Jan Moritz Meyer

Comparison of LPWAN technologies for IoT deployments

paper submitted for examination in Forschungswerkstatt 1
in the study course *Master of Science Informatik*
at the Department Computer Science
at the Faculty of Engineering and Computer Science
at University of Applied Science Hamburg

Supervisor: Prof. Dr. Thomas Schmidt

Submitted on: 23.04.2025

Jan Moritz Meyer

Abstract

This paper compares two groups of IoT communication technologies: LoRa-based solutions (LoRaWAN and DSME-LoRa) and cellular standards (Nb-IoT and LTE-M). The paper looks at aspects like speed, energy usage and latency. LoRa-based systems are very energy efficient and can be adjusted to different needs but have a limited coverage area. Cellular technologies use existing networks and offer wider coverage, though they come with higher costs and less flexibility. The paper shows that the best choice depends on the specific needs of the application although LoRaWAN has the best energy efficiency.

Contents

1 Introduction

With advancements in technology, the connection of physical objects with the digital realm becomes increasingly prevalent. This field is known as the Internet of Things (IoT) and aims to create an interconnected world. For example, a use case for an IoT application can be found in the digitalization of the automotive industry. Here, the application of IoT could be that the gas level of a car can be checked with a mobile device, thereby enhancing real life user experience.

In some cases, battery-powered devices are required. However, battery-powered devices and sensors face problems in application. One major reason is the limited battery capacity, consequently leading to constraints in connectivity. For instance, built-in sensors cannot be replaced easily and need to work efficiently to ensure a long battery life. Nevertheless, this can limit connection frequency.

One category designed for IoT use cases with energy limitations is Low Power Wide Area Networks (LPWANs). These technologies try to find the balance between power consumption and sufficient transmission range and speed. However, multiple technologies exist and choosing the right technology presents a challenge as it greatly depends on the use case.

The objective of this paper is to compare LPWAN technologies and their limitations. First, LoRa-based technologies such as LoRaWAN and DSME-LoRa are introduced. Following that, cellular-based technologies such as Nb-IoT and LTE-M will be described. The introduced technologies will be compared with regard to the factors of range and transmission speed. Lastly, the power consumption will be compared. This paper aims to give decision guidelines for the usage of LPWAN technologies.

2 Technologies

The following chapter will focus on both LoRa technologies—LoRaWAN and DSME-LoRa and cellular-based standards. In general, these technologies can also be separated by whether they use licensed or unlicensed frequencies. Other technologies like Sigfox are not covered in this paper.

2.1 LoRa technologies

LoRa is a radio technology that is popular for long-range communications [14]. LoRa itself defines the type of communication on the physical layer of the OSI model which is used between the devices [8]. It is based on the Chirp Spread Spectrum modulation [19]. LoRa was developed by Cycleo, which was later acquired by Semtech, and is used as a foundation for several long-range technologies [1]. LoRaWAN builds on top of LoRa to allow the devices to exchange data using the LoRa standard. It works with network routers and a star topology. DSME-LoRa tries to eliminate the need for network routers by allowing communication between any type of device. In the following, both technologies are evaluated.

LoRa works on unlicensed frequencies, which means that the exact frequencies depend on the region of the setup. One of the options is the ISM band from 433.05 to 434.79 MHz [6]. In general, LoRa makes use of the lower frequency band instead of other unlicensed frequencies like 2.4 GHz to achieve a better range. Although those frequencies are unlicensed and free to use in the European Union, there are regulations that aim to keep the bands usable by everyone [25]. These limits specify the maximum transmission rate and, depending on the bandwidth used, set a duty cycle and require additional methods such as Listen Before Talk and Adaptive Frequency Agility [4]. Listen Before Talk requires the device to check if the channel is free before transmitting data. When the channel is in use, the device either has to wait a random time or change the frequency. Duty Cycle Policies restrict the time a device is allowed to transmit per hour [25].

LoRa makes use of the CSS (Chirp Spread Spectrum) modulation. This modulation produces “chirps” in the frequency band, which allows the receiver to decode bits from those chirps [24]. The CSS modulation is parameterized by a bandwidth and a spreading factor, which allows for a trade-off between bit rate and reliability. Depending on these parameters, LoRa allows transmission speeds from 0.3 kb/s to 27 kb/s [1].

