Evaluation of IoT gateways for developing communities: Smart Maputo

Salomão David[†]
Marconi Lab
International Centre for Theoretical Physics
Trieste, Italy
Salomao.david@gmail.com

Ermanno Pietrosimoli
Marconi Lab
International Centre for Theoretical Physics
Trieste, Italy
mzennaro@ictp.it

Marco Zennaro
Marconi Lab
International Centre for Theoretical Physics
Trieste, Italy
ermanno@ictp.it

ABSTRACT

Connectivity is the essential requirement for a smart city, and traditional techniques are too costly to connect a great number of devices which might be served with lower data throughput, but require longer ranges to accommodate the requirements of IoT. Although cellular technologies and Wi-Fi have proved an enormous success in connecting billions of users to the Internet, they are not the best to connect objects with limited throughput requirements, limited processing power and low power consumption requirements. These needs are being addressed by Low Power Wide Area Networks (LPWAN) that use unlicensed frequencies and by newer cellular protocols aimed at lowering the cost of the devices by limiting their bandwidth capabilities in the licensed bands. This paper discusses these technologies and the choices made to provide an IoT infrastructure for the city of Maputo in Mozambique.

CCS CONCEPTS

• CCS → Networks → Network performance evaluation → Network performance analysis

KEYWORDS

LoRa, SigFox, Low-Power Wide-Area Network

ACM Reference format:

Salomão David. 2019. Evaluation of IoT Gateways for developing communities: Smart Maputo. In *Proceedings of ICTD'19 (ICTD'19). ACM, Amedabad, India, 4 pages.* https://doi.org/10.1145/3287098.3287142

1 Introduction

The Communications Regulatory Authority of Mozambique – INCM in collaboration with the International Centre for Theoretical Physics (ICTP) and the Centro de Informática da Universidade Eduardo Mondlane (CIUEM) are deploying an Internet of Things (IoT) network in Maputo, Mozambique. The initiative aims to collect data about utility management, environment monitoring, city public transportation, road safety, social security and agriculture. Given the specific requirements of developing countries, the infrastructure must be capable to sustain reliable connectivity with a variety of technologies, including the TV White Spaces network previously installed in Maputo, be as efficient as possible in terms of energy consumption, require minimum maintenance and sustainable operating costs, and allow for harmonious scaling after initial installation.

Developing countries host more than 70% of SIM cards in the world, providing extensive GPRS services that can be used for data communication [1]. However, this requires payment of monthly fees for each SIM deployed, which can be acceptable for some applications requiring high throughput and reliability, but does not lend itself to the realisation of the IoT (Internet of Things) paradigm, in which a myriad of devices must be connected, many of which can make do with a few bytes per day [2]. The past decade has seen an extensive development of methods and techniques to provide IoT connectivity, ushering the lead technology bringing changes in our daily lives, moving interactions between people at a virtual level in several contexts spanning from professional life to social relationships. IoT can convey real-time data while also provide access to historical data [3] facilitating inference and knowledge based responses.

This scenario promises a future in which digital and physical things can be connected, share information and enable a whole new class of applications and services. As IoT is built over the Internet, communication and security problems of the Internet will also show up in IoT, aggravated by the limitations imposed in connecting devices with limited processing power, memory, and communication capabilities.

For developing countries, IoT promises integrated systems capable of providing timely information collected and accessible at a lower cost. It is no surprise that the strongest advocates for IoT and smart city are big business (e.g., IBM, Microsoft, Oracle, SAP) pushing forward the adoption of their technologies, seeking deregulation, privatization and more open economies [4].

IoT is appealing for smart cities as it prioritizes data capture and analysis as means for underpinning evidence-informed policy

ICTD'19, January, 2019, Ahmedabad, India

https://doi.org/10.1145/3287098.3287142

development, enacting new modes of technocratic governance, empowering citizens through open, transparent information and economic innovation.

Alternatives to cellular networks are being widely deployed. These low-power wide area networks (LPWAN) are designed to increase the communication range by lowering the data rate while offering low-power consumption. They operate in unlicensed bands in the UHF (Ultra High Frequency) spectrum, thus allowing them to be deployed by small organizations, independent from the commercial communication server providers, who must pay significant fees for the use of licensed spectrum and consequently pass this cost to their customers.

