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Narrowband IoT: A Greener Solution for Large Scale Deployments

Sudhir K. Routray[1,*], and Sasmita Mohanty[2]

[1]Department of Electrical and Computer Engineering, Bule Hora University, Bule Hora, Ethiopia
[2]Department of Economics, Management, Industrial Engineering and Tourism, University of Aveiro, Aveiro, Portugal

Abstract

Internet of things (IoT) has become a pervasive technology with ubiquitous presence in the modern digital ecosystem. Several types of IoT are available in the recent years based on their features and applications. Narrowband IoT (NBIoT) is one of the 3GPP standardized solutions for massive machine type communications (mMTC). It is designed for the large scale mMTC to provide coverage over a large area. Therefore, NBIoT is one of the most attractive low power wide area (LPWA) technologies. It is preferred for the large scale deployments in the large projects such as smart farming, healthcare, smart cities and smart grids. However, it is also suitable for low power domestic applications such as smart home and pets' tracking. The LPWA features of NBIoT make it the primary choice for several emerging applications such as healthcare, agriculture, utility management, tracking of objects, smart city monitoring, retail management, smart grid monitoring, and industry applications. In this article we provide the principles and applications of NBIoT for the large scale deployments.

Keywords: Internet of things, Narrowband IoT, Green IoT, Energy efficient IoT.

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*Corresponding author. Email: sudhir.routray@gmail.com

1. Introduction

In the recent years, Internet of Things (IoT) has emerged as one of the disruptive technologies that has the ability to create absolutely new businesses and applications. It has tremendous potentials for large scale digital transformation across many sectors [1]. It can be seen as a multi-trillion dollar technology of the twenty first century. IoT is basically a large scale sensor network that integrates both the static and moving devices with the Internet using the techniques of information and communication technologies (ICTs). Of course IoT is much more than a sensor network and it has very capable actuators which can execute several remote operations [2]. In fact, the ICT environments and applications have been changed to a very large extent due to the arrival of IoT. In 5G, massive machine type communications using IoT is one of the prime focus areas [3]. However, the challenges found in IoT are multiple. IoT is regarded as the next revolution in the Internet technologies and expected to connect many objects and things which did not exist before a decade [4]. In the IoT paradigm, millions of sensors will be deployed in a city in different applications. That is a large number as far as the energy and bandwidth consumption issues are concerned. Therefore, there is a need of a green IoT which is energy efficient and takes a very small bandwidth [2].

In the energy efficiency context, several low power wide area (LPWA) technologies have been proposed. Some of them are cellular meaning they can be deployed alongside the cellular networks [5]. Others are non-cellular meaning they cannot be deployed over the cellular networks and thus they needed their own networks for their operation. Both cellular IoT and non-cellular IoT have their advantages and disadvantages. However, for large scale deployment cellular IoTs are preferred because they provide a lot of cost saving options which are not generally available in the non-cellular IoTs. In the long term evolution (LTE) cellular framework the first cellular IoT proposed was Cat-1 (in Release 8). It had several short comings in its scalability and compatibility aspects [5]. Therefore in its Release 12, LTE came up with three different IoT variations for large scale deployment [2].

