



# Narrowband-IoT as an Effective Developmental Strategy for Internet of Things in Sub-Saharan Africa: Nigerian Case Study

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**Abstract.** With the recent standardization of Narrow-Band Internet of Things (NB-IoT) as a category of Low Power Wide Area (LPWA) technology by the 3GPP, the endless possibilities it brings for IoT development cannot be overemphasized. Nigeria as a developing nation, has continued to struggle in the development and deployment of Internet of Things (IoT) technology. The approach of this paper is basically to critically analyze the current state and the technological deficiencies of IoT development in Sub-Saharan Africa by using Nigeria as a case study, and to show how the emergence of NB-IoT can help to significantly improve the penetration and optimal development of this relatively modern technology in Nigeria and consequently in Africa, as it is in developed nations. Relevant features of NB-IoT are enumerated, we propose possible NB-IoT use cases that are suitable for the Nigerian eco-system and finally, we give a summarized developmental plan for the mobile network operators (MNOs) in Nigeria.

**Keywords:** Development strategy · Internet of Things · Low Power Wide Area · NB-IoT · Nigeria

## 1 Introduction

The nations in Sub Saharan Africa has continue to take the back seat when it comes to technological advancements and innovations. However, in recent years, sub-Saharan African countries such as Nigeria, South Africa, Kenya and Angola has witnessed a tremendous increase in technological advancements. Specifically, the mobile internet penetration and tele-density has continued to be on the rise in the last five years. Nigeria which is unarguably by far the most populous country in Africa with an estimated population of over one hundred and ninety million has an approximate fifty one percent (51%) internet penetration with an average increase of rate 2.5% every year [1]. One of the most recent technological innovations currently shaping the connected world of humans and objects is the Internet of Things (IoT). Nigeria and few other sub-Saharan African countries lead the pack in the deployment and development of IoT.

The acclaimed discovery of Internet of Things (IoT) in 1999 by Kevin Ashton might be one of the greatest technological innovations of mankind. It is a technology that is currently revolutionizing wireless communications by allowing connectivity between humans, machines and objects. Machines, appliances, buildings, healthcare, transport systems, energy systems, agricultural systems are some of the few aspects that will be significantly transformed when IoT has been fully and effectively developed. IoT seeks to create a world where everything and everyone becomes relatively smarter and are all connected via the internet.

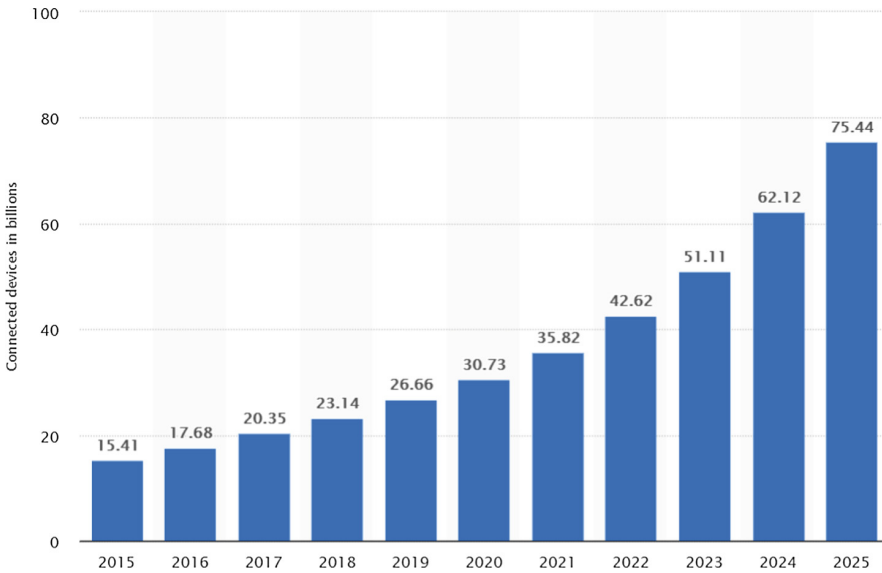
The Internet of Things works by embedding highly intelligent sensors and chips on physical things around us, these sensors can transmit useful data of how these physical things not only work, but also how they can seamlessly work together. The useful data are securely transferred to a common IoT platform that allows connectivity between devices/physical things and apps, and at same time perform real time data analytics that are shared with industries to address their specific needs.

