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Narrowband IoT:
Principles, Potentials, and Applications

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ABSTRACT

Narrowband Internet of things (NBIoT) is a low energy and low resource consuming version of IoT. As its name suggests, it needs a narrow bandwidth for its operations. Its energy consumption is also very low, and thus it is suitable for low energy applications. It is compatible with all types of cellular communication infrastructure such as 2G, 3G, 4G and 5G. It is also possible to deploy NBIoT in the standalone mode where cellular networks are not available. It can cover a large area with a very small amount of power. So, it is a popular low power wide area (LPWA) technology. Due to its LPWA features, it is popular for the connected living applications at home and workplace surroundings. Its LPWA features make it a popular green technology for digital transformation. In this article, the authors provide the main characteristics of NBIoT, its standards, its potentials, and applications in different domains.

KEYWORDS

applications of NBIoT, characteristics of NBIoT, low power wide area technology, Narrowband IoT

INTRODUCTION

Internet of things (IoT) is now an integral part of the modern digital ecosystem. It has the ability to connect every object and living beings with the Internet. Therefore, it is one of the leading technologies in the current digital transformation across the world. Looking at the widespread deployment of the IoT components such as the sensors, actuators, servers, edge computing infrastructure, and other facilities; it is clear that the energy and other IoT resources will be needed in a large amount. In order to reduce the energy and other resource consumption there is a need of a leaner and thinner version of IoT. Narrowband IoT (NBIoT) is one such resource efficient version available now (3GPP, 2016). It was evolved from the need of large scale machine type communications over the LTE networks (GSMA, 2018). It is one of the most popular low power wide area (LPWA) technologies. It does not have adverse effects on the human and other living beings. That is why it is considered as a main technology for ambient living ecosystem (Routray, 2021). It is also preferred for the large scale

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deployments over a large coverage area. Cost wise, it is one of the economical forms of the available IoT (Chen et al., 2017). Its deployment is simpler when compared with other types of IoT (Routray, 2019). Its standardization has been completed and new provisions are added with the new application demands. It can be deployed over the cellular infrastructure as well as in the standalone mode (3GPP, 2016). It has enormous potential for low power applications. It is one of the most attractive LPWA technologies in a large number of technology and non-technology sectors in recent times. Therefore we find a lot of applications of NBIoT in the low power regime (Xu et al., 2017).

Large scale machine to machine communication is a primary requirement in the beyond 4G networks (Routray, 2019). In order to handle these connectivity issues several solutions have been proposed. In the mobile cellular framework, there are three different solutions viz. NBIoT, LTE-M, and EC-GSM. There are a few differences between these cellular IoT (CIoT) solutions. Though they are designed for the emerging demands of 5G and beyond 5G networks, they are also compatible with the legacy networks such as 2G, and 3G and 4G (Routray & Sharmila, 2017). NBIoT was proposed by the Third Generation Partnership Project (3GPP) for machine type communications in the LTE framework in Release 13 (3GPP, 2016). It was custom designed to be compatible with the LTE networks and their legacy systems. Its main goal was to compete with the existing low power non-cellular IoT technologies such as LoRa and SigFox. New physical layer signals and channels were designed to fulfil the demands of LPWA applications (GSMA, 2018). Its LTE features make it suitable for rural, urban and remote deployments over the mobile cellular infrastructure. Due to its low energy consumption characteristics it is regarded as a green technology (Routray & Sharmila, 2017). Due its LPWA characteristics it can be applied in a wide range of applications such as agriculture, healthcare, cattle tracking, localization in logistics, policing, utility management, traffic management, smart cities, smart grids, retail management, waste management, and smart homes (Routray & Hussein, 2019; Sharma et al., 2017; Routray et al., 2019; Routray et al. 2020). These applications of NBIoT indicate a lot about the popularity of NBIoT in the recent years. It is also a sustainable technology of the long term (Ramnath et al., 2017). Energy and bandwidth efficiency are essential for the global sustainability of the telecommunications industry (Mohanty & Moreira, 2014). NBIoT has both the attributes and it is essential for the global sustainability in the massive machine type communication (mMTC) sectors. Security and privacy aspects of NBIoT are essential for its sustained applications in the coming decades (Routray et al., 2017). In this regard, NBIoT is currently better placed than majority of the IoT in practice. NBIoT uses the security provisions of LTE and it has also its own initiatives at the upper layers (Yang et al., 2017). Several new initiatives have also been proposed for NBIoT which are certainly the game changers in the coming years (Routray et al., 2017). NBIoT is basically built for low data rates. However, in some of the applications higher data rates are needed. In such cases, NBIoT data has to be compressed using efficient techniques. IoT and other low bandwidth networks need support of the advanced compression techniques. These efficient compression techniques are essential for the overall success of NBIoT and other low bandwidth IoT networks (Routray et al., 2020b). It shows that effective compression techniques are essential to overcome several difficulties of low bandwidth networks. Resources for NBIoT such as the bandwidth for practical deployment are scarce. Bandwidth scarcity is a modern reality in the large cities and places with high density population. Several options for new bandwidths and management of existing bandwidths have been proposed for emerging services in the recent years[25]. NBIoT can be deployed over the cellular networks in different ways which we have discussed with more clarity in the deployment section of this paper. Due to the large size and large traffic, NBIoT needs some supporting technologies such as software defined networking (SDN) for proper control and management. Main issues related to the SDN approaches in IoT networks have been presented in some recent works (Muñoz et al., 2018; Ninikrishna et al., 2017). These works show that a dedicated slice for IoT based services is essential for the future demands. Various emerging issues of NBIoT such as the physical layer design, cloud implementation and future complexities are very relevant for its practical deployment (Kanj et al., 2020; Beyene at al., 2017; Routray & Mohanty, 2021). Centralized clouds are not suitable for NBIoT due to its wide coverage. Fog or edge nodes with small cloud facilities are better than the centralized cloud facilities (Beyene at al., 2017).

