

LPWAN TECHNOLOGIES FOR IOT APPLICATIONS: A REVIEW

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ABSTRACT

By 2025, there will be more than 75 billion Internet of Things (IoT) devices linked to the network. In recent years, as the IoT industry has evolved, low-power wide-area networks (LPWANs) have emerged as a preferred technology for IoT applications because of their cheap cost, low-power consumption, and wide coverage communication capability. LTE-M, NB-IoT, LoRaWAN, and Sigfox are the four most popular LPWAN technologies for large-scale deployment of IoT. This study will attempt an effort to review and compare these communication protocols, emphasizing the primary features and behaviors of key power consumption metrics, quality of service (QoS), latency, and other characteristics. The study shows that for applications requiring low latency and QoS support, LTE-M and NB-IoT are preferable. On the other hand, LoRaWAN and Sigfox are chosen when battery life and cost are the primary concern. Furthermore, this paper provides guidelines for researchers to choose the most appropriate protocol for various IoT applications.

KEYWORDS: IoT, LPWAN, Sigfox, LoRaWAN, LTE-M1, NB-IoT

1. INTRODUCTION

In the contemporary world of technology, IoT has received a great deal of attention due to its ability to connect billions of intelligent devices and sensors. Many institutions, such as governments, businesses, hospitals, and civic societies, can utilize and evaluate the data collected and shared by these real-world objects. Moreover, IoT enhances the quality of life in many aspects.

By 2022, more than 29 million devices will be connected to the internet as per Ericsson estimation, including automobiles, sensors, consumer electronics, machinery, POS terminals, wearables, meters, etc. (Niwa, 2018). According to a Forbes IoT survey, over 75 billion IoT devices are to be connected by 2025 (E Pasqua, 2018) and IHS Markit states that they will reach 125 billion by 2030. Everything from production to distribution is being affected by the IoT. Due to this shift, networks, data, clouds, and connections are being redefined, rebuilt, managed, and maintained. With the swift progress of IoT technology, the number of practical applications is increased in various IoT sectors, including smart city, smart meter, smart home, agriculture, asset monitoring, and security. IoT applications require using specific

technology (Ratasuk, Mangalvedhe, & Ghosh, 2015), and applying criteria, including energy-efficient and low-complexity nodes in scalable networks (Chaudhari & Zennaro, 2020). Connection is considered the most significant constraint for IoT applications, which arise from installing devices in problematic areas. Therefore, the key solution for this limitation is to increase coverage for devices in any Non-Line Of Sight (NLOS) situation (Andreev et al., 2015).

Although short communication range Wireless Personal Area Network (WPAN) technologies such as Bluetooth Low Energy (BLE) and ZigBee are tailored for low-power operation, they are not designed for extended transmission range. Instead, the systems based on Wi-Fi or mobile cellular technologies like 3G, 4G, and 5G ensure a more extended transmission range and high data rates. However, these technologies degrade battery life due to their high energy requirements. Therefore, LPWAN, which is a new paradigm of IoT, has been developed to satisfy such requirements. As early as 2013, the term 'LPWAN' did not exist (Sinha, Wei, & Hwang, 2017). The term "LPWAN" refers to a set of technologies as well as a class of wireless IoT communication protocols and solutions that offer

low data rates, small packet size, long range coverage, and efficient power usage to extend battery life (Alliance, 2015a). It provides a range of up to 50 kilometers in remote regions, and up to 10 kilometers in urban areas (Centenaro, Vangelista, Zanella, & Zorzi, 2016), with an extended battery life that lasts up to 10-years

(Patel & Won, 2017). These devices cost less than \$5 with a connectivity subscription less than \$1 per device each year (Raza, Kulkarni, & Sooriyabandara, 2017). It was created specifically for applications that require sending a few short messages every day across a long range, as demonstrated in Figure 1.

