Internet of Things and LoRa^{TM} Low-Power Wide-Area Networks: A Survey

Alexandru Lavric, Valentin Popa
Computers, Electronics and Automation Department, Stefan cel Mare University of Suceava, Romania
lavric@eed.usv.ro

***Abstract*— Nowadays there is a lot of effort on the study, analysis and finding of new solutions related to high density sensor networks used as part of the IoT (Internet of Things) concept. LoRa (Long Range) is a modulation technique that enables the long-range transfer of information with a low transfer rate. This paper presents a review of the challenges and the obstacles of IoT concept with emphasis on the LoRa technology. A LoRaWAN network (Long Range Network Protocol) is of the Low Power Wide Area Network (LPWAN) type and encompasses battery powered devices that ensure bidirectional communication. The main contribution of the paper is the evaluation of the LoRa technology considering the requirements of IoT. After introduction in Section II the main obstacles of IoT development are discussed, section III addresses the challenges and entails the need for solutions to different problems in WSN research. Section IV presents the LoRaWAN communication protocol architecture requirements while in Section V the LoRa modulation performance is evaluated and discussed. In conclusion LoRa can be considered a good candidate in addressing the IoT challenges.**

Keywords*— *LoRa; wireless communications; LPWAN; LoRa (Long Range) modulation; WSN; Internet of Things;

I. Introduction

Nowadays there is a lot of effort on the study, analysis and finding of new solutions related to high density sensor networks used as part of the IoT concept.

The development of the WSN sensor networks is a topical subject in several research centers. The applications that can integrate these WSN networks range from the military to the medical field. During the past few years, there has been a constant development of the WSN communication protocols, also supported by the development of the Internet of Things concept.

Even though the Internet of Things (IoT) concept is often mentioned in the professional literature, there is a certain ambiguity to it, due to the numerous other concepts it entails, and also due to its name [1]. Thus, the term has been defined is various ways, for instance, according to [2], IoT refers to a worldwide network (WWW- World Wide Web) of interconnected objects uniquely addressable, based on standard communication protocols.

The rest of this paper is organized as follows: in Section II the main obstacles of IoT development are discussed, section III addresses the challenges and entails the need for solutions to different problems in WSN research. Section IV presents the LoRaWAN communication protocol architecture requirements while in Section V the LoRa modulation performance is evaluated and discussed.

II. Main Obstacles

The professional literature also includes a number of scientific papers that present the different conceptual models and applications where WSN modules perform by using the Internet IP infrastructure as means of communication. Thus, the IoT concept also includes the WSN sensor networks. The IoT concept also includes the M2M (Machine-to-Machine) communications.

The main obstacles that hinder the development of the IoT concept are:

Connectivity: the main challenge faced by this concept consists in assuring the interconnectivity between the devices built by different manufacturers. The use of a single communication protocol is not a viable choice, in light of the various communication channels and related applications. Thus, the main goal is to ensure the interconnectivity of the various data formats on a worldwide scale. Equally vital is the analysis of the standards used nowadays in the IoT concept.

Efficient energy management: most WSN modules are battery powered, and thus there is a constant need to reduce the energy consumption. Since the cost of these devices is rather low, the battery replacement cannot be considered efficient, as this operation would be more costly than the replacement of the entire module. Therefore, the battery life cycle should amount to decades. This entails the development of sophisticated communication strategies focused on energy efficiency. Another possible solution would be the improvement of the energy harvesting techniques.

Security: the provision of high security levels should definitely be taken into account. Thus, it is highly necessary to develop new authentication and encryption protocols that are able to use limited WSN node specific hardware resources.

Complexity: The integration of the communication capabilities is also a highly complex task. Researchers are now looking for new ways to increase the efficiency and facilitate the programming of these modules.

Fast-paced development: the IoT concept is an extraordinarily fast paced developing concept, hundreds of new nodes being added every day. Many of the difficulties are not yet known, as these occur with the increasing number of IoT nodes and with the increased complexity of the applications used for the remote information transfer in the Cloud. The IoT vision is constantly changing and developing.

978-1-5386-0674-2/17/$31.00 ©2017 IEEE

III. CHALLENGES

IoT entails the development of an invisible, intelligent network that can be controlled and programmed. The devices used on this network use the embedded technology, which allows them to communicate either directly or indirectly by using the Internet infrastructure [3].

