Low Power Wide Area Networks (LPWANs) Technology

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***Abstract*—By 2025, approximately 27 billion devices will connect to the internet. These increasing IoT devices need new connectivity requirements to have reliable and effective communication. Low-Power Wide Area Network (LPWAN) is a wireless data communication protocol that fulfills the requirements of the Internet of Things by offering multiple features like Low latency, and long-range communication at low power and low cost. LoRa, Sigfox and NB-IoT are the three widely used WAN technologies that compete for wide-ranging IoT applications and overcome the range and scalability limitations of traditional short-range wireless sensor networks. In this paper, we discuss the key technologies of LPWAN, their technical differences, some IoT-based application scenarios in terms of IoT factors, and the challenges of these technologies.Where LoRa and Sigfox technology offer cost-efficient devices with high coverage and extended battery lifetime. In contrast, NB-IoT provides low latency and high Quality of Service that ensures communication reliability.**

***Index Terms*—IoT, LPWAN, Connected devices, LoRa, Sigfox, NB-IoT**

I. Introduction

According to the most recent State of IoT-spring 2022 report, the number of worldwide IoT connections increased by 8 percent in 2021 to 12.2 billion devices. Internet of Things (IoT) is an emergent technology and is predicted to equip billions of everyday objects with connectivity in the coming years. If supply constraints ease and expansion accelerates, it is estimated that there will be around 27 billion connected IoT devices by 2025 [1].This technology is used in various application areas such as logistics, asset tracking, factory automation, smart utilities, agriculture,Smart Emergency,and Smart cities [2].

When creating an IoT application, there are several factors to consider. For example, low energy consumption, relatively low data rate, and long transmission range are prominent factors. The extensively used telecommunication and short-range technologies are not feasible for these instances because of excessive device energy consumption and short-range transmission. In these regards, Low Power WAN has emerged as a solution for IoT applications that need low power consumption, long transmission range, and low-cost infrastructure.

Low Power WAN technology is a class of wireless communication technologies designed for power efficient, longer-range, and low-cost communication between IoT devices. As per the most recent LPWAN market research report 2021–2026, despite COVID-19 and chipset shortages, LPWAN market grew significantly during the last two years. It offers relatively long single-hop transmission, low power consumption rates,and simplified network design [3], [4]. The main goal of these technologies is to operate IoT applications that run on low cost, low-power devices and require connectivity across a large geographic region. There are different categories of low power WAN technologies that work on licensed and unlicensed frequency bandwidth. Currently, Nb-IoT, LoRa, and Sigfox are the most widely used technologies in different industries, such as logistics, factory automation.

The Sigfox technology was created in 2010 by Sigfox Corporation, a France-based global wireless network operator [21]. To build such wireless network connectivity, it uses the Ultra-Narrowband (UNB) modulation technique, which can help to operate devices that emit tiny data and require continuous power for long periods of time. Another leading technology, LoRa was developed by Cycleo in 2009, a France based company, but three years later it was purchased by Semtech, which is a USA-based company [20]. It is the de-facto wireless infrastructure for the low power IoT objects. The other most used technology is NB-IoT, which was developed by the 3rd generation partnership project (3GPP). This technology is also designed for low power IoT devices and operates using narrowband radio technology.

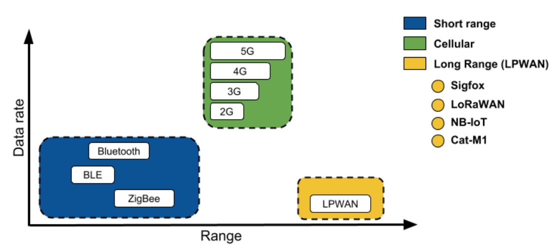

Fig. 1. Range capacity of LPWAN technologies [18]

Throughout this paper, we have analyzed the low-power

WAN technology. In the first two sections, we introduced the importance of Low Power WAN in today's IoT connected world and a general overview of LPWAN such as its definition, characteristics, and architecture, in the last three sections, we discussed the three most used technologies (NB-IoT, LoRa, Sigfox) and their architecture. We also discussed some possible application scenarios and challenges for these technologies.