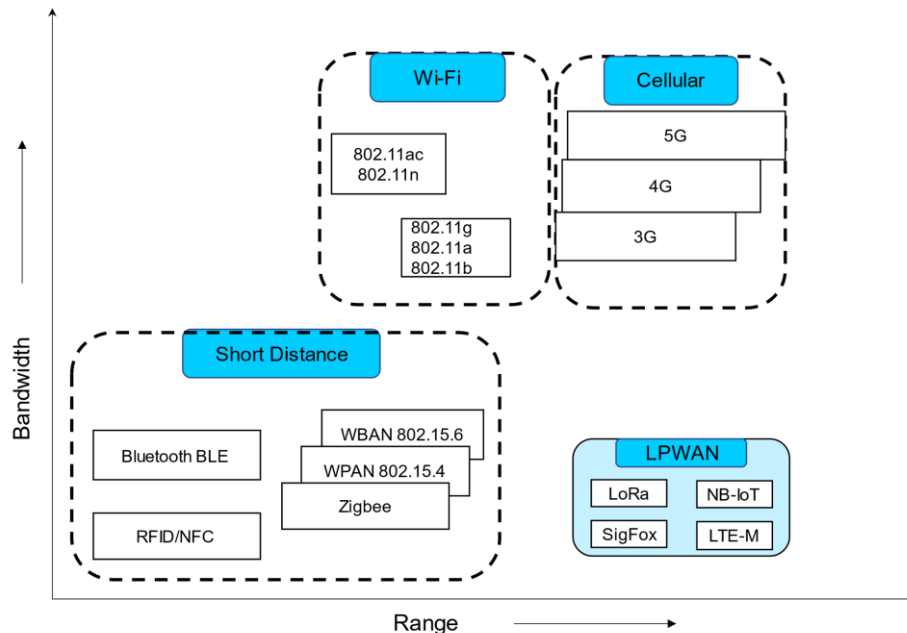


Fig. (1): Bandwidth vs. range of cellular, WPAN, and LPWAN technologies

These benefits have led to different LPWAN performance investigations in outdoor and indoor environments (Baharudin & Yan, 2016; Guibene et al., 2017; Vondrouš, Kocur, Hégr, & Slavíček, 2016). LPWAN has become one of the fastest expanding IoT areas as a result of the rapid increase in the IoT market. Many leading LPWAN technologies have arisen, such as Sigfox, LoRaWAN, NB-IoT, and LTE-M, due to the recorded increases in their respective markets. In 2019, a survey showed that 92% of these technologies are used in the LPWAN-

connected devices and will continue to dominate the IoT market; while the remaining 8% will have a limited contribution, as illustrated in Figure 2 (Eugenio Pasqua, 2020). Therefore, a technical comparison among NB-IoT, SigFox, LT-M1, LoRa, unlicensed LPWA based solutions was made in both licensed unlicensed frequency bands. Each LPWAN technology has advantages and disadvantages such as latency, scalability, power usage, coverage, and other parameters.

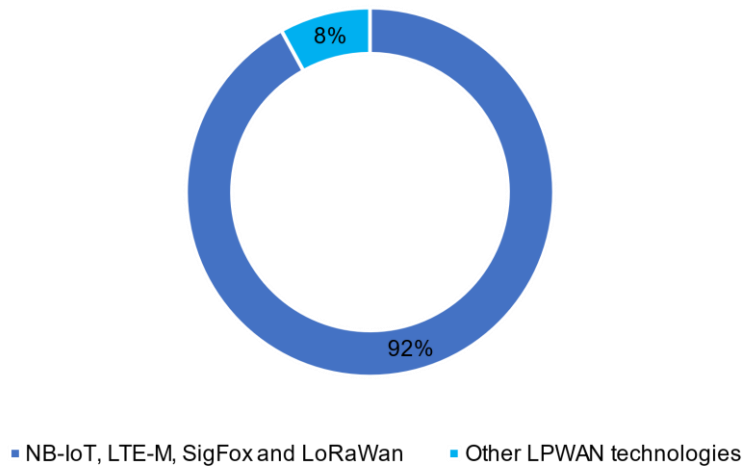


Fig. (2): LPWAN connected devices in 2019

The remaining sections of the paper are structured as follows: Section two presents Sigfox, LoRaWAN, NB-IoT, and LTE-M LPWAN technologies regarding architecture, limitations, and benefits. Section three compares these technologies' technical differences and IoT factors, subsequently it illustrates which technology is most suitable for application scenarios. Finally, a conclusion is made to bring this study to a close.

2. LPWAN TECHNOLOGIES

LPWANs run on either unlicensed Industrial Scientific and Medical (ISM) spectrum or licensed cellular. Licensed LPWANs use licensed radio spectrum to connect to public cellular networks and adhere to GSM and 3rd Generation Partnership Project (3GPP) standards. These protocols are renowned for promoting string mobility, seamlessly enabling devices to migrate between networks. Unlicensed LPWANs run on an unlicensed radio spectrum, which is publicly available. Due to the

limitations of unlicensed LPWAN handling high speeds and excellent mobility, it is arguably better suited to rural operations. This section describes developing technologies and technical details about NB-IoT, Sigfox, LoRaWAN, and LTE-M summarized in Table 1.

2.1. LoRaWAN

Long Range Wide Area Network (LoRaWAN) is a standard established by Semtech and developed by LoRa Alliance as a standardized wireless communication technology that functions inside unlicensed frequency bands. LoRaWAN technology is used as low-power, high capacity, and long-range protocol in IoT networks. LoRaWAN and LoRa are not synonymous, because LoRa works in the physical layer and LoRaWAN works in the MAC layer, as shown in Figure 3. Generally, multiple factors can determine the technology's performance, such as end devices' power consumption, size of network, and data rates used inside the network of uplink (UL)/downlink (DL) for various applications (Alliance, 2015b).

