Performance evaluation of LoraWan physical layer integration on IoT devices

Christos Bouras
Computer Technology Institute & Press "Diophantus", Computer Engineering and Informatics Dept., Univ. of Patras, Patras, Greece
bouras@cti.gr

Vasileios Kokkinos
Computer Technology Institute & Press "Diophantus", Computer Engineering and Informatics Dept., Univ. of Patras, Patras, Greece
kokkinos@cti.gr

Nikolaos Papachristos
Computer Engineering and Informatics Dept., Univ. of Patras
Patras, Greece
papachristosn@upatras.gr

***Abstract*— Due to the constant motion of wireless devices in the Internet of Things (IoT), current wireless networks cannot provide connectivity in each case using altering topolgoies, in comparison with ad hoc networks. LoraWan, as a Long Range Wide Area Network recommended by the LoRa Alliance, is an upcoming candidate for low power and long distance communication IoT environments and applications to different concepts such as tracking, healthcare agriculture. This IoT concept is gaining a rapid growth on the IoT market and is simultaneously improving our living environment. In this paper, we first briefly introduce LoRa as an efficient solution of physical layer integration on the IoT devices. We then conduct a performance evaluation taking into consideration values such as bit error rate, time on air transmission based on Signal to Noise Ratio (SNR) and Spreading Factors modifications for different bandwidth values.**

Keywords*— *Low power wide area networks; Internet of Things; LoraWan; Spreading Factors;

I. Introduction

Nowadays, the Internet of Things (IoT) interconnects a massive number of devices, e.g. machines, vehicles and sensors. It's a fact that the lack of sufficient Quality of Service (QoS) guarantees in real time smart applications, many times forces companies and organizations to embody adaptation schemes in order to work efficiently mainly in the area of IoT where the limitations on battery life and power are of the utmost importance.

Last years new technologies have being introduced in many IoT concepts enabling power efficient communication over long distances so as to solve power consumptions as well as coverage problems. There are many existed solutions such as Bluetooth, Z-Wave, ZigBee & Bluetooth which are relative candidates for wireless (short-range) networks. Also wireless local area networks (WLANs), HiperLAN, and cellular networks such as global system for mobile communications (GSM) and long-term evolution (LTE) even though they allow the wireless connection of the IoT devices in the network, they are usually of high cost, high energy consumption, high complexity and low reliability approaches [1].

This was the main reason that leads low-power-wide-area-neworks (LPWANs) in their recent development. LPWANs are almost the new candidates for IoT concepts, promising low power consumption, high energy efficiency, and high coverage capabilities up to 15km Line-of-Sight (LOS) [2][3].

In this paper, following the above approach and the fact that this technology has not yet attracted similar levels of attention from the academic and research community, we present a simulation of LoraWan in the area of IoT, that allows things communicate with their surroundings widely and collect or transmit information with low power consumption, exploiting LoraWan apabilities. Therefore; we compare LoraWan's spreading factors generated for a data transmission for different bandwidth values. Our goal is to provide connectivity for a variety of heterogeneous IoT devices scattered over a wide geographic area achieving the QoS in our smart environment. Such a requirement is defined by major applications integrated to LoraWan such as intelligent systems suitable for metering applications (medical alerts & metering, position localization for vulnerable groups of people and etc.). Especially in smart cities where a massive number of IoT devices will be deployed for several use cases, key challenges to enable a large-scale uptake of massive IoT such as device costs, battery life, scalability, latency and coverage are required [4].

The rest of this work is organized as follows: The next section introduces the LoraWan technology whereas Section III refers to the physical metrics of LoraWan. Section IV contains a reference of the most important IoT metrics, some of them used in our research study. Simulation scenarios and results are discussed in Section V. Section VI includes the usage of LoraWan on IoT systems and the last section analyses the conclusions and discusses the future work and remarks on the implemented system.

II. LoraWan Technology

LoRa operates in a non-licensed band below 1GHz for long range communication operations. The above technology is part of chirp spread spectrum modulation (CSS) and trades data rate for sensitivity within channel bandwidth. To this research study, several well-known standard developing organizations (SDOs) such as the European Telecommunications Standard Institute (ETSI), the Third Generation Partnership Project (3GPP), the Institute of Electrical and Electronics Engineers (IEEE), and the Internet Engineering Task Force (IETF) are developing products and IoT solutions to further extend the existed standards such as LORa™ Alliance [5].

