A Comparative Survey Study on LPWA Networks: LoRa and NB-IoT

Emmanuel Migabo, Karim Djouani, Anish Kurien and Thomas Olwal
Department of Electrical Engineering and F'SATI
Tshwane University of Technology
Pretoria, South Africa, 0001
University of Paris-Est Créteil (UPEC), France
Email: {MigaboME, KurienAM, OlwalTO}@tut.ac.za and djouani@u-pec.fr

***Abstract*—According to recent studies, billions of objects are expected to be connected wirelessly by 2020. The Low Power Wide Area (LPWA) networks are already playing an important role in connecting billions of new devices making up the IoT. Long Range (LoRa) and Narrowband-IoT (NB-IoT) are currently the two leading technologies triggering considerable research interest. This paper focuses on providing a comprehensive and comparative survey study on the current research and industrial states of NB-IoT and LoRa in terms of their power efficiency, their capacity, quality of service (QoS), reliability and range of coverage. The outcome of this research survey demonstrates that the unlicensed LoRa is more advantageous than the NB-IoT in terms of its energy efficiency, its capacity and cost while the NB-IoT gives benefits in terms of its reliability, resilience to interference, latency and QoS. It is further shown that despite the considerable research and development that has so far been carried out on existing LPWA technologies, there are still challenges to be addressed. This paper therefore proposes potential research future directions to address the identified challenges.**

Keywords—Low Power Wide Area (LPWA); Long Range (LoRa); Narrowband IoT (NB-IoT); comparative; energy efficiency; quality of service (QoS)

I. Introduction

It is predicted that there will be around 28 billion connected devices by 2021, of which more than 15 billion will be connected M2M and consumer-electronics devices as depicted in Fig. 1 [3].

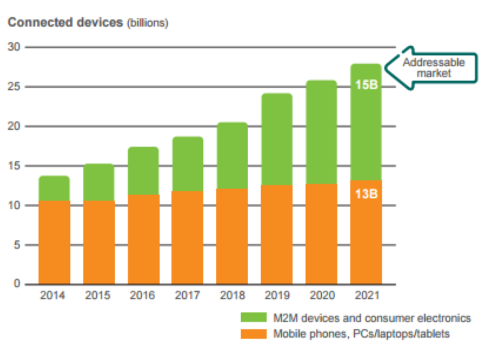

Fig. 1. Expected growth in number of connected devices [3].

As it can be observed in Fig. 1, the number of IoT M2M devices and consumer electronics is expected to almost doubled from 2014 to 2021 while the number of Mobile devices, PC/laptops/tablets which involve the human's interaction is only very slightly changing. This once again demonstrates the increasing impact of IoT, and therefore, the necessity for the development of appropriate network infrastructures to meet the demands associated with this increase.

A new class of wireless network technologies is therefore required to support the fast growth and development of the Internet of Things (IoT). This is also due to the specific requirements and characteristics of IoT objects such as low power consumption, long range, low cost and security.

Low Power Wide Area (LPWA) describes a category of wireless communication technologies designed to support Internet of things (IoT) deployments. LPWA therefore represent the group of technologies aimed at enabling power efficient and cheap wide area communication that Machine to Machine (M2M) communication can rely on for a much more power efficient deployment and operation.

LPWA technologies are expected to serve a diverse range of vertical industries and support a range of applications and deployment scenarios, which existing mobile technologies may not currently be best placed to connect. The main aim of the LPWA technologies designs consists of delivering strong coverage over large areas, great power efficiency, massive scale, low cost communications and low bandwidth [2].

Low-power wide-area (LPWA) technologies promise to open new market opportunities by providing power-optimized IoT connectivity instead of data-optimized connectivity that is the hallmark of existing mobile wireless protocols or short-range technologies [4].

To date, as LPWA has become one of the fastest growing markets in IoT with many LPWA technologies being developed both in the licensed and unlicensed spectra. Some of the most popular LPWA technologies can be classified as given in Table I.