They are: narrowband IoT (NBIoT), extended coverage GSM (EC-GSM), and LTE-M [5]. Out of these three, NBIoT has become very popular due to its attractive features and versatile application capabilities. Though EC-GSM and LTE-M are comparable in terms of scalability and battery life, they do not provide the other deployment advantages offered in NBIoT. In [6], global figures of information and communication technologies (ICT) have been addressed with their recent trends. It shows the increasing trends of resource consumption in ICT. For IoT and other emerging applications bandwidth sharing is going to be very common. Even the unused bandwidths of the LTE and other networks have to be used for cellular IoT applications. In [7] – [10], several design and technological issues of IoT and NBIoT have been addressed with respect to their practical implications. Energy efficient design in IoT is essential for large scale deployments. In [11] and [12], green initiatives and energy efficient IoT designs and provisions have been presented with several examples. Principles and standards of NBIoT have been presented in [13] – [15]. It shows the main principles and techniques used in NBIoT in different deployment modes. Due to the popularity of the NBIoT several applications have been developed in different sectors. In [16] – [32], several applications of NBIoT and its different variations have been illustrated with practical instances and case studies. These applications show that NBIoT is suitable for a wide range of sectors such as agriculture, healthcare, localization, tracking, smart grids, policing, smart homes, and smart cities. Every year new applications emerge with new market demands for NBIoT deployments. In [24] – [27] several IoT applications for healthcare have been presented. It shows several issues and challenges found in the healthcare sectors and how IoT and NBIoT can handle them. Healthcare is a very large sector and IoT has a lot of potentials in its overall transformation. In [30] – [32], continuous deployment of IoT and NBIoT over a large geography for large projects such as smart cities and smart grids has been presented. In [33] – [36], several advanced research issues of IoT and NBIoT have been addressed. Emerging IoT technologies, their principles, and their applications have been presented in these works. As the size and coverage of IoT gets bigger, it deserves a dedicated slice in the networks. Therefore, software defined networking approaches get popular in IoT and NBIoT [36]. Overall from the presented literature we found that there is a big demand for IoT in almost all sectors. NBIoT is suitable for LPWA applications across sectors. For large scale deployment it is the first choice among the cellular LPWANs.

In this article, we present narrowband IoT as a green version of IoT and also propose few other measures for making IoT green. We present its advantages for the large scale deployment and long term sustainability. We also present some of the typical applications of NBIoT.

The remainder of this paper is organized as follows. In Section 2, we present the basic features of NBIoT. In Section 3, we present the commonly used architecture of NBIoT. In Section 4, we present the practical deployment aspects of NBIoT considering its practical features. In Section 5, we present the main applications and the issues related to the practical deployments such as the security and limitations. In Section 6, we conclude this article with the main points.

2. NBIoT and Its Basic Features

Currently, the common questions in this regard are: How these sensors will gather the energy for their operations? Can they harness their own energy? How reliable and sustainable will be those self energy harnessing processes? If battery power is required, is it possible to provide that for a long time? In fact, all types of IoTs are not same. The leaner, thinner and greener version of IoT is available to us now. That is known as narrowband IoT (NBIoT). It can do several wonderful things in the low energy regime. Its standards have been finalised in LTE Release 13. It not only extends the machine type communications (MTCs), but also provides several new applications which will make IoT really attractive in the pervasive arena. Over and above this, it is the greener IoT. It takes a very small amount of energy for its operations. As the name suggests, NBIoT uses very small bandwidth in comparison to the other forms of IoTs. A bandwidth of just 180 kHz is enough for NBIoT operations.
NBIoT is a low power wide area (LPWA) technology which means, it can provide the IoT services at a very low energy and still covers a large area. This is essentially the greener version of all the IoTs available now. So, the search for a green IoT over a long time has some answer now. Its energy consumption is among the lowest of all the IoTs available in practice now. It has two different power classes of 23 dBm and 20dBm. With this power it can cover up to 164 dB which shows its capabilities as a greener IoT. The battery life time in NBIoT is estimated to be more than 10 years. In addition to that, self energy harvesting mechanisms are in place to provide the energy to the sensor nodes. Appropriate energy conserving mechanisms such as the sleep modes are also in place. It can operate with the existing LTE and GSM infrastructure. It takes lower power than the LTE / GSM devices.

2.1 Features of NBIoT

NBIoT does not need a large bandwidth for its operations. Only 180 kHz is sufficient for it according to the current standards of LTE Release 13. The energy requirements of NBIoT sensor nodes are also less in comparison to the other versions of IoTs. At this moment, there are two different input energy specifications for NBIoT: 20 dBm and 23 dBm. The spectral efficiency of NBIoT is not very attractive yet. It uses mainly BPSK and QPSK schemes at the moment. However, for short range deployment, spectrally efficient modulation schemes can be used in the future. Thus, higher data rates are possible with the existing bandwidth. The main features and operational characteristics have been shown in Table I. In addition to the positive features and widespread popularity, NBIoT has some demerits as well. We show these aspects later in this article.