II. Overview of Low Power WAN

A. Defination of LPWAN

LPWAN is an emerging radio communication protocol that uses minimal energy to enable long-range communication between IoT objects. It is suitable for IoT devices that need to operate autonomously for many years at a low data rate. This technology is used in IoT-based applications that use small-sized sensors which need low-battery power supply units and send only a tiny amount of data in real-time. This technology continuously utilizes a variety of methods to meet the increasing needs of IoT systems [5].

B. LPWAN Characteristics

The following are the main features of LPWAN networks:

- Long-Range Connectivity- LPWANs provide wide-area network coverage at low power and relatively cheap cost. It enables end devices to stay connected with their ground stations over tens of kilometers [7].
- Deployment and Operational Cost- Low-cost deployment and maintenance are the prominent features that help to increase the popularity of LPWANs. In addition, unlicensed spectrum-based technology does not require any infrastructure that makes Low Power WANs a commercially viable option [4].
- Low power consumption- Low-energy sleep mode is another feature of this network that helps to increase the battery lifetime of end devices. This feature enables IoT devices to only wake when they need to communicate with the base station [7].
- Reliability and Robustness- It supports reliable and robust communications between IoT devices. LPWAN technology uses robust modulation and a spread spectrum approach to provide wider bandwidth signals [3].

C. Architecture of LPWAN

The two goals of LPWAN networks are scalability and large network capacity. Rather than using the mesh or tree topologies, where network scalability is complex, this technology uses a simple star topology, here end devices are directly connected to the base station using transmitters. Figure 2 shows that a base station can connect multiple end nodes [18]. In this architecture, the first step is to collect data from the sensor or end nodes and then send it to the central base station using radio frequency. There is a duty cycle regulation in the base station, which ensure no need to send large volumes of data from the gateway to the end nodes. It limits the data transmission volume. There is a duty cycle regulation in the central base station that limits the data transfer rate from the gateway to the end nodes. This duty cycle regulation will reduce energy consumption rates and enhance communication efficiency. This deployment approach enables devices to communicate over a lightweight, scalable infrastructure that extends across several kilometers.

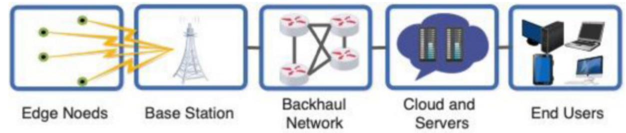

Fig. 2. Low power WAN network architecture [7]

III. Key Technologies of LPWAN

A. LoRa

LoRa is a physical layer Low power WAN technology that uses the spread-spectrum approach to modulate signals in the sub-GHz ISM band [11]. It is a low-power radio communication protocol for long-range communication between M2M and Internet of Things (IoT) end devices. It operates on an unlicensed spectrum that varies from region to region. For example, It utilizes an unlicensed ISM spectrum of 868 MHz,915 MHz, and 433 MHz in Europe, North America, and Asia respectively. These spectrums are part of the Radio frequencies, that are being used worldwide such as in commercial, scientific, and healthcare applications. In addition, this technology can also transfer signals at 2.4 GHz, which is better than the sub-gigahertz frequency in terms of speed. Furthermore, it utilizes multiple spreading factors which helps to increase the data rate and network coverage tradeoff. These spreading factors range from SF7 to SF12 where a higher spreading factor (SF12) allows large network coverage at relatively low data rates to a small spreading factor.

The data rate of LoRa varies from 300 to 50 kbps according to the spreading factor and channel capacity [20]. There is a requirement of message payload length which is a maximum of 243 bytes. In LoRa, to transmit information from end nodes to the base station several things to consider. Firstly information has to be encrypted on radio waves which can be done using the chirp pulses technique and then send this encrypted message by applying multiple spreading factors. The base stations can receive all of these spreading factors continuously at the same time and send them to the targeted end-user [12].

1) LoRa Class: There are three classes for IoT devices in LoRa communication. These classes can be used to meet the needs of specific applications with varying requirements of endpoints, where end nodes can select any classes considering the Latency, Power efficiency, and downlink communications tradeoffs.

- Class A- Bidirectional end nodes
- Class B- Bidirectional nodes with scheduled receives lots.
- Class C- Bidirectional nodes with maximal receive slots

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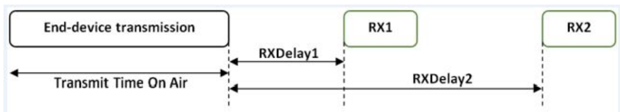

Fig. 3. Bidirectional communication in LoRaWAN class A [18]

2) LoRa Architecture: There are several components in LoRa architecture. These are the given below.

