TOWARDS THE SUCCESSFUL DEVELOPMENT OF INTERNET OF THINGS: A REVIEW OF THE NIGERIAN CASE

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Abstract

Internet of Things (IoT) possesses the potential to exponentially transform the economy of developing countries by coordinating the provision of essential services that will benefit the people. However, this can only be realized if IoT investments are made in critical sectors of the economy while the challenges hampering its successful deployment and use are identified and addressed. Thus this paper summarizes the extant and emerging areas of IoT application at a global level and in Nigeria over a period of ten years, identifying the technical and non-technical challenges impeding IoT development, recommending possible solutions and identifying possible areas for future research. Relying on information synthesized from the analyses of vast volumes of available literature from academia and the industry, the paper explained how simple IoT solutions could be adopted to improve key sectors of our economy, analyzed some of the challenges impeding IoT development and recommended strategies to overcome those challenges. It appears that effective use of IoT solutions will rely on regulatory amendment in the areas of spectrum and data security to make the former more available and cheap for use and the latter more secure, respecting the user's privacy. Furthermore, adoption of renewable energy solutions, extension of fiber to unreached areas, re-farming of GSM networks and inclusion of IoT courses in schools are some solutions that can curb these challenges. Achieving successful deployment and use of IoT in Nigeria will require concerted efforts from all the stakeholders in order to surmount the existing challenges in the areas of spectrum availability, data security, power, network connectivity, standardization and human capacity improvement which are critical for its deployment and use.

Keywords: IoT, deployment, regulation, privacy, spectrum

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1. INTRODUCTION

IoT is a novel paradigm which promises to transform the world by bringing together technologies such as wireless and mobile communications, embedded systems, radio frequency identification (RFID), sensors and actuators with the sole aim of interconnecting physical objects - bridges, fridges, cars, homes, etc., to enable them collect and exchange data (Biggs et al., 2016). The exchange of data between these physical objects is coordinated to provide services that will benefit people.

When adopted, IoT possesses the capability to transform lives and impact positively on the economy of nations. Therefore, people, organizations and countries have adopted it to drive their work as well business processes in critical sectors of the economy such as education, health and agriculture, resulting to positive results and success stories. Some of the application areas are education, health, agriculture, etc.

IoT has helped to advance basic and quality education as well as improve teaching and learning methods, monitor attendance of students and staff to classes and track locations of pupils with a view to ensuring their safety. Currently, solutions such as internet connected smart boards that provide access to real-time data, which is often more valid than textbook content, RFID enabled cards that track a pupil's whereabouts, and smart ID cards with biometric features that monitor attendance to classes, etc. have been developed and implemented for use schools. In addition, IoT solutions that enable students become co-creators of knowledge has been developed. An example in(Barakat, 2016) uses real-time data generated by weather sensors to understand weather patterns. Such a solution help in accelerating students' learning, enabling them to have a deeper understanding of the subject area.

IP cameras and motion detectors installed in toilets to monitor in real-time whether people wash their hands after using the toilets have helped in reducing the spread of communicable diseases such as cholera among young people (Elimian et al., 2019). Wearables such as blood pressure monitors, body temperature monitors, and glucose monitors are being used to observe a patient's vital signs and report anomalies to professionals in distant locations, with little or no human involvement. In addition, IoT has been applied to provide emergency care during life-threatening emergencies caused by road accidents, obstetric complications

and other illnesses (Adegoke & Ajuluchukwu, 2019).

IoT can help improve their quality and entrench practices that will guarantee their sustainability. Sensors can be used to remotely measure in real-time, the PH level, turbidity, temperature and total dissolved solids (TDS) of water to determine its quality. In the food supply chain, sensors can be deployed to monitor in real-time, the production environment with a view to ensuring that standard procedures are followed in order to increase food quality. Such sensors could detect impurities by identifying specks and color variations in food, and monitor and control temperature, thereby preventing spoiling and wasting of food; these solutions can be accomplished at very minimal cost.