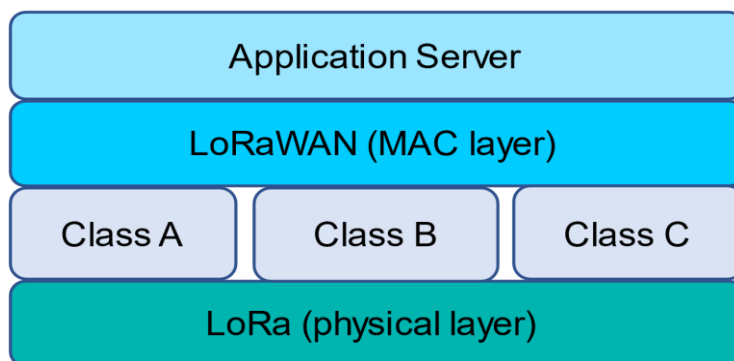


Fig. (3): LoRaWAN protocol stack

The LoRaWAN network uses star topology. The mesh architecture, on the contrary, requires transmission of data between nodes over long distances and large cell sizes. With star topology, the complexity of the network is reduced, and its capacity is increased. The power

efficiency of the node is achieved by eliminating unnecessary propagation between nodes. The main parts of LoRaWAN architecture are: application servers, network servers, gateways, and end nodes, as shown in Figure 4 (Ertürk, Aydın, Büyükakkaşlar, & Evirgen, 2019).

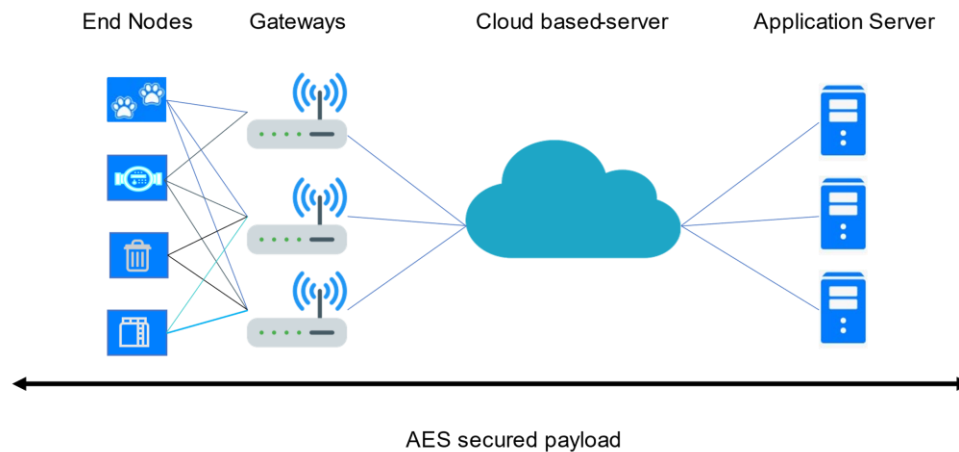


Fig. (4): LoRaWAN Architecture

Most wireless technologies employ Frequency Shift Keying (FSK) modulation to obtain efficient-power use. However, LoRaWAN is based on Chirp Spread Spectrum (CSS) as its modulation to preserve low-power consumption features while extending the coverage and providing good interference immunity. Furthermore, it operates in an unlicensed band below 1 GHz, specifically 868 MHz (Europe), 433 MHz (Aisa), and 915 MHz (USA) (Sinha et al., 2017). One of the key features that LoRaWAN includes is the Adaptive Data Rate (ADR) scheme, which enables dynamic control of the output data throughput of the end nodes. In return, it provides longer battery life which can reach up to 10 years, in addition to the network capacity (Alliance, 2017). Regarding the data rate of LoRaWAN, it ranges from 0.29 – 50 kbps and spreads up to 15 km based on the density of the medium (Alliance, 2015b).

LoRaWAN has three classes, where each one provides specific data rates based on the network requirements. Class A allows bidirectional communication between User Equipment (UE) and eNodeB. It is known to have quite a high collision rate because it uses pure Aloha as its medium access scheme, which would eventually reduce the network performance but provide the most extended battery life compared to other classes. Class B is similar to Class A with an additional receiving window to synchronize with

the cloud-based server. On the other hand, Class C end devices are always powered ON for data exchange, leading to extensive energy usage. Class C is suitable for IoT applications that do not have power restrictions and demand low-latency. Overall, LoRaWAN provides multiple options to cover most IoT application requirements (Ali, Henna, Akhuzada, Raza, & Kim, 2019).

As LoRaWAN works in a non-licensed and free frequency band, it works under national regulations, limiting the duty cycle (to only 1%) and maximum transmitted power, and affecting the latency and data rate transmission LoRaWAN (Tsavalos & Abu Hashem, 2018).

2.2. SigFox

SigFox is a wireless low-power communication technology that can be used in various low-energy devices like M2M applications and sensors. It offers transmission of a few bytes of data to distances up to 50 Km. Sigfox operates in Ultra-Narrow Band (UNB) frequencies, offering long-range communication. This method is only used for devices that run on a small battery and require low-speed data transmissions of 10 bps to 1,000 bps (Al-Sarawi, Anbar, Alieyan, & Alzubaidi, 2017). Sigfox protocol stack composes of the application, physical, MAC, and frequency band layers, as shown in Figure 5. Sigfox's frequency band layer transfers power needs and frequency allocation for end nodes and gateways. The physical layer

inserts at transmit end and removes preambles at the receiver end. In contrast, the MAC layer manages MAC packets and constructs frames following the uplink and downlink formats.

Finally, Application layer allows the support of various applications (Lavric, Petrariu, & Popa, 2019).