Table 1. Main Features and Specifications of NBIoT

#	Parameters	NBIoT Specifications
1	Bandwidth	180 kHz (maximum 200 kHz)
2	Maximum Data rate	250 kbps (Normally uses 150 kbps or lower)
3	Energy Coverage	164 dB (better than LTE)
4	Duplexing Techniques	Half duplex and Frequency division duplex
5	Power Saving Mechanism	PSM I-DRX and PSM C-DRX
6	Input Power Class	23 dBm and 20 dBm
7	Battery Lifetime	More than 10 years

3. Architecture of NBIoT

NBIoT can be deployed in both cellular and non-cellular forms. The cellular architectures are very organized and follow the processes similar to the cellular networks. Cellular NBIoT inherits majority of the features from LTE technologies. The layer-wise architecture is simple to understand the architecture of any network. Here, too we show a multi-layer architecture for NBIoT. We separate entire NBIoT into six different layers. The bottom one is the physical layer that takes care of the signal transmission in the physical channel and the aspects related to the signal degradation and its protection in the channel. Above it is the MAC layer which takes care of the multiple access and several control aspects of the network. MAC layer provides error correction facilities with the help of hybrid Automatic Repeat Request (HARQ) and coordinates with the ARQ of the radio link control (RLC) layer which is just above it. NBIoT information report scheduling and padding are carried out in the MAC layer. Besides these, MAC layer also provides mapping of transport channels and logical channels; transport format selection; radio resource selection and allocation; packet filtering; prioritizing different user equipments by making use of the dynamic scheduling. RLC layer provides all the vital functions needed for radio links. The main functions of the RLC layer include: authentication; duplicate detection; protocol error detection; RLC Service Data Unit (SDU) discard; transfer of upper layer Protocol Data Units (PDUs); error correction through ARQ; concatenation, segmentation and reassembly of RLC SDUs; re-segmentation of RLC data PDUs; reordering of RLC data PDUs. Delivery of data blocks in a sequence is carried out in this layer as long as the radio links are available.

The concept of packet data convergence protocol (PDCP) is borrowed from LTE. This layer has similar functions in NBIoT (just like the LTE). The main services and functions of the PDCP layer includes: data integrity provisions; header expansion and compression; ciphering and deciphering; user data transfer; duplicate detection of lower layer SDUs. The other main services and functions of the PDCP for the control plane include: control plane data transfer; integrity protection and ciphering. Radio resource control (RRC) layer performs all the key control related functions of the radio resources and also serves as the interface between the access stratum (AS) and non-access stratum (NAS) functions such as the broadcasting of system related information of both AS and NAS. It establishes the radio connections through the available radio resources and continuously provides the maintenance as well. The uppermost layer is the NAS. It performs all important functions of the upper layer such as authentication, registration, location identification, and the activation as well as the deactivation of the bearers. Security mechanisms of NBIoT can be provided in this layer. NAS layer carries out the connection and session management related functions. Several mobility management aspects in NBIoT between the user equipment (UE) with server are looked after in this layer. It facilitates communication between the end devices. In this process, the central server bypasses the mid-level arrangements. Traffic and signalling related communications between the UE and the main server are also supported by this layer. In Figure 1, we show the layered structure of NBIoT architecture. It shows the different layers and their relative locations in the hierarchy. It shows that the wireless medium is there between the NBIoT devices and the end components such as the sensors and actuators.

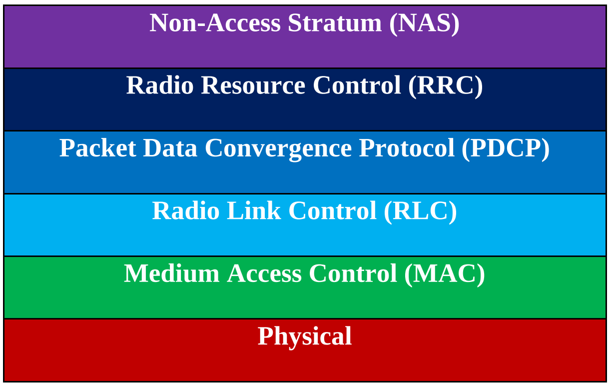

Figure 1. Different layers of NBIoT. It inherits several features of LTE. Thus a lot of similarity with the LTE is found in the layered structure of NBIoT [33].