Precision agriculture has helped to improve crop yield while ensuring the sustainable use of agricultural resources such as soil nutrients, land and water. As shown in Figure 1, sensors (S1, S2, S3 and S4) placed at different locations on a farm measure the soil's moisture content, temperature and quantity of nutrients (e.g. nitrogen, phosphorus and potassium), transmitting the measured data wirelessly to a central repository (Ramli et al., 2020). Such data has been harnessed to provide information on the type, quantity of fertilizer and volume of irrigation to be applied at various sections of the farm, increasing yield at a reduced cost, while controlling environmental hazards often caused by over-application of fertilizers and irrigation.

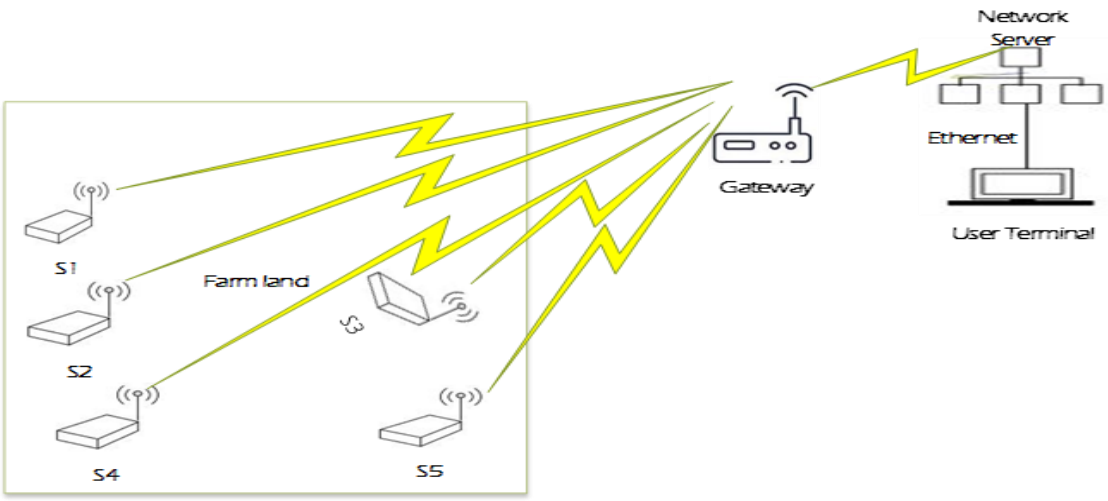

Figure 1: Conceptual illustration of precision agriculture

In developing countries such as in Nigeria, people still encounter several difficulties from lack of access to quality education, quality healthcare and portable water, spread of communicable diseases and hunger due to food inadequacy (UNICEF Nigeria, n.d). For example, a World Health Organization's report published by (Tandon *et al*. 2016) revealed that Nigeria has one of the worst health indicators in Africa, ranking 187. Performance indicators used in the study include but are not limited to: overall level of health, distribution of health in populations, responsiveness and distribution of finance. Furthermore, according to (UNICEF Nigeria, n.d), only about 26.5% of the Nigerian population use improved drinking water sources and sanitation facilities and over 200,000 persons die of food poison annually as a result of food contaminated through improper farming, processing and preservation techniques (Ezirigwe, 2018). As exposed in the application areas above, IoT can be applied to address these problems.

Already, efforts are being made by public and private institutions in Nigeria to develop IoT and also, create a fertile ground that for its deployment. Some of these efforts could be seen in the following initiatives:

a. Indigenous firms such as GRIT systems, Facmicro and iHabitat manufacture IoT products and solutions such as G1, Zenvus and Obuno IoT engine respectively (Okunola, 2018).
b. The federal government through the National Information Technology Development Agency (NITDA) and in partnership with Cisco systems built and equipped six IoT laboratories in six federal universities across the six geopolitical zones of the country.
c. The NCC, in partnership with MTN and Huawei Technologies, ZTE and Ericsson performed a non-commercial trial for 5G in November and December of 2019 in Abuja, Lagos and Calabar (Nigeria Communications Commission [NCC], 2019). It is commendable to note that NCC is the first regulator to do so in West Africa. Prior to that, it approved the release of dedicated spectrum for 5G trial and information from unconfirmed sources states that the commission has reserved spectrum in the 26GHz, 38GHz and 42GHz bands for 5G networks.