It is estimated that by the year 2025, the number of connected devices around the world would have risen to about 75 Billion (see Fig. 1), out of this enormous amount, it is expected that the entire sub-Saharan Africa would only be able to account for about 2% by projection and analytics [2]. Although, sub-Saharan African nations are mostly developing, but we believe that they should contribute meaningfully to this number especially because they are about 14% of the world's population.

There are instances where there is need for deployment of internet of things devices in areas where coverage is significantly low. NB-IoT has a wide coverage area because it was designed to have an extra coverage range of 20 dB. The coupling pathloss for GSM is estimated to be 144 dB, with an increment of 20 dB extra, the maximal coupling path loss for NB-IoT is given as 164 dB. In addition, the devices can be able to transmit and acquire data irrespective of environments that they are installed.

For scalability, easy development and deployment, and to cater for the growing number of connected devices in IoT, different wireless technologies are developed. These wireless technologies are broadly classified into two; short range radio connectivity such as Bluetooth, ZigBee, NFC/RFID and the long-range radio connectivity, which is generally referred to as Low Power Wide Area (LPWA).

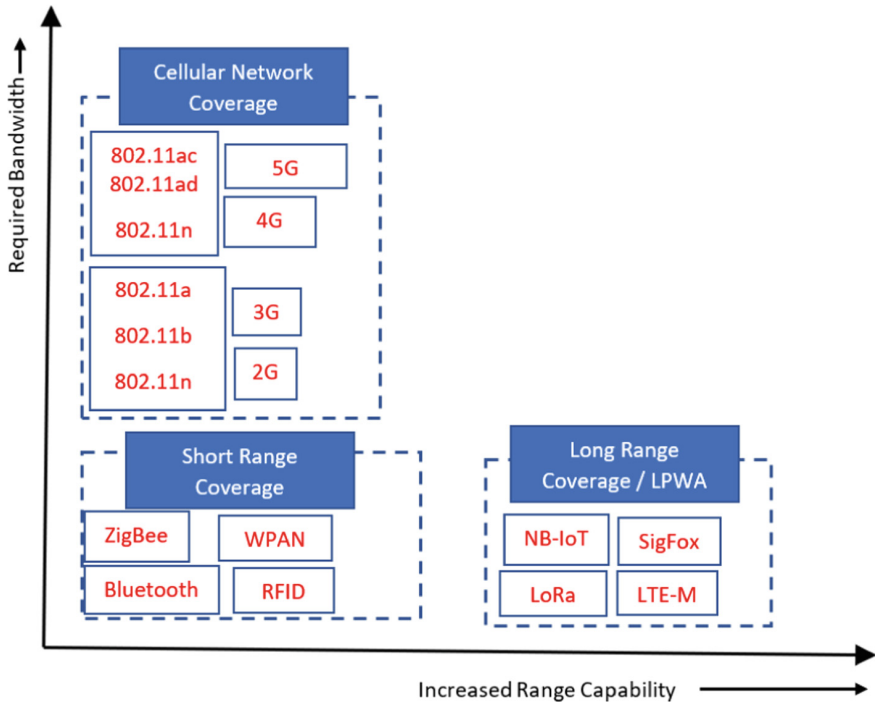
Low Power Wide Area (LPWA) is a standardized 3GPP wireless and mobile technology that is used to describe a wide range of all IoT devices that are low powered, cost effective, wide/long range of network coverage, data transmission efficient and highly secured. With an increased requirement and diverse application scenarios for IoT, there is need to introduce a technology that will cater for the transmission of minute amount of information over a long distance. Furthermore, LPWA can also be grouped into authorized and unauthorized spectral usage depending on the licensed spectrum used. The unauthorized spectral usage is basically customized or proprietary based, examples are LoRa and SigFox, while the authorized spectral usage are standardized by 3GPP; 2G cellular network, LTE network and the NB-IoT are in this category [3]. The NB-IOT which this paper will critically analyze, is a LPWA technology that is key to the optimal development and deployment of IoT because it is known to support massive number of connections, it has very low power consumption rate and supports a wide coverage area.



**Fig. 1.** Internet of Things projected installed base worldwide [2].

The traditional cellular network and short-range network technologies as shown in Fig. 2 are known to be unable to address the growing demands, deployment and penetration of IoT, this is particularly prevalent in the African market where cost and power consumption are key. In Nigeria, where power supply is at an all-time low and cost of living is very high, it is necessary for IoT operators to deploy technologies that is accessible by the bulk of the population and at the same time profitable. It is estimated that approximately one fourth of the over 30 billion projected IoT devices in 2020 are to be connected to the Internet using LPWA [4]. With a ready ecosystem and its population, we expect that Nigeria to significantly contribute to this number.

