

Comparative study of the cost of implementing wireless technologies for IoT and M2M for the last mile: A case study

Estudio comparativo de costo de implementación de tecnologías inalámbricas para IoT y M2M para la última milla: Un estudio de caso

Fernando Ulloa-Vásquez¹ Dante Carrizo^{2*} Luis García-Santander³

Recibido 06 de enero de 2022, aceptado 17 de mayo de 2022

Received: January 06, 2022 Accepted: May 17, 2022

ABSTRACT

The need to determine which wireless IoT technology, currently available on the market, will be able to support a sizeable simultaneous load of information, types of electrical emergency alarms, required bandwidths, delays-latency, area coverage, and economic cost to serve areas of 600 square kilometers of surface and several users of around two million homes. This article compares Sigfox, LoRa, NB-IoT, and WiMAX technologies as possible solutions for last-mile communications. For this purpose, a network of hundreds of smart meters has been simulated, each transmitting different types of information. In conclusion, it has been obtained that, for a context with the priority of alarms and a large amount of information transport in massive last-mile communications in smart grids and for electrical metering traffic, it is highly recommended that it be done through WiMAX, which in the evaluation shows the best result compared to the other technologies.

Keywords: Sigfox, LoRa, NB-IoT, WiMAX, Smart grid.

RESUMEN

Existe la necesidad de determinar qué tecnología inalámbrica para aplicaciones IoT y M2M, disponible actualmente en el mercado, podrá soportar la gran carga simultanea de información, tipos de alarmas de emergencias eléctricas, anchos de banda requeridos, retardos-latencia, así también como la cobertura y el costo económico para atender áreas de 600 kilómetros cuadrados de superficie y un número de usuarios de alrededor de dos millones de hogares. En este artículo se presenta un análisis comparativo de tecnologías Sigfox, LoRa, NB-IoT y WiMAX como posibles soluciones para comunicaciones de la última milla. Para esto, se ha simulado una red de cientos de medidores inteligentes, cada uno de los cuales transmite diferentes tipos de información. Como conclusión se ha obtenido que, para un contexto con prioridad de alarmas y gran transporte de información en comunicaciones masivas de última milla en redes inteligentes y para tráfico de medición eléctrica, es muy recomendable que se realice a través de WiMAX, la que en la evaluación muestra el mejor resultado frente a las otras tecnologías.

Palabras clave: Sigfox, LoRa, NB-IoT, WiMAX, Smart grid.

¹ Universidad Tecnológica Metropolitana. Dpto. de Electricidad. Santiago, Chile. E-mail: fulloa@utem.cl

² Universidad de Atacama. Dpto. de Ing. Informática y Ciencias de la Computación. Copiapó, Chile. E-mail: dante.carrizo@uda.cl

³ Universidad de Concepción. Dpto. Ing. Eléctrica. Concepción, Chile. E-mail: luis.garcia@udec.cl

* Autor de correspondencia: dante.carrizo@uda.cl

INTRODUCTION

The Standard IEEE 2030-2011 provides understanding, definitions, and guidance for designing and implementing smart grid components and end-use applications for both legacy and future infrastructures. According to [1], the smart grid comprises seven domains, the so-called bulk generation, transmission, distribution, customer, markets, control and operations, and providers domains service, where inter-operating electric power and communications entities and their interfaces are defined. Among these, to achieve the smartness of the grid, the Std. IEEE 2030 describes the most relevant communication features with a telecommunication infrastructure model. Communication requirements are different and domain-dependent. In this work, we are interested in last-mile communications: communications that happen between the household customer and control and operations domains.

Last-mile communications occur between several households and one distribution access point, forming a neighborhood area network (NAN), one smart meter per household communicates periodically with an application server via a gateway and through the Internet, as shown in Figure 1. In it, n_i (stands for “node”) is a subscriber station (SS) provided with customer premises equipment (CPE). The nodes communicate to a base station (BS) which serves as a gateway (GW), providing the link between the field and the cloud.