So far, the universe of IoT devices comprises around 5 billion interconnected modules. The present estimates show that, by 2020, the number of these devices will exceed 50 billion [3].

This number of interconnected devices will only be reached with the help of technological progress, by improving/simplifying and developing new communication protocols.

The IoT concept has now become an extension of the Internet. Its impact on the way mankind approaches its present problems will be extensive in the years to follow.

Some of the IoT applications include:

Smart Power Grid: During the past few years, attempts have been made to transition to renewable energy sources. All these sources are unpredictable and geographically dispersed, which means it will be necessary to implement remote monitoring and information transfer.

e-Learning: IoT must first facilitate access to education. Distance learning must be accessible to anyone, and this will be made possible by the interconnected WSN networks that would allow for long distance transfer of information.

Smart City: The more efficient use of resources is one of the advantages brought about by IoT. The impact of WSN technologies on intelligent cities has been analyzed in many papers.

HealthCare: WSN technologies bestow the ability to monitor and protect people in their own homes, thus contributing to the increased quality of medical services.

Environment Protection: The protection of the environment is a topical problem that must not be overlooked or neglected. WSN sensor networks enable the remote monitoring of pollution levels and of the impact mankind has on nature.

The development of WSN networks in IoT is crucial, as it allows for the improvement of the quality of life, also contributing to the lowering of pollution levels by rendering the resource consumption more efficient.

The challenges and the limitations faced in the WSN field are:

- Difficulties when integrating a large number of sensors;
- Issues related to coexistence, occurring in a congested RF environment;
- The congested state of an RF (Radio Frequency) environment often leads to low efficiency. Thus, new solutions should be found to enable the automatic selection and adjustment of the communication channel depending on the level of interference.
- The absence of mathematical models that would allow the simulation of a very large number of WSN nodes;
- The existing WSN simulators are limited as concerns scalability. Thus, in order to simulate complex applications, one should integrate the interoperability between different manufacturers. Therefore, the level of difficulty of the IoT concept is rather high.

IV. LORAWAN

The LoRaWAN protocol is relatively new and became the focus of several research centers across the world. LoRa (Long Range) is a modulation technique that enables the long range transfer of information with a low transfer rate. The LoRa modulation has been patented by Semtech Corporation.

LoRa is a type of SS- Spread Spectrum modulation, and the novelty of this technique consists in the use of a chirp signal that varies constantly with the frequency. The advantage of using this method is that the offset in time and frequency to the sender and receiver is the same, thus considerably reducing the complexity of the receiver [7].

A LoRaWAN network (Long Range Network Protocol) is of the Low Power Wide Area Network (LPWAN) type and encompasses battery powered devices that ensure bidirectional communication. The LoRaWAN specification ensures the perfect interoperability between the IoT objects, without the need for complex local implementations [8].

The LoRa network is implemented by using the star network topology. The structure of a LoRa architecture can be separated into a back-end and a front-end part. The back-end part consists of the network server that stores the information received from the sensors. The front-end consists of the Gateway modules and the end-device nodes. The Gateway modules act as a bridge between the end-device nodes and the network server. The information between the network server and the Gateway modules is sent through the IP connection. Fig. 1 presents the LoRa architecture.

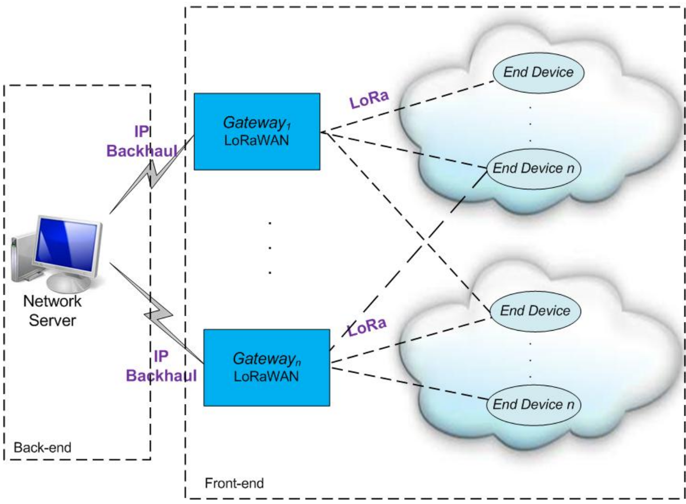

Figure 1. LoRa architecture.

