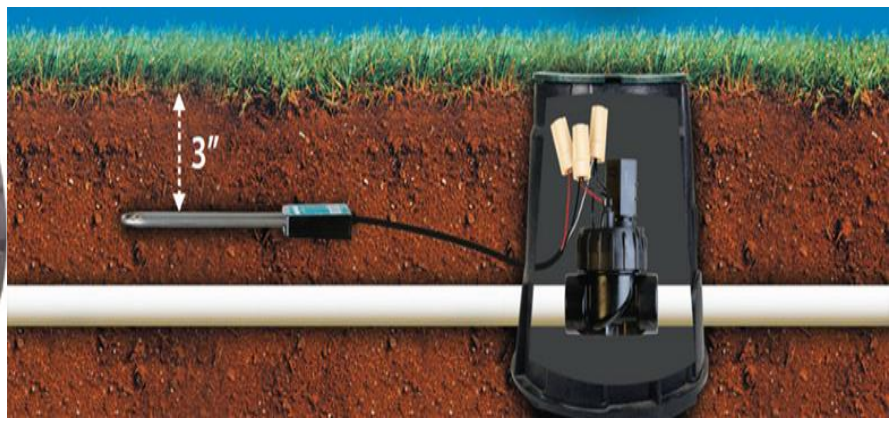


Fig 4. Proposed solution with application of IoT

5.1 Practical demonstration of the architecture:

For example, in commercial farming model, each block of land can be equipped with a water **flowmeter** at the water pump, a **battery-operated moisture probe** that measures different levels of soil moisture where different crops are grown and a **weather station** to measure air temperature and other conditions. An IoT gateway continuously monitors data from the various sensors and transmits it wirelessly to agroPlatform. Having all of this information will help the company in applying chemicals to different blocks. The weather station can be used to monitor solar radiation, wind velocity, humidity and temperature in the air above the farmland. Using this data, the company can time and target its use of fungicide sprays to prevent disease and rotting, which can be caused by heavy condensation. AgroPlatform will make data available on a dashboard through which smart phone can be used to check the information in real-time and adjust growing processes accordingly [2].



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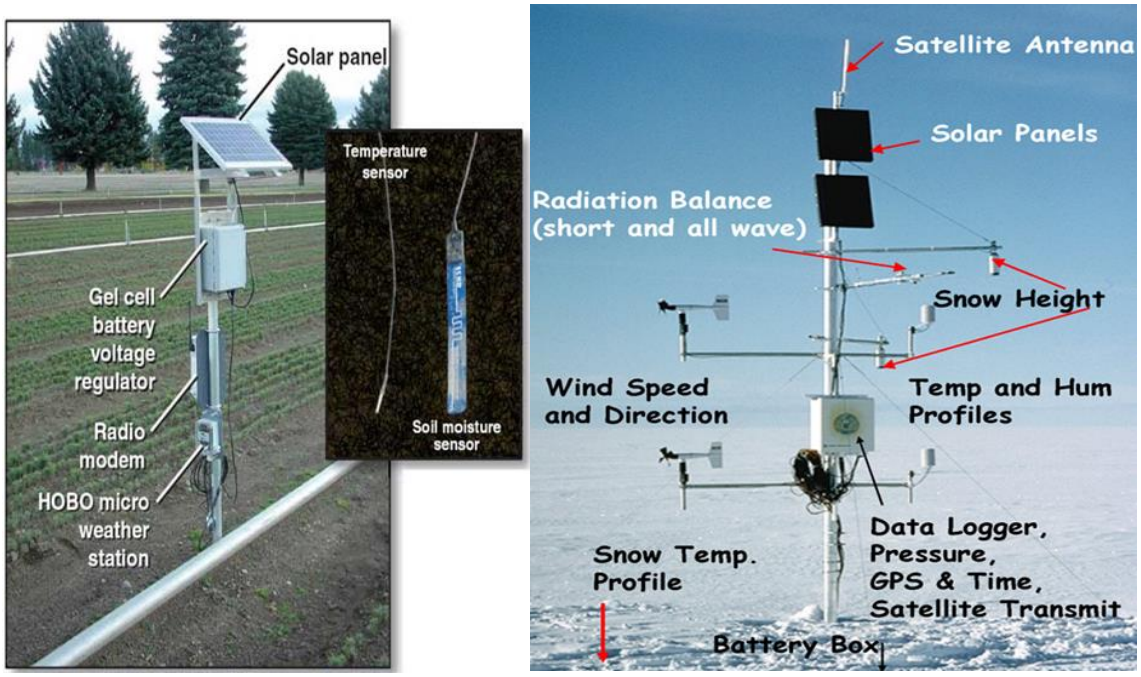