Just like the TCP/IP model of the Internet, there is a practical model of NBIoT which is very much realistic and widely used for its deployment in different applications. We show this practically implementable model in Figure 2. This practical model is based on the widely used protocols of NBIoT. It clearly, separates the functions of one layer from the functions of the others.

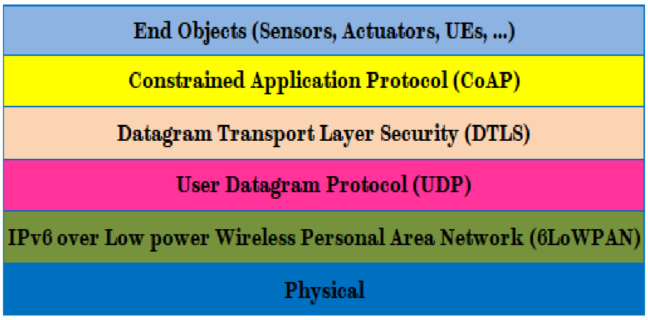

Figure 2. Practically implementable layered structure of NBIoT.

The lowermost layer in this model is the physical layer. It is the wireless medium for communication for the different components of NBIoT. Just above it is the 6LoWPAN (the short form for IPv6 over Low power Wireless Personal Area Network). This is the much lighter version of the IPv6 optimized for low power wireless communication networks. The wireless packet communication and traffic flow are controlled through user data gram protocol (UDP). This is same as the UDP used for wireless communications. The datagram transport layer security (DTLS) is provided through the DTLS layer. Just above it is the constrained application protocol (CoAP) layer. CoAP is similar to hypertext transfer protocol (HTTP), but much lighter than HTTP. CoAP is very much suitable for low bandwidth applications. Thus CoAP has been provided for NBIoT.

4. Practical Deployment of NBIoT

Practical deployment of NBIoT is comparatively simpler than other cellular and non-cellular IoT available in the recent times. NBIoT follows the architecture which is similar to the Internet (with a few variations) and the LTE. Thus multiple options are available to deploy NBIoT for the practical applications. Depending on the applications and resources available the final deployment is decided by the vendors and operators.

4.1 Deployment Options

NBIoT was developed in the LTE framework for massive machine type communications to assist with the value added services [15]. Therefore, it is compatible with the LTE and its legacy systems. NBIoT can be deployed over both cellular and non-cellular infrastructure. Cellular deployment is very common as it is cost effective and does not need many resources. In addition to the infrastructure support, NBIoT takes the advantages of operational similarities of LTE and its legacy networks in the cellular deployment. Non-cellular deployment is very rare and normally used where the cellular networks are not available. Non-cellular deployments are standalone in nature and thus need more resources than the cellular deployments. Even standalone deployments cannot be deployed over the cellular bands and they are migrated to non-cellular bands. Normally these standalone deployments use sub-cellular bands [11].

4.2 Frequency Allocation and Bandwidth for Practical Deployment

In LTE Release 13, NBIoT has been standardised for practical deployment. In the cellular form NBIoT can be deployed in three different ways. The first one is the standalone deployment in which the bands of NBIoT will have their independent spectrum preferably in the 700 MHz to 800 MHz range. These initiatives are becoming popular in several European countries as the 700 and 800 MHz range frequencies are available for NBIoT applications. The second option is to use the guard bands of the GSM and LTE bands. In the GSM and LTE spectrum, some guard bands are provided for better performances and to avoid spectral overlapping. These bands in fact are not used for communication. Therefore, these guard bands can be utilized for NBIoT deployment as the bandwidth required is really narrow. The guard bands used to be vestigial spectral components in GSM and LTE. Any use of these vestigial spectral components is beneficial for the operators. This is in fact a win-win situation for both the LTE and NBIoT communities. Thus the guard band deployment is certainly saving the spectrum and makes the NBIoT a green technology. The third option is to deploy the NBIoT in the communication bands of GSM and LTE. This is known as in-band deployment. In this case, some part of the GSM or LTE spectrum is allocated for NBIoT operations purpose. In order to avoid the collision or overlapping of same frequency, several frequency hopping mechanisms are provided. These hopping mechanisms change the usage band of NBIoT as soon as it is allocated to any of the GSM or LTE bands. In Figure 3, we have shown the three different scenarios of NBIoT deployment as proposed in LTE Release 13 [5].