LPWAN are low-power-wide-area networks; a new type of radio technology used for wireless data communication in different IoT applications and M2M solutions. Their key features are long range of communication, low bit rate and small power consumption.

The most successful LPWAN technologies are SigFox and LoRa, both based on proprietary technologies, but differentiating in the modulation techniques employed to increase the power budget and with two different market strategies.

Satellites have been considered as a potential solution to cover IoT devices in remote areas (e.g., deserts, oceans, and forests) [5], but existing solutions are presently too expensive. Several offers that should make satellites affordable for IoT are being touted but none is currently available.

This paper provides a review of the leading technologies for IoT. It also provides motivations for the selection of LoRaWAN in Mozambique as the technology to use in the ISM sub 1- GHz band. The lower frequency can span longer distances and penetrate walls better than the 2.4 GHz used in Wi-Fi.

2 Research methodology

This study aims to assess the state of IoT solutions by examining the published information about communication technologies used in IoT. It will help in understanding the trends, implications and serve as a systematic reference for the burgeoning LPWAN literature. Various journals and conference proceedings were examined, but Master theses and doctoral dissertations were excluded. Particular attention was devoted to the gateway’s capabilities such as bandwidth, frequency of operation, sensitivity, link budget and type of security.

3 IoT in a nutshell

The term IoT is broadly used in different research disciplines with no standard definition or understanding of what encompasses [6], [7]. Researchers agree in attributing the origin of IoT to the work of the Auto-ID Labs at the Massachusetts Institute of Technology (MIT) on networked radio-frequency identification (RFID) [7].

From an economic perspective, IoT is related to “machine-to-machine” (M2M) communication technologies, were a series of networked “smart devices” are equipped with microchips, sensors, and wireless communication capabilities [8].

The International Telecommunication Unit (ITU) defines IoT as “a global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies” [9]. A literature review on IoT, by Madakam et al., defined IoT as a “technological revolution that represents the future of computing and communications as it evolves technically in some important fields such as wireless sensors to nanotechnology” [10]. The lack of a universal definition does not hinder the growth of the discipline since there is an accepted fact that everyday objects can be equipped with identification, networking, sensing and processing capabilities that will allow them to communicate over the internet to achieve some useful objective. IoT is maturing and continues to be an exciting concept; current estimates suggest that the IoT could grow into a market worth \$7.1 trillion by 2020 [11].

4 IoT short and long-range connectivity

The paradigm of IoT refers to a network of interconnected things, to build a global infrastructure relating physical and virtual objects. IoT has been categorized as an opportunistic network, a concept originated from the research outcomes in pervasive computing, social computing, and mobile social networking [2].

For short range applications, typically less than 100 m in range, technologies like Radio Frequency ID, (RFID), near-field communication (NFC), ZigBee and Bluetooth low energy (BLE) have been successfully deployed.

However, there is need to cover longer distances and also to provide services deep inside buildings for which a greater power budget than the one provided by the short-range technologies is required. As mentioned, cellular solutions can satisfy the range and penetration requirements but at a cost that precludes its application in many areas of interest.

Many IoT applications will require connectivity between end devices. Peer-to-peer (P2P) connectivity can be supported depending on the latency requirements and the type of information exchanged. The demand for mobility will require higher reliability even in harsh operating environment. Hence link adaptation protocols, modulation, interference mitigation, device collaboration or redundant path need to be improved. Often the device to device communication must be conducted through a Gateway since star-based technologies do not support direct end-device to end-device communication.

The threat posed by LPWAN has been addressed by The 3rd Generation Partnership Project (3GPP), the organization behind the standardization of cellular systems, with several new standards aimed at providing long range by reducing the transmission bandwidth, like LTE-M, specifically aimed at M2M communication, and NB-IoT which reduces the occupied bandwidth to 200 kHz in order to increase coverage, consequently reducing the throughput and also the power consumption. Since they use license protected bands, they are not affected by interference from other users of the spectrum and are not subject to air time limits. In order to allow sharing of the spectrum in unlicensed bands, the regulators impose constraints in the maximum airtime usable by a given device in a particular frequency, which is the major drawback of LPWAN solutions.