Some of the most important products which have already integrated LoRa is SIGFOX which was founded in 2009. SIGFOX has developed a system using Upper sideband (USB) modulation where each base station can handle up to a million objects, with a coverage area of 30–50 km in rural areas and 3–10 km in urban areas. On the other hand Weightless, supports narrowband channels of 12.5 kHz, with Frequency Division and Time Division Multiple Access modes, adaptive data rate from 0.2 kbit/s to 100 kbit/s, time-synchronised aggregators, and low-cost highly energy efficient modulations; One technology mainly targeted to metering and SmartGrid applications and conversely to the other LPWAN solutions, working in the 2.4 GHz band is On-Ramp Wireless. The above technology works on long-range wireless links and under the most challenging RF environments.

III. Physical Differences

The difference between LoRa and LoraWan is that the first one is related to the physical layer in contrast with the first one which is responsible for the communication protocol. End-nodes in case of LoraWan, can use one or more Gateways (GWs) for their communication. Each different GW is responsible to pass the packet received from the end-node through single-hop LoRa to a network server (mainly cloud-based) by using cellular or Wi-Fi network connectivity. In LoraWan protocol an intelligent mechanism to filter duplicate packets from different GWs has been developed by sending temporarily ACKs to the different GWs, and pass the delivered packet to the cloud-application server. Because of the fact that the end-nodes may be moving or static in a topology there is no handover issues to be discovered GW to GW. This is a great feature making it a good candidate for IoT tracking applications used for location detection. Finally it also keeps the risk of radio signal perturbation low and allows less gain speed and redundancy. The spread spectrum provides orthogonal separation between signals by using a unique spreading factor to the individual signal so as to achieve a better data rate ratio. Inversely, when a device is far from the GW, radio signal perturbations may occur. So, we can transmit further but the speed is lower. The formula below shows the mathematical relation between chirp and symbol rate and the the required data rate for the transmission:

$$R_b = SF * \frac{1}{\left[\frac{2^{SF}}{BW}\right]} \; bits/s \quad (1)$$

where SF is the spreading factor and BW is the modulation bandwidth (Hz).

These spreading factors are used to adjust the radio signal speed depending on the distance. A LoRa symbol is composed of 2SF chirps, which covers the entire frequency band. The chirp rate in each case depends only on the bandwidth value as it is equal to the bandwidth (one chirp per second per Hertz or bandwidth). This has several consequences mainly on low power devices. This concept is very important as in IoT environments, the smart devices often encounter energy-related issues, especially when their battery life is a few hours. The suitable selection of the SF determines the communication range and the data rate of the physical IoT device to the central GW.

For the evaluation of a modulation technique, BER vs E_b/N_0 (Energy per bit to Noise density ratio) mathematical relationships are required. The general mathematical formula for BER calculation based on SNR values is given in the formula below:

$$E_b/N_0(dB) = SNR(dB) + 10\log\frac{BW}{R_b}\,(dB) \quad (2)$$

IV. LoRa in Terms of IoT Factors

LoraWan is an efficient as well as a secure transmission technology having transmission range from 1 km^2 in urban zones to 60 km^2 in rural or open space land. LoraWan uses an unlicensed spectrum with bandwidth values between 125 and 500 kHz. Table I shows the most important metrics and each value. In the current research study we take care of Bandwidth, modulation and spectrum of the LoraWan technology in terms of SF modifications.

TABLE I. Physical Metrics on LoraWan

Parameter	**LoraWan**
Spectrum	Unlicensed
Modulation	CSS
Bandwidth	125 – 500 kHz
Energy Efficiency	< 10 years battery life
Device Capacity	Depends on GW

TABLE II. IoT LoRa Simulation Metrics

Technology	**LoraWan**
Peak Current	32 mA
Sleep Current	1 mA
Spectrum Cost	Free
Network Cost	$100 – 1000/GW

LoraWan uses ALOHA protocol, which is asynchronous and gives the opportunity to embedded devices to sleep a short while they are idle. Following Table II, we can see the value of the currents for LoraWan technology. The table above shows that applications that don't need too many data for transmission should use LoRa as a service protocol. The cost of network installation varies from 100$ to 1000$ per GW, according to the needs of the topology for multiple GWs. In this current study we study the time-on-air data transmission of IoT device to a central GW for different SF values.