Fig.5 Water flowmeter & Battery-operated moisture probe

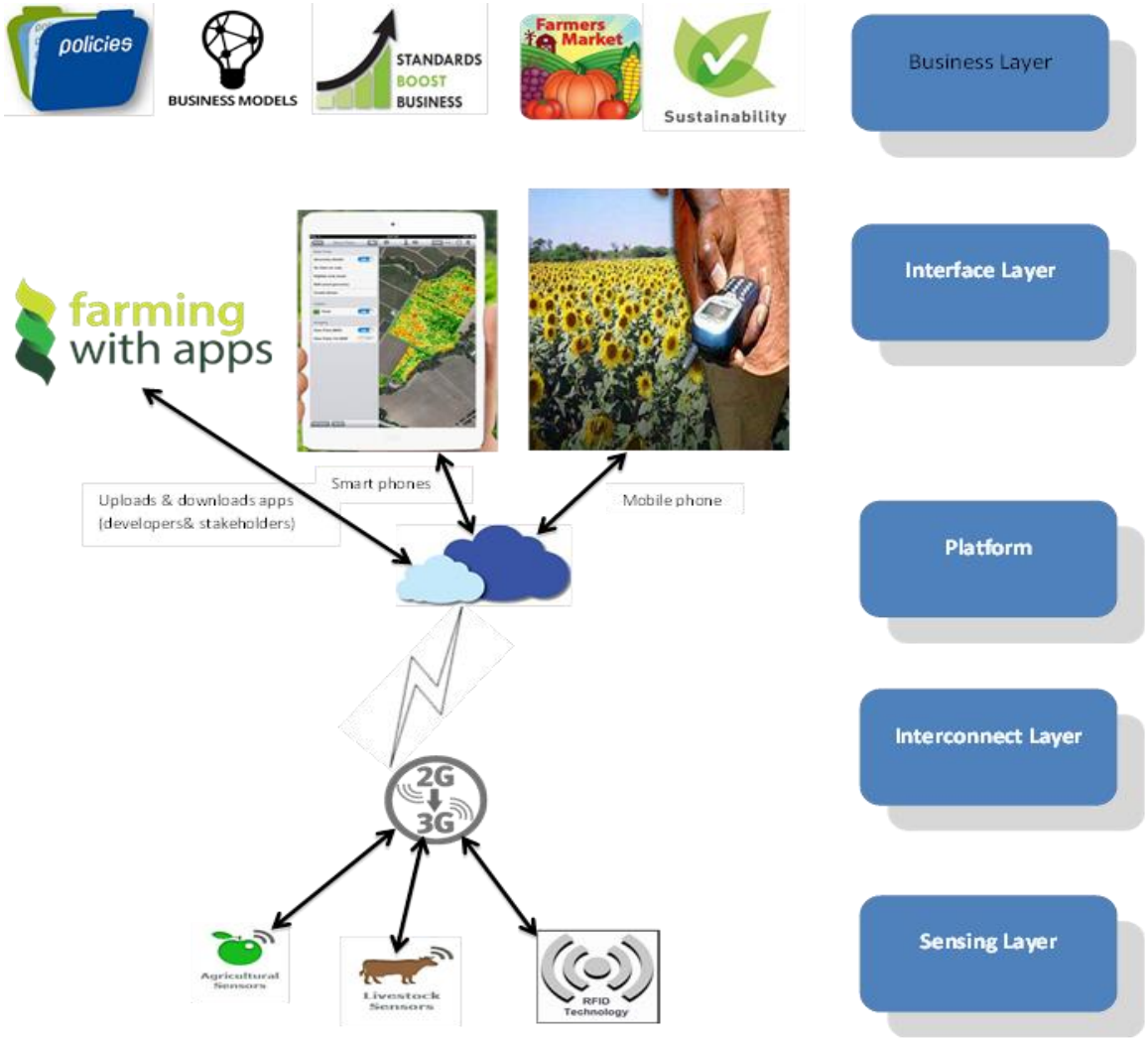

Fig.6 Agro application and implementation description using the new IoT architecture

The model suggested in this paper is suitable and can be applied in the following farming application areas.

1. Arable farming, large and small field farming
2. Livestock monitoring
3. Indoor farming – greenhouses and stables
4. Fish farming
5. Forestry
6. Storage monitoring
7. Fleet management – tracking of farm vehicles.

VI. CONCLUSION AND FUTURE RESEARCH

This paper provides up to date information on the concept of precision/smart agriculture based on previous research works, states its advantages, presents IoT as the driver of precision farming, and how it can be applied in Nigeria agriculture sector to increase crop yield and ensure agriculture contributes largest percentage to the country GDP in the next 5 to 10 years if properly implemented. The application of IoT is based on the new IoT architecture described in this paper for sustainable adoption of IoT in agriculture sector. It connects all the stakeholders as ecosystem. There are two critical layers- the business and platform layers. Precision agriculture is driven by data analysis which is the major function of the platform layer. Implementation issues or failure at these two layers will have serious implications on the entire system.

The solutions in this paper based on the new IoT architecture can be adjusted and adapted in any country especially developing countries not only for a sustainable farming but also other areas of applications. Notable among them are education, health, industry, gas and energy, e-government, smart city etc. The future research will focus on sustainable business model for the entire ecosystem and Big Data analysis as the platform is expected to grow with data over time. Managing this data to provide real time information and decisions might be of serious concern. Also, the future research will look into how the data can be used to provide better services and create additional values for the country.

I hope this paper will be a reference point and solid foundation for the implementation of smart agriculture in Nigeria and also provide other developing countries the needed information to embark on smart agriculture to ensure the world is food sufficient. I also believe this paper will add to the literature works on smart agriculture using IoT.

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