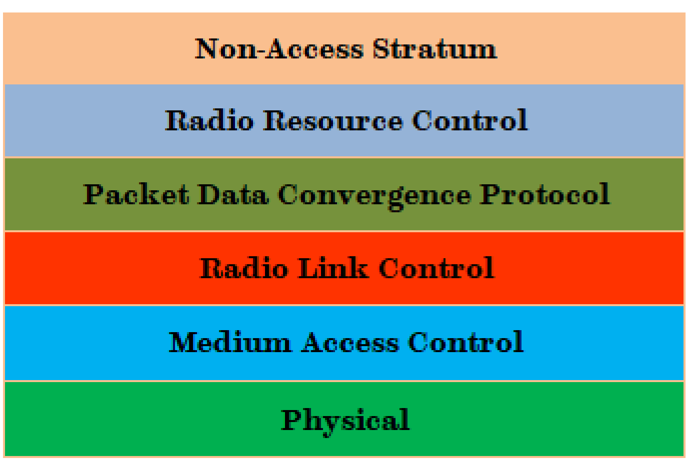
In this paper, we present the main principles of NBIoT. Subsequently, we present its standardization and deployment related issues with practical focus. We show its potentials for the low power digital ecosystem and large scale digital transformation. We also show that it is one of the main technologies for the LPWA applications.

The reminder of this paper is organized in four different sections. In the next section, we present the main principles of NBIoT. Then we present the standardization and deployment related issues of NBIoT. Then we present the potentials and applications of NBIoT in the practical applications.

PRINCIPLES OF NBIOT

NBIoT has been designed to provide mMTC services in the LTE environment. However, it is compatible with the legacy cellular systems and the emerging networks such as 5G (Routray, 2021). NBIoT has a systematic technological framework, and it can be explained with the help of its different functional layers just like the Internet. The Open Systems Interconnection (OSI) model shows its layers according to their functions (Routray, 2019). According to the OSI model of the NBIoT, it has six different layers as shown in Figure 1. The lower most layer in the OSI model of NBIoT is the physical layer. It has several wireless channels used for NBIoT communications. These channels facilitate the communication between the NBIoT end devices and the NBIoT servers (Routray & Sharmila, 2017). Above the physical layer we find the medium access control (MAC) layer. This MAC layer is very similar to the MAC layer of the Internet and the LTE networks. It provides the common functions such as coding and decoding of the information and facilitates the multiple access techniques. Radio link control (RLC) is just above the MAC layer. Its main function is to establish and terminate the radio links for NBIoT communications (). It normally uses the user datagram protocol (UDP) for its functions. Packet data convergence protocol (PDCP) layer is situated just above the RLC layer (Routray, 2019). It provides the order sequencing and convergence of the incoming packers which are received by the RLC layer. Radio resource control (RRC) is just above the PDCP layer. Its function is to allocate and control the available radio resources for the NBIoT communications (Routray, 2019). At the top of the OSI model is the non-access stratum layer. It deals with several control and security mechanisms at the upper level (Routray & Sharmila, 2017). It also provides the sessions for communication between the user equipments (UEs) and the servers.