NB-IoT networks using licensed spectrum, are being deployed in Europe as they provide higher coverage even indoors and in dense urban areas. For low-speed applications there are not many differences between NB-IoT, LoRa and SigFox as all of them can send a few hundreds of bytes at long distances but in some applications having the ability to use a faster modulation rate implies that NB-IoT is better than LoRa and LoRa is better than Sigfox.

The long range, low cost and energy efficient wireless communication in IoT introduces new possibilities for information and communications technologies for development (ICTD). Apart from the already known fields for which IoT is used in smart cities, LPWANs can become the enablers for new applications in other fields, such as agriculture, healthcare, general communication and sustainable livelihoods.

SigFox, launched in 2009, was the first LPWAN technology addressing the IoT market, and has been growing since then. SigFox has been deployed in France, Spain, Italy, the Netherlands and South Africa. It uses Ultra-Narrow Band (UNB) Binary Phase-Shift Keying modulation at 100 bps, providing high resilience to interference and anti-jamming capabilities. When it comes to security there is little information since the technology is proprietary. The traffic is mostly uplink, from the end-device to the Gateway, although downlink traffic is also possible.

LoRa uses a proprietary spread spectrum chirp modulation technology owned by Semtech which has licensed several manufacturers to manufacture the chips which are incorporated in a number of modules from different vendors.

LoRaWAN is an open standard protocol controlled by an international organization called the LoRa Alliance (https://lora-alliance.org/about-lorawan) that uses the LoRa physical layer but adds all the required features to provide a complete network solution with an end to end encryption for security. LoRaWAN architecture, as shown in Figure 1, is based on a number of end-devices that connect to one or more LoRaWAN gateways using the LoRaWAN protocol, which add extra bytes to each transmitted LoRa packet to provide the additional features of security, identification and addressing. The LoRaWAN gateways connect to a Network server using any available IP network, like Ethernet, WiFi, ADSL, TVWS, Satellite, etc. The Network server in turn connects to a number of Application Servers, specific to each service required, again using the IP connectivity. Both Network and Application servers can either be local or remotely located in the cloud.

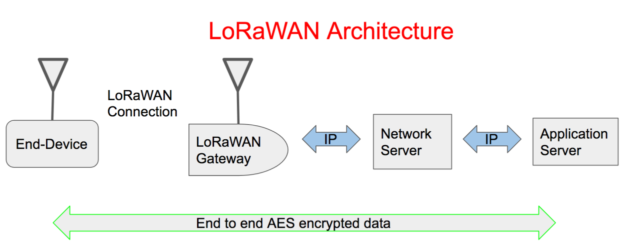

Figure 1. LoRaWAN Architecture

The end-device has typically a microcontroller that manages the LoRa transceiver and some connected sensor or actuator. GPS receivers are often on board to provide tracking capabilities. By leveraging the deep slip capabilities, the battery of the module can last years. The packets sent by the end-device can be decoded by any LoRaWAN Gateway within reach. After finishing transmission and waiting for the target propagation time, the end-device will open two receiving windows in sequence to accept messages from the Gateway. Always-on reception could be implemented but it is discouraged, so the majority of the traffic is uplink, although downlink packets from the Gateway to the end-node are allowed for control messages and for acknowledgments.

The LoRaWAN gateway is normally grid powered, so as to be able to forward end-devices messages to the network server in realtime, but it can also be solar powered given that its modest power requirements. There are a number of vendors that offer commercial gateways, and also a few open solutions based on LoRa modules, concentrators and some embedded computer like the Raspberry Pi. A LoRaWAN Gateway should listen simultaneously to 8 frequencies in every spreading factor. Traffic is protected end-to-end by the Advanced Encryption Standard (AES).

