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Evaluation of LPWAN technology for Smart City

Hussein Mroue[1], Guillaume Andrieux[1], Eduardo Motta Cruz[1], Gilles Rouyer[2]

[1]Polytech Nantes IETR laboratory La Roche sur Yon, France
[2]SPIE City Networks Saint Herblain, France

Abstract—In this paper, we explore technologies for low power wide area networks (LPWAN) serving the Internet of Things (IoT). These networks are ded-icated to long-range and low-speed communication to ensure a good autonomy up to 10 years and a budget link up to tens of kilometers. The performance of two LPWA technologies is investigated, where the well known LoRa and Sigfox technologies are evaluated according to their sensitivity to the interference and the impact of the spreading spectrum technique on the receptor sensitivity. Numerical results are presented and discussed.

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I. Introduction

Today, we are going to live the Internet of Things (IoT) era, where objects become more and more communicative and need to be connected to disseminate the information they hold. The IDATE [1] announces 80 billion connected objects for 2020. Their aim is to evolve in the years to come and spread in all sectors. These objects could be devices, automata, sensors present in our houses, our workplaces and also in public places. They can transmit information of type, temperature, humidity, the state of a door (open or closed), the parking place (occupied or vacant), and a multitude of other information such a type of connected object will be explained in details in this paper by highliting the possible uses areas..However, the connection of these objects to the Internet network that we know requires a compatible and scalable infrastructure

capable of absorbing the exponential evolution of the connected objects. It therefore raises a technical problem that will be investigated.

The standardization bodies then quickly pushed the search towards infrastructures with wireless access network taking into account the technical specificities of the connected objects. There is now a multitude of radios technology capable of supporting connected objects but are they all capable of responding to the specificities imposed by the IOT? We will describe the existing solutions by focusing on the Low Power Wide Area Network (LPWAN) which is the solution of low-energy wireless links. LoRa and Sigfox, LPWAN's key players, will be presented and confronted as well as other players positioned on LPWAN solutions such as the 3GPP for LTE-M.

This paper deals the specificities of deployment and implementation of the end-to-end interconnection of the LPWAN system, taking into account the connected object itself, the radio infrastructure (Or access network), interconnect gateways, cloud, LPWAN backbone. Moreover, a study of the physical layer for SIGFOX and LoRa and we propose a model to know which technology is more sensitive to the interference. Then, we discuss the role of spread spectrum on the sensitivity of the receptors.

II. LPWAN : LOW POWER WIDE AREA NETWORK

A. Principles of LPWAN

LPWAN has been proposed to be the solution to the Internet of objects being supported by most media-driven technologies such as LoRa, SigFox and LTE-M. This technology allows the sending and receiving of messages of very small sizes, over very long ranges up to 40km. The major advantage of this technology is that the equipment set up in its network is very inexpensive and does not consume much energy[2]. LPWAN technology is perfectly suited to connect equipment that needs to send small amounts of data over a long range while maintaining their autonomy. Some IoT applications may only transmit small amounts of information, such as a parking parking sensor, which transmits only when there is a change in state (vehicle detected yes or no). The low energy consumption of such a device makes it possible to carry out this task with the least cost and little energy consumed.

LPWAN is often used when other wireless networks, such as Bluetooth-BLE and to a lesser extent Wi-Fi and ZigBee, are not suitable for long-range performance. As well as M2M cellular networks are expensive, consume a lot of energies, and are expensive with regard to hardware and services. In order to identify the specifications and benefits of this technology, here is a brief comparison of current technologies:

- GSM networks, 3G, 4G, 5G
- ZigBee (home automation technology)
- Bluetooth, BLE, Wifi

B. Emerging LPWAN Solutions

The LPWAN wireless network has emerged in recent years. The precursors of this LPWAN technology are today SigFox, Lora and LTE-M, they will be detailed more in this sector.