Figure 1. The OSI model of NBIoT

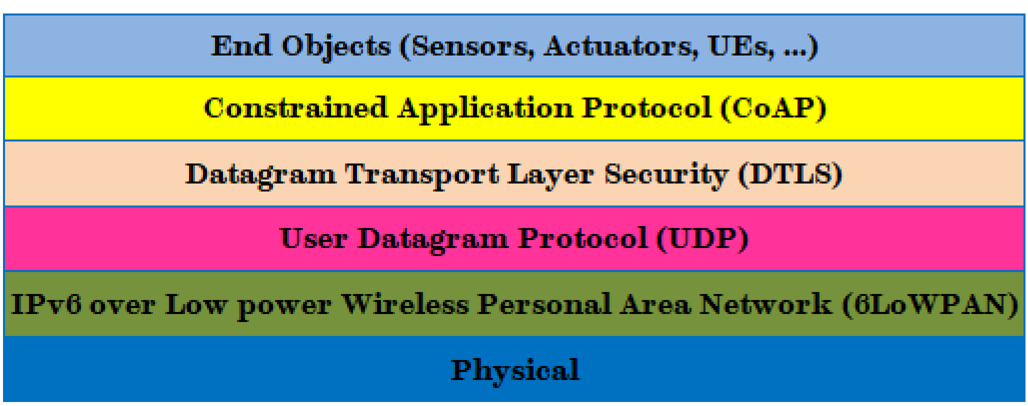


However, for the practical implementation of an NBIoT system or technical applications points of views this OSI model is not much helpful. Rather the protocol based version shown in Figure 2 is more realistic and appropriate for deployment (Routray, 2019). Similar to the OSI model, the lower most layer in this model is the physical layer. For NBIoT, it is the wireless channel through which it communicates with different ports, nodes, devices and components. Just above the physical layer is the Internet protocol (IP) layer in its lighter form (because the NBIoT systems and components do not have large memory to carry the original form of the IPv6). It is called IPv6 over Low Power Wireless Personal Area Network (6LoWPAN). This lighter version is suitable for bandwidth limited applications (Xu et al., 2017). Above that, we find the UDP layer. It is the transmission control protocol for the connectionless mediums. Above the UDP layer, we find the datagram transport layer security (DTLS) layer. Its function is to provide the security to the datagrams using appropriate mechanisms (Routray, 2019). Above the DTLS layer, we find the constrained application protocol (CoAP) layer. This is very much similar to the hypertext transfer protocol (HTTP). But CoAP is much lighter than the HTTP. CoAP uses only UDP information in its functions (Routray, 2019). It is optimized to function in the constrained application scenarios. The uppermost layer is the end objects layer. It deals with the end objects such as the sensors, actuators, UEs, and other end objects. This practically implementable model is very popular in the real deployments. It is adopted in almost all the practical deployments (Routray, 2019). It saves a lot of time and provides better system efficacy in design and implementation.

STANDARDIZATION OF NBIOT

NBIoT is a standardized technology. It was designed for mMTC applications over the LTE based cellular networks (3GPP, 2016). In fact, it was evolved from the LTE for massive machine type communication (LTE-M). In LTE Release 12, LTE-M was proposed for long range applications of LTE in the IoT related applications. Several problems were found in the LTE-M framework such the bandwidth allocation and resource sharing. In Release 12, LTE-M was designed for high data rates which are normally not useful in majority of the mMTC cases. Bandwidth for LTE-M was provided from within the cellular bands. It was directly interfering with the cellular services. Also, the non-3GPP standards such as LoRa and SigFox performed better than LTE-M in several LPWA applications. Therefore in Release 13, NBIoT was proposed as the new technology for mMTC for long range communications. EC-GSM was also proposed as an alternative of LTE-M for the IoT related application in the cellular framework. However, NBIoT was preferred due to its low bandwidth, easy deployment, lower costs, and low power requirements (3GPP, 2016). The LPWA features of

Figure 2. The protocol based practically implementable layers of NBIoT



NBIoT were introduced in Release 13. Some of the adaptive features of NBIoT were enhanced in Release 14 (GSMA, 2018). In Release 15 also a few enhancements have been done to improve the performances of NBIoT.

