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Long Range SigFox Communication Protocol Scalability Analysis Under Large-Scale, High-Density Conditions

ALEXANDRU LAVRIC[1], **ADRIAN I. PETRARIU**[1,2], **AND VALENTIN POPA**[1,2]
[1]Faculty of Electrical Engineering and Computer Science, Stefan cel Mare University of Suceava, 720229 Suceava, Romania
[2]MANSiD Integrated Center, Stefan cel Mare University, 720229 Suceava, Romania

Corresponding author: Alexandru Lavric (lavric@eed.usv.ro)

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ABSTRACT In recent years, the IoT concept is more and more powerful, having set the goal of integrating billions of devices to the Internet. Thus, from this perspective, the interest allocated to low-power wireless networks of sensors is higher than ever. In this paper, the SigFox scalability is analyzed from the IoT concept point of view. In the scientific research, there are a series of papers which tackle the SigFox issues, oftentimes at a comparative study level, without evaluating the performance level of the communication protocol. This paper comes to fill this gap by creating a realistic SigFox communication model. Moreover, a developed and tested generator of SigFox traffic has been implemented, using SDRs. This allows the possibility of evaluating the performance level of WSN networks, of a large-scale high-density-type. Both of the suggested instruments represent the novelty of this paper. The obtained results show that the maximum number of sensors that can transmit data at the same time, using the proposed scenarios, is of approximately 100, in order to obtain a high level of performance when the number of available channels is 360. If we are to increase the number of sensors, an avalanche effect ensues which triggers the sharp decrease of the performance of the SigFox network. At the end of this work, a series of solutions are being suggested with the main purpose of increasing the performance level of large-scale, high-density SigFox networks.

INDEX TERMS Internet of Things, scalability, wireless sensor networks.

I. INTRODUCTION

Nowadays, thanks to the fast expansion of technology, we are living in a world in which the concept of IoT (Internet of Things) is being used more and more often. It could help us in overcoming the top global challenges due to population expansion, energy crisis, resources depletion, environmental pollution or natural disasters that might occur. Today, IoT has achieved significant improvement in performance and also in data acquisition and processing, especially for big data [1]. If we need a communication mechanism to allow us to gather and visualize data from a distance, referring to humidity, temperature, air quality, home automation, lighting control, the management of parking lots, the speeding of road traffic, and so forth, we can make use of the IoT infrastructure, in which a good deal of sensors can be integrated so that they can transmit real-time data [2]–[4]. In this way, over the following decade, we might see that by means of Internet, one can access everyday furniture, food containers, and even paper documents using the same connectivity network, called IoT. From the statistics gathered in [5] it is estimated that, by 2025, the IoT concept will host over 75 billion of devices linked together within the IoT network, in different fields of interest.

Owing to this great deal of applications which can make use of this concept, it is a must that, when it comes to the infield sending of data read by means of the Internet, this should be done by a sturdy, but moreover scalable wireless sensor infrastructure [6], [7]. This infrastructure must have the ability to support the connectivity of hundreds, thousands or even hundreds of thousands of sensor nodes, which will gather and send values concomitantly, using one

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single, Internet-tied, Gateway (GW) or Base Station (BS) type module. Figure 1 displays the fields in which LPWAN (Low-Power Wide Area Networks) technologies can be integrated. For such network, one possible fix would be the use of narrow-band communication techniques, from within the ISM and SRD unlicensed domain. The ideal candidates for this approach are LoRaWAN, SigFox and NB-IoT (Narrow-Band IoT). An in-depth analysis dealing with the use of these technologies to gather data from sensors, in a number of different domains is presented in [8].

Narrow-Band and Ultra-Narrow Band modulation techniques confer a high communication budget by encoding the bandwidth signal in a frequency band less than 25kHz or 100Hz. The advantage of such an approach is that the noise level present in a narrow-band communication channel is minimal. There is no need for spectrum scattering, leading to the reduction of implementation costs. SigFox communication uses a frequency band of 100Hz, thus increasing the total number of nodes that can communicate within a WSN (Wireless Sensor Network) at the expense of the transfer rate.

Within this article there is a heightened focus on SigFox by the screening of the scalability of this technology, whilst keeping in mind the specifications imposed by the SigFox technical overview [9]. One first analysis of the scalability of LPWAN type networks is met in [10], where a comparative analysis between LoRaWAN and SigFox, from a MAC point of view is followed through. The MATLAB and NS-3 simulation results show that SigFox has a large coverage and can support a larger number of devices, while LoRaWAN is less sensitive to interference and offers higher throughput. Moreover, this approach is also presented within [11]. Mo *et al*. [12] come up with an effective method for achieving optimal results when it comes to SigFox, that being: to apply signal combining and interference cancellation technologies across multiple base stations, in order to take advance of their spatial diversity. Other works present comparative studies between the different LPWAN type networks, that tackle main common features and singularities, focusing on the supported network topologies [13]–[15], yet their scalability is not delved into.