Objects	NB-IoT	LoRa	Sigfox
Bandwidth	200 kHz	from 8 to 500 kHz	100 Hz
Frequency, MHz	Licensed	433/868/915	868/915
Maximum Sensitivity	-150 dBm	-148 dBm	-142 dBm
ISM	Licensed	Yes	Yes
Link budget	160 dB	152 dB	152 dB
Security	Yes	Yes	Yes

Table 1 Capabilities of IoT gateways

5 LoRa and SigFox coverage

The power budget in dB of a wireless link is the difference between the effective transmitted power and the receiver sensitivity and it is directly proportional to the range. Since the maximum transmitting power in unlicensed bands is limited by the local regulations in each country, the maximum range achievable is determined by the receiver sensitivity **S**, defined as the minimum received power required to reliably decode the signal. Typically, S corresponds to the minimum received signal level required to maintain the PER (packet error rate) below 1%. The lower the **S**, the greater the range and the better the penetration inside a building. S is proportional to three factors: a) the thermal noise KTB, where K is the Boltzmann constant, T is temperature in kelvin and B is bandwidth in Hz, b) the noise factor NF of the receiver, which depends on the quality of the receiver construction and varies between 3 and 10 dB, and c) the signal to noise power ratio SNR required to correctly demodulate the signal, which depends on the type of modulation employed.

At ambient temperature, the receiver sensitivity in dBm is given by:

$$S = -174 + 10\ Log_{10}(B) + NF + SNR \quad (1)$$

To obtain the minimum S, SigFox and LoRa have used two different strategies: SigFox uses an ultra-narrow bandwidth of 100 Hz and a modulation technique that requires about 10 dB of SNR, so assuming NF = 5 will yield:

$$S = -174 + 10\ Log_{10}(100) + 5 + 10 = -139\ dBm \quad (2)$$

LoRa has chosen a spread spectrum technique, using a chirp modulation that increases the transmission bandwidth much beyond that needed for the baseband the data, employing a variable spreading factor SF which determines the actual transmission time, but allows LoRa to demodulate signals with an SNR as low as -20 dB (100 times lower power than the ambient noise). So, for a typical LoRa signal with a bandwidth of 125 kHz, SF of 12, NF = 5 dB and a SNR = -20 we get:

$$S = -174 + 10Log_{10}(125000) + 5 - 20 = -138\ dBm \quad (3)$$

We can see that in terms of range both approaches are comparable, but LoRa is much more flexible since it can use different orthogonal spreading factors, which do not interfere with each other despite using the same carrier frequency. It can also provide much higher data rates than the meagre 100 bits/s that SigFox offers.

6 Smart Maputo

Smart Maputo is a project which builds the foundation for a smart technology-driven city. It involves many functions: research, technology transfer, product development and technological innovation as a hotbed to create innovative solutions from the community to the community [13]. At the initial stage, Smart Maputo aims to create a network for collecting and organizing IoT data and develop solutions capable of providing information on the quality and performance of urban services (energy, transportation, air quality). The Smart Maputo network is comprised of 10 Gateways, operating in unlicensed bands, capable of receiving data from many very low power consumption sensors deployed in public transportation buses and also in some fixed locations. Figure 2 shows the location of the Gateways, selected on the basis of coverage and the existence of TV-White Spaces backhaul. The initial project aims to collect information about the location of public transportation buses, water usage and weather information.

Figure 2. Smart Maputo gateway deployment

The LoRa technology was selected since it can be installed independently from any commercial IoT provider, while SigFox services must be purchased from commercial providers. The fair sharing of the unlicensed spectrum is accomplished by respecting a maximum duty cycle of 1% at each of the 8 frequencies of operation which limits the volume of traffic. The whole system is quite affordable: end-devices can be bought from 40 USD while Gateways range from 250 USD to several thousand, depending on added features. An open Initiative, The Things Network (TTN) (https://www.thethingsnetwork.org/) will provide free network and application servers that allow anyone to test the waters of LoRaWAN.

Furthermore, the maintenance costs are limited to the eventual replacement of the low-cost LoRaWAN equipment installed and those associated with the extra traffic in the already present IP network connecting the gateways to the network servers.

The evaluation process of the 868 MHz spectrum in Maputo, revealed that the SigFox network operated by SqwidNet in South Africa bleeds into Maputo as shown in Figure 3. SigFox does not sell gateways, instead, it licenses a network operator that offers the service for a fee that must be paid for each end-node deployed.