d. The Nigerian Communications Commission (NCC), in a bid to deepen broadband access (an enabler of IoT), has licensed six telecommunications infrastructure companies (Infracos) to deploy broadband to the unserved and underserved areas of Nigeria in line with the principles of the Open Access Model (NCC, 2019). These companies include: i) O'duaInfraco Resources Limited (for the south west region); ii) Fleek Integrated Solutions (for the North West region); iii) Brinks Integrated Solutions (for the North East region); iv) Main One Limited (for Lagos region) and; v) Zinox Technologies (for the South East region).
e. In July 2019, the NCC with the aim of developing 5G and IoT, called for submission of research papers on "5G Technology" from academics in local tertiary institutions. Such research papers, according to the regulator, should provide local solutions to some 5G and IoT challenges such as spectrum availability, suitable business models, security and regulations.
f. The present administration in a bid to ensure seamless delivery of essential digital services within and outside the country declared telecommunications facilities as critical national infrastructure and directed that necessary physical protective measures be put in place to protect telecommunications equipment from vandalization and theft ("FG declares telecoms," 2020)

Nonetheless, Okunola (2018) acknowledged that the IoT segment in Nigeria still lags behind that of some African countries such as South Africa and Kenya. For example, in some parts of South Africa, smart meters are already being used to accurately determine volumes of water usage (Koetze & Coetzee, 2018) while the Limabora Remote Farm Monitoring system, which guarantees food security and land sustainability has been commissioned in Kenya (Mabele & Mutegi, 2018). Therefore, the need arises to speed up IoT development so that Nigeria will assume a leading role in Africa.

Successful development and adoption of IoT in the developed world has been achieved by strengthening the physical infrastructure (either through upgrade or total overhaul) and

the regulatory framework (either through amendment or formulation of new policies). For example, in the United States of America (USA), 2G cellular technologies are being replaced with Low Power Wide Area (LPWA) technologies (Gray, 2017) which are better suited for the low power requirement of IoT devices. In the same vein, the UK government has approved the establishment of a new IoT code of practice called the Secure by Design to increase security of connected devices in IoT (Hogewoning, 2018). We posit that developing countries that want to tap into the benefits of IoT should also go in that direction.

It is evident that for IoT solutions to be deployed across Nigeria, considerable improvements of our critical physical infrastructure such as power and telecommunications as well as careful amendment of the relevant institutional infrastructure such as existing regulations respecting data accessibility, security, privacy, anonymity, spectrum licensing, competition, standards, interoperability, infrastructure sharing and should be carried out by all the IoT stakeholders. It is pertinent, from a Nigerian perspective, to enumerate these stakeholders, explaining their roles in the IoT value chain.

a. Government - formulates policies/regulates the IoT through her agencies which include:
   i. National Frequency Management Council (NFMC): Serves as the focal coordinator of all spectrum activities in Nigeria by planning and allocating radio spectrum to the regulatory bodies (Odufuwa, 2010). The council also performs an additional role of advising the Minister of Information and Communications on Nigeria's representation at international and multi-lateral frequency spectrum bodies. The council consists of representatives from ministries of aviation, transportation, science and technology, Nigeria Communications Commission (NCC), National Broadcasting Commission (NBC) and the security services.
   ii. The Ministry of Information and Communications (MOIC): Issues spectrum licenses to government bodies and non-commercial users such as the military, diplomatic missions, security services,

voluntary organizations and non-profit groups.

iii. The Nigeria Communications Commission (NCC): Regulates the telecommunications industry and issues spectrum licenses to commercial telecom operators.

iv. National Broadcasting Commission (NBC): Regulates the broadcast industry and issues spectrum licenses to public and private broadcast stations.

v. National Information Technology Development Agency (NITDA): Responsible for promoting IT penetration and serves as the clearing house of public sector IT projects.

b. The Consumer Protection Council (CPC): Regulates public and private economic/business activities with a view to entrenching market competition and eliminating anti-trust issues thereby ensuring that the consumer is protected from any form of abuse or ill treatment in the event of purchasing a product or service.