The LoRa modulation technique can be understood as a MFSK modulation on top of a Chirp Spread Spectrum (CSS) type. It uses different modulation Spreading Factors (SF) raging from SF7 to SF12. This mechanism provides resistance to interference and multipath fading. Thus, it is possible to adjust the modulation rate and the transmission power individually per node. A chirp encodes one symbol of information. If the SF is increased the package size will be reduced, resulting in a higher power over the channel and a longer communication distance [6].

V. Performance Evaluation

LoRa PHY, based on CSS modulation is capable of delivering low power, long range communications. The choice of the suitable SF for the transmission determines the communication range and the data rate. Table III shows our testbed simulation parameters used in matlab simulation of a LoraWan use case.

TABLE III. TESTBED SIMULATIONS

Parameter	LoraWan
Spreading Factor	7 to 12
Channel Bandwidth	125 – 500 kHz
Code Rate	4/5
Total Bits Transmitted	30000
Sampling Frequency	125000

In the physical layer LoRa includes 8 preamble symbols, 2 synchronization symbols and physical payload. Because of the fact that LoRa uses SF7 to SF12 spreading factors in this current research paper we will try to study the relation between Time and Frequency for the above spreading factors [7].

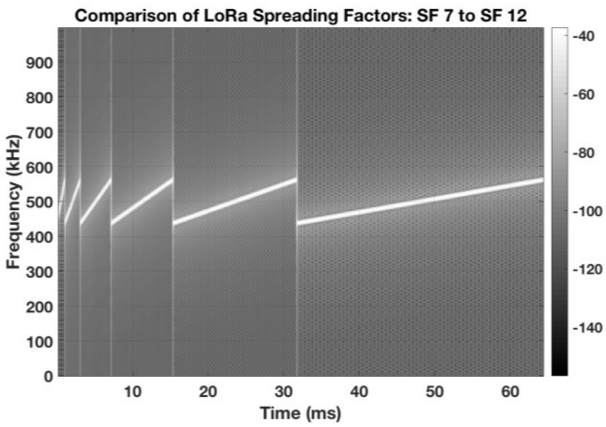

Fig. 1. SF generation using 125kHz BW.

LoRa uses three different bandwidth 125 kHz, 250 kHz and 500 kHz. Fig. 1 shows the difference on data rate and over-the-air time during signal transmission. From the experiments above we can extract that the higher the spreading factor is, the higher the over-the-air time achieved. By observing the diagram in Fig. 1, we can see that as long as the values of the spreading factors change from 7 to 12, the over-the-air time for transmission increases. The above is also perceived through the diagram, as the number of SF increases, the chart seems to stretch.

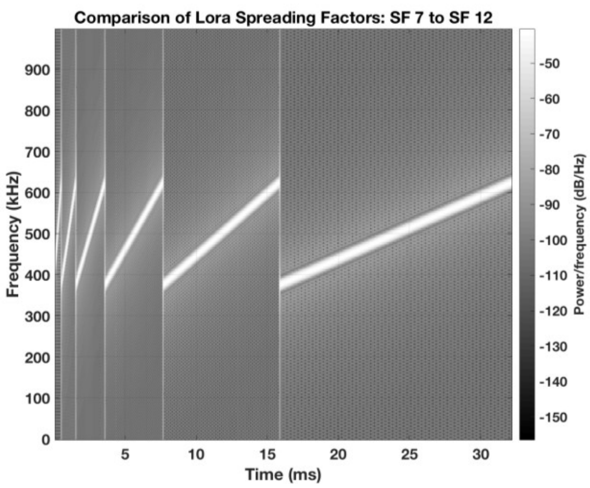

Fig. 2. SF generation using 250kHz BW.