TABLE I. Most Common LPWA Technologies

Unlicensed	Licenced
LoRa	NB-IoT
SigFox	LTE-M(LTE Cat-M1)
Symphony Link	NB-Fi (Narrowband Fidelity)
iFrogLab	LTE-MTC
ThingPark Wireless	UNB (Ultra Narrow Band)
Ingenu [7]	WEIGHTLESS-P [6]

This paper mainly focuses on a performance-based comparison between the LoRa and the NB-IoT technologies as reported in the literature. This survey paper therefore aims at serving as guidance to both research and industrial users of IoT in terms of the choice of LPWA technologies to adopt. Therefore, this paper clearly depicts the key technical differences between LoRa and NB-IoT and by extension of licenced and unlicensed LPWA in order for the user to make a meaningful and supported choice depending on each specific IoT application area. This is because each specific application area requires a different technology as they have specific requirements and considerations.

The remainder of the paper is organised as follows. Section II discusses the general LPWA design objectives and techniques. In Section III, the technical comparison between LoRa and NB-IoT technologies at the different network layers are presented and discussed. Section IV presents the current key industrial and research challenges faced by LoRa and NB-IoT design and deployment and Section V concludes the paper.

II. LPWA Design Objectives and Techniques

The use of LPWA technologies mainly aims at offering energy and cost efficient connectivity to a large number of objects distributed over a wide geographical area. It can be argued that these objectives are conflictual. This section describes and discusses some techniques that LPWA technologies use to achieve these objectives. It is also important to stress that LPWA technologies share some certain design goals with other wireless technologies. However, the main goal of LPWA technologies remains to achieve long range communication with power consumption that is as low as possible and cost unlike other wireless technologies which mainly focus on achieving higher data rate, lower latency and higher reliability.

A. Long Range Communication

In order to achieve wide area coverage, the design of LPWA technologies should produce excellent signal propagation and deeper signal penetration capable of reaching basements and deep areas of buildings. According to [5], this type of design targets signals that are often quantitatively estimated to ± 20 dB gain over average cellular signals. This gain translates into end-to-end device connections over a distance ranging from a few to tens of kilometers and vary with respect to the type of deployment environments (rural, urban etc.). Two main techniques are used by LPWA technologies in order to achieve long range capability. These techniques are the use of Sub-GHz band and the use of special modulation schemes.

1) Sub-GHz band: Most LPWA technologies use the Sub-GHz range in order to improve the robustness and reliability of communication at lower power costs. The sub-GHz band provides better signal quality at a wider coverage area and longer distance mainly for two main reasons. Firstly, unlike the 2.4 GHz band, the sub-GHz band consists of lower frequencies which therefore experience less attenuation and multipath fading caused by obstacles and dense surfaces such as concrete walls as mathematically modelled by the following Friis formula,

$$L = 20 \times \log_{10}(\frac{4 \times \Pi \times d \times f}{c}) \qquad (1)$$

where L represents the approximation (ideal case: isotropic antennas and free space) attenuation, d represents the distance between the transmitting and receiving antennas, f and c represent the frequency and the speed of light, respectively.

Secondly, the sub-GHZ band is proven to be less congested when compared to the 2.4 GHz and 5 GHz bands which are bands used for common wireless technologies such as Wi-Fi, cordless phones, Bluetooth, ZigBee, and other wireless technologies specific to home appliances [5]. By achieving robust and highly reliable communication, the use of the Sub-GHz band results in longer communication range and lower power consumption.

2) LPWA Specific Modulation Schemes: The technique used by LPWA modulation schemes consists of trading off high data rate for higher energy in each transmitted bit (or symbol) at the physical layer (PHY). This design technique allows LPWA technologies to have a signal that is more immune and that can travel longer transmission distances. Therefore, in general LPWA designs at PHY aim to achieve a link budget of 150 ± 10 dB which can translate into a few kilometers and tens of kilometers in urban and rural areas respectively. Encoding more energy into signal's bits (or symbols) results in very high decoding reliability on the receiver side. Typical receiver sensitivities of LPWA technologies could be as low as -130 dBm.