In Release 13, all the main operational standards of NBIoT were framed. These standards were very much different from the provisions of LTE-M (in Release 12). Of course, in Release 13, LTE-M itself went through a lot of changes. The three mMTC solutions developed in the LTE framework were made competitive for the long term mMTC applications. Both EC-GSM and NBIoT are designed for large coverage. But, in practice, NBIoT has several advantages over EC-GSM in the LPWA applications. The coverage of each node in NBIoT has tremendously large. In terms of power, it is 164 dB, meaning the power difference between the NBIoT node and the end sensors can be as large as 164 dB (Routray, 2021). Both the EC-GSM and NBIoT were provisioned with long battery lives. Energy efficiency was improved using suitable duty cycles in which the sleep period is long when the end nodes and devices are not in active operation. EC-GSM normally deals with higher output power than NBIoT. Therefore, EC-GSM uses larger power transmitters (i.e., up to 33 dBm) than NBIoT (GSMA, 2018). For NBIoT two power levels have been specified: 20 dBm, and 23 dBm (Chen et al., 2017). In the optimized conditions, NBIoT battery life outperforms both EC-GSM and LTE-M battery lives. The bandwidth allocated for NBIoT channel is just 200 kHz and out of this only 180 kHz is used for data transmission. The data rates for NBIoT vary between 150 kbps to 250 kbps. In the large coverage area, it is limited to 150 kbps. However, when a high data rate is needed it can be enhanced to 250 kbps. The modulation techniques used in NBIoT are: binary phase shift keying (BPSK) and quadrature phase shift keying (QPSK). Normally BPSK is used in the majority of the cases. QPSK is proffered when there is a demand for higher data rates. In case of EC-GSM the modulation technique has a higher spectral efficiency. In addition to BPSK and QPSK it can also use 8-PSK modulation technique which provides it to communicate with higher data rates. Similarly, LTE-M can use higher data rates just as its Release 12 provisions. The downlink packet sizes are same for all these three cellular IoT and it is 65 bytes long. However, two different uplink packet sizes (50 bytes and 200 bytes) have been specified for the NBIoT, EC-GSM, and LTE-M. In terms of latency, EC-GSM is slightly better than NBIoT as it uses higher power levels. Also its higher spectral efficiency and higher data rates help in reducing the latency. According to Release 13, NBIoT can be deployed in three different ways (3GPP, 2016). More about these issues have been presented in the next section. NBIoT was designed for half-duplex communications in both the up and downlinks. However, in Release 14, it was enhanced for full-duplex in specific cases.

In Release 14 and Release 15, several operational parameters and specifications were revised for NBIoT to enhance its performances. In Release 14, new multicasting facilities for NBIoT were introduced. Device mobility and peak data rates were enhanced to make it suitable for several complex applications. New carriers and frequency bands were allocated for NBIoT. Location and positioning protocol (LPP) was introduced in NBIoT in Release 14 to improve the location and tracking applications. LPP supports new positioning techniques which can be shared with other localization methods and then further improved using the locations of the NBIoT nodes (Ramnath et al., 2017). In Release 15, some for the compatibility issues of NBIoT with the 5G new radio were introduced. In 5G the LPWA technologies are going to play important roles. NBIoT was enhanced for time division duplex and better connectivity with the new radio provisions for 5G and beyond 5G application scenarios (Routray et al., 2021).

DEPLOYMENT ISSUES

There are several issues in the practical deployment of NBIoT. First of all, the bandwidth in which the NBIoT services are to be provided is determined by the cellular operators (Routray, 2019). Based on their choice, three different types of deployment is possible. In case of the urban scenarios, a more complex hybrid deployment is preferred where a lot of users subscribe for the NBIoT services.

Similarly, the edge computing facilities and the sensor and actuator deployments are important for the overall effectiveness of the NBIoT performances (Xu et al., 2017).