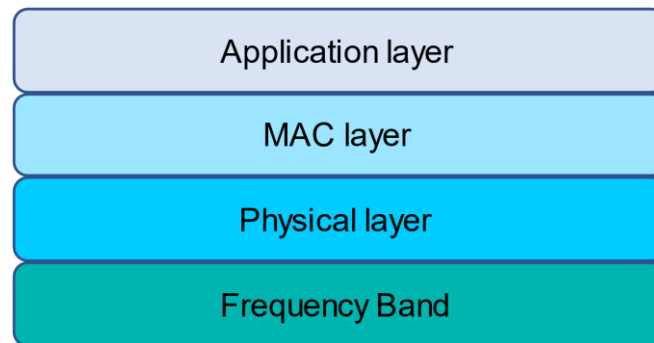


Fig. (5): Sigfox protocol stack

Binary Phase-Shift Keying (BPSK) is used in Sigfox applications as a modulation method. The use of ultra-narrow band minimizes interference and improves receiver sensitivity. Sigfox transmits data packets using the Random Frequency-Time Division Multiplex (R-FTDMA) method. Nodes do not need to be synchronized because they choose any accessible frequency for random transmission. End nodes in R-FTDMA transfer data without sensing the channel, much like in pure Aloha. This technique does not require to be synchronized with the gateways before transmitting data and hence using less energy. On the other hand, random frequency selection may lead to collisions increasing co-channel interference (Ali et al., 2019).

Sigfox gains advantage from the unlicensed 1GHz frequency channel to achieve long-range communication and stable transmission properties. It is permitted to utilize the unlicensed frequency band, although it is subject to regional limits on the duty cycle, which transmits maximum power. Since each uplink transmission at the end node is restricted to a 1% duty cycle, it affects Sigfox latency and downstream transmission. Sigfox provides a low transmission rate of 100 bps to 600 bps and a message with a payload length of up to 12 bytes, as its major drawback that limits its applicability in high-data applications (Tsavalos & Abu Hashem, 2018).

Sigfox is an LPWAN operator that independently or in collaboration with other network operators based on their patented technologies, provides an end-to-end IoT connectivity. Sigfox Network Operators (SNOs) install proprietary base stations equipped with

cognitive software-defined radios connected to the backhaul servers with an IP-based network. BPSK modulation is used in an ultra-narrow ISM band, 902 MHz (USA) and 868 MHz (Europe), to connect end nodes to the base station, requiring a yearly subscription (Hernandez et al., 2017). Because of UNB, Sigfox is able to make the best use of its bandwidth which is 100 Hz despite very low noise contribution. This results in ultra-low energy consumption, an affordable antenna design, and high receiver sensitivity. All these advantages are at the cost of a maximum data transfer of only 100 bps, which is clearly lower than most LPWAN technologies supplied throughput, limiting application numbers that use SigFox. Initially, Sigfox supported only the uplink communication but the system was later developed into a bidirectional system by supporting downlink and uplink with considerable connection asymmetry (Raza et al., 2017).

Downlink transmission takes place before uplink transmission, after which the end device listens to receive a reply from the backend. The uplink transmission allows each node to have 140 messages with packets of 12-bytes per day to conform to the regional regulations on the use of an unlicensed spectrum. However, an asymmetric downlink connection is deployed from the backend to the end device, where the transmission is limited to four messages per day with a payload length of 8-bytes. Consequently, it does not support the acknowledgement of all uplink messages. An end device multiple transmissions of a single message is allowed over multiple frequency bands. For this purpose, in Europe, the spectrum is divided into 400

channels between (868.180 MHz - 868.220 MHz) with a bandwidth of 100 Hz. Base stations are able to scan every channel to decode messages, and in order to increase the success of message reception probability, each message is sent three times by default. Moreover, end devices select a random frequency band to send their packet independently, resulting in less complexity in the end-device design (Raza et al., 2017).

As aforementioned, Sigfox network architecture is deployed in a star topology, as shown in Figure 6. For instance, data transmitters (often sensors in smart metering

applications) communicate with the Sigfox base stations through air, as radio frequency waves do. Once the base stations receive the message, it is sent to the Sigfox cloud network using the mobile network provider's 3G/4G or Ethernet backhaul. It activates the communication module and sends the message when it detects an event or measures anything. The network then picks up the message, and the data is delivered to the server. Sigfox is optimized for energy efficiency. When transmitting data, Sigfox consumes very little electricity and requires minimal maintenance.