1) Sigfox Network: SigFox is a French company founded in 2009 [3] whose goal is to build wireless chains to connect energy-saving appliances, such as electricity or water meters, alarm systems, Which must be continuously lit and emit small amounts of data. Sigfox has set up proprietary technology that enables M2M communication using the industrial, scientific and medical ISM radio band which uses the 868MHz frequency in Europe and 902MHz in the United States. This technology uses a broadband signal that passes freely through solid objects called "Ultra NarrowBand" and requires very little power. The network is based on a one-hop star topology and requires an access network connection from a mobile operator to carry the generated traffic. The signal can also be used to easily cover large areas and reach underground objects. Sigfox has partnered with a number of LPWAN industry companies such as Texas Instruments, Silicon Labs and STMicroelectronics[4]. Although the ISM radio band allows for bidirectional communication, Sigfox supports only uplink applications limited to 15 bytes of traffic at a time and an average of 10 messages per day. On the technical side, SigFox is a connection hierarchy using signals in the Ultra Narrow Band (UNB) for the M2M system [5], this band allows to send signals to long ranges. The emitted signal can be inserted anywhere, even in enclosed areas. SigFox is present in a very wide area of coverage in the world. This company has a cloud system for its web interface as well as the management of its devices (API Access Point Interface) and data configuration. The company offers a secure, responsive and efficient network with low throughput, but can support a wide range of products and sensors. The emission absorption for a SigFox modem can vary from 20 mA to 70 mA and its use is negligible when it is stagnant. The transmission power can be adjusted up to 14 dBm. The antenna radiation power should not exceed 25 mW. In the SIGFOX network, communication is two-way, meaning that devices send and receive data from a cloud platform.

On this network, objects can send up to 140 messages of sizes equal to 12 bytes per day. This functionality is implemented as a polling, for which the object remains the leader, it avoids to remain permanently connected and allows him to ask the information system if there is information to download. This correspondence serves to dispose of a considerable time of autonomy in order to save energy from the batteries. Objects exchange and share data and commands. In this case, we are talking about connected objects that are not very sophisticated such as coffee machines and the electricity meter. SigFox technology is easily incorporated into connected objects thanks to its miniature modem which allows the object to exchange information and data on the SigFox network. The data frames are transmitted over the SIGFOX network via antennas and then received by the proprietary server in the SigFox Cloud[6]. This frames are directly retransmitted in a secure way thanks to the HTTPS protocol to the client server which can appropriate them on its software applications and then allows the use of the data to ensure that the appropriate services are used, namely that the information sent Are difficult to decrypt in themselves. SigFox's personal data protection system seems impenetrable, but it is different for customers thanks to the IP level security between the Gateway and the Cloud, as shown in the figure 1: The reliability of the information

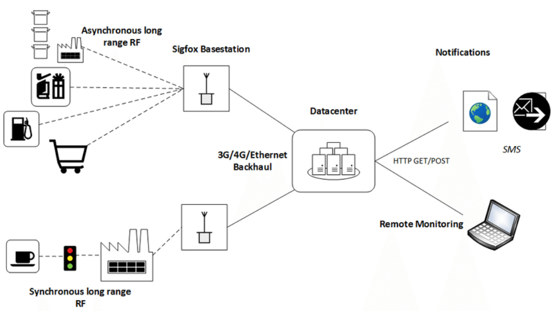

Figure 1. Sigfox Network Architecture

sent over the network as well as the security of exchanges between the connected objects are ensured in the SIGFOX chain despite the use of the licensed frequency bands which are also exploited by other companies. The risk of interference does not exist between different companies operating the same frequency band in view of the new emission techniques developed in recent years. The waterproofing is therefore ensured in this context. The entire network is well protected against jamming. Only Device vendors are eligible to understand the nature and quality of the information exchanged between the computer sensor and the object itself. In other words, Sigfox has good access control over its network. Moreover, it is essential and very important to choose the location of the sensor because, like any radio signal, there may be a reception problem facing a thick concrete wall or a metallic surface.