Deployment Bands of NBIoT

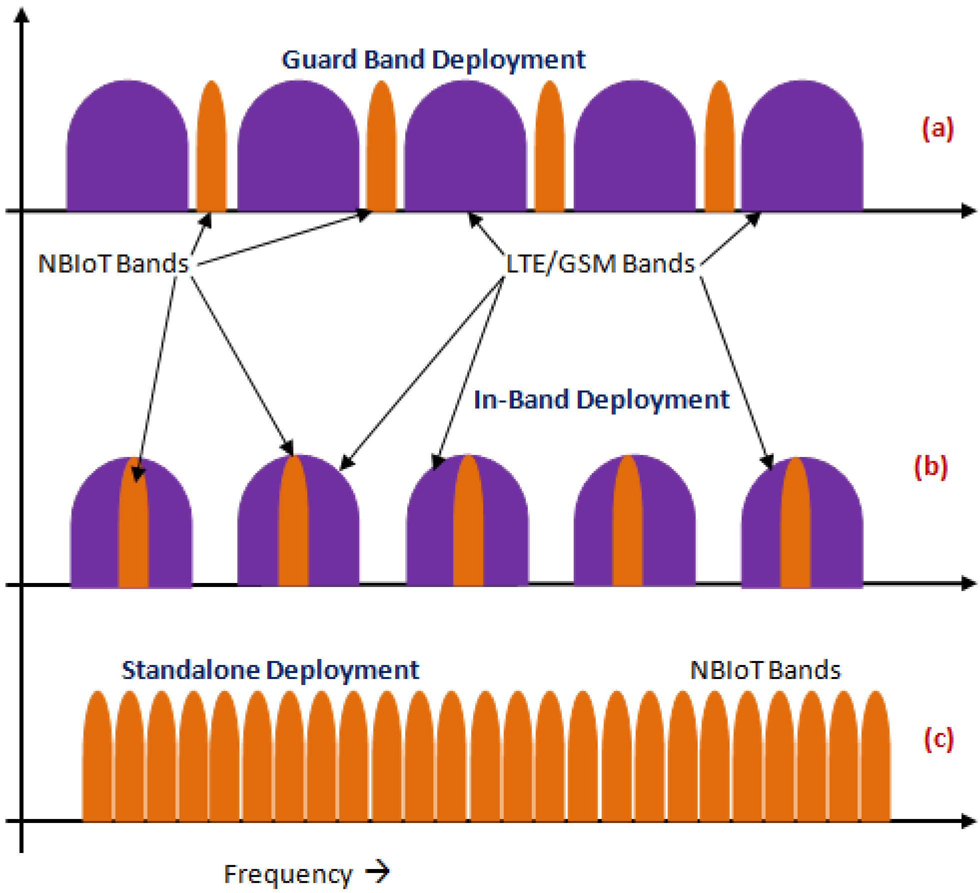
NBIoT can be deployed in different forms. In terms of the bandwidth, it can be deployed in three different ways: standalone deployment, guard band deployment, and in-band deployment (Chen et al., 2017). In the standalone deployment, the NBIoT bands are normally not used by the LTE networks. Rather a dedicated band is provided for this type of deployment. Normally standalone deployments are preferred in the areas where there is no LTE coverage is available or the LTE bands remain occupied most of the time (Routray, 2019). In the guard band deployment scheme, the guard bands of the LTE/UMTS/GSM are allocated for the NBIoT deployment. It is an efficient use of the spectrum as the guard bands in these networks remain unused. In the recent survey of Grand View Research, more than 70% deployments of NBIoT were in the guard bands. This trend is expected to remain as the pot priority in the coming years according to Grand View Research. In the in-band deployment, the NBIoT bands are part of the allocated LTE bands. Normally when the LTE bands are not in use, they are provided for the NBIoT services (Routray & Sharmila, 2017). Whenever the LTE bands are back in use, the NBIoT services are shifted from that band to another LTE band which is not in use. This is done using frequency hopping mechanisms (Kanj et al., 2020). All these deployment schemes have been depicted in Figure 3. In addition the above, the hybrid deployment schemes are also possible in which more than one of the above schemes can be used. Normally for the in-band deployment, during the peak times, we see all the LTE bands remain completely occupied by the LTE users. Therefore, there needs to be an alternative band for the NBIoT services. It is possible if hybrid arrangements are placed instead of just the in-band scheme. In fact, most of the in-band deployments are now shift towards the hybrid deployments (Routray, 2019).

In the hybrid deployments, two or more of the above mentioned schemes are utilised. Normally, hybrid deployments are essential for the multiple service-providing NBIoT networks (Routray, 2019). Real-time applications too demand the hybrid deployments. Any disruption or obstruction in the services may result in big losses. Therefore hybrid deployment is essential to avoid such unwanted incidents. It is noteworthy that hybrid deployments are more expensive than the simple one-type of deployment (Routray, 2019). They are also more complex and demand more resources than the simple one-type deployment. For high priority services such as mission critical applications and real-time critical applications hybrid deployments are preferable. In almost all the hybrid deployments guard band usage is common.