Modulation techniques used for most LPWA technologies can be classified into two main categories, namely the narrowband technique and the spread spectrum technique. Narrowband modulation techniques provide high link budget often less than 25 KHz, are very efficient at frequency spectrum sharing between multiple links and experience very small noise level experienced within each individual narrowbands. In order to further reduce the experienced noise, some LPWA technologies, such as SIGFOX, WEIGHTLESS-N and TELENSA, use ultra narrow band (UNB) of width as short as 100 Hz [8].

On the other hand, spread spectrum techniques spread a narrowband signal over a wider frequency band but with the same power density. The actual transmission is a noise-like signal that is harder to detect by an eavesdropper, more resilient to interference, and robust to jamming attacks (secure).

One of the major differences between narrowband modulation techniques and spread spectrum techniques is that spread spectrum techniques often require more processing gain on the receiver side to decode the received signal(below the noise floor) while no processing gain through frequency de-spreading is required to decode the signal at the receiver for the case of narrowband modulation techniques, resulting in simpler and less expensive transceiver designs. Different variants of spread spectrum techniques such as Chirp Spread Spectrum (CSS) and Direct Sequence Spread Spectrum (DSSS) are used by existing standards LPWA technologies.

B. Low Power Operation

In order to bring maintenance cost down, battery powered IoT objects should at least have a lifetime of 10 years or more. This is a key design requirement for IoT/M2M designs. The battery lifetime is often dependent on a number of factors among which the network topology, the duty cycle being used and the task distribution between end-devices and Base Stations (BS).

1) Network Topology: According to [9], when LPWA consist of a high number of connected objects over a wide geographical area, mesh network topology not only suffers from high deployment costs but also suffers from the "bottleneck problem". This is because, as the traffic is forwarded over multiple hops towards a gateway, some devices get more congested than others depending on their location or network traffic patterns. This results in shortening their battery lifetime therefore limiting the overall network lifetime to only a few months to years.

Therefore, most LPWA technologies use the star network topology by connecting end devices directly to base stations, obviating the need for the dense and expensive deployments of relays and gateways altogether. This technique results in huge energy savings. Compared to the mesh topology, the devices need not to waste precious energy in busy-listening to other devices that want to relay their traffic through them. In the star topology used by LPWA technologies, the base station is kept always switched ON in order to provide convenient and quick access when required by end-devices. It is important to point out that although most LPWA technologies use the star topology, some of them do make use of a tree or mesh topology. However, the later often requires quite complex protocol designs.

2) Duty Cycle Management: Another technique that is often used to achieve power efficient operation of LPWA technologies consists of opportunistically turning off M2M/IoT devices of high power consumption such as the radio transceiver circuit. Applying a good duty cycling on the radio transceiver circuit's power by only turning the radio when data needs to be transmitted or when data is received, has been proven to considerably reduce the overall power consumption of the network [10].

Other design factors such as designing of a lightweight MAC layer [11], offloading of complexity from end devices [12] are considered as part of the technique for reducing the overall power consumption of the LPWA network.

C. Low Cost Design

The Low cost design specification has been a key player in the commercial success of LPWA networks. This design condition can be better expressed by the following cost optimization formulation: "Achieving the connection of a large number of devices (as many devices as possible) while keeping both the hardware cost low (e.g. below $5 [13]) and the subscription cost per unit device as low as possible (e.g. $1 [14])". Some of the most common techniques, mechanisms and approaches used by LPWA technologies for achieving the objective of low cost design include the reduction in hardware complexity, the use of minimum possible network infrastructure, the use of licence-free bands (to cut down on licencing cost) and many more.

