

# LoRaWAN Analysis from a High-Density Internet of Things Perspective

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**Abstract** In order to cope with the new challenges and IoT applications LPWAN (Low-Power Wide-Area Network) networks have been created. The IoT (Internet of Things) concept is currently in the focus of the entire academic community. The main contribution of the work is the performance level evaluation associated to the LoRaWAN scalability. Within the scientific literature, there are a series of scientific papers which attempt to analyze the performance level of LoRaWAN communication technology, but none of them use a specialized software like SimpleIoTSimulator. This paper comes to fill in the gap and tries to materialize a study that allows for the analysis of the performance level. The user can easily generate the traffic from tens of thousands of LoRa nodes. The SimpleIoTSimulator platform can be directly connected to the TTN Server that receives the traffic as it is generated by real LoRa sensors. From the obtained results we can conclude that SimpleIoTSimulator ensures a high level of performance and will contribute to the opening of new research directions in the field of high density LoRa sensor networks.

**Keywords**— *LoRa; communication scalability; large-scale; high density; Internet of Things;*

## I. INTRODUCTION

The IoT (Internet of Things) concept is currently in the focus of the entire academic community. There are many communication protocols that promised to solve the IoT challenges and problems, but only a few as seen as a Holy Grail. In this work we will focus on LoRa (Long Range) [1] modulation which is integrated in LoRaWAN (LoRa Wide Area Network) [2] communication protocol.

The communication protocols can be separated depending on number of categories such as those that work within a licensed bandwidth, other technologies that are open-source or vendor-locked and technologies that use mesh type network topologies or those that share a star type structure.

In this section a brief introduction related to the state-of-the-art of IoT technologies that are able to meet the requirements of high-density, large-scale wireless networks [3]. Introducing communication capabilities to different objects that surround us in our daily life entails the creation of complicated network architectures. Thus, is mandatory to create and implement new communication protocols that can meet these demands in order to ensure a remarkably high level of performance. In order to cope with the new challenges and IoT

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This work was partially supported by a grant of the Romanian Ministry of Research and Innovation, CCCDI-UEFISCDI, Project Nos. PN-III-P1-1.2-PCCDI-2017-0776 and 36 PCCDI/15.03.2018, within PNCDI III.

application LPWAN (Low-Power Wide-Area Network) networks have been created. The main contribution of the work is when it comes to evaluating the performance level associated to the LoRaWAN scalability [4]. Within the scientific literature, there are a series of scientific papers which attempt to analyze the performance level of LoRaWAN communication technology, but none of them use a specialized software like SimpleIoTSimulator.

This paper comes to fill in the gap and tries to materialize a study that allows for the analysis of the performance level. From the obtained results we can conclude that SimpleIoTSimulator ensures a high level of performance and will contribute to the opening of new research directions in the field of high density LoRa sensor networks [5]. The paper is organized as follows: Section II presents the main challenges of LoRaWAN communication protocol and architecture and requirements. In Sections III, the experimental results are presented. The final section of the paper is represented by the conclusions. This paper comes as a continuation of our previous published work [6] -[11].

## II. LORAWAN COMMUNICATION PROTOCOL

In this section we focus our attention onto the RF (Radio Frequency) and MAC (Medium Access Control) layers particular to the LoRa technology. Unlike direct sequence spread spectrum (DSSS) where the payload is modulated onto a pseudorandom code, LoRa makes use of a modified FSK (Frequency Shift Keying) modulation technique that integrates an up-chirp or down-chirp type of signal thus modulating the payload type of signal as shown in Figure 1. This mechanism is specific to radar systems and is patented by Semtech Corporation. One of the main advantages is related to the large communication range even in urban configurations. This advantage together with the scalability possibilities makes from LoRa modulation the perfect candidate for the build of the IoT concept.

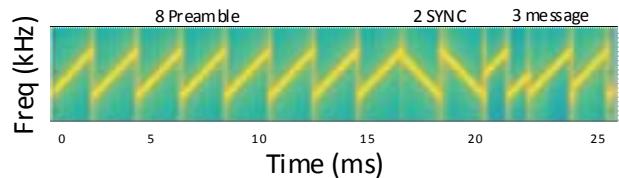


Fig. 1. Up-chirp and down-chirp of a LoRa demodulated signal.