2) LoRa Network: The creation of the Lora Alliance[7] was announced at the CES in 2015. It is a consortium aiming at stripping a competing offer from Sigfox. This Open Source (OS) open system, based on LoRa technology, is certified by the French-based company Cycleo in 2012. Today, the alliance comprises 127 members including French players such as Bouygues Telecom, Actility and Sagecomm. The LoRa Alliance is an open, non-profit association of members who are confident that the Internet of objects is the future of the communications world. It has been launched by industry leaders whose mission is to standardize the networks (LPWAN) that are deployed worldwide to enable Internet (IoT), machine-to- machine(M2M), smart city and industrial applications. Alliance members will cooperate in the global success of the LoRa protocol (LoraWan), sharing knowledge and experience to ensure interoperability among operators in a single open global standard. LoraWan is a network specification (LPWAN) for wireless connected objects. LoraWan targets the main Internet requirements of objects such as secure two-way communication, mobility and location services. The LoraWan specification provides seamless interoperability between smart objects without the need for complex local installations and gives the user, developer and enterprise the freedom to deploy the IoT network. It's open technology. This means that any company can create its own LoRa network and then exploit it, having purchased the necessary chips and gateways for network operation. LoRa is the designation attributed to the technology that relies on spread spectrum modulation of the LoraWan protocol. The 3G and 4G cellular mobile networks are based on a communication protocol known by the abbreviation IP (Internet Protocol) whereas LORA itself is based on its own LoraWan protocol [8]. This technology is accessible (Open Source), allowing any company to design its own Lora network and market it. To set it up, it is necessary to have an antenna connected to the Internet by means of a WIFI, Ethernet or 3G connection or via a base station broadcasting at the frequency of 868MHz (band used in Europe). The coverage capacity for a Lora network is approximately 20Km in rural areas and up to 2Km in urban areas. The flow rate varies from 0.3 to 50 kbps and adapts with the power of transmission mechanically according to the need of the objects in order to optimize the bandwidth and to conserve as much as possible the use of the energy. The technology is not free, each component LoRa must pay royalties to the company Sem Tech, originally LoRa, to benefit from its use. The architecture of the LoraWan network is generally presented in a star-shaped star topology in which the gateways are a transparent bridge connecting messages between the sensors and a central network server in the back end[9]. The gateways are connected to the network server via standard IP connections, while the sensors use wireless communication to one or more gateways. All communications from the sensors are generally bidirectional, but they also support operation such as multicast, allowing software upgrade on the AIR interface or mass message distribution to reduce the communication time on air. The communication between the sensors and the gateways is distributed over different frequency channels and data rates.

Selecting the data rate is a compromise between the communication range and the length of the message. Using Spread Spectrum Technology, communications with different data rates do not

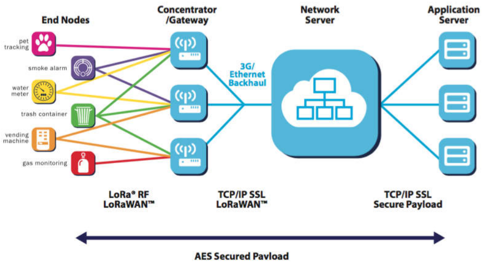

Figure 2. LoRa Network Architecture

interfere with each other, and create a set of virtual channels that increase the gateway's capacity. LoraWan data rates range from 0.3 kbps to 50 kbps. To maximize the battery life of the sensors and the overall network capacity, the LoraWan network server individually manages the data rate and RF output for each terminal device by means of an adaptive data rate scheme (ADR Adaptive Data Rate).