Large Scale Deployment and Edge Computing

LPWA features of NBIoT make it a primary choice for the large scale deployment over a large area. In such large scale deployments there are several challenges such as long latency, delay in decision making, poor control over the remote nodes, and poor resource allocation (Muñoz et al., 2018). In such cases local control and better resource sharing mechanism are essential for better quality of service. Edge computing is essential for the large scale deployment of NBIoT. In the large projects, the central control of the sensors and actuators become very much complex. Therefore, the decentralization of the control and management related functions are essential. Edge computing infrastructure provides these decentralized facilities (Routray, 2019). When the NBIoT network is stretched beyond a certain limit the edge computing facilities are needed to keep the performances intact. Edge facilities provide all the common control and management related support to the edge nodes which are normally far away from the central facilities. Small scale cloud support can also be provided to the edge facilities if they deal with significantly large amount of data. Such edge facilities are known as fog computing centers. For large networks, network slicing and other softwarized services are needed to make the operations smoother (Ninikrishna et al., 2017). This

Figure 3. Different types of bandwidth deployment of NBIoT in: (a) guard band deployment, (b) in-band deployment, and (c) standalone deployment



is normally not simple without edge or fog computing. Thus SDN approaches are preferred using the edge computing facilities (Muñoz et al., 2018). For large scale projects such as smart cities or smart grids these edge facilities are essential.

POTENTIALS OF NBIOT

NBIoT has strong potentials for several practical applications (Routray & Sharmila, 2017). Especially, in the long range and low power regime it is one of the best choices in the wider scope of the connected living paradigm. Its LPWA features are the main attractions for its business potentials. As we have seen in the previous sections, NBIoT has excellent sensitivities. The bandwidth needed for its operations is just 180 KHz and the data rate needed is 150 Kbps (Routray, 2021). Its low power requirements make it the primary choice for the safe digital ecosystem. Therefore, it is preferred over other forms of IoTs for healthcare, smart homes, pet tracking and parking. In addition to that its LPWA features make it suitable for smart cities and smart grids (Routray et al., 2021). The lower costs make it the premier choice in the developing countries. It is essential for the widespread digital transformation of developing countries. It can provide the expected digitalization goals in the industries, retail management, and logistics. The low energy consumption makes it a green technology. It is preferred in all the green applications. Overall, it is one of the front runners in many applications.

Artificial intelligence (AI) is widely used to enhance the performances of the engineering systems. It optimizes the system performances and reduces the costs. It has scopes for NBIoT as well. Using AI several new and advanced services can be included in the broad NBIoT domain. Machine learning (ML) is used for the improvement of the operations. It has the ability to provide optimized outcomes. Using ML several optimal outcomes are possible. IoT is a suitable to tool to make the systems intelligent using the advanced algorithms based on AI and ML. Many such smart systems such as smart classrooms and IoT based smart grids are popular in different application sectors. NBIoT is equally supportive in such intelligent applications. Many of such applications have been presented in some of the recent works which show the tremendous potentials of NBIoT (Anand & Routray, 2017; Routray et al., 2021).

Several new frontiers of NBIoT emerge in the recent years. For instance, the satellite based NBIoT applications for large scale surveillance and monitoring are very new and their demands are high. Satellite based NBIoT applications have several advantages over the existing satellite based applications (Routray et al., 2019). Similarly, under water applications of NBIoT to measure and monitor the ocean surface ecosystem is very new. It opens new frontiers for the ecosystem monitoring. Applications of NBIoT in the mining and other difficult terrains find popularity due to the LPWA and high longevity of the systems. NBIoT can also be deployed faster and comparatively with less difficulty in these environments. Every year several new applications are found and the real potential of NBIoT is explored with these new services.

APPLICATIONS OF NBIOT

There are several applications of NBIoT. Every year we find new applications of NBIoT emerge in different fields. In the LPWA domain it is considered as a prime choice. The low power regime of NBIoT makes it a suitable choice for the connected living applications. In this section, we show a list of applications of NBIoT in which it is one of the prime choices. In Figure 4, we show the main list of applications of NBIoT in recent years. However, there are many more applications of NBIoT than what are shown in Figure 4.

Smart city initiatives need a large number of sensors and actuators. Smart city projects are not limited to the cities rather they cover large peripherals of the cities. These projects need a large amount of power and complex arrangements. Ubiquitous infrastructure for these projects can be easily provided by the cellular IoT technologies such as NBIoT. Otherwise, completely new IoT deployments cost a lot of revenue for these projects. NBIoT can reduce the energy and bandwidth required for the large scale deployments (Zanella et al., 2014; Routray et al., 2021; Routray et al., 2021b). In terms of deployment, it is much simpler and easier to deploy than the other cellular and non-cellular IoT networks. These features naturally make NBIoT an attractive choice for smart city projects.