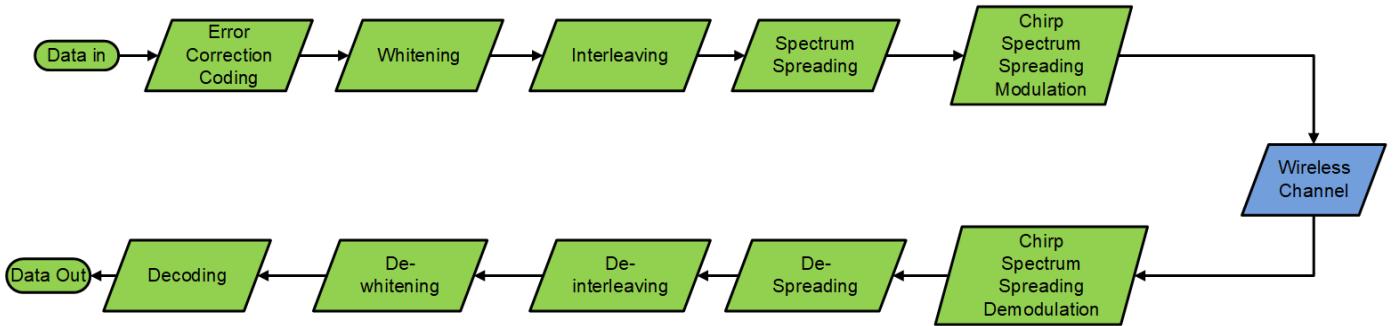


Fig. 2. Physical layer of LoRa modulation techniques.

The technology also integrates a Spreading Factor, which creates a spectrum spreading effect, thus contributing to the separation of transmissions by introducing orthogonality providing a large communication range.

The operations and processes that take place at the physical level of the LoRa communication protocol are shown in Figure 2. Operations such as the following are observable: error correction, whitening, interleaving and finally the chirp spread spectrum techniques. The LoRaWAN is the communication protocol that includes at the physical layer the LoRa modulation discussed previously. The LoRaWAN communication protocol is defined by the LoRa Alliance [2]. LoRa Alliance defines the network layer and the application layer of the LoRaWAN communication protocol in order to ensure interoperability of devices from different manufacturers. Another aspect that must not be neglected relates to the duty cycle (DT) restrictions regulated by different local authorities.

The standard architecture contains the following elements: the LoRa sensors, the LoRaWAN Gateway that receives the messages from the sensors and retransmits them to the Network Server. The Network Server is usually managed by a third party being a date service aggregator like The Things Network [12]. All the information is centralized here and extracted by the User Application Server.

This architecture has the advantage of being a scalable one. Theoretically, it can integrate thousands of LoRa sensors, which communicate in a star like network topology so each node can communicate directly with the Gateway module. The used frequency band is the SRD (Short Range Devices) one so no license and additional costs are needed.

Because of the star network topology, the hardware structure of a node is simple, so the initial deployment costs are very low. The Gateway has the ability to communicate simultaneously on 8 different channels, thus the data volume collected can be pretty big. Another advantage relates to the LoRaWAN communication protocol is the high communication range of the order of tens of kilometers even in urban propagation conditions. Thus, with a relatively low number of Gateways the entire coverage of a city can be easily achieved.

The LoRaWAN specification defines three classes of LoRa sensor nodes Class A, Class B and Class C as presented in Figure 3. In order to achieve the energy efficiency, goal the

sensor can communicate with the Gateway module in a restricted manner. As seen the most efficient class is the class A that must be implemented by all devices according to the LoRaWAN specifications. This class implements and offers support for bidirectional communication between the sensor and the server. The sensor can make an uplink operation (send a message from the sensor to the Server) unrestricted if respects the Duty Cycle parameter [13] for the specific geographic region (e.g. ISM region a Duty Cycle 1%).

The downlink messages (send from the Server to the node) are restricted to only 2 time slots, for class A devices, slots at 1 second and respectively 2 seconds after the uplink period. This mechanism contributes to the efficient consumption of energy and enables connectivity for years. Class B comes to implement a beacon enabled communication for application where the downlink slot is controlled by a specific beacon packet.

Class C comes to fill in the gap for applications that need by design unrestricted communication abilities. Usually these sensors are mains powered and can listen unrestricted for messages from the Server. The developer must correctly select, the class of the deployed sensors considering the specific and the particularities of the applications.

It is important to mention that even if a class C is selected the LoRa sensor must comply with the duty cycle restrictions corresponding to the geographical region in which it operates.