2.1.1 LoRaWAN

LoRaWAN is a network implementation for LoRa devices and builds on the LoRa communication protocol. It consists of three types of devices: Gateways, end-devices, and a central network server. The network typically works with a star-of-stars topology that connects all end-devices to one or many gateways [3]. This connection uses LoRa as the standard for the physical layer, where end-devices directly send data to the gateway. Although the communication is bidirectional, uplink communication from the end-device to the gateway is the main purpose of LoRaWAN [3]. The LoRa gateways are connected to the network server via standard encrypted IP connections. The network server is then responsible for sending the packets to the application server, where they are processed. To secure the communication, symmetric cryptography is used by deriving session keys from root keys that are located on each end-device. The root certificates of the end-devices are stored on a Join Server. The transmission speed is specified by the LoRa protocol and therefore ranges from 0.3 kbps to 50 kbps. LoRaWAN features several mechanisms that aim for low power consumption as well as a stable network [5].

The specification of LoRaWAN includes three device types. Device Type A is the minimum requirement that all devices need to fulfill. The difference between the device types is the ability to receive downlink packets. Device Type A is only able to receive a packet in two RX receive windows. These windows start after two separate delays following the device’s transmitted packet. When those receive windows have passed, they only open again after another transmission. This means that data packets addressed to a Type A device potentially have to wait until the device has data to transmit to the server. This limits this device type to use cases where the retrieval of data has no strict time constraints [5].

Class B devices feature periodic receive windows that are aligned to beacon frame broadcasts from the network. Each beacon starts a beacon period in which two receive windows exist. This means that receiving a packet does not require a packet to be sent to the server [5].

Class C devices are able to receive packets continuously, as long as they are not busy transmitting data. This further reduces potential delay and allows scenarios in which data needs to be received in a timely manner. However, this also means that the radio unit needs to stay active all the time, which impacts power consumption [5].

To optimize power consumption and network stability, an Adaptive Data Rate (ADR) scheme is used. It is used to control transmission power and transmission speed. It therefore optimizes power consumption by potentially reducing the transmission power [11]. In addition, it increases network stability since optimizing the transmission speed leads to a shorter "time in the air" and consequently fewer collisions. The usage of the ADR scheme is optional and is enabled by setting an ADR bit. However, it should be used, as it has a positive effect on the whole network in addition to potentially extending battery life. When the device starts sending messages, the default transmission power and the default transmission speed are used. The default transmission power is the maximum transmission power that the device is capable of while staying within regulatory limits. The gateways then measure the link quality, which allows them to estimate whether it is possible to increase the transmission speed or reduce the transmission power. A reduction in transmission power can then have a positive impact on battery life. To ensure that the messages from the end-device are still reaching the gateways, the network acknowledges the number of messages it receives in a specified interval. When the acknowledgment fails, the device increases the transmission power and lowers the transmission speed to regain connectivity. When the end-device is moving and therefore experiences a fluctuating radio situation, it should unset the ADR bit and is consequently excluded from the ADR mechanism [5].

To reduce interference and improve the stability of the network, each device uses a pseudo-random channel every time it transmits data [1].

As the communication is completely asynchronous, a device can sleep as long or as short as the application needs. Since the communication connection is not permanent, the latency is not reliable and LoRaWAN is not suitable for low-latency or real-time use cases [26].

2.1.2 DSME-LoRa

DSME-LoRa integrates the DSME Mac layer into the the LoRa physical layer. It therefore enhances LoRa with the Deterministic Synchronous Multichannel Extension (DSME) as a MAC layer to allow end-device-to-end-device communication [2]. The motivation behind DSME-LoRa is to work without central network components such as the LoRa gateways. When considering an example in which one end-device communicates with another end-device to send a command, direct communication could be established. In contrast, when working with LoRaWAN, the packet has to go to a gateway first, then to a communication server, which then sends the packet to a gateway that sends the packet to the end-device. However, when the data of a sensor needs to reach a central server, it still needs to travel via a device that is connected to both the DSME-LoRa network and the internet [2].