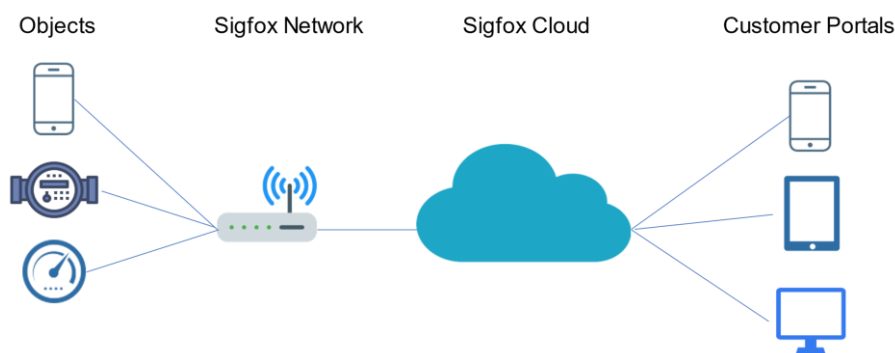


Fig. (6): Sigfox Architecture

2.3. NB-IoT

Narrowband Internet of Things (NB-IoT) was presented by 3GPP as a part of Release 13 to provide more coverage, lower power consumption and costs, and to support an enormous number of devices (Xu et al., 2017). The NB-IoT protocol stack features improve the NB-IoT development and planning and is therefore considered as one of the most power-efficient form of an IoT worth studying. The NB-IoT protocol layers are identical to Open Systems Interconnection (OSI) reference model developed by the international standard organization (ISO), with the exception of the five uppermost levels (Fattah, 2018). Two planes compose the NB-IoT layer architecture, which are the control plane and the data plane. The control plane denotes the protocols that control radio-access payloads and UE network connection. While the data plane specifies the data transmission of user between nodes. The 3GPP describes the NB-IoT as six layers as a valuable solution for communication of cellular

networks. The NB-IoT stack protocol layers are: radio resource control (RRC), non-access stratum (NAS), radio link control (RLC), packet data convergence protocol (PDCP), physical layer (PHY), and media access control (MAC). The latter two layers compose the access stratum. The only layers demarcated by protocol stack 3GPP are air access and access stratum techniques, which are responsible for physical transmission of data over the medium. The non-access stratum refers to the other five levels. The non-access stratum performs the same protocols and duties across all physical media, making it exceptional and to an extent incomparable. The contrast between the OSI and 3GPP protocol stack model is shown in Figure 7. The OSI presentation, session, and application layers may not be in the control plane (Gbadamosi, Hancke, & Abu-Mahfouz, 2020). For effective cost, design, planning, and dimension network deployment, it is necessary to understand the protocol stack of NB-IoT.

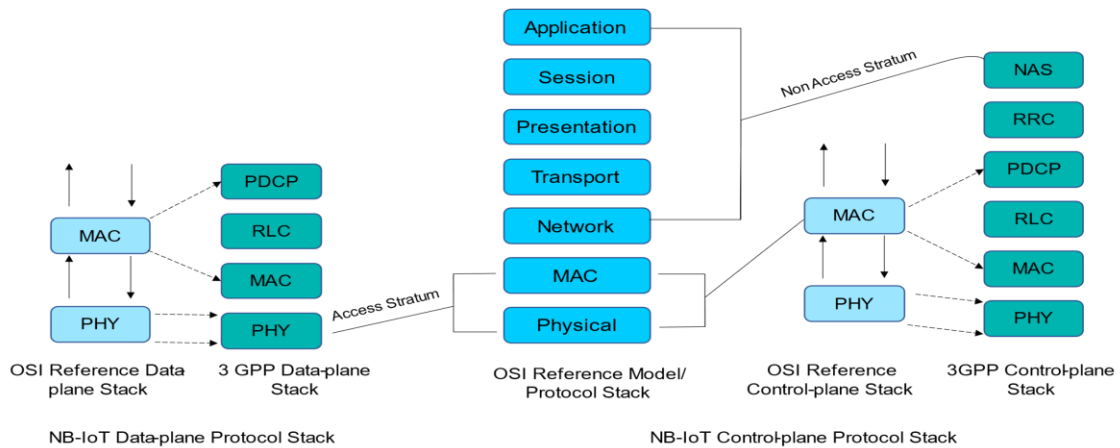


Fig. (7): NB-IoT Protocol Stack vs. OSI Protocol Stack

NB-IoT operates in three deployment modes: in-band inside a wideband LTE's occupied bandwidth of (180 kHz), while the guard-band requires one LTE physical resource block of an existing carrier of (180 kHz) and stand-alone as a dedicated carrier that uses a single GSM channel of (200 kHz). In the uplink, NB-IoT utilizes single-carrier FDMA (Frequency Division Multiple Access) with a data rate that can reach up to (20 kbps). In the downlink, orthogonal FDMA is used, with a transmission rate of (200 kbps). QPSK (quadrature phase-shift keying) is employed as its modulation scheme (Ballerini, Polonelli, Brunelli, Magno, & Benini, 2020). The batteries of NB-IoT modules can survive up to ten years while delivering low data rate and frequency services, with each cell enabling up to 52,000 connections (Aldmour, 2017).

For enhancement of efficiency and performance, NB-IoT provides two power-saving schemes: Power Saving Mode (PSM) and Extended Discontinuous Reception (eDRX). PSM allows devices to go into a deep sleep mode for best efficiency by turning off the

majority of their circuitry while remaining connected to the network. eDRX, on the other hand, saves a lot of power by prolonging the terminal's sleep cycle. Receiving cells are awakened unnecessarily during sleep cycles. eDRX considerably improves downlink accessibility (Nair, Abu-Mahfouz, & Lefophane, 2019).