D. Quality of Service(QoS)

LPWA networks are designed in such a way that they can provide a certain level of Quality of Service (QoS) over the same underlying technology. For example, at one extreme, a LPWA network should cater for delay tolerant smart metering applications, while on other end it should deliver the emergency alarms generated by home security applications in minimum time. To the best of our knowledge, current LPWA technologies provide no or limited QoS. For cellular standards where the underlying radio resources may be shared between LPWA and mobile broadband applications, mechanisms should be defined for co-existence of different traffic types.

E. Network Scalability

There are a number of existing techniques and techniques that are under development that are used to ensure that LPWA technologies keep their operational performance despite the increase in the number of devices. This scalability design criteria is motivated by the fact that the number of IoT devices keeps on increasing exponentially and therefore requires existing network designs to accommodate new devices without compromising on the overall network performance.

III. LoRa and NB-IoT: Technical Comparison

As mentioned in the introduction section, NB-IoT and LoRa are the two most promising LPWA technologies. Therefore, this survey paper discusses and pays close attention to the key technical differences between them. This section systematically presents in a comparative manner those technical differences at the different layers of network.

A. Physical (PHY) Layer Comparison

The LoRa LPWA technology operates in the non-Licensed band below 1 GHz for long range communication. It uses Chirp Spread Spectrum (CSS) modulation at its PHY layer which allows it to tread data rate (low) for sensitivity within a fixed channel bandwidth making it quite robust against interference. CSS modulation is known for its long range capabilities mainly due to its robustness against interference. It has therefore mainly been used in military applications [15].

By using a spread spectrum modulation technique, LoRa not only provides long range capability but also a great link budget. It is important to note that the spread spectrum provides orthogonal separation between signals. This is done by using a unique spreading factor to individual signals. This approach is advantageous in terms of data rate management. The relationship between the necessary data rate and the chip rate and symbol rate being used for the LoRa network has been modelled in [15] as,

$$R_b = SF \times \frac{1}{[\frac{2^{SF}}{BW}]} \quad bits/sec, \tag{2}$$

where SF is the spreading factor and BW is the modulation bandwidth (Hz). As is clearly shown in (2), the data bit rate is directly proportional to the modulation Bandwidth.

In LoRa modulation the spreading of the spectrum is achieved by generating a chirp signal that continuously varies in frequency. An advantage of this method is that timing and frequency offsets between transmitter and receiver are equivalent, greatly reducing the complexity of the receiver design.

The LoRa technology also has other advantages including adaptive data rate, scalable bandwidth, high-power efficiency and multipath resistance.

On the other hand, the NB-IoT can be regarded as a new air interface on its own despite the fact that it is integrated into the LTE. This is because NB-IoT removes many features of LTE, including Handover, Measurements to monitor the channel quality, Carrier aggregation, and Dual connectivity in order to satisfy the energy efficiency and low power operation (energy efficiency) LPWA design criteria as elaborated in subsections II-B and II-C, respectively .

Unlike the LoRa technology that uses a non-licensed band, the NB-IoT uses the same frequency bands as the LTE which are licenced frequency bands subdivided into 12 sub-carriers of 15 kHz each in the downlink (DL) using OFDM access method and 3.75 or 15 kHz in the uplink(UL) using the single carrier FDMA (SC-FDMA) access scheme. It is also important to note that the NB-IoT uses the same modulation technique as the LTE which is the QPSK modulation technique.

The NB-IoT technology occupies a frequency band of 180 kHz bandwidth, which corresponds to one resource block in LTE transmission which result in three possible operational modes depending on where the block is located within the LTE spectrum, as illustrated in Fig. 2.