c. Industry - Designs and develops the identification, sensing and actuating devices, develops resilient application/system/network software, provides adequate and secure access/core network connectivity (Weber & Weber, 2020), as well as provide secure and adequate cloud storage for the enormous data that will be generated by IoT devices. The industry players cut across healthcare, manufacturing, transport, retail utilities and agricultural domains.

d. Academia/Independent Researchers - Collaborate with the government and the industry to proffer (through multi-disciplinary research) technical and non-technical solutions to the challenges of IoT which border on security, privacy, ethics and standards with a view to making IoT systems safe and secure and to inform evidence-based policy making by the government. The academia also incorporates IoT-related courses/subjects in the schools' curricular, thus helping in raising awareness about IoT which will open the minds of young people to many possibilities that can be achieved through IoT.

e. End users - Purchase and use the various applications/services provided by IoT service/application vendors (BEREC, 2016) and provide

feedback (to the vendors) on the behavior/performance of their products. They also supply data to academia, government and independent researchers for research (technical and social) purposes, thereby assisting in helping the government and industry regulators design effective policies and regulatory frameworks that will enshrine ethical practices and establish trust in the use of IoT systems

Therefore, in this paper, we expound from a global perspective, the state of the art research in IoT in the technical and non-technical domains over a decade, identifying research gaps and directions for future research. Subsequently, we make an attempt to summarize the extant and emerging areas of IoT application in Nigeria over the sameperiod, identifying in general terms, the technical and non-technical challenges impeding its development and recommending possible solutions. We also try to shed more light on the regulatory concerns respecting data security, privacy and spectrum management.

We believe that some of our recommendations especially those geared towards addressing the regulatory issues, if implemented, will go a long way in helping all the stakeholders realize the benefits of IoT to Nigeria. We also believe that identifying the key areas of application will help incentivize the local industry and the academia to work towards developing local IoT solutions that will solve some of the challenges we face in our country. Therefore, the target audience for our paper includes stakeholders in public and private sectors with an interest in IoT such as government regulators and policymakers, application developers, local IoT industries and adopters of IoT-related products and services.

The rest of this paper is organized as follows: Section two is the outline of the approach adopted for this research. Section three, is the IoT progress at the global level and in Nigeria, identifying technical and non-technical challenges impeding its development at both levels. Section four contains the conclusion and recommendations.

2. Approaches

This describes the strategies adopted to search and select data for our research with a view to ensuring that the best available

information is used. In this sub-section, we explain in details the activities that make up each strategy.

A. Search Strategy

After defining the objective of the paper, we selected databases which were searched to find all available information relevant to our research.

Our approach was partly influenced by that adopted by the authors in (Sheepers et al., 2014). We searched the electronic databases of Scholar Google, Scopus, Research Gate and Arxiv, the repositories of relevant associations, industries and regulators such as Internet Society, Cisco and NCC as well as the websites of government regulatory agencies such as (National Information Technology Development Agency [NITDA], 2019) among others for academic publications and IoT-related reports published from the earliest possible time till 2020 when we concluded this review.

We could not focus on only peer-reviewed articles as some articles focusing on information and communications technology (ICT) and IoT development in Nigeria as well as other countries were not peer-reviewed; reason being that some of these articles like (Body of European Regulators for Electronic Communication [BEREC], 2016) were reports submitted on request to government by relevant agencies. We chose not to put a start date because we wanted to glean relevant information from all the available literature to enable us adequately cover all the aspects of our work. English was the search language used and only publications and reports published in English were returned by the search queries conducted.

B. Information Extraction

This describes the strategy adopted to glean articles relevant to our work from all the databases and online repositories visited.

We performed simple searches with keywords such as IoT, Regulation, and Deployment to retrieve the sources we assessed for eligibility and inclusion in our work. Boolean operators such as OR and AND were used to combine keywords with a view to broadening or narrowing the results to enable us retrieve vast articles from various countries which we read and analyzed to develop our work. We also used the website http://www.connectedpapers.com to identify the key reference papers of articles. This helped us easily navigate to these key reference papers, making the retrieval

process faster.To save time and resources, for each extracted article, we read the abstract before reading the other sections. We only proceeded to read the full text if the abstract matched what we were looking out for. When it did not match, we disregarded the full text and moved on to read the next downloaded article.