Therefore, in this paper, we first highlight the status of IoT in Nigeria and identify the main socio-economic and technical problems preventing penetration and development of IoT in the Nation. Furthermore, we explore the usefulness of NB-IoT as a key enabler for the development of IoT in Nigeria, we do this by objectively considering the technical specifications/features and use cases that makes NB-IoT suitable for IoT development in the Nigerian ecosystem. In addition, a developmental plan is summarized, and finally, we present our conclusion.



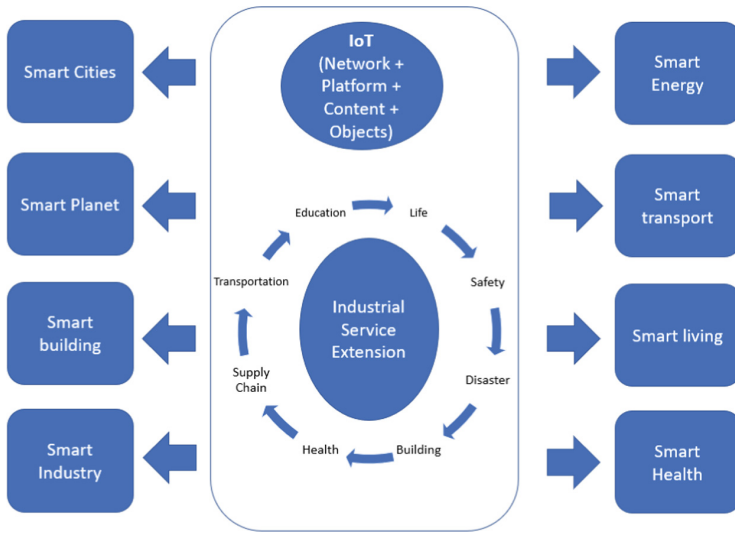
**Fig. 2.** Bandwidth required vs increase range of capability of short range, long range and cellular networks [5].

## 2 Internet of Things in Nigeria

Nigeria has continued to consistently remain relevant in the sub-Saharan Information and Communications technology sphere. With increased digitization of systems and technological innovations around the globe, Nigeria is always one of the first nation in sub-Saharan Africa to have a feel of these innovations and this is largely due to its population and tele density. With five mobile network operators and huge presence of mobile, telecom and IT servicing companies such as Huawei, Ericsson, Nokia, Microsoft, Cisco etc., there is a constant awareness to improve the IoT development and deployment in the ecosystem.

### 2.1 Current Developmental Trend

Radio Frequency Identification (RFID) and Unmanned Aerial vehicles also known as drones are two of the first Internet of Things technology to be developed in Nigeria. The former was used largely in the detection of controlled substances and in card readers while the latter was used by the Nigerian military for easy combat of terrorism [3]. More recently, with the availability of scalable technologies for deploying IoT, innovative solutions are beginning to surface. Random Phase Multiple Access (RPMA)



**Fig. 3.** Application and services of IoT [6]

technology powered by Iguenu was recently rolled-out in Nigeria, RPMA is a non 3GPP standard LPWA technology that runs on a 2.4 GHz spectrum and it is supposed to help with the development of IoT by its deployment in logistics, precision farming and smart grid [4]. Also, Smart metering is an IoT based service that is gradually gaining in-road in Nigeria, recently, Huawei technologies partnered with one of the electricity distribution companies to provide smart power meters for its customers. Huawei is also in the forefront of providing a cloud- based platform called the GLOCAL; the target of this system is to provide IoT as a service directly to verticals. MTN Nigeria is the biggest MNO in Nigeria and is collaborating with Huawei to improve the penetration of IoT by providing NB-IoT based services such as user-based insurance (UBI), smart metering and smart refrigerator [5]. SMS for Life 2.0 is an IoT based technology for smart health, the platform has already been deployed by Vodacom in a Northern state in Nigeria.

At the stake holders meeting of International Telecommunications Union on IoT for Sub-Saharan African countries, it was generally agreed that key areas shown in Fig. 3 are the areas that need urgent development.

Although, Nigeria has witnessed somewhat increased development in the last one year, but it still faces some challenges to the development and deployment of IoT.