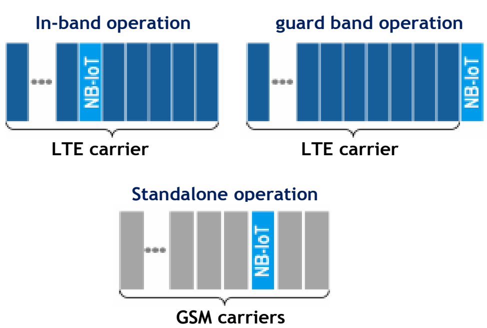

Fig. 2. NB-IoT band operational modes.

The three operational modes include, wide, leftmargin=*, labelwidth=!, labelindent=0pt

1) *In-band operation* utilizing resource blocks within an LTE carrier.
2) *Guard band operation*, utilizing the unused resource blocks within an LTE carrier's guard-band.
3) *Stand alone operation*: A possible scenario is the utilization of currently used GSM frequencies. With their bandwidth of 200 kHz there is still a guard interval of 10 kHz remaining on both sides of the spectrum.

A comparative Table II summarizes the key differences at the PHY layer between the LoRa and NB-IoT technologies as follows,

B. MAC Layer Comparison

In general, the LoRa terminology distinguishes between uplink and downlink messages at MAC layer level. Uplink messages are sent by end devices to the network server, relayed

TABLE II. COMPARATIVE TABLE BETWEEN PHY FEATURES OF LORA AND NB-IOT

PHY parameters	LoRa	NB-IoT
Modulation	CSS	QPSK
Link Budget	154dB	150dB
Spectrum	Unlicensed	Licensed LTE bandwidth
Bandwidth	500 KHz - 125 KHz	180KHz
Peak Data Rate	290bps-50Kbps (DL/UL)	DL:234.7kbps; UL:204.8kbps
Energy Efficiency	$>$ 10 years battery life of devices	$>$ 10 years battery life of devices
Spectrum Efficiency	Chirp SS CDMA better than FSK	Improved by , Standalone, Inband guard band operation
Power efficiency	Very High	Medium High
Area Traffic Capacity	Depends on gateway type	40 devices per household $\approx$ 55k devices per cell
Interference immunity	Very High	Low
Standardization	De-facto Standard	3GPP Rel.13
Mobility	Better than NB-IoT	No connected mobility (only idle mode reselection)

by one or many gateways while downlink messages are sent by the network server to one or many end-devices, relayed by one or many gateways. One major concern when it comes to the downlink messages is latency. Therefore, unlike for the uplink case where a CRC is appended by the radio to the payload to protect its integrity, no payload integrity check is done in the downlink at the MAC layer in order to keep messages as short as possible with minimum impact on any duty cycle limitations of the ISM bands used [15]. The need to satisfy this latency design requirement often affects the energy efficiency performance of the network. Therefore, based on the design need for trading off between network downlink communication latency versus battery lifetime, the LoRaWAN network has been divided into three different device classes, namely,

1) Class A end-devices (baseline): These are battery powered sensor devices (e.g. sensor nodes) for which energy efficiency is primarily a design concern [16].

2) Class-B end-devices (baseline): These are also battery powered devices, but mainly actuator devices. Energy efficiency remains a concern for Class B end-devices but not as much as it is for Class A devices.

3) Class C end-devices (continuous): These are actuator end devices just like class B devices but powered on a permanent (main) source. For this category of devices, the downlink minimum latency is of much more value than the energy efficiency is as they are powered on a main source.

As a result, three different MAC protocols have been designed for these three device classes respectively as shown in Fig. 3.

Fig. 3(a) shows the MAC operation of the Class-A devices from the end Device to the gateway (uplink) and vice versa (downlink). The first reception window (Rx slot1) is opened after a predefined "Receive Delay1" seconds duration following the end of the uplink modulation. The same way the second reception window (Rx slot2) comes exactly another predefined "Receive Delay2" seconds duration following the end of the uplink modulation. It is also important to point out that in the case of Class-A devices, the receiver stays active until the downlink frame is demodulated.