C. Building the Paper

We disregarded articles that contained duplicate information as well as information lacking appropriate citation. We only included articles that contained the aspects which our work set out to study as well as other relevant information needed to develop the necessary insight for our work. At the end, out of over 105 articles which we downloaded, we only used 41 articles to develop our paper.

3. Research Challenges

A. Summary of the State of the Art Research in IoT

The potential of IoT to transform economies and advance social well-being has necessitated considerable research efforts in the two major domains of the IoT ecosystem: technical and social domains (Nicolescu et al., 2019).

i. Research Advancements in the Technical Domain

RFID-based identification has been widely applied in supply chain management, retail, connected health applications and services making large scale identification, monitoring and effective management of inventory, goods, health devices, and even patients more efficient.

Advances in low energy technologies for short range (Near Field Communication, Z-Wave), medium range (Wi-Fi Halow), long range (LoRa, Sigfox) wireless communications and smart sensing technologies have enabled the actualization of IoT services such as smart cities, precision agriculture and just-in-time inventory management. In addition, other communication technologies such as the Extended Coverage for GSM IoT (EC-GSM-IoT), Long Term Evolution for Machine Type (LTE-M) and Narrow Band IoT (NB-IoT) have been developed through a re-farming of the existing GSM, LTE and LTE-M technologies respectively to support IoT's design objectives of low device complexity, cost, greater power efficiency, extended coverage and improved security (Lieberg et al., 2017).

Advances in efficient spectrum utilization technologies have resulted in the development of Cognitive Radio (CR) technology to enable efficient use of the available spectrum to support IoT service requirements. CR technology offers IoT devices (secondary users) the capability to identify available free spectrum and detect the presence of licensed users (primary users) in the spectrum, choose the best available channel from a set of available channels in a spectrum (spectrum management), coordinate the accessibility of the available channels by the secondary users with the primary users (spectrum sharing) depending on the bandwidth requirements of the service as well as to exit the accessed channel on the arrival of the primary user (spectrum mobility) if the bandwidth requirements of the licensed service will not allow for spectrum sharing (FCC, 2012).

These advances have birthed some visible IoT applications and services such as Internet connected smart boards and RFID enabled smart cards (Barakat, 2016), blood pressure, body temperature and glucose monitors, Ambient Assisted Living (AAL) services (Islam et al., 2015) and remote farm monitoring services such as the Limabora (Mabele&Mutegi, 2018).

ii. Research Advances in the Social Domain

Implementation of IoT gives rise to issues ranging from data security and privacy which negatively affects the rate of adoption or acceptance of IoT products by consumers (Nicolescu et al., 2019). The scale of implementation in connected services such as smart cities makes these issues more challenging and complex. Therefore some aspects of research advancements in the social domain are geared towards formulating policy frameworks and regulations to ensure the responsible use consumers' data with a view to preserving the security and privacy of such data. Furthermore policy frameworks and regulations are extended to cover other vital areas such as spectrum management, spectrum licensing and competition.We summarize the requirements of some existing policy frameworks on data management used in Europe and the US: theGeneral Data Protection Regulation (GDPR) and the European Union-United States (EU-US) Privacy Shield Framework.

GDPR

The GDPR is a Pan-European legislative framework aimed at protecting the rights of

consumers across Europe. It spells out the responsibilities of the organizations (custodians of data) in the IoT value chain towards the data owners (FitzGerald, 2016). The requirements of the GDPR include but are not limited to the following:

Security Breach: Custodians of data are required to report personal data breaches to a higher authority within seventy two hours after becoming aware of the breach.

Consent: Data custodians should ensure that prior to the processing of consumer's data, a clear affirmative act establishing a freely given, specific, informed consent should be gotten from the consumer.

Privacy by Design: Organizations that manufacture IoT devices should ensure that privacy is incorporated at the design stage of the manufacturing process.