- End-Point: Endpoints are the initial elements of a LoRa communication network that perform sensing or control. They usually take place in remote areas.
- LoRa gateway: The gateway accept signals from LoRa endpoints and sends them into the backhaul system. This medium of the LoRa network can be Ethernet, cellular, or wireless telecommunications link. LoRa network gateways connect to the central server through standard IP connections [20].
- Network Server: The LoRa network server maintains the network connectivity and keeps the network running smoothly by deleting duplicate packets, dynamic frame routing, traffic management, acknowledgment schedules, and data rate adaption [20].
- Remote computer: This remote computer can take control of the actions of the endpoints or gather targeted data from that endpoints.

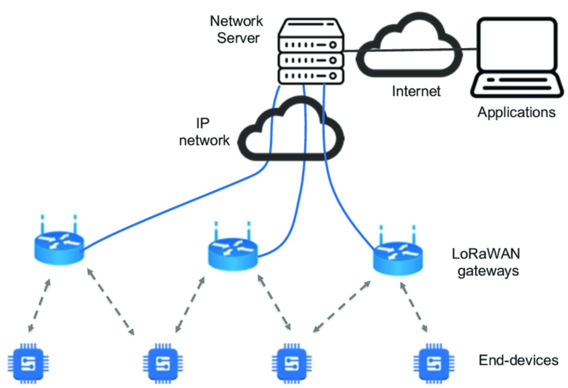

Fig. 4. Netwok architecture of LoRa [12]

LoRa technology provides distinct features for IoT-based end device communication that makes to be an appropriate option for applications that need to transmit small chunks of data with low data rates over a wide coverage area. Furthermore, this wireless protocol provides an extended communication range with minimal bandwidths to other competing wireless data transmission protocols [12]. These distinct features make the LoRa protocol a better option for smart sensor and actuators based end device communication that operates in minimal power mode.

B. Sigfox

SigFox is another proprietary Low Power WAN solution based on Ultra Narrow Band (UNB) wireless modulation on the physical layer [21]. The Sigfox network operates on an unlicensed sub-GHz ISM band carrier using 868 MHz in Europe, 915 MHz in North America and 433 MHz in Asia. Its coverage is about 30-50 km in rural areas and about 3-10 km in urban areas and robustness against noise. The spectrum itself is divided into channels. From the usage of an unlicensed ISM band comes fair usage restrictions, and duty cycle. The duty cycle restriction of a sub-band is commonly set to 1percent. Due to the use of ultra-narrowband, it has very low noise and enables decoding the signals easily [10], [12].

Sigfox network utilizes two types of modulations, separately for uplink and downlink. It uses Differential Binary Phase Shift Keying (D-BPSK) technique for uplink modulation and Gaussian frequency-shift keying (GFSK) for downlink modulation [4]. Uplink modulation allows up to 140 messages each day. There is a requirement of message payload length which is 12 bytes for uplink and 8 bytes for downlink. It takes less than 2 seconds to transmit a message from the end device to the base station. This technology consumes less power and has extended the battery life of IoT devices as it supports tiny message sizes and limits the number of messages per day [6].

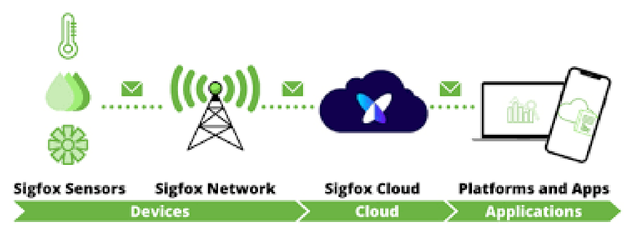

Fig. 5. Sigfox Network Architecture [10]

Sigfox technology offers a relatively low data rate than other low-power WAN technologies. It has a limit on the number of messages transmitted each day which is 140 messages, where each message takes only 3 seconds to send. To provide low-cost and power-efficient IoT devices communication service, this technology utilizes the cloud for processing and reduces network congestion to the base station. There are multiple channels that enable the base station to receive signals simultaneously. Therefore, end nodes can send information using a random frequency channel. These distinct features improve the endpoint design and minimize its cost. This technology also ensures reliability which can be done by transmitting messages multiple times that consume a lot of power energy.