3) LTE-M: The historical ecosystem of cellular networks stands in the face of SIGFOX and LORA. To do this, the 3GPP is studying the specifications to evolve the LTE technology so that it can respond to LPWAN networks Sigfox and Lora. This action will help mobile operators to evolve their existing networks to the IoT-compatible network called LTEM[10]. As most of the time, the standardization phase is a slow process that brings together equipment manufacturers and operators to unify their know-how and compete. Major telecom leaders such as NOKIA and ERICSSON [11] support this combination of 3GPP. LTE-M is the abbreviation for LTE Cat-M1 or Long Term Evolution (4G), of category M1. This technology allows IoT devices to connect directly to a 4G network, without going through a gateway. The strengths of this technology are price, battery life and the low cost of service for access to the LTE network. This is not expensive because the devices can connect to the 4G network with much less expensive chips to manufacture, these chips operate in half-duplex mode and on a very narrow bandwidth. There are two types of modes that allow the batteries to keep a long life, the first is known as "Deep Sleep", PSM Power Save Mode as well as a receive mode (EDRX Extended Discontinious Reception), the sensors are periodically awakened while they are connected. The cost of the LTE-M network access service is very negligible, because LTE-M sensors need a bit rate of about 100 kbps, which means that the 4G network will never be congested. The carriers (Backhauling Network) can offer service plans similar to the old pricing of 2G M2M technology and 4G prices. Below is a table showing the specifications of this technology:

Deployment	In the LTE band
range(max coupling loss)	156 dB ; $\geq 13Km$
Downlink	OFDMA, Bandwidth 15 Khz, Turbo code, 16QAM, 1RX (Half-Duplex)
Uplink	SC-FDMA, Bandwidth 15 Khz, Turbo code, 16QAM
Bandwidth	1.08 MHZ
Bit Rate (UL/DL)	1 Mbps for UL and DL
Duplex	FD and HD (Type B), FDD and TDD
Battery Life (Modes)	PSM (Power Save Mode) and eDRX (Extended Discontinuous Reception)
Power	23 dBm, 20 dBm

Table I. SPECIFICATIONS OF LTE-M

IoT technologies and M2M communications [12] are growing rapidly, LTE, the 4th generation cellular technology known as the long-term Evolution, is well placed to carry a lot of traffic for machine-to-machine communications and this is problematic because the LTE is capable of carrying data at very high bit rates. To solve this problem, an extension of LTE, often called LTE-M, has been developed for M2M LTE communications. New categories launched in the Releases 13 of the 3GPP [13] standards known as LTE Cat 1.4MHz and LTE Cat 200kHz (NB-IoT Narrow-Band-IoT). There are several features for M2M LTE applications cite3gpp1 as well as requirements that make cellular networks viable:

- Wide range of equipment: Any LTE-M system must be able to support a wide variety of different types of equipment. This can be smart meters, vending machines and medical devices as well as safety machines. These different systems have many diverse requirements, so any LTE-M system can be flexible.
- Low cost to purchase equipment: LTE-M must provide the benefits of a cellular system, but at low cost.
- Long Battery Life: Many M2M sensors should be left unattended for long periods in areas where there is no power supply. Maintaining batteries is expensive. This means that the LTE-M system must be capable of draining very little battery and that the battery can last up to 10 years.
- Coverage: LTE-M applications will need to operate in various locations and not just where reception is good. They must operate inside buildings, often in places where there is little access and where reception may be deficient. Therefore, LTE-M must be able to operate under all conditions.
- Large volumes - Low flow rates: The LTE-M must be structured in such a way that

the networks can accommodate a large number of connected devices and require only small amounts of data to be transported at very low data rates.

Some updates are introduced in 3GPP Rel 12 to meet LTEM requirements. These updates require that the cost of an M2M modem should be about 40-50% cheaper compared to a conventional LTE device (Smartphone), making them similar to those of EGPRS (Network Enhancement GSM in the transport of packets). To meet these requirements, a new category of equipment has been implemented under the category LTE category 0. These categories define the overall capabilities of the device so that the base station remains able to communicate properly in the network. In a LTE-M network, M2M devices are low cost while having a limited capacity:

- Antennas: the ability to have a single receiving antenna, unlike other categories of devices
- Transport block size: There is a restriction on the size of the transport block. These low-cost LTE-M devices are allowed to send or receive up to 1000 bits of unicast data per subframe. This reduces the maximum data rate to 1 Mbps in the uplink and downlink
- Duplex: Semi-duplex FDDs are supported as an optional feature, which reduces costs by eliminating the RF switches and duplexers needed for full performance modems. This also means that it is not necessary to have a second phase-locked loop for the frequency conversion, although with only one PLL the switching times between reception and transmission are longer.