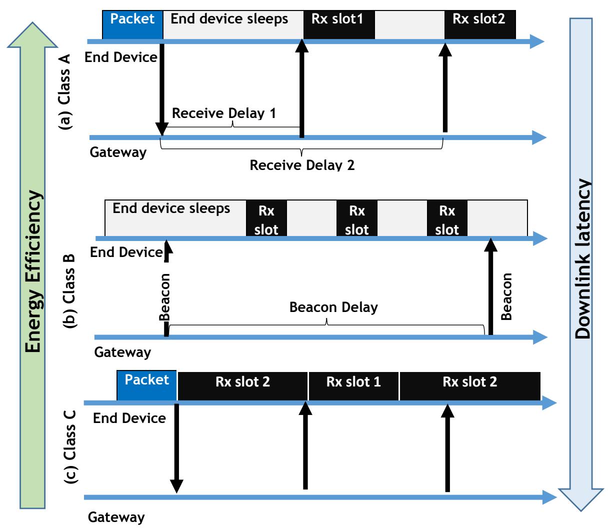

Fig. 3. Three classes device receive slot timing.

In the case of Class-B devices, during the downlink operation, the gateway sends a beacon on a regular beacon delay to synchronize all the end devices in the network. When end device receives the beacon, it can open a short reception window called *ping slot* predictably during a periodic time slot, as illustrated in Fig. 3(b). In the case of Class-C end-devices, not only they open two receive windows as Class A but also open an additional continuous receive window until the end of transmission as illustrated in Fig. 3(c).

On the other hand, from a functional point of view, the MAC architecture of the NB-IoT comprises of two main entities; one in the User Equipment (UE) and one in the Evolved UMTS Terrestrial Radio Access Network (E-UTRAN). The exact functions performed by the MAC entities are different in the UE from those performed in the E-UTRAN. However, both entities handle the Broadcast Channel (BCH), the Downlink Shared Channel (DL-SCH), the Paging Channel (PCH), the Multicast Channel (MCH), the Uplink Shared Channel (UL-SCH) and the Random Access Channel(s) (RACH) transport channels.

The specific protocols associated with the MAC layer of the NB-IoT include the packet data convergence protocol (PDCP) with MAC layer data packets of a size of 1600 bytes, the Non-access stratum (NAS) of protocol stack which serves to convey the non-radio signal between UE and the core network and to perform authentication, security control, mobility management and bearer management. It also serves to manage radio resources in the NB-IoT [1]. It is also good to note that for the NB-IoT the Random Access Channel (RACH) procedure is always contention based and starts with the transmission of a preamble as illustrated in Fig. 4.

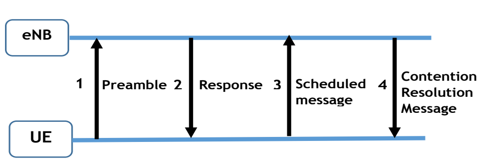

Fig. 4. NB-IoT RACH 4-steps procedure.

C. Network layer comparison

The network architecture of LoRa is defined by the LoRaWAN protocol. The LoRaWAN uses Long range star architecture in which gateways are used to relay the messages between end-devices and a central core network. In a LoRaWAN network nodes are not associated with a specific gateway. Instead, data transmitted by a node is typically received by multiple gateways. Each gateway will forward the receive packet from the end-node to the cloud-based network server via some backhaul (either cellular, Ethernet, satellite, or WiFi).

On the other hand, the NB-IoT core network is based on the evolved packet system (EPS). Two optimizations for the cellular Internet of things (CIoT) were defined. The User Plane CIoT EPS optimization and the Control Plane CIoT EPS optimization. Both planes select the best path for control data packets and user data packets for uplink and downlink data.

D. NB-IoT & LoRa: IoT Metrics Based Comparison

The selection as well as the design of a specific LPWA technology for a specific IoT application requires to be subjected to its performance evaluation in terms of some of the well know IoT design criteria such as battery lifetime, latency, network coverage, Quality of service (Qos), cost and deployment model. The comparison of the LoRa and NB-IoT in terms of these parameters as already described in Table I can be better expressed by the vector diagram in Fig. 5.