C. NB-IoT

NB-IoT is another low-power WAN technology initiated by the Third Generation Partnership Project for IoT-based end device communication using a cellular communication strategy. One of the goals of NB-IoT is to expand coverage beyond what existing cellular technology can provide. This coverage achieves by providing uplink transmission repetitions and multiple bandwidth allocation strategies [18].

As was mentioned above Sigfox and LoRa technologies both rely on free unlicensed ISM band, NB- IoT technology at this point differs as it utilizes licensed frequency bands on which operates Long-Term Evolution (LTE). Since NB-IoT is working on existing Cellular functionality, it is possible to utilize existing infrastructure and distribute frequency without causing interference. It can communicate with up to 50k end devices, which requires a minimum of 180 kHz bandwidth. There are three types of operation in NB-IoT. These are standalone, in-band, guardband. This protocol applies resource mapping to retain the orthogonality of LTE transmissions by eliminating signal mapping to resources that are currently in use by LTE communication [13]. The maximum message payload is 1600 bytes per message, with downlink and uplink throughput rates of 200 kHz and 20 kHz, respectively. Although, it recommends sending 200 bytes per day to attain a battery life of 10 years [13]. But there is no limitation on the number of messages per day.

1) NB-IoT Operation mode: Narrow Band-IoT protocol is based on the licensed frequency spectrum similar to LTE and its modulated signal using Quadrature Phase Shift Keying. This technology has three different installation options. These are:

- Standalone operation
- Guard band operation
- In-band operation

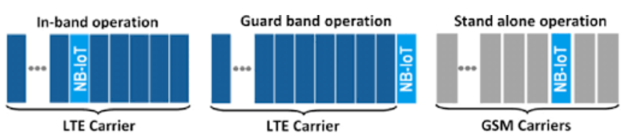

Fig. 6. NB-IoT operation mode [18]

2) NB-IoT Architecture: NB-IoT is a radio communication protocol that enables devices to work via a telecommunication network. This technology utilizes minimal bandwidth signals to communicate within conventional mobile communication and LTE standard. NB-IoT network consists of sensor or end-points, base station, and network server. A device or sensor is the base component of NB-IoT systems that collect data and transmit it to transmission nodes [22]. For centralized monitoring and sensor data analysis, these transmission nodes send this data to the core base station and then connect to the cloud server, from where the end device can easily control its application.

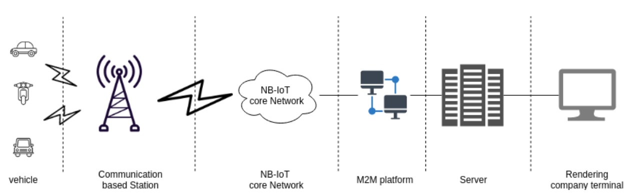

Fig. 7. NB-IoT Architecture [4]

IV. Difference Between LoRa,Sigfox,NB-IoT

SigFox, LoRa, and NB-IoT are radio communication-based LPWAN technology, but they have some distinct features that differentiate them into three different categories. In this section, we have discussed these technical differences. There are two types of spectrums that are licensed and unlicensed frequency. NB-IoT operates on a licensed spectrum but SigFox and LoRa operate on unlicensed spectrum-based technology. Fig.8 shows the overview of these technologies.

As discussed above LoRa, Sigfox, and NB-IoT are low-power WAN technologies. There is another difference between these protocols. NB-IoT network architecture deploys under the cellular IoT, but LoRa and Sigfox network architecture are non-cellular. All of these technologies have one thing in common: they all require their own networking system, base stations, and network antennas. Cellular technologies communicate on charged frequencies, and people cannot choose to broadcast on these frequencies at random. This technology ensure a better quality of service, such as control signals sent at the same time. Non-cellular technologies are networks that are not built in the same way as cellular technologies [18]. Sigfox and LoRa fall into this category.With Sigfox and LoRa, each country has frequencies where everyone can transmit, subject to limits per hour but free of charge but they did not provide Quality of service.

LoRa and Sigfox technology offer robust and reliable internet connectivity between IoT devices as it has low transmitting power and also operates on an unlicensed frequency spectrum. On the other hand, licensed spectrum-based technology like NB-IoT has lower data rates than LoRa and Sigfox technology [4].