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## 2.2 Technical Challenges

*Broadband connectivity* is a major bottleneck for the deployment of IoT. Presently in Nigeria, broadband penetration is estimated to be less than 50%, deploying an IoT system that involves massive connectivity between machines, objects and humans

becomes a herculean task. *Cost* of modules and related sensors for IoT is also another issue. A solution such as precision farming needs farmers to be able to buy and pay for services, but most of these farmers are peasants and paying for the IoT service becomes difficult. Total cost of ownership is a problem network operator face in the deployment of IoT. *Power* is a threat to the development of IoT in Nigeria, IoT devices need to constantly have power to be able to send and receive data, electricity supply in Nigeria is currently rated one of the worst in the world. *Scalability of MNOs equipment* is also impeding the development of IoT, the current architecture of is not suitable for the growth pattern of IoT.

Interoperability, security, privacy and regulatory standards are some other challenges facing the development of Internet of Things.

In the next part of our paper, we present a NB-IoT approach of how IoT can be effectively developed and deployed.

### 3 The Narrow-Band Internet of Things Approach

NB-IoT is a recently standardized protocol by the 3GPP that is used for cellular communication. It is a low bandwidth protocol that is basically intended to optimize the needs of Internet of things (IoT) applications, and consequently help in the easy deployment and development of IoT. Smart metering, precision agriculture, smart parking, smart health, industrial controls are few of the numerous IoT applications that has been found suitable for the African or Nigerian ecosystem. The flexibility of using existing telecom infrastructure like GSM and LTE for NB-IoT deployment, makes it particularly useful in Nigeria, considering that GSM coverage in Nigeria is over 75%.

A review of historical development and standardization process of NB-IoT by 3GPP indicates that it is created to optimize all Machine Type Communication (MTC) services. MTCs are generally classified into; firstly, services such as video surveillance and fleet tracking that require an enormous amount of data for uplink while they are unmovable and a minute amount of data during handovers, and secondly, services which require meter reading for water and power usage. Devices used to achieve the latter services are considered to always remain stationary and handover is always required. Furthermore, the amount of data transferred is usually small and the devices have the tendency of increasing geometrically. The first specification released by 3GPP was mainly focused on these devices. In June 2016, 3GPP introduced R13 which clearly standardized the NB-IoT technology and set five (5) objectives for MTC, these includes; flexibility to support various latency features, support massive number of devices and connections, enhance indoor coverage, optimized energy efficiency and finally, lower cost and reduced terminal complexity [7].

#### 3.1 NB-IoT Network Architecture

With eNodeB upgrade and deploying of NB-IoT core integrated into the existing LTE system architecture, operators can deploy the NB-IoT system. However, it should be noted that interoperability and integration with other network elements such as HSS, PCRF, Customer IT etc., will be dependent on lifecycle of the equipment (Fig. 4).

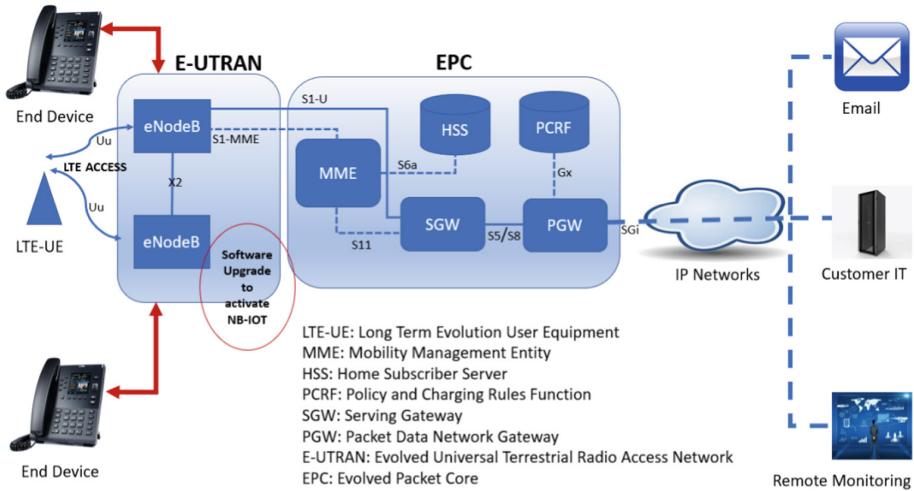


Fig. 4. The network architecture of NB-IoT (I)