The end-device modules do not have routing capabilities, and the messages are sent directly to the Gateway concentrator through a one hop mechanism. The LoRaWAN technology transfer rates range between 0,3 kbps and 50 kbps. In order to maximize the battery life span, the devices manage their RF communication power and the transfer rate through an Adaptive Data Rate (ADR) mechanism.

The LoRa communication operates in the unlicensed frequency band [9]:

- EUROPA 863-870MHz ISM Band: 3 channels, central frequencies: 868.10 MHz, 868.30 MHz, 868.50 MHz;
- EU 433MHz ISM Band: 3 channels, central frequencies: 433.175 MHz, 433.375 MHz, 433.575 MHz;
- US 902-928MHz ISM Band;
- China 779-787MHz ISM Band;
- China 470-510MHz Band;
- Australia 915-928MHz ISM Band;
- ISM Band 923-923.5MHz.

In the scientific literature, there are a many papers that address LoRa communications [10] - [22] but none of them evaluates LoRa technology by entailing the challenges and the main obstacles of IoT concept.

Fig. 2 presents the LoRa communication stack.

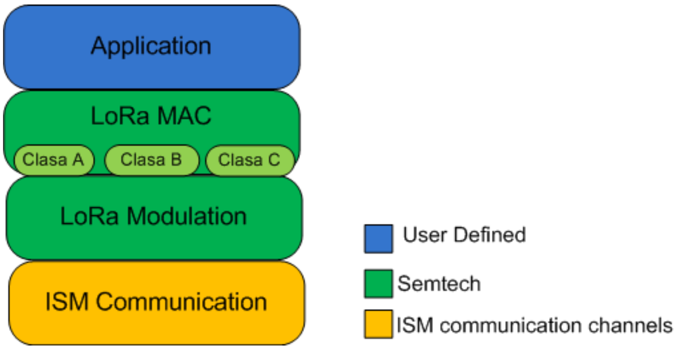

Figure 2. LoRa communication stack.

LoRa has several types of end-devices, depending on the communication mechanism employed.

- Class A: Class A devices have bidirectional communication capabilities. The time slot during which the device is transmitting is followed by two short time slots during which the device can receive information. Devices included in this category can receive data from the server only after they had sent information. Thus, class A devices ensure the highest energy efficiency. If one wishes to send the data from the server, one will wait for the next scheduled slot uplink [8].

- Class B: Class B devices have bidirectional communication capabilities and an additional time slot that allows them to receive data. Apart from the random time slots during which data can be received that the type A device allows for, the type B device can also use a series of receiving slots activated by a Beacon type of message sent by the Gateway [8].

- Class C: Class C devices have bidirectional communication capabilities and time slots during which they can receive unlimited information. The only time when a class C device cannot receive information is when it sends it [8].

According to the LoRa standard, each module must implement the class A communication mechanism, while the specific functions of the other categories are optional.

LoRaWAN technology advantages are:
- Use the unlicensed ISM frequency band.
- It is a flexible solution that can be easily adapted.
- It is scalable.
- It supports bi-directional communication.
- Provides a high level of security due to encryption algorithms.
- Provides energy efficiency.

LoRa technology is a LPWAN (Low-Power Wide-Area Networks) standard, which proposes the compromise of lowering the data rate at the expense of longer communication ranges.

Fig. 3 presents a comparison of the wireless communications protocols. As can be observed LoRa technology assures very large communication distances for an extreme low bandwidth.

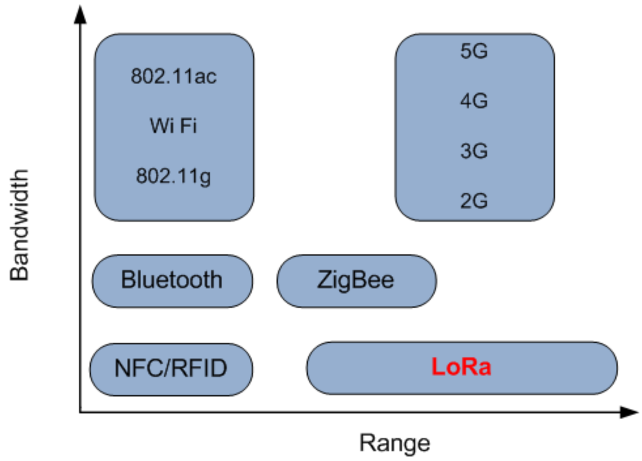

Figure 3. Wireless communication protocols comparison.