The IEEE 802.15.4 DSME standard is used to allow this behavior. The IEEE 802.15.4 standard targets low-power, low-rate networks. It is designed for fixed, portable, and moving devices that either have no battery or require very limited power consumption. It defines the physical and medium access control layers. Additionally, the goal was to create a simple standard with low complexity to allow for the creation of simple and cheap devices in the context of the Internet of Things. The idea behind DSME is to organize multiple devices into a personal area network (PAN) where a PAN coordinator manages the network. The PAN coordinator sets an interval in which he organizes super frames. Each super frame has a Beacon TX, which is responsible for the communication required by the PAN coordinator. In addition, a contention access period (CAP) exists in which random communication is possible. After the CAP, a contention-free period (CFP) starts in which guaranteed time slots (GTS) are assigned. Each GTS exclusively assigns a portion of the CAP, in combination with a fixed channel, to a device. This allows for guaranteed communication [13].

DSME-LoRa proposes standard settings for the LoRa modulation to achieve a compromise between transmission range, time on air, and throughput. Currently DSME-LoRa is designed to allow for a throughput of 5.5 kbps. The throughput is limited by the configuration of the physical layer, although it is possible to change these settings [2]. The 16 channels are designed for the EU868 region. One channel resides in a band where a 10% duty cycle is applicable, while the other 15 channels need to be used in a 1% duty cycle. A 1% duty cycle means that each device is allowed to transmit data for 36 s when considering the last 60 minutes. As LoRaWAN works on the same frequency, the synchronization word of the preamble is defined to reduce conflicts with LoRaWAN [13].

DSME-LoRa lacks a data basis which would allow for an estimation of power consumption in real scenarios. However, with the right configuration, the power consumption is less than 1 mW. To save energy, battery-powered devices can turn the receiver off during the CAP. This allows the devices to only listen to the beacon frame of each super frame in addition to the relevant GTS times in the CFP [2]. The time during which a device can turn off the radio is limited by the super frame duration.

2.2 Cellular technologies

Cellular technologies play a major role in the field of IoT communication. In contrast to LoRa, cellular technologies make use of licensed frequencies [26]. A huge benefit is that the infrastructure is provided. However, fees for the network service provider exist, which affect the costs for the deployment [3]. Currently, several technologies such as GSM, 4G, and 5G are available. For older technologies such as GSM, mobile operators have announced that these technologies will be shut down within this decade. With the development and the spread of 5G, 5G-based technologies are gaining popularity. For use cases such as Industry 4.0, private 5G networks are also possible, which would lead to the need for self-managed infrastructure [7]. However, this scenario will not be considered in this paper.

In the past, IoT devices were deployed utilizing 2G/GSM and 3G networks [10]. However, these networks were not designed for IoT use cases, which results in limited capacity regarding the number of IoT devices, in addition to high power consumption on the end devices. Therefore, communication standards such as Nb-IoT and LTE-M were designed, which are elaborated in the following sections.

In contrast to LoRa, the pricing model of cellular technologies is based on the number of devices. There are many different pricing models which, for example, allow grouping of data consumption packages; however, a SIM card or a module with a built-in eSIM needs to be purchased from a provider in addition to a data package. This makes cellular technologies more expensive when taking a look into the costs per device [20].

2.2.1 Nb-IoT

Nb-IoT was released and developed by the 3GPP (3rd Generation Partnership Project). It was originally designed for 4G (LTE) but will be supported by 5G networks [12]. The goal of Nb-IoT was to create a communication standard that allows easy communication while enabling the manufacture of cheap devices with low energy consumption [21]. To achieve this, Nb-IoT is based on the LTE protocol [20]. Some of the LTE features were removed, such as handover, channel quality monitoring, and dual connectivity [26].

The operation takes place in bands with a width of 180 KHz, which is identical to the bandwidth used in LTE operation [16]. A deployment on a 200 KHz channel—which reflects the occupation of one GSM channel—is also possible in stand-alone mode [23]. Operation is possible in a stand-alone mode, where frequencies of GSM are used. In addition, it is possible to utilize guard bands from LTE carriers or use frequencies inside the LTE carrier band [20].