In the access network of the NB-IoT architecture, data packets and messages sent from the NB-IoT User equipment are transferred to eNodeB via the air interface, and subsequently transferred to SGW and MME via the S1 interface. At the core network, the CIoT EPS (Cellular Internet of Things Evolved Packet Switch) carries out optimization processes for both the user plane and the control plane. The optimization of the control plane CIoT occurs when non-IP data packets are transferred to the SCEF or PGW via the SGW before being finally forwarded to the cellular internet of things (CIoT) services. This is particularly useful for transmission of minute data packets that are inconsistent. The SCEF is designed to be able to handle only delivery of non-IP data packets. On the other hand, user plane optimization occurs when IP data or non-IP data transferred over radio bearers are sent to the cellular internet of things (CIoT) services via the PGW and SGW. This optimization is more useful for exchange of data between the CIoT platform server and the customer end device (Fig. 5).

### 3.2 Features of NB-IoT

The unique physical or technical features of NB-IoT technology has made it a superb and future oriented technology that helps for the deployment of IoT services around the globe. In Nigeria, some of these features are key for the development and actualization of Internet of things services. They are highlighted here.

**Flexibility in Deployment.** The available options required for deploying the NB-IoT technology makes it a suitable way for the development of internet of things in Nigeria. Telecom operators are currently facing a huge challenge deploying modern technologies such as IoT because of the currency devaluation in Nigeria. However, this challenge can be surmounted with deployment flexibility available using NB-IoT. Operators already have existing infrastructure that can be used, they can either use the

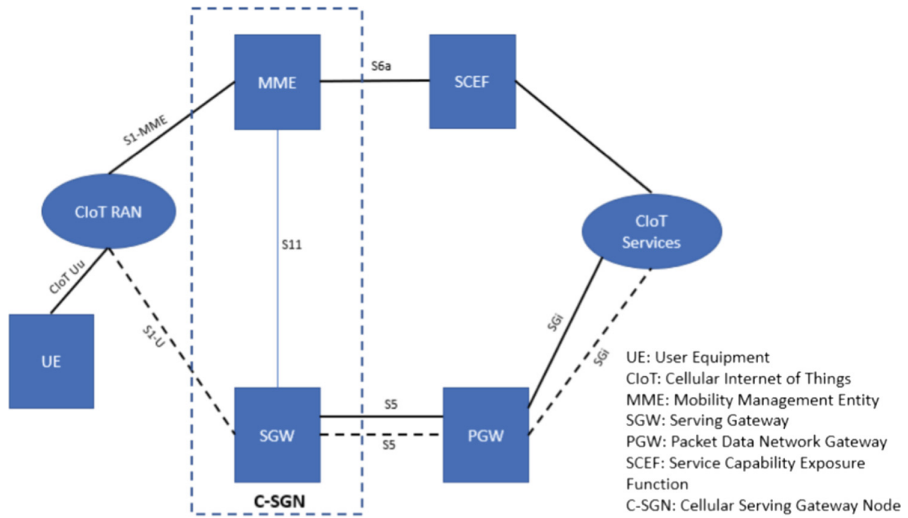


Fig. 5. The network architecture of NB-IoT (II) [8].

well-established GSM architecture or the recently deployed LTE network. Deployment options shown in the latter part of this paper.

**Excellent Power Consumption of Devices.** The power consumption design of NB-IoT modules makes it a commercially viable technology, especially in places where provision of stable power supply is a challenge. These devices have a battery lifetime of 10 years. Nigeria is generally known for the erratic power supply and deploying IoT services that rely solely on power from the national grid becomes a huge burden for telecom operators. NB-IoT devices are built to last and operate for years, they can do this because the modules for data communication save energy by activating the sleep mode when in idle state [9] (Table 1).

**Cost of Device and High Capacity of Device Connection.** The Internet of things technology is a cost-effective technology that requires high capital for it to be fully deployed, investment by operators will have a negative effect on the consumers and return on investment is not guaranteed. However, the cost of deploying NB-IoT service is minimal and average the cost of a device is about \$5. The technology behind the design of NB-IoT modules makes it cheap. Furthermore, NB-IoT technology has the capability to massively support up to 50K simultaneous device connections in a single cell.

**Significant Network Coverage.** There are instances where there is need for deployment of internet of things devices in areas where coverage is significantly low. NB-IoT has a wide coverage area because it was designed to have an extra coverage range of 20 dB. The coupling pathloss for GSM is estimated to be 144 dB, with an increment of 20 dB extra, the maximal coupling path loss for NB-IoT is given as 164 dB. In addition, the devices can be able to transmit and acquire data irrespective of environments that they are installed.