The Std. IEEE 2030 envisages several parameters for the last-mile communications. As a case study, we will assume a scenario in which each smart meter transmits every 1 to 5 minutes 202 bytes of

metered electric data and occasionally some alarm with a high-level latency (~ 1 s) [2].

The main idea of this work is to evaluate from the information available in the public literature what technologies could match the requirements.

One can think naturally that last-mile communications could be accomplished through WiFi via the installed DSL and cable modem technologies in most parts of the globe. However, others IoT and non-IoT communication solutions could get into the equation. This scenario is especially true in countries where DSL and cable modem have not a complete market penetration, and WiMAX has appeared as an alternative as broadband access technology [3, 4], or where a dedicated solution is preferred.

Besides the multi-purpose broadband access technologies available today, Low Power Wide Area Networks (LPWAN) are currently the most popular low cost, long battery lifetime, and long-range communication technology for specific IoT applications. According to [5], three LPWAN technologies are gathering the most attention, the so-called Sigfox, LoRa, and NB-IoT. Beside these LPWAN technologies, WiMAX, a technology conceived for wireless broadband internet access, as said above, is gaining great interest in the context of smart grid last-mile communications as well [6, 7, 8, 9]. While Sigfox, LoRa, and NB-IoT are naturally conceived for IoT applications, and WiMAX is not, we will focus on these four technologies.

This article presents a comparative review of these four long-range communication technologies in terms of their suitability as a last-mile access network

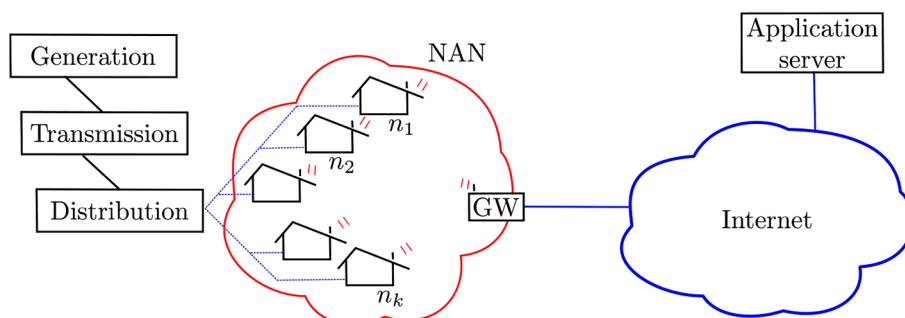


Figure 1. Typical access network topology.

for the smart grid, assuming that their physical deployment will be made from scratch.

The rest of this article is organized as follows: in the next section a brief overview of the four technology candidates for the smart grid last-mile communications is given. After that, the suitability of each technology as possible solution for the smart grid last-mile communications is assessed. Then, the implementation cost for each technology is analyzed, and a case study for the city of Santiago de Chile, is included. Finally, we give some conclusions.

BACKGROUND

Sigfox was developed in 2010 in Toulouse, France. It is both a company and an LPWAN network operator currently in 31 countries around the globe and still under roll-out in others [5]. Sigfox uses a proprietary patented Ultra Narrow Band (UNB) physical layer with a Differential Binary Phase Shift Keying (DBPSK) modulation at a very low rate of 100 bps. Sigfox CPEs use Random Frequency and Time Division Multiple Access (RFTDMA) for transmission, accessing the wireless medium without any contention-based protocol (it can be thought of as an ALOHA-based protocol) [10]. Sigfox utilizes the unlicensed sub-GHz Industrial, Scientific, and Medical (ISM) bands of 868 MHz in Europe, 915 MHz in North America, and 433 MHz in Asia. The ISM band regulations order two spectrum sharing mechanisms: duty cycle or listen before talking. Sigfox uses 1% duty cycle spectrum sharing method.