Healthcare is one of the primary sectors and provides services to everybody. This sector is very large and it needs low power sensors to monitor the patients and their conditions. Remote health monitoring and pre-hospitalization cares have to be given outside the hospitals. These facilities have to be provided using low power sensor based systems. NBIoT is suitable in healthcare due to its the low power and cost effective solutions (Anand & Routray, 2017). In emergency healthcare, continuous monitoring is essential and the use of sensors and actuators should not present any unwanted effects on the patients. In such situation, NBIoT is the right solution which does not have adverse effects on the patients (Routray & Anand, 2017).

Digital transformation and industrialization need large scale IoT deployment. NBIoT is a potential solution for the widespread digital transformation (Routray et al., 2021c). It can also help the industrial digital transformation. In the developing countries it is one of the main choices due to its cost effective solutions. NBIoT can improve the resource and utilities management such as water, electricity and gas distributions in the cities and villages (Routray et al., 2021). Leakage and wastage can be minimized using appropriate sensors and alarm systems. In agriculture, NBIoT is preferred for its fast deployment and LPWA features. It can help the farmers in the monitoring and management of the crops (Routray et al., 2019).

In transportation, tracking and localization related tasks NBIoT can play many significant roles. Logistics and supply chain operations need a large number of sensing and information exchange. Due to the large volume of these tasks an economical IoT is needed to carry out these operations economically. Reliability of NBIoT is very much comparable with other cellular and non-cellular IoT options available. In recent times, tracking and localization too need improved accuracy in their tasks. As NBIoT uses many sensors, the accuracy from the NBIoT based localization and tracking can be more accurate than the existing methods (Ramnath et al., 2017). The sensors can localize and track in the areas where the cellular networks do not provide good accuracies. Thus NBIoT provides added advantages in these applications.

In the retail industries, NBIoT can help in the rack and inventory management. It can provide the information on time so that the retail space can be managed properly. It is estimated that the use of NBIoT would improve the inventory management in retail sector to the extent of 40% which is certainly significant. Similarly, parking in the cities and other public places can be managed using NBIoT (Routray et al., 2021). It has already become popular in many cities now. Policing and surveillance related applications are very much popular in the NBIoT application domain (Routray et al., 2021b).

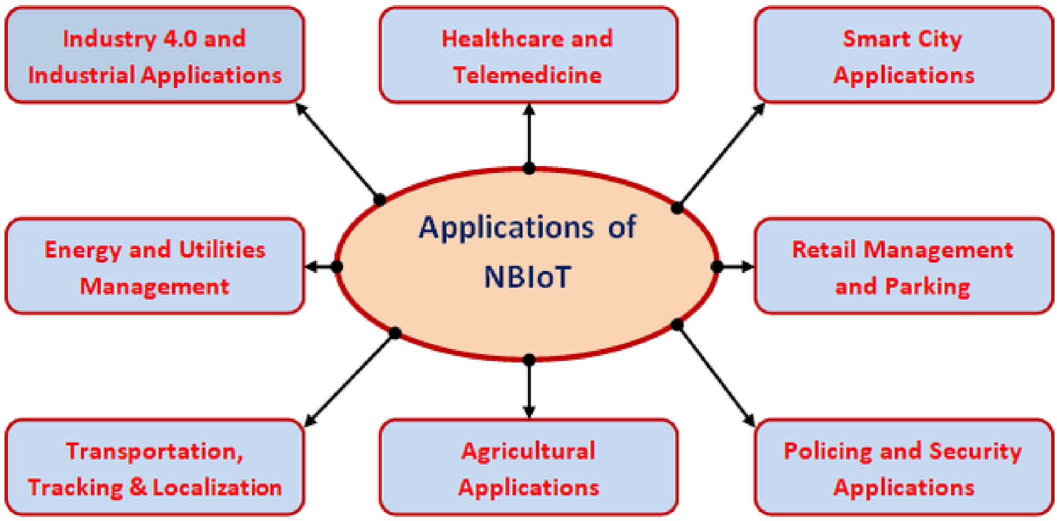
Smart grids are essential in the modern context due to the major short-comings of the conventional grids. These smart grids need a lot of support functions which are not common in the traditional grids. For the smart city operations, smart grids are essential. Smart grids are large networks and their control, operation, and monitoring needs the support of IoT. In addition to that smart metering functions can also be carried out using NBIoT. Due to the LPWA nature, NBIoT fits well in the smart grid applications such as the remote measurement, control and large scale monitoring of the smart grid parameters (Routray et al., 2021).