The main contribution of this paper lies within its use when it comes to the analysis of the scalability of SigFox technology. The varied parameters within the developed module are the number of nodes and the number of communication channels, thence, a series of scenarios are thought of and implemented. Packet Error Rate (PER) and the number of collisions are calculated and determined for each scenario. In the scientific research, there are a number of papers that discuss the SigFox networks on a comparative level, rather than shedding light upon its performance. This work comes to fill this gap by developing a realistic SigFox communication model.

Moreover, a SigFox traffic generator has been implemented, developed and tested. This system provides the possibility of testing the performance level of WSN large-scale high-density networks. Both of the submitted instruments represent the novelty of this work.

The paper is structured as follows: first, a brief introduction related to the state-of-the-art, followed by the Section II, where the main challenges of SigFox technology are presented. In Section III, the SigFox communication mechanism is analyzed in detail. In Sections IV and V, the experimental results following the mentioned scenarios are related and discussed. The ending is represented by the conclusions section.

II. SIGFOX TECHNOLOGY

SigFox technology is part of the LPWAN family of technologies, employed mainly for the development of the IoT networks, when the volume of data sent (data that is oftentimes taken from the sensors) is low (ranging from a few bytes and reaching hundreds of kilobytes), the operating range is great (reaching tens of km), and the current consumption is very low (in the order of mA or tens of mA per transmission). SigFox makes use of the D-BPSK (Differential Binary Phase-Shift Keying) modulation for which the message has a fixed bandwidth of 100Hz and is being sent with a speed of 100bps (for the Europe) or 600bps (for the U.S.), within an unlicensed frequency spectrum that is below 1GHz, for Europe region 868MHz and of 915MHz for the U.S. region. This modulation technique is part of the UNB (Ultra-Narrow Band) modulation type, which, along with Chirp Spreading Spectrum (used by LoRaWAN systems) and Narrow-Band (used by NB-IoT), that requires low-power consumption to ensure connections between nodes and BS. The advantages of using D-BPSK modulation are that it brings a high efficiency in the spectrum medium access and is easy to implement. A low bit rate enables the use of low-cost components in the transceiver part.

The Base Station or the Gateway receiver is highly sensitive as it can demodulate signals that are very close to the limit of noise level without any coding layer. The central frequency of 868MHz being part of the SRD860 frequency band is used in Europe, whilst the ISM900 frequency band with a central frequency of 915MHz is used in the U.S.

SigFox technology has a duty-cycle, whose restrictions vary within the transmitting band from 0,1% to 10%, depending on frequency and global region restrictions. The power level for the Europe area is limited to 14 dBm or 25mW ERP (Effective Radiated Power) with a duty cycle of 1% [16]. In such networks, the star-based topology (one-hop star topology) is employed. In this case the end-devices are directly connected to a base station. In this way, the architecture of the network is simplified and the centralization and sending of information to the Internet is done within a well-defined frame at the level of one physical equipment (e.g. BS or GW). Concomitantly, within such an architecture, the information-transmitting devices (or end-devices) need a transceiver that has special requirements of low-power consumption, an ever-greater operating distance, granting the best coverage possible, guaranteeing the transfer of a limited-volume data stream.

FIGURE 1. LPWAN applications across different sectors.

III. SIGFOX COMMUNICATION MECHANISM

The signal generated by the SigFox technology can also be employed for the effortless coverage of a large area and can delve down to objects found underground. The SigFox communication technology has been created to connect great spans of land, of the order of tens of kilometers in the countryside and a few kilometers in the urban area [17]. The transfer speed of data is low, supporting either 4, 8 or 12 bytes, the maximum data rate is approximately 100bps [18]. Gateway modules are implemented with SDR (Software Defined Radio), the network being usually deployed in partnership with mobile operators. The SigFox infrastructure is still under construction in Europe, meanwhile new agreements are being worked upon by the biggest mobile network operators, so that a great coverage stretch that aims at farther areas than those dealt with nowadays, can be realized [19].

The SigFox communication stack is depicted in Figure 2.

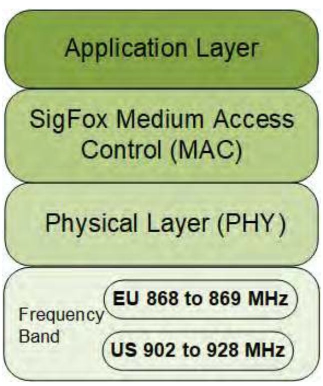

FIGURE 2. SigFox communication stack.

The radio frequency layer includes the SigFox communication channels, the Physical layer includes the modulation scheme, the medium access control, as well as the error detection and the channel access and the application layer defined by the user's requirements and specifications.