Nb-IoT limits the payload size to 1600 bytes and can achieve theoretical data rates of 200 kbps in the downlink and 20 kbps in the uplink. It is designed for small devices such as sensors and actuators, which send small data packets. The benefit of these limitations is the reduced power consumption, which can lead to a battery life of approximately 10 years when transmitting a payload of 200 bytes every 24 hours with a battery capacity of 5 Wh [17].

To allow the IoT device to sleep and save energy, Nb-IoT implements DRX (discontinuous reception) modes. The idea behind this concept is that, instead of listening the whole time for potential data, the radio wakes up at specified intervals to fetch available information. In general, the radio has an idle and a connected mode. It enters idle mode as soon as it is not sending any data, while connected mode is active when the device has data that needs to be exchanged. For both modes, DRX is available—either I-DRX (Idle DRX) or C-DRX (Connected DRX). I-DRX allows sleep times of up to 10.24 s [16]. To further extend battery lifetime, eDRX (extended DRX) mode was defined by the 3GPP group. eDRX is an extension of DRX that allows sleep phases of up to 2.91 hours per cycle [16].

As Nb-IoT is designed for sensors that sporadically send data, latency can vary considerably—up to 10 s. Therefore, Nb-IoT cannot be used for time-critical or real-time applications [23].

Nb-IoT features a Maximum Coupling Loss of 164 dB, which is 30 dB higher than that of GSM. This allows Nb-IoT to achieve enhanced coverage, even in rural areas. The increased coverage is due, among other factors, to the low-order modulation used in Nb-IoT [9]. Although Nb-IoT can be used for indoor scenarios, the power consumption increases when the signal quality deteriorates [3].

The number of supported devices per cell varies depending on the location and the quality of the coverage enhancement, although the specification limit is 52547 devices per cell when the communication is evenly distributed over a day [23].

2.2.2 LTE-M

LTE-M is also developed by the 3GPP, but focuses on a higher data transmission rate. LTE-M builds on the LTE network with the goal of manufacturing low-cost radio modules and accommodating a high number of nodes per cell. LTE-M uses a channel bandwidth of 1.08 MHz and supports only in-band deployment [27].

LTE-M also builds on DRX modes to enhance battery life. The sleep duration is divided into I-DRX and C-DRX. When using LTE-M, C-DRX allows sleep times of up to 10.24 s, while I-DRX extends this limit to up to 43.69 minutes [7].

The main difference in comparison to Nb-IoT is the performance of LTE-M. LTE-M can achieve speeds of up to 384 Kbps in the downlink and 1 Mbps in the uplink. The latency is around 50–100 ms, which allows for more time-critical use cases [3]. However, this speed comes with the drawback of higher power consumption, usually leading to a shorter battery life than that of Nb-IoT [22].

It features a Maximum Coupling Loss of 156 dB, which is still significantly better than GSM [18].

3 Comparison

Choosing the right technology stack for an IoT application can be challenging, as many parameters influence the decision.

LoRaWAN and DSME-LoRa offer a wide range of configuration properties, which allow for detailed adaptation to the use case. In contrast, cellular technologies like LTE-M and Nb-IoT must fit into an existing infrastructure, which is usually shared. This introduces several limitations.

A device that only sends data and therefore falls into LoRaWAN Class A is able to turn on its radio whenever data needs to be transmitted [26]. These intervals can be chosen flexibly by the device. When using Class B or C, the radio must be turned on periodically or even continuously. However, this comes with the benefit of being able to receive data with much lower latency. DSME-LoRa-powered devices need to adhere to superframes, which limits the potential duty cycle [2]. As the duration of a super frame is still configurable, the setup remains relatively flexible.

LTE-M and Nb-IoT applications can choose from various eDRX cycle times. These cycle times are given by the standard, thus reducing flexibility.

The possible range and coverage of LoRaWAN and DSME-LoRa is limited by the LoRa technology. In rural areas, the range is limited to a few kilometers [15]. LTE-M and Nb-IoT rely on a provided infrastructure which is usually available in most parts of the country or even an entire region. As Nb-IoT uses a slower and more robust modulation, it features a slightly better range, which is mostly relevant for use cases in which sensors and devices are placed inside buildings.