Thus, the standard is suitable for applications where a reduced amount of data is transferred and the information collected from the sensors does not change rapidly over time. LoRa devices' ERP (Effective radiated power) is limited to 25 mW in the European frequency band of 867-869 MHz. This regulation is imposed because the communication channel bandwidth is reduced.

This limitation causes a data transfer rate between 300 bps and 5.5 kbps. Another parameter which is the duty cycle should be less than 1%. These aspects further limit the transfer rate.

For more efficient communication transfer of the data from the sensor to the Gateway module is facilitated. LoRaWAN is the protocol at physical layer the LoRa modulation is used. The main advantage of using this modulation is the increase of the receiver's sensitivity.

V. LoRa Modulation

The LoRa modulation technique is of 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 individually per node the modulation rate and the transmission power. 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.

Table 1 presents the LoRa spreading factors for 125 kHz bandwidth. As can be observed if the Spreading Factor is increased the bitrate is decreased, the time-on-air parameter is increased but the SNR limit is significantly improved.

The number of symbols encoded decrease meanwhile the Spreading Factor is decreased.

TABLE I. LoRa Spreading Factors for 125 kHz Bandwidth

Spreading Factor	Symbols /second	SNR limit	Time-on-air for 10 byte packet	Bitrate
7	976	-7.5	56	5469
8	488	-10	103	3125
9	244	-12.5	205	1758
10	122	-15	371	977
11	61	-17.5	741	537
12	30	-20	1483	293

The main advantage is given by integration capabilities of a large number of nodes. Gateway modules can communicate simultaneously on 8 different channels. As discussed in the previous section we can have on the same channel signals modulated with different SF. In case of a collision the strongest signal is decoded,

This scalability advantage refers primarily to the possibility of increasing the number of Gateways thus increasing network's capacity. If a node is situated closer to a Gateway it will have a higher communication data rate, because of the integrated ADR (Adaptive Data Rate) mechanism. This mechanism entails the adjustment of the SF gradually and individually per node in order to increase the data rate.

VI. Conclusions

The Internet of Things (IoT) concept entails the connection of various devices to the Internet, thus providing remote monitoring and control services. This definition only refers to M2M (Machine-to-Machine) communications. The main contribution of the paper is the evaluation of the LoRa technology considering the requirements of IoT. At present, the concept is much more complex. In conclusion LoRa can be considered a good candidate in solving these problems.

References

[1] Wu, X., Xiong, Y., Li, M., Huang, W., Distributed spatial-temporal compressive data gathering for large-scale WSNs, Computing, Communications and IT Applications Conference (ComComAp), pp. 105-110, 2013.

[2] INFSO D.4 Networked Enterprise RFID INFSO G.2 Micro Nanosystems in Co-operation with the Working Group RFID of the ETP EPOSS, 2008.

[3] The Evolution of the Internet of Things, On-line http://www.ti.com/lit/ml/swrb028/swrb028.pdf.

[4] Alexandru Lavric, Valentin Popa, Ştefan Sfichi, Adaptive Channel Selection Algorithm for a Large Scale Street Lighting Control ZigBee Network in the Presence of WLAN Interference, Elektronika ir Elektrotechnika Journal, Vol. 19, Nr. 9, pp. 105-109, 2013, Web of Science Core Collection.

[5] IEEE Std. 802.15.4, IEEE Standard for Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (LR-WPANs), 2003.

[6] LoRa Alliance, On-line: https://www.lora-alliance.org/what-is-lora/technology

[7] Semtech, AN1200.22 LoRa™ Modulation Basics, Application Note, http://www.semtech.com/images/datasheet/an1200.22.pdf

[8] LoRa Technology, https://www.lora-alliance.org/What-Is-LoRa/Technology

[9] LoRaWAN™ Regional Parameters, LoRa Alliance, https://www.lora-alliance.org/

[10] Wixted, Andrew J., Peter Kinnaird, Hadi Larijani, Alan Tait, Ali Ahmadinia, and Niall Strachan. "Evaluation of LoRa and LoRaWAN for wireless sensor networks." In SENSORS, 2016 IEEE, pp. 1-3. IEEE, 2016.