The transmission mechanism uses redundancy, thence, data is transmitted for 3 times on different channels (to ensure frequency diversity) at different time intervals (to ensure time diversity). This redundancy makes the communication more robust to interferences. The Gateways listen to the frequency bandwidth spectrum (from 868.034MHz to 868.226MHz for the Europe region) [13]. The initial configuration of SigFox was a unidirectional communication link, where only the node to Gateway communication was permitted (uplink). The Gateway to node communication (downlink) mechanism to ensure bi-directional communication scheme was added later. The node can send a number of 140 messages per day with a maximum payload of 12 bytes (limited by regulations and therefore by policy of the network) and can receive from the application via the Gateway 4 messages per day with a maximum payload of 8 bytes. All these restrictions have power efficiency in mind and must respect a ''gentleman's agreement'', as the official SigFox website mentions it [20]. Similar to a LoRaWAN class A device, when the application wants to send a message to the node, it will have to wait for the receiving time slot to be allocated. A SigFox end-device may only transmit 36 seconds per hour, meaning approx. 6 seconds as time on air per transmission. As a consequence, this will result in only 6 messages per hour, having the payload of 12 bytes, with 2.08s for packet [9]. This slot is activated 20 seconds after the node sends a message. The receiving window has a length between 20.1 seconds and 44.5 seconds in which the node listens for a message from the Gateway [21]. The application sends a message to the node via the nearest Gateway. The random access is a key feature to achieve a high QoS (Quality of Service).

A SigFox node is battery-powered and will transmit data for decades. For example, the current consumption of the AX-SIGFOX ON Semiconductor module is at approximately 19mA, named modulated transmitter current, considering the output power of 0dBm, meanwhile for the maximal output of 14dBm the current consumption is up to 49mA [22]. In this case, the impedance mismatch and the power losses by the

TABLE 1. SigFox characteristics.

Technology	SigFox
Technique	Ultra-Narrow Band (UNB)
Modulation	UL: DBPSK DL: GFSK
Channel Bandwidth (uplink)	ESTI (EU): 100 Hz FCC (US): 600 Hz
Band	SRD860, ISM900
Proprietary	SigFox

action of reflection are neglected and are not considered. Given this situation, if the 140 packets/day/node are taken and if 2xAAA type batteries are used as power supply, each having a capacity of 1500mAh and a scenario of one OOB (Out Of Band) frame transmitter per day at P_{out} of 14dBm, that would work for up to 6,5 years.

The packet is received by the Gateway module and will be sent to SigFox Cloud using an IP-based network. The architecture uses the SigFox Cloud which is an interface between the SigFox customers and the SigFox partners. The Cloud offers services for map predictions related to coverage and can provide management of network devices of the user accounts. As stated in the SigFox technology documentation, the SigFox Cloud is an OSS (Operation Support System) [9].

The SigFox technology uses small packets, so for a 12 bytes payload on air, the frame will have 26 bytes. The protocol overhead is significantly reduced and uses a lighter protocol frame, so less energy is consumed, whilst increasing the network capacity.

Some related papers by Lavric *et al.* [4] and Lavric and Popa [7] analyze and test other LPWAN technologies. SigFox communication uses a frequency band of 100Hz, thus increasing the total number of nodes that can communicate within a WSN network, this being done at the expense of the transfer rate.

SigFox technology offers the possibility of interconnecting LPWANs by proprietary technology.

In Figure 3, the SigFox architecture is presented. The architecture is made of the nodes as well as the Gateways that relay the messages from the node side to the SigFox Cloud and the customer server with the application.

The nodes that have the SigFox technology integrated are sending data to the SigFox BS, which then send the data further towards the SigFox Cloud. At that point, the data is processed before being sent to be screened by customer servers. This means that data is handled by SigFox through its own cloud servers, which find themselves in continuous development.

In Table 1, the main characteristics of the SigFox communication protocol are being displayed.

IV. SCALABILITY PERFORMANCE EVALUATION

Within this section, some of the results whose main goal is the performance evaluation of the SigFox technology are presented. When a new LPWAN-capable technology is developed, there is a need to consider its scalability, evaluated by the ability of supporting a great number of sensors for the same BS or GW. By doing this, one can avoid eventual limitations within the field, concerning the connectivity of devices to the network.

The SigFox communication protocol provides a huge advantage when it comes to the IoT concept. From the obtained results presented within this research paper, one can see that the obtained performance level is high. Within this study the open source model has been included, this model being presented in [23]. This model has been modified, customized and adapted, so that one can effectively analyze the scalability of the SigFox technology.

The bandwidth that is assigned to SigFox communication in Europe is of about 192kHz. The size of a channel is of about 100Hz, which determines a total number of 1920 of channels [9].

This channel number is theoretically obtained because in practice, there is a frequency shift that is specific to each SigFox module. Thus, to obtain elevated performance and implicitly a low PER parameter, adjacent channels are to be avoided. The SigFox technology makes use of a spatial diversity technique due to the fact that the implementation and the planification of the radio network engineered as a data packet to be received by 3 different base stations.

These functions, next to the diversity by means of time and frequency determined by the frequency hopping mechanism, must ensure a heightened QoS. However, in order to have a correct evaluation of performance, one needs to analyze the number of collisions. The frequency on which a SigFox module will communicate is pseudorandomly selected. Thus, the base station is tasked with receiving all the data packets sent by a SigFox node.