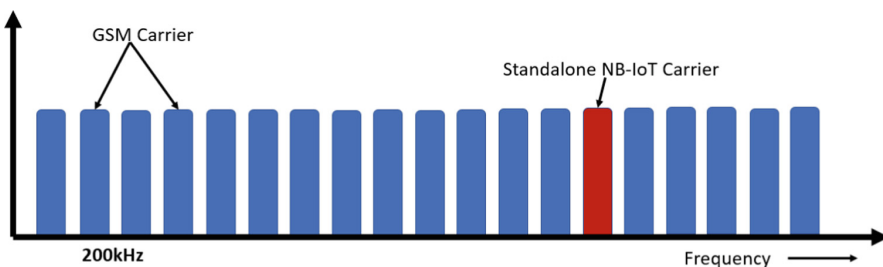
**Table 1.** Summary of the key features of NB-IoT [6, 10]

Features	Value
Coverage range	<35 km
Estimated life of battery	>10 years
Spectrum/frequency bands	Licensed LTE bands
Bandwidth	200 kHz carrier bandwidth
Modulation technique	DL: QPSK, subcarrier space of 15 kHz, transmission rate of 160 kbit/s–250 kbit/s UL: QPSK or BPSK, single carrier with subcarrier space of 3.75 kHz and 15 kHz, transmission rate of 160 kbits/s–200 kbits/s
Link budget	164 dB
Peak throughput	DL: 32.4 kbps UL: 66.7 kbps
Device connection capability	About 50,000 devices per cell

### 3.3 Deployment Strategy

As explained in the introductory part of our paper, Nigeria has over 75% nationwide coverage of GSM. Also, three out of the five telecom operators have deployed the LTE infrastructure. Therefore, leveraging on the existing infrastructure and with little or no CAPEX, operators can deploy NB-IoT using any of the following 3GPP standardized methods;

**Using GSM Band.** This is a deployment done as a standalone or independently using the available GSM band with the help of GSM channel re-farming technique. Spectrum re-farming is a worldwide recognized technology used to reassign available frequency bands for other purposes to save cost in deployment of new services. NB-IoT can make use of GSM frequency with bandwidth of 200 kHz between guard bands of 10 kHz for a stand-alone operation [11] (Fig. 6).



**Fig. 6.** The stand alone operational mode

**Using LTE Band.** As the name same implies; it simply involves making use of the existing LTE infrastructure for deployment. The deployment method can either be guard-band mode or in-band mode. Guard-band operational mode is based on unused resource block within a LTE carrier’s guard band, while the In-band operational mode is based on using the resource blocks within a normal LTE carrier.

There are 12 subcarriers of 15 kHz interval in the downlink using Orthogonal Frequency Division Multiple Access (OFDMA) with a transmission rate of 160 kbit/s–250 kbit/s and 3.75 kHz & 15 kHz subscriber interval in the uplink using Single Carrier Frequency Division Multiple Access (SC-FDMA) (Figs. 7 and 8).

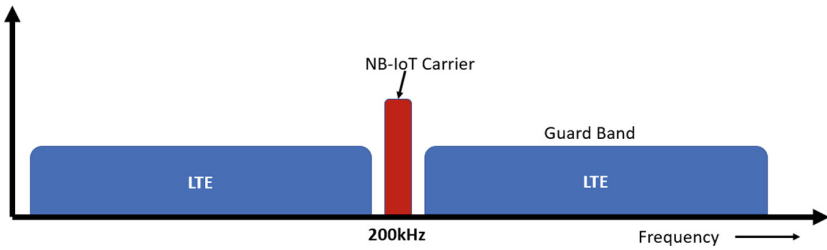


Fig. 7. The guard band operational mode

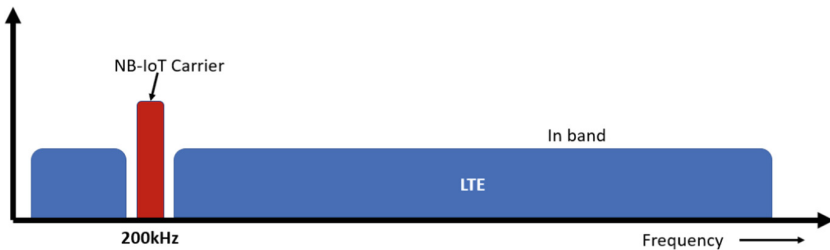


Fig. 8. The In band operational mode

### 3.4 Proposed NB-IoT Use Cases for Nigeria

There are several use cases that have been deployed by different operators around the world, but the cases enumerated below have been carefully selected considering the current available infrastructure in Nigeria, and how commercially viable these cases are. Also, for the deployment and easy development of internet of things, these NB-IoT use cases are most suitable.