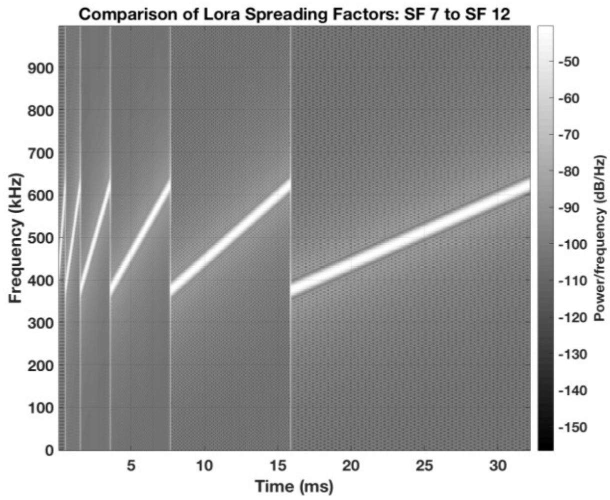

Fig. 3. SF generation using 500kHz BW.

By increasing the bandwidth value from 125kHZ to 250 kHZ and 500 kHZ respectively, we want to see the changes in transmission time and data rate. As can be seen from Fig. 2 and Fig. 3 respectively as the bandwidth increases, the data rate value increases according to the given formula above and the transmission time tends to decrease by approaching half the value every time. Regarding the physical significance of the above results, when an IoT device processing a message to the GW, extra processing gain is being achieved due to constant ramp chirp signal filtering. This is one case how high sensitivity is achieved in IoT devices for sensor networks, where sensors exchange packets with the server by using a low data rate and relatively long time intervals (e.g. transmit every hour or even days). As an inexpensive chip with a cheap crystal can achieve a very high sensitivity in data transmission. The above simulation experiments extend the pre-built simulation model of Sakshama Ghoslya on [8] from the perspective of the Internet of Things. The results of a use-case of 125kHZ SF analysis are presented in Fig. 4.

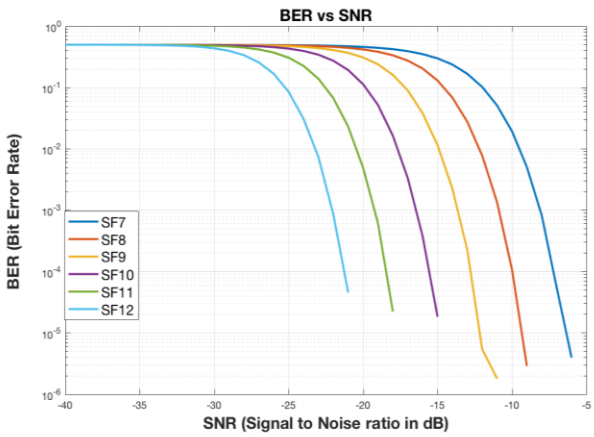

Fig. 4. BER vs SNR for different SF values.

In this experiment, we can see the changes in the bit error rate value as the spreading factors change from 7 to 12 throughout the transmission of 30.000 bits by also improving the SNR value. The initial value of SF=7 gives us a SNR of approximately -23dB and for SF = 12 an SNR = -6dB is obtained. The advantage of LoRa is that it is possible to adjust the transmission power and modulation rate in each different node of the topology individually. In general, a chirp encodes one symbol of information. If the SF is decreased the package will be increased giving the opportunity for long range transmission distance. Table IV presents the LoRa spreading factors for 125kHz bandwidth.

TABLE IV. LoRa Spreading Factors for 125kHz bandwidth

Spreading Factor	SNR (dB)	Bitrate (bit/s)
7	-7	5471
8	-9.5	3125
9	-12.5	1760
10	-15	979
11	-18	536
12	-22	294

The above example can improve the system performance if our IoT topology consists of many end nodes. General GW modules can support simultaneously 8 different channels communications [9][10]. The study of the other two cases of 250kHZ and 500 kHZ of bandwidth did not have any appreciable effect on our study as the number of bit error rate decreases significantly and approaches 0 at a similar rate in all different spreading factor cases. In other words that means that low-data rate applications can get much longer range using LoRa due to good receiver sensitivity making it an alternative candidate for priced radio technologies in the world of IoT.