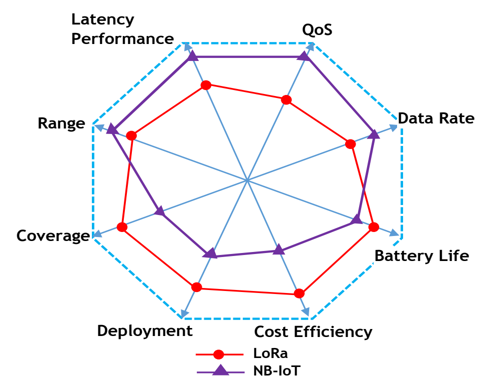

Fig. 5. NB-IoT & LoRa: IoT factors based comparison.

The diagram in Fig. 5 is a good comparative illustration between the LoRa and the NB-IoT LPWA technologies in terms of the major IoT performance metrics. As it can be clearly shown on the diagram, the LoRa LPWA technology exhibits better performance than the NB-IoT in terms of,

1) Network coverage and deployment: The network coverage of the LoRa technology could be as large as a full city (e.g. Brussels with its 30500 km^2 [17]) while the coverage of the NB-IoT technology is limited to the 4G/LTE Base station coverage area (cell size) since the NB-IoT depends on the 4G/LTE network infrastructure. This also implies that NB-IoT is not a suitable technology for sub-urban and rural areas which often do not have 4G/LTE coverage while LoRa would be an excellent LPWA technology for such areas for example.

2) Cost efficiency: The total cost of the LoRa is often lower than that of the NB-IoT. This is mainly due to the spectrum cost which could be more than 500 $millionUSDs/MHz$ for the NB-IoT while it is free of charge in the case of LoRa. The network and deployment cost of the NB-IoT is also higher as it could be estimated to 15000 $USDs/Base\ Station$ while it could be as low as 100 $USDs/gateway$ for the LoRa technology according to the data by [1].

3) Battery lifetime: Due to its asynchronous ALOHA based protocol, devices can sleep or be in idle state as long as there are no activities in the LoRa network operation. This is not the case with the NB-IoT operation which consists of infrequent but regular synchronizations that cause the devices to consumes additional batter energy. The other reason why the NB-IoT often consumes more energy than the LoRa is that OFDM or even FDMA multiple access techniques used with the NB-IoT require more peak current values ≈ 120 to 130mA) as they use linear transmitters unlike the LoRa which only reaches peak currents in the order of 32 mA [5].

On the other hand, the NB-IoT exhibits better performance than the LoRa in terms of,

a) Data rate: Being based on the 4G/LTE network, the NB-IoT provides a better data rate performance than the LoRa technology. Although high data rates are not always targeted by most of IoT technology, it is key for some IoT applications.

b) QoS: Despite the fact that LoRa uses unlicensed spectrum, an asynchronous MAC protocol, a secure modulation technique (CSS) (immune to interference, multipath and fading), it stills cannot provide better quality of service than NB-IoT. This is because once again the NB-IoT is based on the 4G/LTE network infrastructure which is designed for optimal QoS in terms of the licensed spectrum and the synchronous slotted protocol it uses.

c) Latency: Although the NB-IoT requires extra energy demands than the LoRa, these demands offer NB-IoT the advantage of low latency and high data rate.

d) Range: In general, the NB-IoT provides better network ranges than the LoRa. This is because in general Base Stations (BS) offer larger radio coverage ranges than gateways.

IV. LoRa and NB-IoT: Challenges and Open Research Issues

LPWA technologies have been proven to be a key player in the success of the IoT design, deployment and efficiency. This has been expressed and quantified in terms of what is nowadays called *carrier grade performance*. However, LPWA technologies are still faced with a number of technical and business challenges that need to be overcome for them to reach maturity.