Figure 8 depicts a generic architecture of the NB-IoT technology (Zayas & Merino, 2017). NB-IoT UE forms a wireless connection with eNodeB, and radio is the way of communication between them. eNodeB is responsible for cell management and processing air interface access. The eNodeB sends Non-Access Stratum (NAS) messages to the IoT Enhanced Packet Core (EPC) for processing. The IoT EPC sends data to the IoT platform for processing while connecting to the UE's NAS. These data are collected by the IoT platform from multiple IoT access networks and are sent to the appropriate application server. The application server is the final data aggregation point and recipient of IoT data processed in accordance with customer standards and requirements (Nair et al., 2019).



Fig. (8): NB-IoT Architecture

2.4. Lte-M

CAT-M1, Release 13, also known as Long Term Evolution- Machine Type Communication (LTE-MTC), is one of two 3GPP proposals for cellular LPWA applications released in 2016 (Tsavalos & Abu Hashem, 2018). Continuous upgrades are made to the initial standards for LTE-M and NB-IoT. This software is upgradable from LTE as a seamless path towards a 5G MTC solution (Borkar, 2020). LTE-M protocol structure is based on the LTE radio protocol stack illustrated in Figure 9. The stack includes a control-plane on the UE side and data-plane layers on the eNodeB side. The user plane manages data transfer via MAC, RLC, and PDCP protocols and provides signaling support via RRC protocol (Khan et al., 2021).

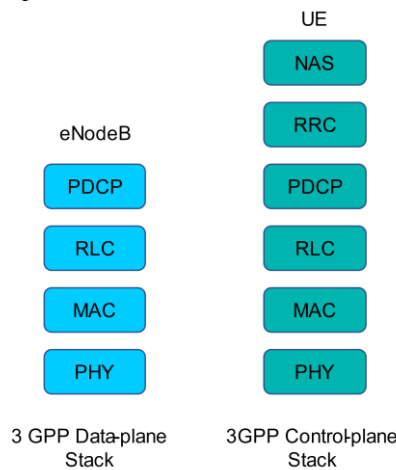


Fig. (9): LTE-M Protocol Stack

LTE-M1 facilitates the use of more than 100,000 of low-priced devices that improve coverage by 15 dB, per access station. This is in particular related to circumstances whereby devices demand extremely low data throughput, support very low-power operation with a battery

life up to a decade, and a latency of less than 10 seconds. A new UE category (Cat-M1 UE) was introduced to keep device costs low. Cat-M1 UE has an RF bandwidth of 1.4 MHz, one receive antenna chain that normally operates in half-duplex mode with a maximum block size of 125 bytes (Ratasuk, Mangalvedhe, Bhatoolaul, & Ghosh, 2017). OFDMA medium access scheme is used for the downlink and SC-FDMA is used for uplink. Both medium methods are utilized with a tone spacing of 15 kHz and turbo code using 16 QAM modulation.

Adding two energy-saving modes to the chipset contributes to power efficiency, making the CAT-M1 even more appealing. The first mode is LTE PSM where the CAT-M1 UE consistently goes into sleep mode and only wakes up to transmit data to the network during a specified period. As a result, each device contributes considerably to the decrease of power consumption. The second mode is LTE eDRX, which adds extended sleep periods between LTE paging cycles that may last from 10.24s to 43.69 minutes. This mode is an excellent choice for CAT-M1 UEs that must be active at all times while waiting for network input. LTE eDRX is less power efficient than LTE PSM (Borkar, 2020). CAT-M1 makes use of the current LTE network architecture; this feature makes it an appealing LPWA technology. The only changes required are the implementation of CATM1 UE on the user side and a software upgrade on the LTE network's eNodeB base stations. Data and applications can be received by the user through the application server offered by the region's network provider, as illustrated in Figure 10.



Fig. (10): CAT-M1 Network Architecture

A wide range of IoT applications is supported by LTE-M LPWAN technology. Mobility, high data rate, energy efficiency, low latency, and broad coverage are just a handful of good features targeted towards IoT applications. Voiceover LTE (VoLTE) is also an option. All

the 3GPP security and privacy features, including entity authentication, confidentiality, UE identity, and data integrity, are supported in LTE-M. Wearables that monitor critical parameters and industrial applications are just a few of the many potentials uses for these

attributes. LTE-M also supports IoT applications that need comprehensive coverage but with fewer restrictions on latency, voice capabilities, mobility, and data speed. Smart grids, smart cities, and home automation are examples of this application type (Borkar, 2020).

2.5. Comparing Technologies

Since there is no technology that can fulfill all the requirements of IoT applications, some of the latter may benefit from one technology more

than others. The appropriate choice contributes to meeting IoT applications' requirements in terms of cost, time, and efficiency. By evaluating their relevance and suitability against various criteria, the preeminent selection may be determined. Table 1 compares several IoT technologies in respect to important IoT factors like QoS, payload length, latency, battery life, scalability, coverage, and deployment cost.