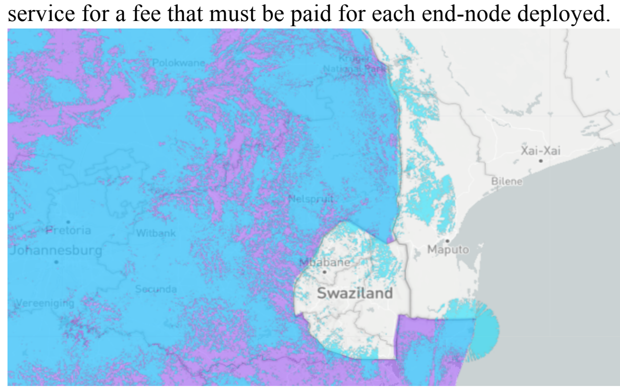

Figure 3. Bleed from SigFox Network (source - SigFox)

6 Conclusion

This work analyzed some LPWAN technologies with respect to range, modulation, coverage, frequency used, independence from commercial server providers and cost. When comparing the transmission rates NB-IoT is better than LoRa and LoRa is better than Sigfox.

In terms of range SigFox and LoRa are comparable, but LoRa is much more flexible since it uses different spreading factors which are mutually orthogonal, small spreading factor offer greater throughput but lower range, while bigger spreading factors allow for better range at the expense of longer time on air and lower throughput

For the needs of Smart Maputo, LoRaWAN complies with the requirements of independence from commercial providers, lower operation expenses, and a good prospect for sustainability. SigFox license scheme imposes sustainability constraints. NB-IoT is not currently offered in Mozambique.

Once the 10 Gateways deployment in Maputo is completed, additional nodes can be deployed by any enthusiast which wishes to offer any new services leveraging the installed infrastructure. This should be a great opportunity for new business cases to be tested.

REFERENCES

[1] M. N. S. Miazi, Z. Erasmus, M. A. Razzaque, M. Zennaro, and A. Bagula, “Enabling the Internet of Things in developing countries: Opportunities and challenges,” 2016, pp. 564–569.
[2] B. Guo, Z. Yu, X. Zhou, and D. Zhang, “Opportunistic IoT: Exploring the social side of the internet of things,” in Computer Supported Cooperative Work in Design (CSCWD), 2012 IEEE 16th International Conference on, 2012, pp. 925–929.
[3] H. A. A. Al-Kashoash and A. H. Kemp, “Comparison of 6LoWPAN and LPWAN for the Internet of Things,” Aust. J. Electr. Electron. Eng., vol. 13, no. 4, pp. 268–274, 2016.
[4] R. Kitchin, “The real-time city? Big data and smart urbanism,” GeoJournal, vol. 79, pp. 1–14, Nov. 2013.
[5] Z. Qu, G. Zhang, H. Cao, and J. Xie, “LEO Satellite Constellation for Internet of Things,” IEEE Access, vol. 5, pp. 18391–18401, 2017.
[6] M. Centenaro, L. Vangelista, A. Zanella, and M. Zorzi, “Long-range communications in unlicensed bands: The rising stars in the IoT and smart city scenarios,” IEEE Wirel. Commun., vol. 23, no. 5, pp. 60–67, 2016.
[7] F. Wortmann and K. Flüchter, “Internet of things,” Bus. Inf. Syst. Eng., vol. 57, no. 3, pp. 221–224, 2015.
[8] A. Castillo and A. D. Thierer, “Projecting the growth and economic impact of the internet of things,” 2015.
[9] I.-T. S. Group, New ITU standards define the Internet of Things and provide the blueprints for its development. ITU, 2012.
[10] S. Madakam, R. Ramaswamy, and S. Tripathi, “Internet of Things (IoT): A literature review,” J. Comput. Commun., vol. 3, no. 5, p. 164, 2015.
[11] D. Lund, C. MacGillivray, V. Turner, and M. Morales, “Worldwide and regional internet of things (iot) 2014–2020 forecast: A virtuous circle of proven value and demand,” *Int. Data Corp. IDC Tech Rep*, vol. 1, 2014.
[12] D. Yim et al., “An experimental LoRa performance evaluation in tree farm,” in Sensors Applications Symposium (SAS), 2018 IEEE, 2018, pp. 1–6.
[13] N. Komninos and E. Sefertzi, “Intelligent cities: R&D offshoring, Web 2.0 product development and globalization of innovation systems,” Second Knowl. Cities Summit, 2009.
[14] N. Jovalekic, E. Pietrosemoli, M. Rainone and M.Zennaro, "Smart and Very Distant Objects" in Proceedings of MobiCom SMARTOBJECTS' 2017