[11] Kim, D.Y. and Kim, S., 2015. LoRaWAN Technology for Internet of Things. Journal of platform technology, 3(1), pp.3-8.

[12] Toussaint, Joël, Nancy El Rachkidy, and Alexandre Guitton. "Performance analysis of the on-the-air activation in LoRaWAN." In Information Technology, Electronics and Mobile Communication Conference (IEMCON), 2016 IEEE 7th Annual, pp. 1-7. IEEE, 2016.

[13] Kim, Dae-Young, and Minwoo Jung. "Data Transmission and Network Architecture in Long Range Low Power Sensor Networks for IoT." Wireless Personal Communications (2016): 1-11.

[14] Schroder Filho, H. G., J. Pissolato Filho, and V. L. Moreli. "The adequacy of LoRaWAN on smart grids: A comparison with RF mesh technology." In Smart Cities Conference (ISC2), 2016 IEEE International, pp. 1-6. IEEE, 2016.

[15] Centenaro, Marco, Lorenzo Vangelista, Andrea Zanella, and Michele Zorzi. "Long-range communications in unlicensed bands: The rising stars in the IoT and smart city scenarios." IEEE Wireless Communications 23, no. 5 (2016): 60-67.

[16] Trasviña-Moreno, C. A., Blasco, R., Casas, R., & Asensio, Á. (2016). A Network Performance Analysis of LoRa Modulation for LPWAN Sensor Devices. In Ubiquitous Computing and Ambient Intelligence: 10th International Conference, UCAmI 2016, San Bartolomé de Tirajana, Gran Canaria, Spain, November 29–December 2, 2016, Part II 10 (pp. 174-181). Springer International Publishing.

[17] Gregora, Lukas, Lukas Vojtech, and Marek Neruda. "Indoor signal propagation of LoRa technology." In Mechatronics-Mechatronika (ME), 2016 17th International Conference on, pp. 1-4. IEEE, 2016.

[18] Vondrouš, Ondřej, Zbyněk Kocur, Tomáš Hégr, and Ondřej Slavíček. "Performance evaluation of IoT mesh networking technology in ISM frequency band." In Mechatronics-Mechatronika (ME), 2016 17th International Conference on, pp. 1-8. IEEE, 2016.

[19] Gardašević, Gordana, Mladen Veletić, Nebojša Maletić, Dragan Vasiljević, Igor Radusinović, Slavica Tomović, and Milutin Radonjić. "The IoT Architectural Framework, Design Issues and Application Domains." Wireless Personal Communications 92, no. 1 (2017): 127-148.

[20] Augustin, Aloÿs, Jiazi Yi, Thomas Clausen, and William Mark Townsley. "A study of LoRa: Long range & low power networks for the internet of things." Sensors 16, no. 9 (2016): 1466.

[21] Song, Qipeng, Loutfi Nuaymi, and Xavier Lagrange. "Survey of radio resource management issues and proposals for energy-efficient cellular networks that will cover billions of machines." EURASIP journal on wireless communications and networking 2016, no. 1 (2016): 140.

[22] Bouleogeorgos, Alexandros-Apostolos A., Panagiotis D. Diamantoulakis, and George K. Karagiannidis. "Low Power Wide Area Networks (LPWANs) for Internet of Things (IoT) Applications: Research Challenges and Future Trends." arXiv preprint arXiv:1611.07449 (2016)

Authors' response

The authors want to thank the reviewers for their useful suggestions.

The paper quality was improved.

Fig. 1 was slightly changed to illustrate the possibility of an End Node to be connected to multiple Gateways. Also, the “IP” mention was modified to “IP Backhaul” in order to be more suggestive.

To further underline the main contribution of this paper the following phrases were added:
“The main contribution of the paper is the evaluation of the LoRa technology considering the requirements of IoT.”
“The rest of this paper is organized as follows: in Section II the main obstacles of IoT development are discussed, section III addresses the challenges and entails the need for solutions to different problems in WSN research. Section IV presents the LoRaWAN communication protocol architecture requirements while in Section V the LoRa modulation performance is evaluated and discussed.”
The phrase ”In the scientific literature, (..) but none of them evaluates the technology from an IoT concept.” was reformulated to “In the scientific literature, (…) but none of them evaluates LoRa technology by entailing the challenges and the main obstacles of IoT concept.

Reference [23] was eliminated from the text.