Table (1): Technical Specifications and IoT Factor Comparison of LPWAN Technologies

| Technology/ Properties | LoRaWAN | SigFox | NB-IoT | LTE-M (CAT-M1) |
|--|---|-------------------------------|--|------------------|
| Standardization | LoRa alliance | SigFox | 3 GPP | 3 GPP |
| Topology | Star-on-star | Star | Star | Star |
| Duplex mode | Half-duplex | Half-duplex | Half-duplex | Half-duplex |
| Data rate | 0.29 – 50 kbps | 100 or 600 bps | 250 kbps | <1 Mbps |
| Coverage (Mekki, Bajic, Chaxel, & Meyer, 2018) | 2 - 5 km urban, 15 km suburban, 45 km rural | 10km urban, 50km rural | Urban 1 Km -10 Km rural 15 km | 11 km |
| bandwidth | 250-125 kHz (EU) 500-250-125 kHz (USA) | 100 Hz | 200 kHz stand-alone 180 kHz in-band | 1.4 MHz |
| Operating frequency | 868 MHz (EU) 915 MHz (USA) 433 MHz (Asia) | 868 MHz (EU) 902 MHz (USA) | Varied by region | Varied by region |
| Modulation | CSS | GFSK (DL) BPSK(UL) | QPSK | 16 QAM |
| Duty cycle | 1% | 1% | 100 % | 100% |
| Authentication and encryption | Supported | Not supported | Supported | Supported |
| Interference immunity | Very High | Very high | Low | Low |
| private network | Yes | No | No | No |
| Payload size | 57 bytes | 12 bytes UL, 8 bytes DL | 1600 bytes | 125 bytes |
| Battery life | >10 years | 10 years | 10 years | 10 years |
| Voice | Not supported | Not supported | Not supported | VoLTE |
| QoS | High | High | Very high | Very high |
| Mobility | Yes (non-GPS-based) | Yes (non-GPS-based) | No | Full GPS-based |
| Latency | Medium | Medium | Medium | Low |
| Deployment Cost | Low | Medium | High | High |
| Transmitted power | 14 dBm | 14-27 dBm | 23 dBm | 23 dBm |

3. IoT APPLICATIONS

LPWAN technologies are promising and have the potential to be deployed in a broad range of intelligent applications, including smart cities, environment monitoring, agriculture, health-care industrial automation, and other areas. This section introduces an evaluation in terms of the suitability of four LPWAN

technologies: LoRa, Sigfox, LTE-M1 and NB-IoT for IoT applications based on different criteria.

3.1. Smart City

Energy generation, smart buildings, fleet tracking, and waste management are some areas where Smart City solutions are applied. The connectivity of millions of sensors, gateways, and management platforms is required for all

innovative services. The sensors used in IoT, especially in smart cities, have low cost, can run for a long period, and do not require low QoS or real-time communication. Of the aforementioned characteristics, Sigfox and LoRa are preferable for this category of IoT applications. The first LPWAN network solution to be evaluated for smart city application is LoRaWAN. This technology has already been applied in various countries, such as Netherlands where 10 gateways cover the entire city of Amsterdam (Battle & Gaster, 2017), urban areas of Cusco city in Peru (Villanueva-Bayona, Lezama, & Arizaca-Cusicuna, 2022), as well as Britain (London) and nearby areas (Yu, Zhu, & Fan, 2017).

3.2. Environment Monitoring

Temperature and humidity data are transmitted at reasonably long intervals using weather metering applications. In order to install a high number of devices per customer, radio technology must have a huge capacity (thousands of connected devices) and low-power intake; support a long-range; and be of very low cost. If gateway installation costs are low, LoRaWAN can be regarded as a viable option for most of these applications. As long as the data payload is confined to 12 bytes, Sigfox can also be used. NB-IoT and CAT-M1 are preferable solutions in other scenarios when significant data throughput is required. LoRaWAN is the first option to be considered when designing and implementing a smart system to detect environmental changes and natural disasters as shown in a study conducted in Myanmar (Yangon) and Singapore (Tampines) where a network has been implemented that captures temperature, carbon dioxide, dust, and humidity in the air of these cities (Thu, Htun, Aung, Shwe, & Tun, 2018). Moreover, two additional research in Argentina (La Plata) and Tunisia (Manouba), implemented a smart network based on LoRaWAN technology to monitor the air quality of the cities (Candia et al., 2018; Rahim, Ghazel, & Saidane, 2018).

Land and forest fires, particularly in Indonesia's Riau Province, have caused damage across the country. Seasonal dry conditions, such as the El Nino impact, are known to increase

wildfires. A study was conducted to create a smart monitoring system based on LoRaWAN, which combines low-power wireless data transfer with the IoT technologies (Kadir, Efendi, & Rosa, 2018). Another study was presented in Ruse, Bulgaria where LoRaWAN system, with the help of drones, was used to locate forest fire incidents (Hristov, Raychev, Kinaneva, & Zahariev, 2018).

3.3. Farming

Applications employed in this sector are used to provide water usage, soil moisture, and temperature measurements as they dramatically lower the consumption of water, improve yield, and more. For these kinds of applications, latency is not very important in most cases. Collected data such as moisture level or water only need to be provided at particular periods. Therefore, frequent transmission is unnecessary. The devices utilized in this sector need to have long battery life. As a result, LoRa and Sigfox are suitable technologies in such situation.