The SigFox on air time is at 2.08 seconds. Given the fact that each packet is randomly sent by the means of 3 channels, there is a transmission offset of 45ms. In accordance with the orthogonality condition, from all of the 1920 available channels only 360 are orthogonal. Within Figure 4, we have presented the spectrum allocation when 1000 SigFox devices communicate randomly in a 60 second period.

The packet is transmitted on 3 communication channels for redundancy purpose. Whenever the red color is met in a spectrogram, a collision is occurring.

In Figure 5 we have presented the spectrum allocation when 4000 SigFox devices communicate randomly in a 60 second period. One can observe that the number of collisions is much higher than in the previous case.

In Figure 6 we have presented the spectrum allocation when 5000 SigFox devices are communicating at the same time.

From this configuration, we can conclude that the performance level of the SigFox network is relatively low because of a very high number of collisions. The implemented test scenario is a pessimistic one, because it is very improbable that all the 5000 nodes would want to transmit a packet

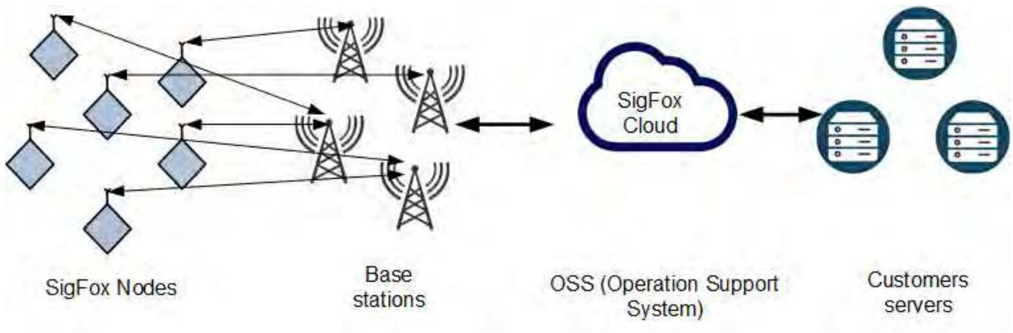

FIGURE 3. SigFox architecture.

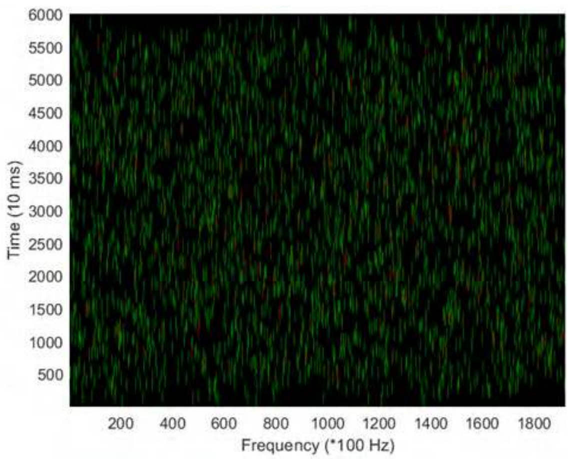

FIGURE 4. SigFox packet collision for 1000 devices.

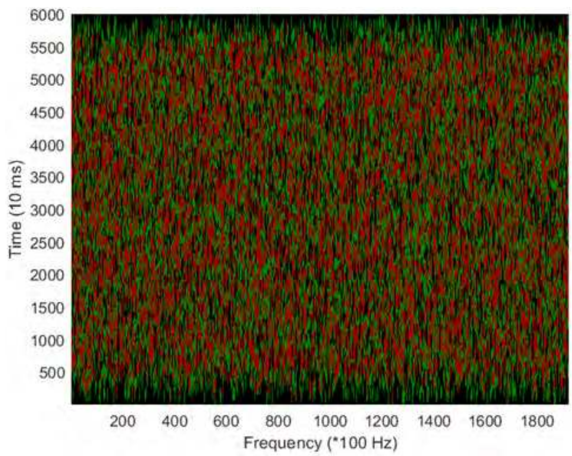

FIGURE 6. SigFox packet collision for 5000 devices.

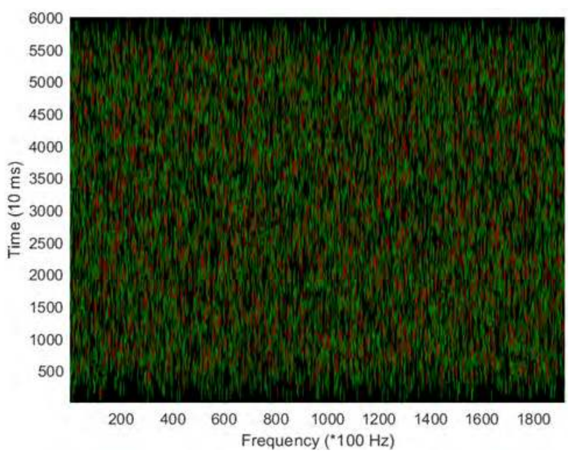

FIGURE 5. SigFox packet collision for 4000 devices.

within the same time period. Usually, considering the SigFox specifications, a node can send a maximum of 140 packets per day, as mentioned earlier. But this assessment is important in order to evaluate and analyze the scalability of the SigFox technology. Within this evaluation of performance level, the messages are sent through all of the 1920 channels, following the diversity mechanism, both in frequency and as well in time, characteristic to the SigFox communication.