**Smart Agriculture.** The alternative to the current over-dependence on oil and gas is Agriculture, and the government of Nigeria recently started investing heavily in this sector. The incorporation of NB-IoT in agriculture will be to increase productivity and save cost for farmers. Possible areas are Animal or livestock monitoring, precision farming, smart greenhouse, aquaponics, smart irrigation etc. Animal monitoring is achieved by installing NB-IoT sensors on the animals, this can be in the form of neck

tags and ear tags, these sensors are able to store and transmit data with regards to the health and location of the animals. This will help to save labor cost and easy identification of sick animal. Furthermore, NB-IoT modules can help in the control of water usage in smart irrigation, sensing of soil moisture and nutrients in precision farming and allow farmers have minimal supervision and cultivation of crops in smart greenhouse [12]. Overall, deploying NB-IoT in Agriculture helps to eliminate operational inefficiency.

**Smart Metering.** The smart metering system works by using highly smart meters which have been pre-installed with NB-IoT modules to remotely monitor and transfer data on usage of water, electricity and gas over a cellular network. With a high amount of water wastage and unaccounted electricity common in Nigeria, smart metering is a solution that will help to cut down wastage. Conventionally, costs are generated through manual meter reading and changing the battery of devices, by deploying NB-IoT, these costs are eliminated. The wide coverage capability of NB-IoT also makes it useful in smart metering because the devices are usually located in manholes, basements or places where signal strength is minimal.

**Pipeline Monitoring, Logistics and Asset Tracking.** There is a high rate of oil theft and pipeline vandalization in Nigeria. Deploying NB-IoT modules and sensors will help to alert relevant authorities when there is a leakage, or a pipeline has been vandalized. Sensors can send data to a monitoring center, and swift action can be taken. Assets can also be monitored by asset owners through broadcasting of asset location by the sensors installed in modules.

**Wearables.** Wearables are objects attached to our body and send Realtime information about location and health status. This is particularly useful for security of individuals (especially kids and elderly) because of the high rate of kidnappings in Nigeria. Wearables can be in form of tags, wristwatches, hand bands, bracelets or necklaces that have sensors embedded into them. Information are sent to a remote server and thereafter transferred to a mobile device which clearly shows the location of the person.

**Smart Parking.** The smart parking services are useful in urban areas where traffic congestion caused by lack of parking space is an issue. This service works by providing parking information to drivers via a geomagnetic NB-IoT sensor installed under the car [8]. Presentation of information is usually through a mobile device.

## 4 Proposed Developmental Plan

In the earlier part of our paper, we have briefly outlined the standardized deployment options that are available to mobile network operators (MNOs). In this part of our paper, we propose a summarized developmental plan by looking at the available frequency bands standardized by 3GPP, deployment bands possible for MNOs in Nigeria and the possible impact on their network.

In Release 13, 3GPP already proposed a set of frequency bands that can be used by NB-IoT. They include; 1, 2, 3, 5, 8, 12, 13, 17, 18, 19, 20, 26, 28, 66 and Release 14 which will include; 11, 25, 31 and 70.

Nigerian MNOs currently have frequency spectrum of Band 3 and Band 8 for Global System for Mobile Communication (GSM), however, some also have Band 1 deployed for 3G. In Sub-Saharan Africa, which Nigeria belongs to, the frequency bands supported are B3 (900) and B8 (1800) [13].

From Table 2, NB-IoT offers a wide range of supportive bands for MNOs depending on the available spectrum.