The range in urban areas is quite decent; the scope of a single gateway may be expanded beyond 5 km with LoRa and around 50 km with Sigfox in rural and open regions. Both LoRaWAN and Sigfox can be used because they have low sensitivity levels to interference. NB-IoT and LTE-M1 are not the best choice for this sector as they depend on LTE cellular coverage, which may not be available in most of the farms that are located in rural areas. In some scenarios, as in Malaysia (Ibrahim, Ibrahim, Mat, Harun, & Witjaksono, 2018), a network has been implemented for monitoring mushroom greenhouses. In Macedonia (Skopje) (Davcev, Mitreski, Trajkovic, Nikolovski, & Koteli, 2018), a smart system composed of water, humidity, temperature, and soil moisture sensors was deployed in a vineyard.

3.4. Healthcare

With the growing adoption of IoT platforms, remote healthcare monitoring has expanded radically in the last few years. The quality of the health care system has improved by using the IoT health system to monitor and process real-time data. Unlicensed LPWAN technologies like Sigfox and LoRa and licensed LPWAN technologies like the NB-IoT and LTE-M1 frequency band are all suited for health

monitoring based on their capacity to lower power consumption and total expenses while increasing coverage. In Turkey (Istanbul) and Italy (Rome), the LoRaWAN system has been used to monitor respiration, blood fluid levels, and heart rate (Buyukakkaslar, Erturk, Aydin, & Vollero, 2017). Also, in Tunisia (Sfax), and Germany (Marburg) (Mdhaffar, Chaari, Larbi, Jmaiel, & Freisleben, 2017), various patients have been remotely monitored by attaching sensors to their bodies and sending the data to the health center using LoRa technology.

Compared to proprietary technologies like Sigfox and LoRaWAN, LTE-M-based solutions are a good alternative for medical applications. The sensors can be portable and wearable, and they can support a large number of properties. Real-time monitoring, early detection, preventative treatment, chronic illness management, and medical emergencies are the most common applications (Borkar, 2020).

3.5. Industrial Automation

Control over different kinds of industrial automation, machinery, and other production facilities varies depending on their needs. NB-IoT and LTE-M are superlative solutions for industrial services that require more frequent two-way connections, high QoS, low latency, and high data rates. LoRaWAN and Sigfox better fit applications like asset/pallet tracking and status monitoring that require long battery life and a low-cost sensor.

In many industrial applications, deploying a private network is preferable. An open network does not meet the needs for a stable connection and better degrees of security. Having complete network control is vital for critical applications regarding business performance, safety, and security. Thence, Sigfox and public LoRaWAN networks suffer from the drawback of being an open network used by several users, increasing the risk of packet collision, interference, and bandwidth saturation. In addition, Sigfox and LoRaWAN do not have a transmission limit.

3.6. Smart Grids

A smart grid refers to the application of digital technology to enhance the stability, adaptability, security, and productivity of the power distribution network. Power network services demand stringent criteria for

communication technology due to their high dependability and low latency time characteristics. The four mentioned LPWAN technologies satisfy the aforementioned requirements. Nevertheless, LoRaWAN is considered as an excellent technology for this field of application. LoRaWAN was used in Brazil for deploying smart grid solutions in Santa Maria's rural areas (Barriquello et al., 2017), by installing 130 nodes to cover the area. A similar scenario was tested by Seliva et al. (e Silva, Barriquello, Canha, Bernardon, & Hokama, 2018). Moreover, LoRaWAN was used with electric energy meters in Meylan city, France (Varsier & Schwoerer, 2017). Additionally, LoRaWAN can also be used in urban locations where the duty cycle issue is legal and the transmission is possible. In order to make use of LoRa technology in urban areas, a research in Ghent, Belgium was conducted (Laveyne, Zwaenepoel, Eetvelde, & Vandeveldel, 2017). The SX1276 was utilized as a component of commercial module RFM95 to manage power transmission lines in an attempt to control temperature parameters. This service optimizes the smart cities deployment of energy. Nonetheless, congestion and packet losses are common when a large number of terminals attempt to access the network simultaneously.

CONCLUSION

IoT technologies like Sigfox, LoRaWAN, CAT-M1, and NB-IoT are mainly categorized according to their operating spectrum, where CAT-M1 and NB-IoT operate on a licensed frequency, and SigFox and LoRa operate on an unlicensed spectrum. Each technology has a role to play in the IoT market. Sigfox and LoRaWAN can be beneficial for their cost-effectiveness, high coverage, low communication rate, and long battery life. Unlike Sigfox, LoRaWAN supports private network implementations, with its own cloud-server and gateways that could be linked to application servers as per client demands. This enables the technology to be deployed in remote regions without the need for a pre-existing infrastructure. In comparison, NB-IoT and CAT-M1 can serve higher-value IoT

applications that are ready to pay a premium for extremely low latency and QoS support.

To select the optimal LPWAN technology, this study explored the technical details of LoRa, Sigfox, CAT-M1, and NB-IoT technologies and their benefits in terms of IoT features and fundamental issues. This paper reveals that no technology can fulfil the needs of all applications.

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