Another parameter that was analyzed was the PER calculated by measuring the number of collisions and the number of failed transmissions. The number of channels of the SigFox communication that are being integrated in the model is about 1920, at the level of the SigFox specification. For each channel there is a bandwidth of 100Hz. Each node sends random packets within a limited time span. The time needed for a single packet with a payload of 12 bytes to be sent is about 2.08 seconds.

In Figure 7, we have presented the PER parameter when the SigFox network has 200 to 3000 nodes. A number of 2 scenarios have been considered for evaluation. The former is where each packet is simultaneously retransmitted through three randomly-selected communication channels at different time intervals. The latter scenario is where the packet is sent only through one single communication channel. The goal of this evaluation is impact analysis, which the simultaneous transmission of the packet has upon the performance of the network.

A packet is considered lost if it isn't received, despite the effort of simultaneous transmission by the means of 3 SigFox

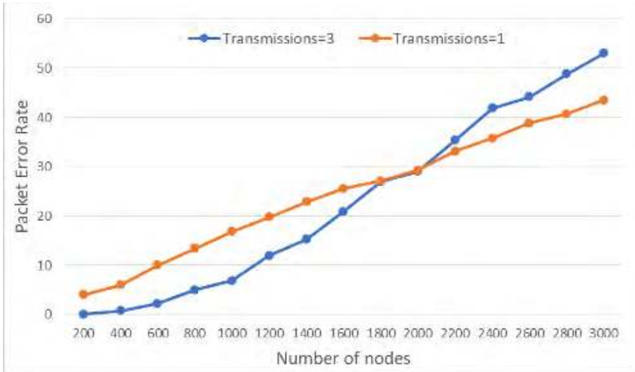

FIGURE 7. PER parameter when the number of nodes is varied from 200 to 3000.

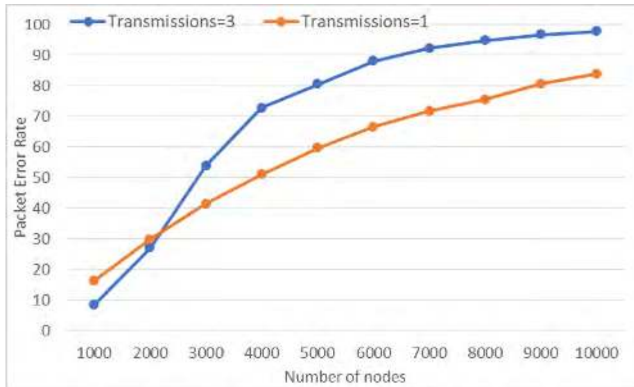

FIGURE 8. PER parameter when the number of nodes is varied from 1000 to 10000.

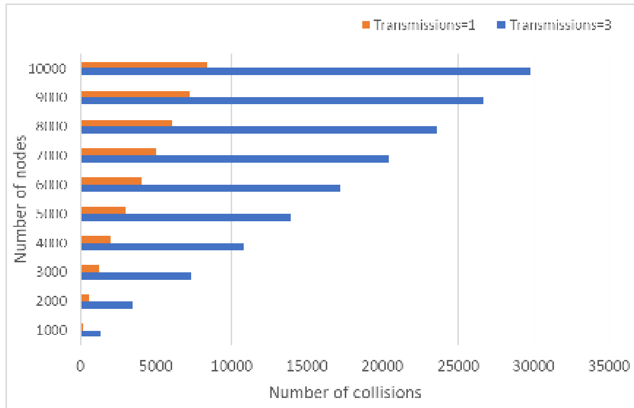

FIGURE 9. Number of collisions when the number of nodes is varies from 1000 to 10000.

channels. The goal of this mechanism was the insertion of redundancy at the data level.

From the obtained results, one can see that the highest value of the PER parameter is at approximately 53% and 43.5%, respectively, whenever the packet is sent by the means of 1 and 3 communication channels, respectively. The SigFox communication mechanism doesn't integrate the possibility of verifying the communication channel occupancy. On the grounds of the crowded RF spectrum, the performance level sharply decreases. For a high level of performance to be reached, it is recommended for the PER parameter to be under 10%. In this case, the maximum number of nodes which can talk to each other at the same time within a network is of approximately 1100 when the number of channels is 1920.

One possible solution could be the decrease in the number of transmissions, so that the number of redundancy-harming collisions is itself lowered. The results show that as long as the number of sensors is either lower or equal to the number of communication channels, the communication mechanism in which the packet is randomly sent through 3 channels guarantees a heightened performance level for the inputted redundancy works and some of the packets are correctly received, despite the collisions.