Extension of the NBIoT related applications is possible using hybrid systems such as the satellite integration (Routray & Hussein, 2019). Satellite based NBIoT systems cover a large area and provide better network availability, reliability, and flexibility (Routray et al., 2019). Satellite based NBIoT systems are good for monitoring large scale projects and to provide multi-layer support (Routray et al., 2020). In agriculture, healthcare, smart cities, smart grids, military applications, and in several other areas these systems get high demands (Routray & Hussein, 2019). These satellite based services will get better in the 5G and beyond 5G frameworks. In 6G, each cluster head of the NBIoT networks are expected to be connected with the satellites (Routray & Mohanty, 2021). Of course that is going to happen when 6G is expected to be rolled out in the 2030s.

Every year we find new applications of NBIoT get added to the existing pool of applications. From these view points, it is clear that NBIoT will have new applications in the emerging fields of science and engineering. In the previous section, we have shown the potentials of NBIoT in the emerging areas such as satellite conjugation, under water monitoring and difficult terrains. These applications will further get enhanced with the new standards and requirements (Routray et al., 2021c). IoT and NBIoT both have entered into several critical applications in industries. Even, power electronics also gets better through IoT (Routray et al., 2021c). The edge computing facilities make NBIoT a popular choice for large scale deployment. Edge computing servers can be spread around the main server and deployed at the proper locations where the data acquisition from the IoT nodes becomes efficient and flexible (Routray, 2019). Edge servers can be connected with the main central servers through high data rate communication channels such as the optical fibers.

While considering the large pool of applications of NBIoT, it is noteworthy that there are some limitations as well. For instance, NBIoT uses low data rates and thus it cannot send the high definition information which demands large data rates (Routray, 2019). Similarly, its bandwidth is a natural

Figure 4. Main applications of NBIoT



limitation for higher data rates. Of course using quadrature amplitude modulation (QAM) and QPSK techniques the data rates are increased as per the provisions of Release 14 (Routray & Sharmila, 2019). But still the scope is very limited. Large constellation QAM still has not been incorporated in the NBIoT standards. In addition to that, latency is comparatively high for the NBIoT based systems. Therefore, for low latency applications it is not the first choice. For critical low latency applications broadband IoT services are preferred over NBIoT. Data compression is a basic need of NBIoT. However, the advanced data compression schemes cannot be implemented in their full form in the NBIoT nodes due to their small sizes. Those schemes may be implemented in their standard form in the edge computing facilities (Routray et al., 2020b). It is expected that some of the limitations of NBIoT will be removed in the coming years.

Future Scope

Currently, NBIoT is a popular LPWA technology which has several applications in both the domestic and industrial environment. Its new applications emerge every year and it provides new smart services in almost all the domains. We expect new applications of NBIoT in the coming years. Both AI and ML are proposed to enhance the abilities of NBIoT for new applications. Starting from the domestic applications to the large projects such as smart cities there are a lot of new applications for NBIoT. AI and ML have the capabilities to enhance the functions of NBIoT in several frontiers. 5G and NBIoT are very much compatible with each other. It is predicted that 5G in this decade and 6G in the 2030s will open the new frontiers for mMTC (Routray & Mohanty, 2021). NBIoT has great prospects in the future mMTC applications in the cellular IoT frameworks. Smart cities and smart grid like large projects will need NBIoT for their long term sustainability. Currently, several smart city and smart projects have already deployed NBIoT. In the future it will be further enhanced at a large scale.

CONCLUSION

NBIoT is an energy efficient form of IoT. It also needs other resources at very low amount. Therefore it is an economical form of the IoT. It is a suitable form of the IoT for the large scale deployment for connected living applications. Its deployment is also less complex when compared with other forms of the IoT. Its LPWA features are very attractive for the large scale projects such as smart cities, smart grids, agriculture, and healthcare. It is also a suitable technology for the developing countries due its economical features. In the long term, it has very bright prospects for the digital transformations. In the developing countries, it is one of the main potential tools for large scale digital transformation. Overall NBIoT is a sustainable technology which provides long term benefits for the humans and the environment.

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