LoRa is a patented spread-spectrum technology [11]. It uses a protocol called LoRaWAN standardized by the LoRa-Alliance in 2015. LoRa is currently deployed in 42 countries and is still under roll-out in other countries [5]. It uses Chirp Spread-spectrum (CSS) modulation with six spreading factors (SF7 to SF12) for adapting data rate to the range, allowing data rates between 300 bps and 50 Kbps, with a maximum payload of 243 bytes [5, 12] (in [13], however, a maximum data rate of 22 kbps for LoRa is stated). LoRa, as Sigfox, operates in the unlicensed sub-GHz band. In Europe, it can operate in the entire 868 MHz ISM band but has three mandatory channels: 868.10, 868.30, and 868.50 MHz [12]. The LoRa MAC layer defines three classes of nodes: A, B, and C, permitting different types of services.

Class C allows the lowest latency at the expense of increased power consumption [10].

NB-IoT is a technology that evolved from LTE with some of its functionalities but reduced to the minimum and adapted as required for IoT applications. NB-IoT is standardized by the 3rd Generation Partnership Project (3GPP). Its protocol was published in Release 13 of 3GPP in June 2016, and it is currently under test in Europe. NB-IoT operates with a carrier bandwidth of 180 kHz, achieving a maximum rate of 200 Kbs [5], with a maximum payload of 1600 bytes according to [5], or 128 bytes according to [12]. NB-IoT can be deployed within an LTE carrier, in the LTE guard band, or as a standalone [5, 12].

WiMAX (Worldwide Interoperability for Microwave Access) is a Broadband Wireless Access (BWA) technology based on the IEEE 802.16 standard. WiMAX emerged as an alternative technology to dispute a space in a market currently dominated by cable modems and DSL systems [4]. The medium access protocol of WiMAX is connection-oriented, supporting five types of Quality of Service (QoS) scheduling services, namely: Unsolicited Grant Service (UGS), real-time Polling Service (rtPS), extended real-time Polling Service (ertPS), non-real-time Polling Service (nrtPS), and Best Effort (BE). Each of these scheduling services supports a specific class of applications [14]. WiMAX uses adaptive BPSK, QPSK, 16-QAM, and 64 QAM modulation over Orthogonal Frequency-Division Multiplexing (OFDM), achieving different bit rates depending on the link's physical characteristics. WiMAX can operate in different bands as the 3.5 GHz and the 2.5 GHz licensed bands and the 5.8 GHz ISM band, among others. The WiMAX's performance is strongly dependent on the band used: the lowest the band, the better the coverage. In a system with 7 MHz channels, WiMAX can provide a maximum rate from less than 3 Mbps to above 25 Mbps [4].

In Table 1, we have summarized some of the main features of the four technologies.

DEVELOPMENT OF STUDY

Electric metering applications require more frequent communication, lower latency, more power consumption, and higher data rate than typical low

Table 1. Main features of SigFox, LoRa, NB-IoT and WiMAX technologies.

Technology Feature				
Modulation	BPSK	Adaptive CSS	QPSK	Adaptive OFDM
Bandwidth	100 Hz	250 / 125 KHz	200 KHz	1.25 - 20MHz
Maximum bit rate	100 bps	50 Kbps	200 Kbps	70 Mbps
Maximum payload length	12 bytes	243 bytes	128 bytes	elastic
Range	10 Km (urban); 40 Km (rural)	5 Km (urban); 20 Km (rural)	1 Km (urban); 10 Km (rural)	50 Km (fixed); 5/15 km (mobile)

power and narrowband IoT applications [5]. Electric metering applications usually require reporting periods for meter readings between 1 and 5 min, with a latency of ~1 min and latency for unexpected alarms less than 1 sec [7].

For the purpose of our analysis, we have assumed a network of several smart meters (CPEs), each of those transmitting two types of information: a periodic packet of 202 bytes of electric metered data every minute, with a latency non greater than 1 minute, and some alarm at some unexpected moment, with a maximum latency of 1 second.

Given that in Sigfox, a CPE transmits the same packet at a rate of 100 bps three times using three different carriers, and each packet is made of 24 Bytes (with a payload of 12 Bytes), 5.76 seconds are required for transmitting each packet [10]. Therefore, Sigfox CPEs are constrained to transmit only during 36 seconds per hour [12], or equivalently six packets per hour, making this technology unsuitable for electric metering applications.