Features	NB-IoT	Sigfox	LoRaWAN
Spectrum	Licensed (>$500 million/MHz)	Unlicensed	Unlicensed
Modulation	QPSK	BPSK	chirp spread spectrum
Power consumption	High	Medium	Low
Cost High	($15,000/base station)	<$5	Low ($100 to $1000/GW)
Peak current	120–300 mA	49 mA	32 mA
Sleep current	5 μA	1.44 × 0.001	1 μA
Battery Life	10+ years	2+ years	15+ years
Bandwidth	180 kHz	100 Hz	125/250 kHz
Latency	<10 s	1–30s	device class dependent
Adaptive data rate	No	No	Yes

Fig. 8. Overview of NB-IoT, Sigfox,LoRa [4]

V. Comparison (LoRa,Sigfox,NB-IoT) Considering IoT Factor

A. Quality of service

Sigfox and LoRa technology use unlicensed frequency spectrum and asynchronous communication channels. Interference, packet forwarding, and signal attenuation all can bounce off them. But these two techniques cannot guarantee the same level of quality of service as NB-IoT technology. NB-IoT incorporates a licensed frequency band and an LTE-based synchronous communication system to provide the highest quality of service level at the lowest possible cost [16]. Therefore, It is preferable to use NB-IoT for those applications that need to guarantee the Quality of Service as NB-IoT offers the highest quality of service at the lowest possible price. For other IoT-based applications where there is no constraint on the Quality of Service then LoRa or Sigfox is appropriate.

B. Battery lifetime and Latency

In NB-IoT, LoRa technology, when there are no operation end devices remains idle most of the time, which reduces the amount of energy consumed. However, because of synchronous message exchange and Quality of service maintenance, endpoints of NB-IoT consume more power than LoRa and Sigfox. In addition, OFDM access mode of NB-IoT requires peak current [17]. This extra power consumption reduces the battery lifetime of the end device. NB-IoT has distinct feature which are low latency. As a result, class-A LoRa and Sigfox are the ideal solutions for applications that don't need to communicate a lot of information and don't concern about latency. For applications requiring low latency, NB-IoT and class-C LoRa are better options [18].

C. Scalability and Payload

The main feature of NB-IoT, Sigfox, and LoRa is they can add a large number of devices. These technologies are well suited to the growing IoT device communication. LoRa, and Sigfox can support 50 K devices per cell, while NB-IoT can support 100 K devices. So, we can say it is more highly scalable than LoRa or Sigfox [17], [18]. In addition, it has a maximum payload length than the other two technologies.

D. Network coverage Range

Sigfox has a maximum coverage area of up to 40 km, while LoRa has a medium coverage area below 20 km [21]. On the other hand, NB-IoT has the lowest range and coverage capabilities, with an area of 10 km. The deployment of NB-IoT is limited to LTE base stations as it reuses the conventional LTE mechanism. As a result, NB-IoT is unsuitable for those areas that lack LTE coverage.

E. Cost

Several costs need to be considered, including the cost of spectrum required for a license, network or deployment costs, and device costs. When compared to NB-IoT, LoRa and Sigfox are much more cost-effective.

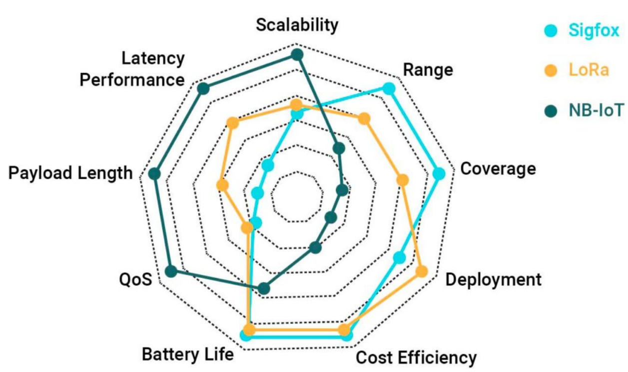

Fig. 9. Factors of NB-IoT, Sigfox, and LoRa technology [18]

To summarize, in terms of the above mentioning IoT aspects, we can say that NB-IoT, Sigfox, and LoRa all have unique features for different application scenarios.

VI. Use cases of LoRa,Sigfox,NB-IoT

Low-power WAN offers the possibility of facilitating a wide range of IoT applications. The IoT aspects and unique differences of these three technologies will evaluate their feasibility for specific IoT applications. All IoT applications cannot be covered effectively by a particular technology. Here we have discussed some use case scenarios of IoT devices, along with an overview of the best-fitting solution.