Many features are proposed and prepared in the 3GPP Release 13 standards, in terms of capabilities. We cite below the possibilities for improvement :

- Reduce bandwidth to 1.4 MHz for uplink and downlink
- Reduce transmission power to 20dBm
- Reduce support for downstream transmission modes
- Release requirements that require high levels of processing, such as downlink modulation.

There is an additional improvement for LTE-M under this Release 13 with a reduced bandwidth option of 200kHz in the uplink and downlink, often referred to as Narrow Band or Narrow-Band LTE-M [14]. By reducing the bandwidth and also the data rate, an additional simplification of the modem can be obtained. The category is called Cat 200kHz. It is possible to compare different categories for LTE-M systems.

Capacity	Rel8 CAT4	Rel12 CAT0	Rel13 CAT1.4MHz	Rel13 CAT200KHz
Downlink (Mbps)	150	1	1	0.2
Uplink (Mbps)	50	1	1	0.144
Antennas	2	1	1	1
Duplex mode	Full	Half	Half	Half
Bandwidth (MHz)	20	20	1.4	0.2
Power (dBm)	23	23	20	23

Table II. COMPARAISON OF LTE-M CATEGORIES

III. SIGFOX AND LoRa PHYSICAL LAYER

A. SIGFOX

This technology uses BPSK as a modulation scheme for uplink. It uses the ultra narrow band with a bit rate is of 100 bps.

B. LoRa

LoRa uses a multitude type of modulation scheme (FSK, OOK,..). It uses the wideband technology based on spread spectrum. Using a scalable bandwidth (B) of 125 KHz or 250 KHz in Europe and in addition of that, the bandwidth of 500 KHz is using in US. A variable spreading factor (SF) can be chosen as function of received SNR. SF adapts the length of a symbol, but also specifies the number of bits per symbol. So, changing the spreading factor results in a variable bit rate between 366 bps for the highest spreading factor (12) and 48 Kbps for the lowest spreading factor (6) as shown in Eq.1

$$R_b = \frac{B}{2^{SF}} \times SF \tag{1}$$

IV. SYSTEM MODEL

The system model used for measurements and comparison is based on an AWGN channel model with only thermal noise with a noise temperature of 25 °C. In addition, we assume a distance dependent path loss with constant attenuation alpha = 2.5 dB. For this model, the 2 base stations will be positioned at the same location and we assume the height of the base station at 100m and the nodes are mobile in an interval of [-200 m, 200 m] (Fig 3) . Here, only the uplink is considered, as the data in sensor networks generally flows in this direction. Finally, the transmitter of the mobile device sends the maximum power allowed in most ISM bands with a power of 25 mW (14 dBm). So we will calculate the signal-to- noise plus interference ratio (SINR) to know which technology is more robust to interference.

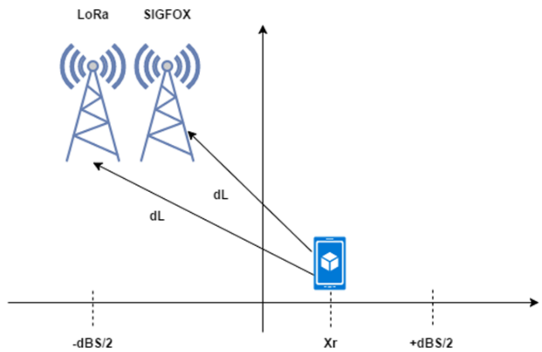

Figure 3. Proposal model

$$SINR = \frac{P_r}{I + N} \quad (2)$$

where P_r is the received power, I is the interference and N is the noise.
After this we will study the influence of spreading spectrum on the sensitivity of the LoRa receiver by comparing the sensitivity of receiver uses the FSK modulation and another uses the FSk modulation with direct modulation chirp spread spectrum DM CSS . The sensitivity is calculated according to the following equation :