If the number of sensors would be higher than the number of channels, the redundancy mechanism triggers the deterioration of the performance level of the SigFox network. Thus, in the case of a large-scale high-density sensor network the lowering of simultaneous transmissions particular to a packet is recommended.

In Figure 8, we have presented the PER parameter when the number of nodes varies from 1000 to 10000 nodes. If each packet is to be sent through one channel alone, the PER parameter is with approximately 14% lower than when the packets are sent on 3 communication channels.

In Figure 9, we have presented the number of collisions when the number of sensors varies from 1000 to 10000.

From the obtained results one can see that the number of collisions is much higher whenever redundancy is allowed for. Under such conditions, the performance level of the SigFox network is a low one. Thus, whenever the redundancy mechanism is active, there are approximately 29772 collisions happening when we are dealing with 10000 nodes and 8375 collisions if the packet is sent only once.

Following the SigFox specifications, the total number of 1920 channels represents the theoretical maximum of channels which the base station can demodulate. In practice, the SigFox modules are able to communicate on some 400 channels, each with a bandwidth of 100Hz, 40 of these being reserved so that the number of channels that a node can send data through is about 360 [15].

This feature lowers the number of orthogonal communication channels and further decreases the performance level.

The SigFox channel structure is presented in Figure 10.

The channels have a fixed bandwidth of 100Hz, beginning from 868.180MHz for channel 0 and ending with 868.198MHz for channel 180. The following channels begin from 868.202MHz for channel 220 and end at 868.220MHz for channel 400 [13], [24].

There is a particular shift when it comes to the communication frequency belonging to a SigFox sensor module. This frequency is randomly selected as well without having a mechanism that deals with channel occupancy. Thence, in practice, one module has 360 channels at its disposal if

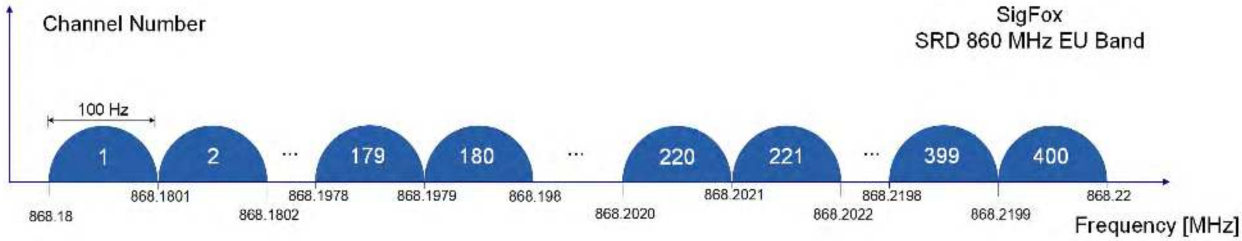

FIGURE 10. SigFox channel allocation.

we are to disregard those reserved. This feature will further lower the capacity of a SigFox network.

SigFox claims that the QoS of the network lowers dramatically whenever the sensors communicate at the same time. This aspect is resolved by closely monitoring the SigFox network performance. From a theoretical standpoint, each SigFox sensor needs to talk to at least 3 base stations so that to fulfill load-shifting from one base station to another.

The following step is to integrate this particularity in the developed model so that one can evaluate and estimate the scalability of the SigFox communication process.

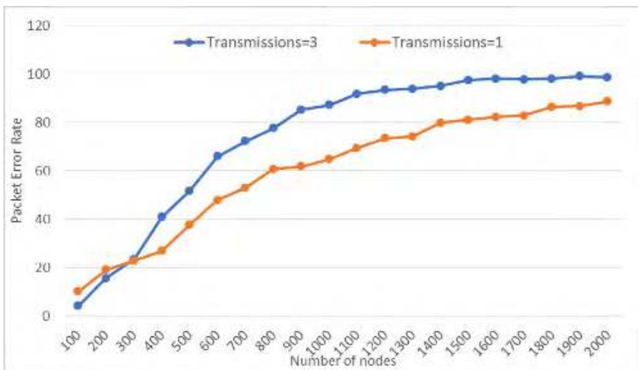

FIGURE 11. PER parameter when the SigFox number of channels is 360.

In Figure 11, we have presented the PER parameter when the SigFox number of channels is 360.

From the obtained results from approximately 360 nodes, the packets that are randomly sent over 3 channels will produce a PER of 26.87%. If we are to ignore the redundancy mechanism, the PER parameter is at 23.7%.

Another possible solution for the increase of performance might be the implementation of a channel occupancy detection system through the development of a collision avoidance mechanism. In this scenario, in order to obtain a high level of performance, the number of SigFox nodes that can communicate at the same time on 360 channels is 100.

V. SIGFOX TRAFFIC GENERATOR

This section presents the development of the implementation and the testing of a SigFox traffic generator. The proposed architecture can be used for the analysis of eventual interferences which may occur when we are dealing with a high-density large-scale network; this instrument allows the performance evaluation of large-scale high density SigFox networks. The novelty and the main contribution are in the development of the system, this being the first of its kind from within scientific research field until now.