Fig. 10. Application areas of LoRa,Sigfox,NB-IoT [4]

A. Electric metering

Real-time electric meter monitoring requires frequent interaction, minimal response time, and a fast data flow. Since electric meters charges continually, energy consumption or extended battery life is not a concern here. The main task is immediate decisions about load, power breakdowns, and delays. For this application, Sigfox and LoRa are inappropriate for their low latency performance. In addition, electric meters are installed in specific locations with extensive LTE coverage. As NB-IoT offers low latency and a high data rate, it is a better option for this application.

B. Smart farming

Sigfox and LoRa are appropriate for smart farming since sensor gadgets in agriculture must have long battery life. Another reason is that this sensor changes its readings only once every hour as atmospheric parameters have not altered drastically. NB-IoT is not the appropriate option for smart agriculture-based applications because most agriculture farms are located in rural areas where they do not have LTE coverage.

C. Smart building

In a Smart building, different sensors such as heat, surveillance, and water flow, notify the building maintenance team to minimize equipment damage and react quickly in the absence of a manual building monitor. Rather than choosing NB-IoT, Sigfox and LoRa technology will be the best option as these sensors need to have extended battery life and be cost-efficient. Here, Low latency or fast response is not the main task. Therefore, LoRa or Sigfox is the appropriate protocol for Smart building applications.

D. Automated manufacturing

Real-time equipment monitoring keeps industrial output lines running which helps to improve production efficiency by remote control. There are two possible scenarios in Manufacturing automation. One possible scenario is factory automation, some operations areas need fast response rates or frequent communication, where NB-IoT is an appropriate option. Another possible scenario is several operations, such as inventory tracking and system status monitoring, may require low-cost IoT devices with long battery life, where Sigfox and LoRa are preferable options.

E. Retail transaction

In a point of sale system, the merchant needs to manage frequent communication with the customer. So retail systems must ensure good quality of service, but there are no limitations on battery life as they have continuous power. There is another requirement needed which is low latency because Long latency can reduce the number of transactions in the retail system. Therefore NB-IoT is more appropriate for this application.

VII. Challenges of Low Power WAN

Manufacturers of Low power WAN technology are attempting new ways to enhance the efficiency of current LPWAN technology. To integrate such functionalities into the existing technology, many trade-offs must be made that can create some difficulties. We have discussed some challenges of these technologies below:

A. Connecting large numbers of IoT devices

In the upcoming years, it is estimated that more than ten million devices connect to the Internet that can use the LPWAN protocol. These IoT devices will share radio frequency and interact at a massive scale with the base station. As a result, these increasing devices can create resource distribution problems in the base station.

B. Inter-Technology Coordination

The deployment of Low Power WAN technologies is increasing quickly. In the coming years, there will be a huge number of simultaneous LPWAN base stations in the particular region, which requires adjustment to the existing base station. In addition, the interconnection between different LPWANs technologies providers may be another substantial issue.

C. Support for High Data Rate

Currently, many LPWAN technologies provide minimal data rates and small payload lengths. In the future, many IoT devices will connect to the internet that may need a high data rate and large message payload length for smooth communication. Therefore, offering a high data rate can be a challenge.

D. Real-Time Interaction

Several IoT-based systems (for example, smart grid, manufacturing, healthcare, data center, and energy management) need interaction in real-time. For this type of application, fast response rate and reliability must ensure as they need frequent communication. But most low-power WAN technology working on the sub-GHz spectrum needs to have a switching frequency of 0.1, making real-time communication extremely difficult.

E. Authentication and Privacy

Signal transmission over the radio wave is vulnerable to jamming attacks. Many LPWAN technologies provide simple encryption and decryption algorithms using a private key that is shared between the device and network base station. This private key can steal at any time by attackers. On the other hand, Mobile communication provides end-to-end verification and security via the Subscriber Identity Module.

VIII. Conclusion

This paper explains three key technologies of Low Power WAN, their technical differences, and some application scenarios. By analyzing these technologies, It can say that LoRa and Sigfox technology offers cost-efficient devices with high coverage and extended battery lifetime. In contrast, NB-IoT provides a fast response rate and high quality of service that ensure communication reliability. Therefore, considering different application scenarios we can say that each LPWAN technology has distinct features which make them suitable to use in different IoT application fields.

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