EU-US Privacy Shield Framework

This provides companies in the European Union (EU) and the United States (US) with a mechanism to comply with data protection requirements when transferring data personal data between the EU and the US. It is based on seven fundamental principles which cover key data protection aspects such as choice, security, access, enforcement, liability, data integrity and purpose limitation. The requirements of the seven privacy shield principles are summarized below.

a. Notice: It is mandatory for organizations to make public privacy notices containing information about their participation in the Privacy Shield Framework.

b. Choice: Consent must be gotten from a customer before his data is shared with a third party. Such opt-in consent should specify the purposes for which such data should be shared and the custodian of data has a legal responsibility to abide by this consent. A mechanism should also be provided to enable a customer opt out of having personal information disclosed to a third party.

c. Accountability for Onward Transfer: This requires organizations to enter into contractual agreements with third parties that will process their customers' data mandating such third parties to transfer a customer's personal data in a way that is consistent with the privacy shield principles.

d. Security: Appropriate measures must be taken by organizations to protect personal data from unauthorized access, loss, misuse, alteration, destruction and disclosure.

e. Data Integrity and Purpose Limitation: Reasonable steps must be taken by organizations to limit data processing to the purposes for which it was collected.

f. Access: Organizations must provide a method by which customers can request access, amend, correct or expunge information the organization holds about them

g. Recourse, Enforcement and Liability: This requirement specifies the steps that should be taken by individuals who are affected by non-compliance to get justice. It also spells out penalties for non-compliant organizations

Furthermore, the EU-US privacy shield framework includes sixteen supplemental principles which expand upon the seven fundamental principles (Privacy Shield Framework, (n.d)).

Various countries have data protection acts which are binding on their citizens and on any organization operating within their boundaries. Examples of such data protection acts in Nigeria include the Federal Competition and Consumer Protection Act 2019, NITDA act, etc.

B. Research Gaps

From the summary, we identify some possible research gaps which need to be filled. They include but are not limited to the following:

i. *Regulation and Policy Framework on Data Management*

On a large scale, IoT will involve communication among billions of devices interconnected by heterogeneous networks; resulting in the generation of huge data that will be stored in the cloud prior to analysis and yielding information that is beneficial to the user. These large number of devices and networks involved will increase the surface area of attack of an IoT system (Hossain et al., 2015). Therefore, the full deployment of IoT, while offering great opportunities, will also unleash

serious and unprecedented social and ethical issues bordering on data privacy which need to be tackled in order to reap its enormous benefits; hence the need for an adequate framework on data management.

ii. *Regulation on Spectrum Access and Use*

To attract investment into the IoT market, the regulation should strive to lessen the entry barriers by encouraging flexible access to spectrum, with a view to deepening competition and promoting innovation. To accommodate across national borders, there will be a need to harmonize spectrum regulations on an international level to achieve global and affordable cellular IoT market.

iii. *Data protection techniques*

The low computational power of IoT devices (e.g. traffic cameras and handheld devices) will make it infeasible to apply standard cryptographic algorithms to protect their data. Therefore the need arises to develop light weight and efficient cryptographic algorithms that will be suitable for low power IoT devices

iv. *Common Standards*

IoT will involve coexistence of different communication protocols, proprietary solutions from different organizations and business alliances from different business sectors. Therefore, there is a need for a common standard to achieve interoperability among the coexisting IoT devices.

C. Directions for Future Research

Based on the research gaps, we identify directions for future research on IoT

i. *Privacy by Design*

To achieve data privacy and security in a world of interconnected things, privacy and security of IoT devices, applications and networks should be an integral part of the design of IoT devices, networks and systems. Research should address the issue of security of legacy systems deployed in critical infrastructure which did not adopt the privacy by design concept in their design stages.

ii. *Harmonization of Data Protection Laws*

As IoT will involve communication among connected devices within and beyond national boundaries, there is a need to update existing data laws and formulate new laws putting the intricacies of IoT in perspective. In addition, there is a need to harmonize legislation surrounding the use of data to ensure that customer's data is protected from unauthorized access.

iii. *Spectrum Access Laws*

Updating existing spectrum laws to ensure that adequate spectrum (at short, medium and long ranges in licensed and license-exempt bands) is available for a wide range of IoT applications (Brown, 2015).

iv. *Standards*

A decentralized architectural model that will accommodate the several technologies and protocols in IoT is needed to facilitate coexistence in IoT.