The first problem resolved was generating the SigFox raw signals which could be later sent by means of a Software Defined Radio (SDR) platform. Thus, Open SigFox Stack Library (Open SigFox Stack) has been therefore implemented in the system. This library is developed in Python and C programming languages and represents an open source implementation of the SigFox communication stack, allowing the possibility of integration within embedded applications which run by microcontrollers. By using this stack, raw files which can be integrated within the SDR system have been generated.

The architecture of the SigFox Traffic Generator is shown in Figure 12.

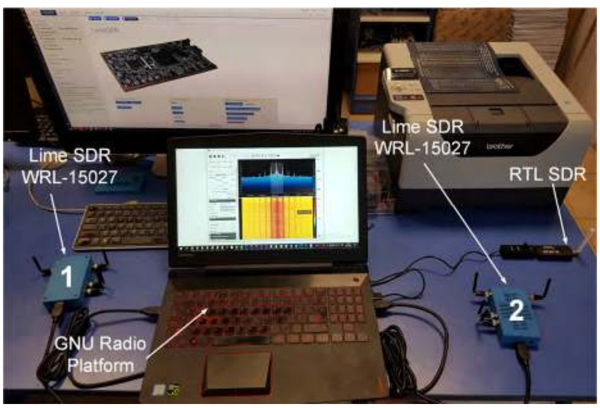

FIGURE 12. SigFox traffic generator architecture.

This features two LimeSDR WRL-15027, as well as a PC station, which runs the application able to generate the SigFox packets with the addition of a GNU Radio interface used for the command of the SDRs. One RTL SDR dongle for the visualization of the generated traffic [25] by the analysis of the spectrum is also integrated with the system.

The logical diagram which is integrated at the level of the SigFox traffic generator is displayed in Figure 13. The generator makes use of many technologies and techniques that allow a greater data stream to be generated.

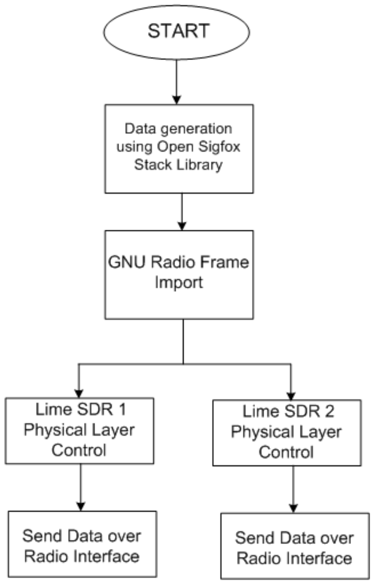

FIGURE 13. SigFox traffic generator logic diagram.

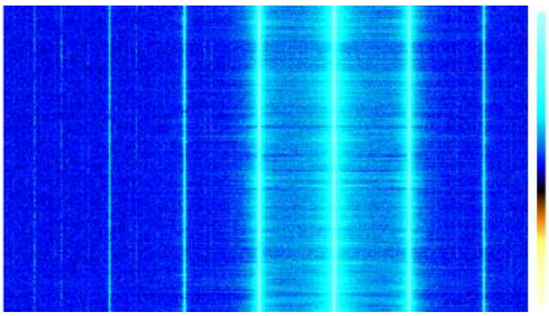

FIGURE 14. SigFox packets spectrogram.

As one can see the Open SigFox Stack Library is used to generate data. This data is interpreted by using GNU radio framework then to be resent by means of LimeSDR platform.

The SigFox packets generated by the proposed architecture can be observed with the help of the spectrogram from Figure 14. Each SDR platform has two emitters which can be used at the same time, each of them integrating a multiplexor type structure.

Each packet is transmitted 3 times on different channels at random time intervals following the SigFox protocol specifications. Each SDR has the ability of emulating the traffic coming from thousands of nodes. The SigFox traffic generator has the potential of becoming an architecture which can contribute to the performance analysis of large-scale high-density sensor networks.

The spectrogram in which the SigFox packets are present is displayed within Figure 15. From the results, one can see that the SigFox communication bandwidth is of 100Hz and on 3 randomly selected channels the packets are sent at various time intervals.

The next step was the evaluation of the emulator by using the SigFox SDR dongle [26]. This is an instrument which allows for the emulation of a SigFox Gateway and also grants

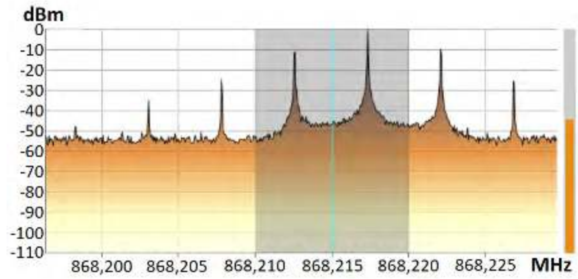

FIGURE 15. SigFox generator spectrogram.