On the technical side, there are challenges related to achieving cheaper hardware designs, reliable network connectivity, full end-to-end application integration. On the business side, there is a evident need by telecommunication service providers to bring their services to the market and capture their share across multiple verticals. This justifies the involvement of major world Telecoms players in the LPWA technology through their research and development teams. This section briefly highlights some of the key technical challenges faced by LPWA technologies, mainly focusing on the LoRa and the NB-IoT technologies, as well as some of the emerging research directions to overcome these challenges.

A. Network Scalability

With the exponentially increasing number of IoT devices facing the limited and shared radio resources, the resource allocation problem becomes more complex. Another emerging problem is the *hot spot* problem which results from the fact that the density of IoT devices in certain geographical areas is higher than it is in other areas. Furthermore, most LPWA technologies use simple ALOHA or CSMA based MAC protocols which are know to not be able to scale well with number of connected devices.

More research studies seem to suggest that end devices should adapt LoRa communication parameters possibly with help from more powerful base stations and exploit base station diversity to overcome this limitation. At MAC layer level, research studies are proposing channel diversity, opportunistic spectrum access, and adaptive transmission strategies.

B. Interference Control and Mitigation

The devices operating in the shared ISM bands will undergo unprecedented levels of both cross-technology interference as well as self-interference which is accentuated with the increasing number of IoT devices.

Current research studies propose that both LoRa and NB-IoT consider adaptive transmission scheduling across the frequency, time and space dimensions as a way to experience the least interference and achieve best reliability. Another trend that is the attempt to solve the problem at the regulation level by proposing rules to enable efficient sharing and cooperation between the different wireless technologies in the unlicensed bands.

C. Coexistence between LPWA & other Wireless Technologies

In most IoT applications, the connectivity of the end-devices is often supplemented with LPWA technologies in addition to the cellular or wireless LANs. This coexistence of the different types of networks results in conflicting design and deployment goals such as energy efficiency, high throughput, ultra-low latency and wide area coverage.

One solution approach that considered in current research consists of leveraging the benefits of each technology. Another research trend consists of exploring the benefits of each opportunistic and contextual network access technique at system level [18]. For example, when cellular connectivity is not available, LPWA technologies can still be used as a fall-back option for sending only low data rate critical traffic.

D. Higher Data Rate Modulation Techniques

Most LPWA technologies are based on the principle of compromising on data rates in order to achieve longer distances.This is the case of some technologies especially those using UNB modulation in the shared ISM bands which offer very low data rates and short payload sizes, limiting the type of applications they can cover. For example, most LPWA technologies such as LoRa do not cater for bandwidth hungry applications. Therefore NB-IoT is often preferred to LoRa for most IoT applications where relatively higher data rate is important.

One research solution approach being proposed consists of implementing multiple modulation schemes for a single IoT device in such a way that depending on the application needs, devices can switch between different modulation schemes. This will allow the network to simultaneously achieve high energy efficiency, long range and high data rate performance.

Other general challenges faced by LoRa and NB-IoT include Link Optimization and adaptability, localization, Authentication, Security, and Privacy, Mobility and Roaming to list few.

V. Conclusion

This survey paper provided an overview of the main technical considerations in the design of LPWA technologies with a specific focus on the LoRa and NB-IoT leading LPWA technologies. The paper provided a clear and systematic discussion on the different LPWA design objectives and techniques before using the later as metrics for comparison between the LoRa and the NB-IoT technologies at the different network layers. The paper further showed that despite the existing developments on both the LoRa and the NB-IoT, there are still open research and development issues that clearly need to be studied in order for LoRa and the NB-IoT and the LPWA technologies to meet their design goals. It has been clearly demonstrated through the different comparative discussions between the LoRa and the NB-IoT that the use of either depends on the type of applications under consideration. This is because each of the two provides its own advantages and disadvantages as discussed in this paper.

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