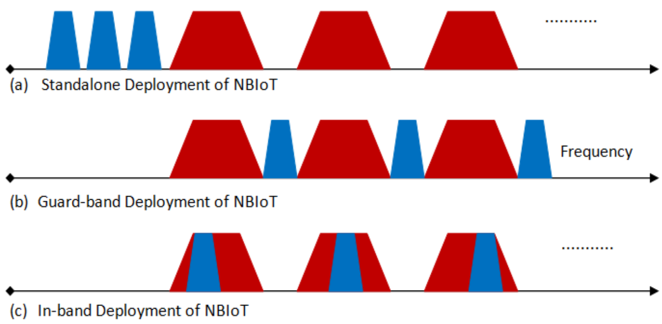

Figure 3. Different options for NBIoT deployment in the cellular architecture. In (a), (b) and (c), we show standalone, guard-band and in-band deployments, respectively. Red colour indicates LTE/GSM bands and blue colour indicates NBIoT bands.

4.3 Edge Computing for NBIoT Deployment

For large scale deployment of NBIoT support of the edge computing facilities are essential. It effectively decentralises different sections of the IoT networks, reduces latency and improves overall performance. Edge facilities are equivalent to the local servers which are connected with the central server through high bandwidth channels. However the NBIoT end devices are connected with the edge servers. These edge servers are also known as Fog computing facilities. In the cellular networks, the cloud RAN can serve as the edge servers. However, if they are overloaded with large amount of data then fully dedicated edge facilities are needed for NBIoT.

5. Applications of NBIoT

Currently, there are several applications of NBIoT. With every passing year new applications are getting added to the pool. Here we provide some typical applications of NBIoT which can be carried out with low power and wide area of coverage using narrow bands. NBIoT is preferred for the cases where energy harvesting is difficult, wide area has to be covered, and the bandwidth available is not quite wide. In such cases, NBIoT provides both energy efficiency and low bandwidth is not a constraint for its operations.

Typical applications of NBIoT covers the broad areas of smart cities, smart healthcare, smart retailing, smart policing, effective and efficient energy management, smart homes, waste management, and smart manufacturing. It can also be used in several other fields such as tracking of animals and children; safety and security in the surroundings; smart agriculture; vehicular networks for better traffic management; detection of environmental degradations and disasters. Besides these areas, NBIoT itself is used as a solution for energy saving and very much popular in the areas of smart metering and energy management. Currently, NBIoT is also considered for large scale industry automation in the Industry 4.0 initiatives [37]. Similarly, for rural microgrids an economical and affordable IoT is required. Considering the rural needs and cost savings, NBIoT is found to be the suitable solution [38]. For the remote parts of the developing countries, this is a perfect solution. This is suitable for small and medium scale industries. In Figure 4, the main applications of NBIoT have been presented.

5.1 Security in NBIoT

Security in IoT is a challenging aspect. In majority of the IoTs, the security framework has not been properly designed yet. However, NBIoT is better placed in this respect. NBIoT can use the provisions of the available security mechanisms of cellular infrastructure when deployed in the cellular form. Thus the security measures used in the cellular systems such as the LTE and GSM can be extended to NBIoT. The standardisation of NBIoT has provided the NAS and PDCP layers at the top. LTE normally provides its main security mechanisms in the NAS and PDCP layers. In NBIoT, similar security measures can be applied. Therefore, NBIoT is not that much at risk like other IoTs as far as the end to end security is concerned. However, it is noteworthy that the LTE security measures are not very robust yet. There are several loopholes which have to be settled. NBIoT too needs a better security in the future. In [18] some advanced security frameworks have been proposed for IoT. These techniques can also be applied for NBIoT.