Furthermore, in [5] LoRa Class C, and NB-IoT are suitable for electric metering applications. In [7], a traffic priority model for smart grid last-mile communications for electric metering traffic WiMAX was successfully evaluated.

From 4 technologies already discussed for smart electric metering network access in terms of reporting period of meter readings (1-5 min), latency for meter readings (~1 min), and latency for alarms (≤ 1 sec), Sigfox does not meet with these requirements.

In Table 2, we present an approximate Capital Expenditure (CAPEX) for BS deployment and CPE and an estimated Operational Expenditure (OPEX) associated with a year's spectrum license fee for each technology [5, 4, 15].

Data in Table 2 were estimated using the information from [5] and [4]. We also suppose that costs in [5] and [4] are referring to France and Finland, respectively. Nevertheless, for our analysis, we will assume that they are referring to Western Europe in general and

Table 2. Approximate capital expenditure (CAPEX).

Technology	Spectrum cost	BS Deployment cost	CPE cost
	Free	>4,000 €	<2 €
	Free	>1,100 €	3-5 €
	>500 M€/MHz	>15,000 €	>20 €
	uncertain	~15,000 €	~34 €

that they can be used as a first approximation for South America.

In Table 2, BS deployment cost includes the BS equipment cost and its installation. Conversely, the CPE installation cost is not included in Table 2. Although for Sigfox, LoRa, and NB-IoT, the CPE installation cost could be negligible, WiMAX outdoor CPE installation could be 100 € [4].

There is a significant discrepancy in the literature regarding the WiMAX spectrum license fee. For example, in [15], a yearly payment of 1,250,000 € for the spectrum license (unspecific bandwidth) is stated, but in [4], it is declared a spectrum license fee of 25,000€ for 8×7 MHz. Accordingly, due to this inconsistency, we will not include the spectrum cost in the case study we will discuss next.

CASE STUDY

This Section is presented the estimated CAPEX for a simulated implementation of LoRa, NB-IoT, and WiMAX technologies in the city of Santiago de Chile, Chile. For this purpose, we have assumed the existence of 2,238,179 inhabited houses in Santiago, according to the Instituto Nacional de Estadísticas (INE, <https://www.ine.cl/>), uniformly distributed in a total area of 641 km².

Table 3 is presented the coverage and capacity of each technology as assumed in our analysis. The average cell range r indicated in Table 3 is for an urban scenario and was taken from [5, 4]. The average number of users (CPEs) per cell was estimated for a reporting period of 1 min, an average payload of 202 Bytes, and a link utilization factor of 80% ($\rho = 0.8$). The utilization factor was estimated using the following bit rates: 22 kbps for LoRa [13], 200 kps for NB-IoT [5], and 3 Mbps for WiMAX [4]. An estimated latency of ~1 min was obtained using an M/M/1/k-PS pure sharing queueing model.

The cell areas in Table 3 were calculated using the formula of equation (1):

$$A = 6r^2/\sqrt{3} \quad (1)$$

In Figure 2, the cell areas per technology are plotted for comparative purposes.

Considering the cell area and the average number of CPEs per cell given in Table 3, we have estimated the number of cells required for complete coverage of the city of Santiago de Chile-based on both criteria: cell capacity and cell coverage. In Table 4, we have summarized the resulting number of cells.

Finally, adopting the costs of BS deployment and CPEs for western Europe indicated in Table 2 in this case, we have obtained the approximated implementation cost for each technology for the city of Santiago de Chile, which are shown in Table 5.