Taking a look at energy consumption and thus potential battery life, technologies that allow longer duty cycles have an advantage. While LoRaWAN is based on LoRa, which is optimized for low-energy IoT use cases, cellular technologies must fit into or alongside existing technologies [26]. When comparing the energy consumption, LoRaWAN therefore has an advantage over DSME-LoRa. Comparing the energy consumption of Nb-IoT and LTE-M is difficult, as it depends on specific details such as the distance to the next cellular cell, specific chip, etc. In general, the range is roughly comparable; however, Nb-IoT seems to have an advantage [22]. Both technologies can achieve battery-powered lifetimes of up to 10 years.

Comparing all technologies together get's even more difficult, as a comparable setup is needed to get comparable results. In general it can be said that LoRaWAN is the most efficient technology, followed by Nb-IoT and LTE-M afterwards [3]. DSME-LoRa has no data basis that would allow a valid comparison with these other technologies. For this, further research would be needed.

The following table shows how the technologies can be compared.

Technology	**Band Type**	**Transmission Speed**	**Energy Efficiency**
LoRaWAN	Unlicensed	0.3 kbps to 50 kbps	High
DSME-LoRa	Unlicensed	5.5 kbps	
Nb-IoT	Licensed	20 kbps uplink, 200 kbps downlink	Medium
LTE-M	Licensed	1 Mbps uplink, 384 kbps downlink	Low

Table 3.1: Comparison of LPWAN Technologies

In general, the set of possible technologies heavily depends on the use case. For example, an application that should track moving objects across a country will likely exceed the coverage of LoRa-based systems. In these cases, technologies relying on licensed frequencies and managed infrastructure are a good alternative. LTE-M and Nb-IoT rely on cellular networks and are therefore good candidates in these cases. Both LTE-M and Nb-IoT have their eligibility, as they target different application types with different transmission speeds, latencies, and transmission ranges.

Nb-IoT is optimized for small sensors that report small amounts of data. This also includes the ability to tolerate delays of up to 10 seconds. LTE-M is a valid option for sensors that require lower latencies in the range of 50–100 ms [3]. While both technologies can achieve a long battery life, the energy consumption of Nb-IoT is usually lower than that of LTE-M [22]. One reason for this is that DRX times in Nb-IoT can be longer. In addition to lower energy consumption, Nb-IoT features a more robust modulation, which allows for better coverage. This can be important when working in rural areas or placing sensors inside buildings. Use cases that allow the use of Nb-IoT should therefore take advantage of this technology when possible. However, in scenarios where the signal is poor, LTE-M can achieve better battery range, as the repetitions in Nb-IoT can consume a lot of power [3]. LTE-M can be a good fit when the latency of Nb-IoT is not sufficient or a higher transmission speed is needed. This includes possible use cases that involve voice transmissions.

4 Conclusion

This paper took a look into current technologies for LPWANs for IoT use cases. Comparing these technologies is really dependent on the scenario for which the technology is utilized. The paper has provided a detailed comparison of the LPWAN technologies LoRaWAN, DSME-LoRa, Nb-IoT and LTE-M.

LoRaWAN is working in an unlicensed frequency band and can require self-managed infrastructure. This is a potential overhead. However, the benefit of this is, that the technology is very energy efficient and flexible. In addition, no monthly fee per device needs to be paid to an internet service provider. DSME-LoRa adds features on top of LoRaWAN which is a benefit for applications that require an inter-device connection. When only relying on inter-device connection central infrastructure such as gateways can be removed. However the positive effect is heavily dependant on the use case. This is due to the limited sleeping ability of the devices.

In comparison to LoRaWAN and DSME-LoRa, Nb-IoT and LTE-M use licensed frequencies and are usually in a need of an internet service provider. This allows to focus on the development of the device itself, without needing to worry about the infrastructure. However, this comes with the price of dealing with data plans and sim cards to access the network, which produces additional costs per device. While Nb-IoT is the solution for devices which send low amounts of data with a latency of up to 10 seconds, LTE-M is the technology that can be used when Nb-IoT is not usable due to it's limitations.

This paper also showed that a detailed evaluation for each use case is necessary in order to find a good solution.

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