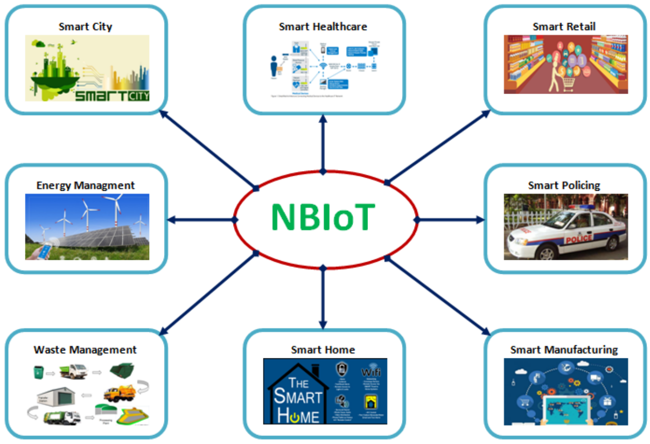

Figure 4. Some of the main application domains of NBIoT are shown. Every year new applications are added to the pool.

5.1 Limitations of NBIoT

Amidst the advantages presented in the previous sections, there are also some limitations of NBIoT. At present, whatever services are provided over the NBIoT platforms are not suitable for real-time applications. However, there are several applications which demand real-time services. The main obstacle found in NBIoT regarding this is its lack of control over the end to end delay [33]. There are several delay tolerant technologies. They have not been incorporated in the current versions of NBIoT yet. There are several applications in healthcare, smart cities and some other sectors that demand real-time communication and information exchange. In such cases, certainly, we cannot rely on NBIoT. In addition to this, some applications need higher bandwidth for better communication and sensing. In such cases, the bandwidth required is more than what has been allocated to the NBIoT now. With 180 kHz these services will not be achieved as desired with high definition images and better quality of information being exchanged between the clients and the servers. The quality of service and quality of experience are two important parameters in IoT related services. At both these fronts NBIoT is not yet at par with the best ICT services available today. Of course, the NBIoT standards will be changed gradually to be compatible with the new demands across several application areas.

5.2 Making NBIoT Greener

NBIoT can be made greener by making its components more energy efficient. The main parts of a typical NBIoT are:

radio frequency identification (RFID) units; sensing units; cloud infrastructure; machine to machine (M2M) communication units; data centers; and the ICT units. Energy efficient algorithms and protocols are in use to improve the energy efficiency of RFID unit. Even the size of the RFID hardware is optimized for energy efficiency. Architectures and protocols are optimized according to the NBIoT environments. Green initiatives in clouds are very much important for overall energy efficiency of NBIoT. As M2M scenarios are very common in NBIoT they are being made energy efficient using smart approaches. Spectral efficiency and full duplex methods are energy efficient because they use less energy per bit. These are being planned for deployment in NBIoT. Data centers store and retrieve information time and again. Their efficiency is increasing every year through efficient algorithms and protocols. Overall, ICT components are optimized in some form or the other. Using all these initiatives, NBIoT can be made completely green.

6. Conclusions

In this article, we have shown the main features, architecture and utilities of NBIoT. It is clear that NBIoT is a primary choice for several emerging sectors. NBIoT is certainly the greener version among all currently available IoT. It takes less power for its operations and covers wide area. It provides majority of the LPWA features. Due to its leaner, thinner and greener characteristics, it has great potentials in LPWA sectors. It can provide cost effective services which are essential for both rural and urban areas. Primary service sectors such as healthcare, agriculture, smart grids, policing, energy management and waste management need smart technologies for better services. NBIoT fits in majority of their requirements. We have also indicated the potential demerits due to the current deficiencies in the technology standards. However, these short comings are expected to be overcome in the future versions of NBIoT. It is also expected that NBIoT will be an integral part of modern digital society.

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