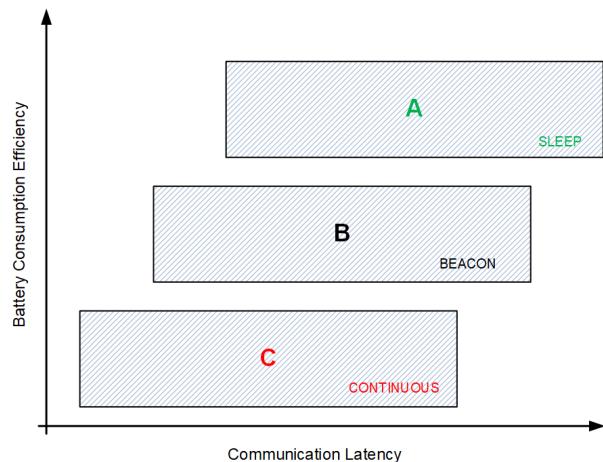


Fig. 3. LoRaWAN classes of nodes.

Another aspect that should not be neglected is the selection of the Getaway device. In the last time period, we have seen the next generation of LoRaWAN Gateways that ensure a very high level of performance. One example is the RAK7249 [14] Outdoor Gateway developed by RakWireless [15]. The advantage of this Gateway is that it has the ability to integrate two concentrators each with 8 simultaneous communication channels. So, the number of sensors connected to a single Gateway increases significantly. In our laboratory, we have installed, such a RAK7249 Gateway, which serves the University LoRAWAN network and the level of performance is very high.

In our opinion the RAK7249 gateway is suitable for many high density, large scale applications, offering a high level of customization when it comes to different backhaul communication technologies to ensure data transfer from the gateway to the Internet side.

### III. SIMPLEIOTSIMULATOR

In this section we focus our attention on a performance evaluation scenario that makes use of a commercial sensor network simulator. The SimpleIoTSimulator [16] simulator represents a very powerful instrument in the validation of LoRaWAN performance evaluation. Currently there is not a single LoRa WAN network simulator commercially available. In the scientific literature, there are some isolated attempts to develop LoRa communication models, but none in an integrated manner commercially available. So, the main contribution of this paper is to evaluate the scalability of the LoRaWAN technology using the first available commercial simulator SimpleIoTSimulator. The simulator offers the possibility to test a specific network server offering the capabilities for cloud testing and data aggregation validation. Figure 4 presents the simulation architecture integrated in our testbed simulation.

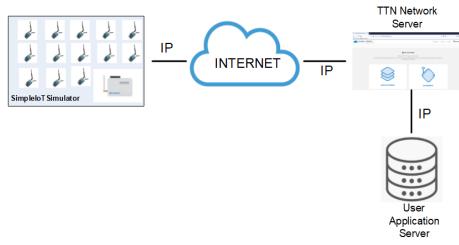


Fig. 4. Simulation architecture.

The simulator can be connected to The Things Network [9]. So, we can emulate thousands of devices that regularly send data to the TTN (The Things Network) data aggregator service. The traffic is received and can be analyzed on the User application server or directly on the TNN Platform. The user has the possibility to test LoRa user application server (Figure 6) or to test the LoRa Network Server (Figure 7). The main difference of the two architectures is the possibility to implement the user application server by data aggregation and collection services. The tested simulation scenario integrated a LoRa Network testbed that integrates a number of 999 LoRa sensor devices and 1 Gateway module. From the configuration profile the user is able to select the class of the LoRa device

(e.g. Class A, Class B or Class C), the activation mode of the sensor ABP (e.g. Activation by personalization) or OTAA [17] (e.g. Over the air activation) and the time interval of sending the packets.

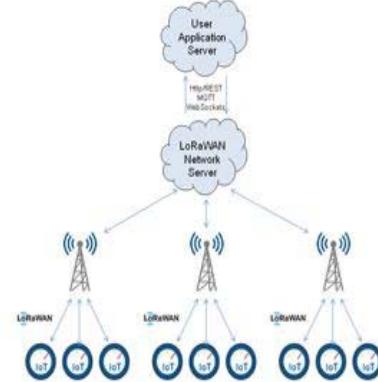


Fig. 5. SimpleIoT Simulation scenario for user application server test.

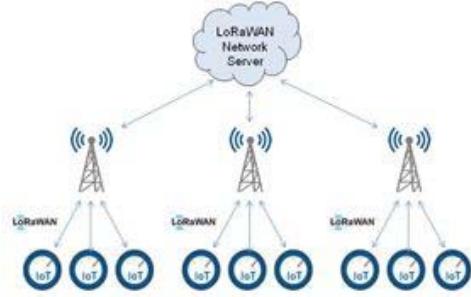


Fig. 6. SimpleIoT Simulation scenario for network server test.