**Table 2.** E-UTRA operating bands as specified by 3GPP [13].

Operating Band	Uplink Operating Band		Downlink Operating Band		Duplex Mode
	BS Receive		BS Transmit		
	UE Transmit		UE Receive		
	$F_{UL_{Low}}$	$- F_{UL_{High}}$	$F_{DL_{Low}}$	$- F_{DL_{High}}$	
1	1920 MHz	– 1980 MHz	2110 MHz	– 2170 MHz	<i>FDD</i>
2	1850 MHz	– 1910 MHz	1930 MHz	– 1990 MHz	<i>FDD</i>
<b>3</b>	<b>1710 MHz</b>	<b>– 1785 MHz</b>	<b>1805 MHz</b>	<b>– 1880 MHz</b>	<b><i>FDD</i></b>
5	824 MHz	– 849 MHz	869 MHz	– 894 MHz	<i>FDD</i>
<b>8</b>	<b>880 MHz</b>	<b>– 915 MHz</b>	<b>925 MHz</b>	<b>– 960 MHz</b>	<b><i>FDD</i></b>
12	699 MHz	– 716 MHz	729 MHz	– 746 MHz	<i>FDD</i>
13	777 MHz	– 787 MHz	746 MHz	– 756 MHz	<i>FDD</i>
17	704 MHz	– 716 MHz	734 MHz	– 746 MHz	<i>FDD</i>
18	815 MHz	– 830 MHz	860 MHz	– 875 MHz	<i>FDD</i>
19	830 MHz	– 845 MHz	875 MHz	– 890 MHz	<i>FDD</i>
20	832 MHz	– 862 MHz	791 MHz	– 821 MHz	<i>FDD</i>
26	814 MHz	– 849 MHz	859 MHz	– 894 MHz	<i>FDD</i>
28	703 MHz	– 748 MHz	758 MHz	– 803 MHz	<i>FDD</i>
66	1710 MHz	– 1780 MHz	2110 MHz	– 2200 MHz	<i>FDD</i>

Although, there would be need for MNOs to take few steps before they can deploy NB-IoT, but these steps are worth taking for the development of IoT. A summarized developmental strategy is shown in Table 3 below.

**Table 3.** Proposed initial use cases for MNOs in Nigeria [14].

Mobile network operator	Available frequency spectrum	Mobile market share (%)	Proposed deployment mode	Proposed use cases to start deployment	Possible impact on network
MTN	<b>GSM900</b> Tx: 950 MHz–955 MHz Rx: 905 MHz–910 MHz <b>GSM1800</b> Tx: 1835 MHz–1850 MHz Rx: 1740 MHz–1755 MHz	40	Stand-alone deployment by GSM Re-farming	Smart metering, Smart Agriculture, Wearables, Logistics	Upgrade of Baseband unit, New RF Modules, Upgrade antenna systems, Frequency planning
GLO	<b>GSM900</b> Tx: 945 MHz–950 MHz Rx: 900 MHz–905 MHz <b>GSM1800</b> Tx: 1820 MHz–1835 MHz Rx: 1725 MHz–1740 MHz	25	Stand-alone deployment by GSM Re-farming	Smart parking, Smart agriculture, wearables	Upgrade of Baseband unit, New RF Modules, Upgrade antenna systems, Frequency planning
AIRTEL	<b>GSM900</b> Tx: 955 MHz–960 MHz Rx: 910 MHz–915 MHz <b>GSM1800</b> Tx: 1850 MHz–1865 MHz Rx: 1755 MHz–1770 MHz	23	Stand-alone deployment by GSM Re-farming	Smart parking	Upgrade of Baseband unit, New RF Modules, Upgrade antenna systems, Frequency planning
9MOBILE	<b>GSM900</b> Tx: 935 MHz–940 MHz Rx: 890 MHz–895 MHz <b>GSM1800</b> Tx: 1865 MHz–1880 MHz Rx: 1770 MHz–1785 MHz	13	Stand-alone deployment by GSM Re-farming	Smart parking, Smart metering	Upgrade of Baseband unit, New RF Modules, Upgrade antenna systems, Frequency planning
NTEL	<b>LTE</b> Tx: 940 MHz–945 MHz Rx: 895 MHz–900 MHz <b>LTE</b> Tx: 1805 MHz–1820 MHz Rx: 1710 MHz–1725 MHz	Relatively new comer, recently lunch LTE-A and VoLTE	In-band, Guard-band deployments	Smart parking	Upgrade eNodeB, Reuse RF modules and Antenna system, No

## 5 Conclusion

The Narrow-band Internet of Things technology remains the most effective and efficient way to develop internet of things in Nigeria. In this paper, we have carefully reviewed the current state of Internet of things technology in Nigeria, and the factors that prevents the development of the technology. We have identified NB-IoT as the most cost-effective technology that can help to improve the penetration of IoT. Specifically, we looked at the unique features of NB-IoT that makes it suitable for the

eco-system, in addition, we explained the different deployment modes possible. Finally, we gave a summary of use cases that can be deployed by each operator based on their infrastructure.

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