$$SRX = SNR \times K \times T_0 \times B \times NF \quad (3)$$

where k is the Boltzmann constant, T is the temperature at the input of the receiver, B is the bandwidth of receiver and NF is the noise figure. For LoRa, there is a gain of the processing belonging to the spreading spectrum where the parasitic signals are also reduced by the receiver process gain [15]:

$$G_p = 10log_{10}(\frac{R_c}{R_b}) \qquad (dB) \quad (4)$$

where R_c is the chip-rate (Chips/second) and R_b is the bit-rate (bits/second)

V. Results

The reason for having a ratio of 1000 is due to the fact that SIGFOX uses an ultra narrow band with a bandwidth of 100 Hz, but LoRa uses a wideband with a bandwidth equal to 125 KHz. In terms of robustness to interference, LoRa is more robust than SIGFOX. To date, there are not enough connected objects deployed running via LPWAN networks, for this reason the probability of interference is very low. Moreover, in the future, we must return to this model of simulation of interference with the densification of connected objects.

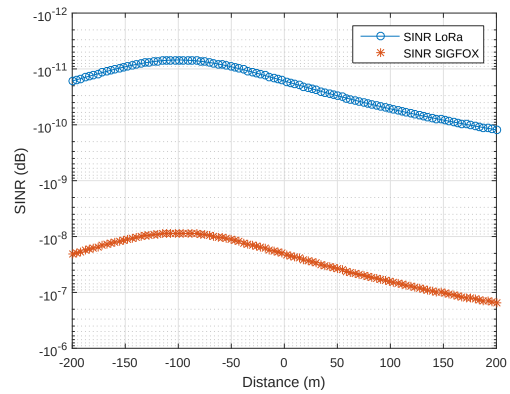

Figure 4. Measurement of SINR

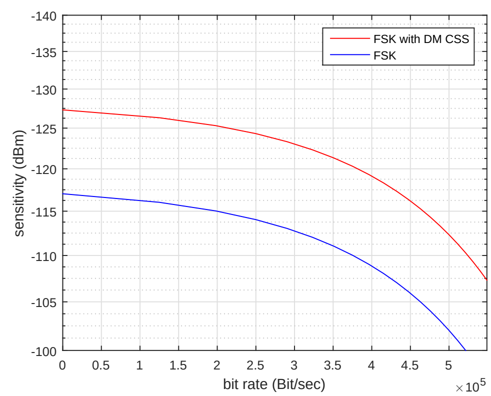

Figure 5. Comparaison of Sensetivity

The sensitivity is affected by the increase of the bit rate for the two cases FSK with DM CSS and traditional FSK. On the other hand, the sensitivity of FSK with DM CSS exceeds the sensitivity of traditional FSK by 10 dB. This difference remains almost the same on the bit rate considered from $0.1 \times 10^5 bit/sec$ up to $6 \times 10^5 bit/sec$.

VI. Conclusion

In this paper, we explored the existing technologies for LPWAN serving the Internet of Things. These technologies have characteristics like autonomy up to 10 years and carried up to tens of kilometers. In addition, we survey 3 LPWA technologies, ultra-narrow band solutions by Sigfox, wideband solutions by LoRa technology based on chirp spread spectrum (CSS) and LTE-M technology by 3GPP. Sigfox and LoRa were surveyed in terms of physical layer. We then proceeded to explore which of these two technologies is the more sensitive to interference. The role of spreading spectrum has be illustrated to improves the sensitivity of the receptor.

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