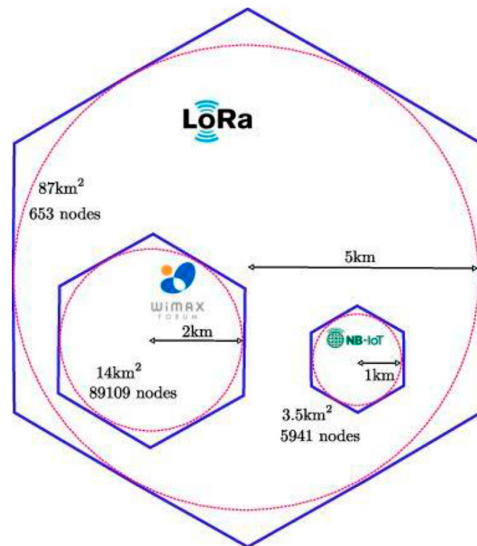


Figure 2. Graphical cell size comparison for the three technologies under revision.

Table 3. Coverage and capacity of each technology are assumed in our analysis.

	LoRa	NB-IoT	WiMAX FORUM
Average cell range r	5 km	1 km	2 km
Cell area $A = 6r^2/\sqrt{3}$	87 km ²	3.5 km ²	14 km ²
Average number of CPEs per cell	653	5,941	89,109

Table 4. The number of cells calculated based on capacity and coverage per technology.

			
Number of cells based on capacity	3,425	377	26
Number of cells based on coverage	8	185	47

Table 5. Implementation cost by technology for Santiago de Chile.

Technology	CPE cost	Qty.	BS cost	Qty.	Total cost
	4 €	2,238,179	1,100 €	3,425	12,720,216 €
	20 €	2,238,179	15,000 €	377	50,418,580 €
	34 €	2,238,179	15,000 €	47	76,803,086 €

From Table 5 can be seen that while WiMAX has the highest deployment cost, LoRa has the cheapest one.

CONCLUSIONS

This paper has described comparatively Sigfox, LoRa, NB-IoT, and WiMAX technologies as possible solutions for the smart grid last-mile communications. It was found that while LoRa, NB-IoT, and WiMAX comply with the communication requirements given in the Std. IEEE 2030-2011, Sigfox does not. Furthermore, an implementation cost case study was also presented for the city of Santiago de Chile, and from the corresponding simulation we have found that Lora technology has the cheapest deployment cost from the corresponding simulation.

Therefore, Sigfox CPEs must transmit for only 36 seconds per hour, or what equates to six packets per hour, making this technology unsuitable for electrical metering applications. On the other hand, LoRa Class C and NB-IoT are suitable for electrical metering applications and economically suitable for a large-scale network (cheaper).

One of the limitations of the study is the computational calculation equipment since to simulate an entire city with an amount of relevant binary traffic

greater than 3.5 million homes: a computational parallelism center is required to be able to have more precise ranges and to be able to evaluate the installed network capacity (optical, copper-coaxial and radio-frequency networks).

The study evidenced the suitability of the four technologies discussed for access to the smart electrical metering network in terms of meter readings reporting period and latency for meter readings and alarms. This evidence is relevant when designing an IoT network that requires responding to an Electric SmartGrid system and a Smart city with energy efficiency and with less impact and smaller carbon footprint.

As future work, it is intended to simulate on the same network structure with wireless IoT technologies the measurements of water and gas consumption and monitoring different types of alarms, be it firefighters emergency or human beings that require some type of panic button.

REFERENCIAS

- [1] IEEE. "IEEE Guide for Smart Grid Interoperability of Energy Technology and Information Technology Operation with