Other settings are related to the device's security like the device address, network server key and the application server key. In Figure 7 we have presented a section of the simulated LoRa map. One can observe the Gateway module and the LoRa devices. The SimpleIoTSimulator used a map hierarchy systematization as to integrate a very high number of nodes.

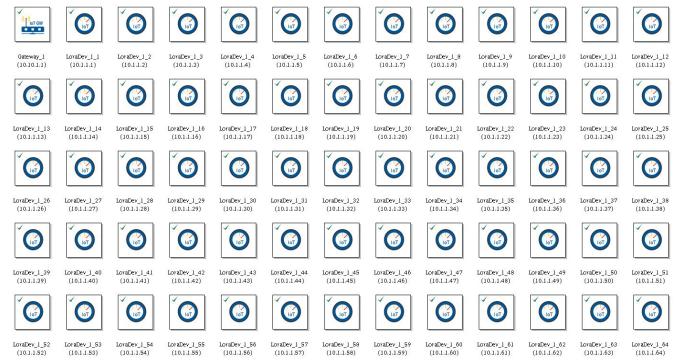


Fig. 7. SimpleIoT selection of the current simulated map.

In Figure 8 we have presented the map statistics for the active protocols involved in the simulation scenario. In a fixed time frame each LoRa node sends an average of 768 packets in the simulation configuration. For the selected map the Gateway

received a number of 3054 packets that are forwarded to the Network Server.

Device	LoRa RxRfw	LoRa Dwmb	LoRa UpLink	LoRa DownLink
10.1.1.79	0	0	768	0
10.1.1.80	0	0	769	0
10.1.1.81	0	0	767	0
10.1.1.82	0	0	767	0
10.1.1.83	0	0	767	0
10.1.1.84	0	0	767	0
10.1.1.85	0	0	768	0
10.1.1.86	0	0	768	0
10.1.1.87	0	0	768	0
10.1.1.88	0	0	768	0
10.1.1.89	0	0	768	0
10.1.1.90	0	0	768	0
10.1.1.91	0	0	768	0
10.1.1.92	0	0	768	0
10.1.1.93	0	0	768	0
10.1.1.94	0	0	768	0
10.1.1.95	0	0	767	0
10.1.1.96	0	0	768	0
10.1.1.97	0	0	767	0
10.1.1.98	0	0	768	0
10.1.1.99	0	0	768	0
10.10.1.1	30541	0	0	0
Total	0	0	768	0

Fig. 8. Map simulation statistics.

The TTN Network Server received the traffic as it is sent by real sensors. The simulator provides the ability to modify the structure of the LoRa packet as to personalize different applications particularities. The simulator runs on a Linux-based distribution so it is very scalable and portable. Using the proposed architecture, a very large number of LoRa sensors can be emulated. From the obtained results we can observe that not a single LoRa packet was lost or corrupted by verifying the statistics from the simulator side to those from the TTN platform. The data level throughput sent from the simulator is immense. The possibility of testing and developing high-density LoRa architecture offers researchers and developers the possibility to fully test their algorithms, protocols and applications before mass deployment. We consider one of the main advantages of the SimpleIoTSimulator to be its scalability being able to simulate and generate the traffic from tens of thousands of LoRa sensors.

#### IV. CONCLUSIONS

The SimpleIoTSimulator offers a high level of performance and entails the possibility of performing close investigations of the scalability of the LoRa technology. In the current Internet of Things context, the LoRa modulation together with the LoRaWAN communication protocol have been seen as a holy grail.

This simulation instrument can be used by LoRa network developers and integrators to fully test their application server or by data service aggregators that want to assess the performance level of their cloud services. The user can easily generate the traffic from tens of thousands of LoRa nodes. The SimpleIoTSimulator platform can be directly connected to the TTN Server that receives the traffic as it is generated by real LoRa sensors. This feature can help with the mass deployment of LoRa technology in large scale, high-density manner. In

conclusion the SimpleIoTSimulator ensures a high level of performance opening new research direction in the field of high density LoRa sensor networks.

#### ACKNOWLEDGMENT

This work was partially supported by a grant of the Romanian Ministry of Research and Innovation, CCCDI-UEFISCDI, Project Nos. PN-III-P1-1.2-PCCDI-2017-0776 and 36 PCCDI/15.03.2018, within PNCDI III.

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