VI. Usage of LoraWan in Healthcare IoT systems

LoraWan as wireless protocol is gaining ground to IoT concepts and production line objects. It's main characteristic is the ability to transmit data up to 15km in the line-of-site with the base station by choosing the suitable SF combined with the bandwidth of the IoT transmitter [11][12]. An other basic feature of this protocol is that do not need extra modules to extend the transmission by working as signal routers of the end nodes. For healthcare application such as identifying people in need of assistance, this is perfect because it not requires external power supply not (low-power consumption) in the fields, while the sensors on wearable devices on these people can run on battery power supply for days or months. For above reason LoraWan is able to provide indoor capacity and coverage for different IoT concepts. The above IoT healthcare ecosystem will be analyzed and discussed in our next research study.

VII. Conclusions and Future Work

Following our experimental study above, LoraWan is an ideal candidate as protocol integration in IoT applications. Our research approach shows that LoraWan QoS metrics measurement are feasible and can be used for lowpower with long range networks. Depending on the IoT device and its capabilities we can choose the best SF and BW regarding the battery of the device, reducing the transmission time, increasing the data rate and significantly reducing the bit error rate. The purpose of this study was to assist our knowledge in the development of models that will help us build IoT simulators and devices able to transmit data in scalable networks taking into account the power and battery life limitations of the IoT devices.

Future work in our approach is the study and implementation of a system that integrates the above technology for data transmission in the world of IoT application positioning. A LoRa simulator combined with various positioning algorithms such as GeoCAST, LAR, DREAM, GeoSpray and GeOpps will be studied to see the feasibility of the above technology and generated results in wearable IoT devices for positioning applications.

Acknowledgments

This research has been co-financed by the European Union and Greek national funds through the Operational Program Competitiveness, Entrepreneurship and Innovation, under the call RESEARCH - CREATE - INNOVATE (project title: WeSAR - Wearable based Search And Rescue system, project code: T1EDK-01520).

References

[1] R. Tadayoni, A. Henten and M. Falch, "Internet of Things — The battle of standards," 2017 Internet of Things Business Models, Users, and Networks, Copenhagen, 2017, pp. 1-7.

[2] Mischa Dohler, Nakamura Takehiro, Osseiran Afif, Monserrat Jose F., Queseth Olaf, Marsch Patrick (Eds.), 5G Mobile and Wireless Communications Technology, Cambridge University Press (2016), pp. 1-48 (Chapter 1–2)

[3] S. Andreev et al., "Understanding the IoT connectivity landscape: a contemporary M2M radio technology roadmap," in IEEE Communications Magazine, vol. 53, no. 9, September 2015pp. 32-40.

[4] Ericsson, Uen 284 23-3278, Cellular networks for massive IoT, Jan., 2016.Available:https://www.ericsson.com/res/docs/whitepapers/wp_iot.pdf

[5] Lora alliance. [Online]. Available: https://www.lora-alliance.org/

[6] LoRa Alliance, LPWA Technologies Unlock New IoT Market Potential, Machina Research, Nov, 2015. Available:https://www.lora-alliance.org/portals/0/documents/whitepapers/LoRa-Alliance-Whitepaper-LPWA-Technologies.pdf

[7] F. Cuomo, M. Campo, A. Caponi, G. Bianchi, G. Rossini and P. Pisani, "EXPLoRa: Extending the performance of LoRa by suitable spreading factor allocations," 2017 IEEE 13th International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob), Rome, 2017, pp. 1-8.

[8] http://www.sghoslya.com/

[9] K. H. Phung, H. Tran, Q. Nguyen, T. T. Huong and T. L. Nguyen, "Analysis and assessment of LoRaWAN," 2018 2nd International Conference on Recent Advances in Signal Processing, Telecommunications & Computing (SigTelCom), Ho Chi Minh City, 2018, pp. 241-246.

[10] P. S. Cheong, J. Bergs, C. Hawinkel and J. Famaey, "Comparison of LoRaWAN classes and their power consumption," 2017 IEEE Symposium on Communications and Vehicular Technology (SCVT), Leuven, 2017, pp. 1-6.

[11] O. Khutsoane, B. Isong and A. M. Abu-Mahfouz, "IoT devices and applications based on LoRa/LoRaWAN," IECON 2017 - 43rd Annual Conference of the IEEE Industrial Electronics Society, Beijing, 2017, pp. 6107-6112.

[12] U. Raza, P. Kulkarni and M. Sooriyabandara, "Low Power Wide Area Networks: An Overview," in IEEE Communications Surveys & Tutorials, vol. 19, no. 2, Secondquarter 2017, pp. 855-873.