- the Electric Power System (EPS), End-Use Applications, and Loads". IEEE Std 2030-2011. Vol. 9, pp. 1-126. 2011.
- [2] F. Ulloa-Vasquez, L. Garcia-Santander, D. Carrizo and C. Hurtado. "Towards a Home Energy Management Model through a Coordinator of Smart Sockets". Latvian Journal of Physics and Technical Sciences. Vol. 55, pp. 35-43. 2018. DOI: 10.2478/lpts-2018-0027.
- [3] D. Pareit, B. Lannoo, I. Moerman and P. Demeester. "The History of WiMAX: A Complete Survey of the Evolution in Certification and Standardization for IEEE 802.16 and WiMAX". IEEE Communications Surveys Tutorials. Vol. 14, pp. 1183-1211. 2012. DOI: 10.1109/SURV.2011.091511.00129.
- [4] T. Smura. "Competitive potential of WiMAX in the broadband access market: a technoeconomic analysis". 16th European Regional Conference. Porto, Portugal. September 4-6, 2005.
- [5] K. Mekki, E. Bajic, F. Chaxel and F. Meyer. "Overview of Cellular LPWAN Technologies for IoT Deployment: Sigfox, LoRaWAN, and NB-IoT". 2018 IEEE International Conference on Pervasive Computing and Communications Workshops (PerCom Workshops), pp. 197-202. Athens, Greece. March 19-23, 2018. DOI: 10.1109/PERCOMW.2018.8480255.
- [6] R.H. Khan and K. Mahata. "Random access performance of a WiMAX network for M2M communications in the Smart Grid". 2014 IEEE International Conference on Smart Grid Communications (SmartGridComm), pp. 362-367. Venice, Italy. November 3-6, 2014. DOI: 10.1109/SmartGridComm.2014.7007673.
- [7] F. Gómez-Cuba, R. Asorey-Cacheda and F. J. González-Castaño. "WiMAX for Smart Grid last-mile communications: TOS traffic mapping and performance assessment". 2012 3rd IEEE PES Innovative Smart Grid Technologies Europe (ISGT Europe), pp. 1-8. Berlin, Germany. 2012. DOI: 10.1109/ISGTEurope.2012.6465616.
- [8] R.H. Khan and J.Y. Khan. "A heterogeneous WiMAX-WLAN network for AMI communications in the Smart Grid". 2012 IEEE Third International Conference on Smart Grid Communications (Smart GridComm), pp. 710-715. Tainan, Taiwan. November 5-8, 2012. DOI: 10.1109/SmartGridComm.2012.6486070.
- [9] R.H. Khan and J.Y. Khan. "Wide area PMU communication over a WiMAX network in the smart grid". 2012 IEEE Third International Conference on Smart Grid Communications (SmartGridComm), pp. 187-192. Tainan, Taiwan. November 5-8, 2012. DOI: 10.1109/SmartGridComm.2012.6485981.
- [10] G. Ferré and E. P. Simon. "An introduction to Sigfox and LoRa PHY and MAC layers". HAL. 2018. URL: <https://hal.archives-ouvertes.fr/hal-01774080>
- [11] O.B. A Seller and Nicolas Sornin. "Low power long-range transmitter". Patent US20140219329A1. USA. 2014. URL: <https://patentimages.storage.googleapis.com/e5/ba/d1/61695e9bfe0b15/US20140219329A1.pdf>
- [12] B. Vejlgaard, M. Lauridsen, H. Nguyen, I. Z. Kovacs, P. Mogensen and M. Sorensen. "Coverage and Capacity Analysis of Sigfox, LoRa, GPRS, and NB-IoT". 2017 IEEE 85th Vehicular Technology Conference (VTC Spring), pp. 1-5. Sydney, Australia. June 4-7, 2017. DOI: 10.1109/VTCSpring.2017.8108666.
- [13] H. Mroue, A. Nasser, S. Hamrioui, B. Parrein, E. Motta-Cruz and G. Rouyer. "MAC layer-based evaluation of IoT technologies: LoRa, SigFox and NB-IoT". 2018 IEEE Middle East and North Africa Communications Conference (MENACOMM), pp. 1-5. Jounieh, Lebanon. April 18-20, 2018. DOI: 10.1109/MENACOMM.2018.8371016.
- [14] A. Bacioccola, C. Cicconetti, A. Erta and E. Mingozzi. "Throughput Analysis of Best Effort Traffic in IEEE 802.16/WiMAX". In Proceedings 13th European Wireless 2007. Paris, France. 2007.
- [15] K.-C. Chen and J. R. B. de Marca. "Mobile WiMAX". Wiley-IEEE Press. First edition. ISBN-13: 978-0470519417. 2008.