D. Current Research in IoT in Nigeria: Emerging Areas, Directions for Future Research and Challenges.

IoT is not yet popular in Nigeria as it is in the developed world. Nonetheless, there are few IoT products developed and deployed in the country already. Majority of these IoT deployments are Machine-to-machine (M2M) applications used in car tracking, fleet management, security monitoring and detection of counterfeit medicines (Ogidiaka, Odion., & Irebhude, 2017).

The Nigerian Satellite Company Limited designed, implemented and deployed an RFID-based Staff Attendance and Access Control System (RFID-SAACS) for staff monitoring and general administration to reduce time theft and compute staff salaries. The system also provides data which assists in monthly staff appraisal exercise (Ndubuaku & Okoroafor, 2015).RFID cards and readers were used in the 2019 general elections to authenticate voters before they are allowed to exercise their franchise.

I. Emerging Areas

a. Air Quality Monitoring

In a research conducted by the Center for Atmospheric Research and the National Space Research Development Agency, IoT was used to monitor the air temperature and

humidity of four states in Nigeria - Lagos, Osun, Delta and Kebbi including Abuja over a period of five to seven months(Abulude & Abulude, 2021). The results indicated that air temperature and humidity in these state are noticeably higher when compared to the international benchmark. If the research is extended to other states, the results will help guide industries as well as the general public towards adopting more responsible approaches in the combustion of fossil fuel which is the main cause of rising atmospheric temperature in these areas.

b. Preventing the Spread of Communicable Diseases

IoT is being applied in preventing the spread of pandemics such as the Covid-19. From a remote location, IoT applications installed in smart phones can capture the location of an infected person, and effectively monitor him to ensure that he adheres to quarantine rules. Doctors can constantly access the patient's health record from a central repository which will help them to administer treatment. By so doing, cases are handled more appropriately and smartly too (Oyeniyi et al., 2020).

c. Reducing the Frequency of Building Collapse

The high rate of building collapse can be attributed to lack of monitoring and enforcement by the regulatory bodies. IoT coupled with data analytics can be used to share data among site engineers, regulators and owners of buildings with a view to ensuring that required standards are met. This will reduce the rate of building collapse in Nigeria (Douglas & Mohammed., 2020)

II. Challenges of IoT in Nigeria

Being a developing country lacking in advanced physical and institutional infrastructure, the prospect of IoT in Nigeria brings a horde of challenges. We enumerate some of these challenges.

a. High cost of deployment

Sensors and actuators are cheap but cost of shipping, landing and insurance is high (Ndubuaku&Okoroafor, 2015). Cost of connectivity (especially for long distance communication) is high.

b. Data Security, Privacy and Trust Issues

IoT attacks could be in the form of denial of service, identity theft, and physical attacks or targeted at the communication channels.

Such attacks compromise the privacy and integrity of the consumer's data. In addition, the data generated in IoT will be subjected to analytics by third party agents to yield relevant information that will be applied to draw specific conclusions. Therefore, it is important that a consumer's data is kept safe at all times and used for other purposes based on his consent.

c. Limited and Expensive Spectrum

Already in Nigeria, there is a high demand for wireless spectrum to support the ever increasing voice, data and multimedia services across the vast landscape. IoT implementation will involve communication among billions of interconnected devices over fixed and wireless channels placing huge demands on the limited spectrum.This demand will increase exponentially putting into perspective IoT services which have huge bandwidth requirements.In addition, as shown in Table 1, the allocated spectrum is highly underutilized. In addition, the high cost of spectrum wil discourage competition in the IoT market. In 2016, MTN was the sole bidder for the 2.6 GHz band for 4G services advertised by the NCC ("MTN Nigeria wins," 2016) because other operators complained that the reserve price of N16 million per lot was too high, discouraging them from bidding for the spectrum.

Table 1: Summary of spectrum occupancy in Nigeria (Wenjian & Kadri, 2013).

Block	Frequency Range (MHz)	Duty Cycle (%)
1	700 - 1000	26
2	1000 – 1297.5	2.13
3	1297.5 - 1500	1.85
4	1500 - 1700	12.7
5	1700 - 1997	25.56
6	1997 - 2200	0.45
7	2200 - 2400	17.42

a. Insufficient/erratic Power supply

Most IoT devices have to be powered 24/7 to perform continuous monitoring. Power generation of 4000 MW is insufficient and

over 20 million people do not have access to power (United States Agency for International Development [USAID], 2020).

b. Internet Connectivity

Some IoT applications demand constant internet connectivity. Internet access in Nigeria is mostly via wireless 2G and 3G with limited 4G connections (Gilwald, Odufuwa, &Mothobi, 2018). These connections are often expensive with unpredictable data rates and latencies. Wired connectivity does not enjoy much coverage compared to wireless and is limited to urban areas such as Lagos and Abuja. Fiber backbone is lacking or not active in most areas where it is present.

c. Data Centers

IoT will result in the creation of huge amount of data which will be stored in cloud servers located in data centers. These data centers should operate all the time to enable anytime access to the data. In Nigeria, there is insufficient number of data centers to match the data storage requirements of the teeming population. Furthermore, the capacity to power these data centers 24/7 is lacking.

d. Dearth of Human Resources

There is a scarcity of engineers, scientists and technicians to drive IoT research in Nigeria. In addition, Nigeria has few research centers dedicated to IoT research.

e. Lack of Open Standards

Presently, most IoT solutions adopt proprietary standards which limit entry barriers, discourage interoperability and limit competition. Open standards are needed to ensure device, data, application and radio access interoperability (Internet Society, 2019).

f. Human Behaviour

Some people find it difficult to adapt to changes in their environment. Therefore, they tend to frustrate such changes from happening.

Conclusion

The development and deployment of IoT in Nigeria promises to transform critical sectors of our nation's economy such as education, health, food and water quality and agriculture. However, for these expected changes to materialize, all the stakeholders should work towards surmounting the existing physical and institutional infrastructural challenges in the areas of

spectrum availability, data security, power, network connectivity, standardization and human capacity improvement which are critical for its deployment and use. This paper reviewed among other things, the extant and emerging areas of IoTapplication in Nigeria as well as the challenges impeding IoT development. It is worthy to mention that amending the existing regulations surrounding data management and spectrum access some major areas that require careful attention. In addition. Future research on IoT deployment and regulation of IoT in Nigeria should be directed at considering regulatory amendment in the areas of standards, interoperability, competition and infrastructure sharing.

In Table 2, we recommend possible solutions that will alleviate those challenges enumerated in this section.

Table 2: Challenges to IoT deployment in Nigeria and possible solutions

S/N	Challenge	Possible Solutions
1.	High deployment cost	i. Government should approve tax rebates for IoT investors. ii. Models that encourage sharing of IoT components such as sensors (e.g. sensor-as-a-service should be adopted in some IoT domains (e.g. agriculture)
2.	Data Security, Privacy and Trust Issues	
3.	Limited and expensive Spectrum	i.Effective utilization of the currently allocated but underutilized spectrum. ii.Freeing up additional spectrum band for IoT use (in the future, but necessitated by demand). iii.Making spectrum prices affordable
4.	Insufficient/erratic Power supply	i.Renewable energy (solar, wind) solutions should be adopted to ensure devices are up 24/7.

		ii. Use of energy harvesting sensors should be encouraged to ease the demand on power.
5.	Internet Connectivity	i. Extending fiber to unreached areas (ongoing). ii. Re-farming of GSM networks to suit IoT requirements (Ajere&Ikerionwu, 2019). iii. Deploying 5G networks (ongoing). iv. Adopting satellite solutions for areas not covered by GSM due to terrain difficulties.
6.	Insufficient number of data centers	Establishment of more data centers across the country.
7.	Lack of open standards	IoT solutions should conform to international (IETF, GSI-IoT, etc.) standards.
8.	Human capacity (Inadequate workforce)	i. IoT courses should be included in the curricular of universities and polytechnics for engineering, computer science and other information technology related courses. ii. IoT applications should be translated into the main languages for deep market penetration. iii. Government should intensify various efforts to improve literacy level.
9.	Human behavior	i. Government, industries, and other major players should launch awareness campaigns before IoT deployment. ii. Designers should adopt user friendly interfaces to attract users.

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