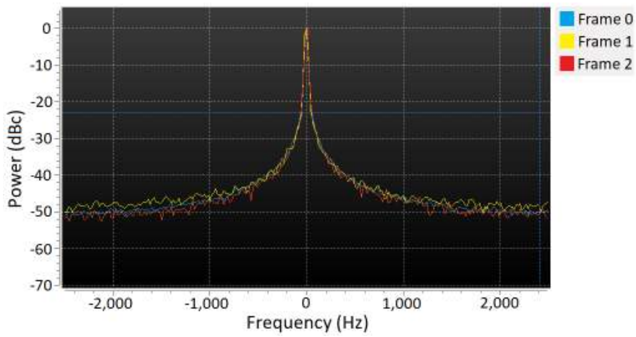

FIGURE 16. FFT analyses using the SigFox SDR dongle.

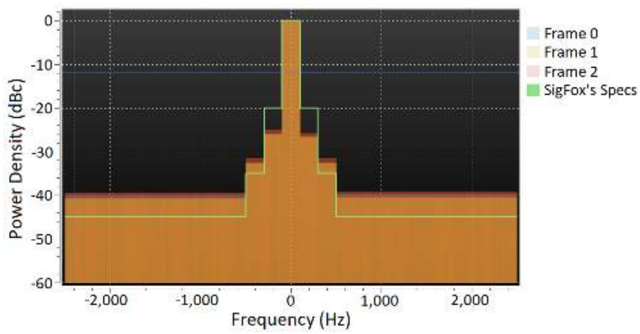

FIGURE 17. Power spectral density.

the ability of testing new nodes and prototypes as well as obtaining the SigFox certification itself. The FFT Analysis using the SigFox dongle in spectrum analyzer mode is presented in Figure 16.

From the obtained results the SigFox packets that are identified by the system as belonging to the SigFox communication can be seen. These can be demodulated. This feature verifies the functionality of the SigFox traffic generator.

The analysis of the spectral power density is depicted in Figure 17. From the given results, one can conclude that the spectral power from the sub-band is higher than what is to be wished for from the SigFox specification; however, this drawback can be corrected from the settings of the Lime SDR platform.

VI. CONCLUSIONS

The SigFox communication protocol provides us with a proper candidate when it comes to the IoT concept. The goal of this evaluation is impact analysis, which the transmission of the packet has upon the performance of the network. From the obtained results one can see that the level of performance obtained is high when we bring the number of transmissions within a packet to one. In the first part of the work the developed model of the SigFox communication is presented. This provides us with an essential instrument to use for large-scale high-density sensor networks. The number of channels is theoretically obtained because in practice, if we aim to get elevated performance and implicitly a low PER parameter, adjacent channels are to be avoided.

From the obtained results one can see that to ensure a high level of performance (e.g. PER below 10%), the highest number of sensors which can communicate at the same time is of approximately 100, if the number of available channels is 360. At the same time, with the increase of the number of sensors, an avalanche effect is triggered which determines the drastic lowering of the level of performance. If 1920 channels are available from those, only 1100 SigFox modules can communicate simultaneously and achieve a PER below 10%. These results are obtained for the tested communication scenarios.

One possible solution could to exclude the redundancy mechanism for specific applications or of a particular scenario like having one base station available. Another idea beneficial to performance could be the implementation of a mechanism that warrants the degree of usage of the channel through the development of a collision avoidance system. This paper presents the development, implementation and testing of a SigFox Traffic Generator. This instrument can be used for the analysis of the possible interferences which may occur when we are dealing with a high-density large-scale network, whenever it comes to evaluating the performance level of such a network. The novelty and main contribution are represented by the development of the system, this being, from the authors' knowledge, the first of its kind that has been dealt with by the scientific literature. Each SDR has the ability of emulating the traffic gathered from thousands of SigFox sensors, with odds of becoming an instrument that lends to the performance analysis of SigFox sensor networks.

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ALEXANDRU LAVRIC was born in 1987. He received the bachelor's degree in administrative sciences and the master's degree in business affairs from the Faculty of Economics and Public Administration, Stefan cel Mare University of Suceava, in 2008 and 2010, respectively, and the M.Sc. degree in computer and communication networks and the Ph.D. degree in computer technology from the Stefan cel Mare University of Suceava, in 2011 and 2013, respectively. He is currently with the Faculty of Electrical Engineering and Computer Science, Stefan cel Mare University of Suceava. He has published more than 50 scientific papers. His research interests include WSN, the IoT systems, smart sensors, and wireless communication technologies.

ADRIAN I. PETRARIU was born in 1984. He received the M.Sc. degree in electronics and the Ph.D. degree in computer technology from the Stefan cel Mare University of Suceava, in 2009 and 2013, respectively, where he has been a Lecturer with the Computers, Electronics and Automation Department and a member with the MANSiD research team, since 2016. He has published more than 20 papers. His research interests include RFID systems, antenna design, impedance matching circuits, and wireless communication (ZigBee, Bluetooth, LoRa, SigFox, and the NB-IoT).

VALENTIN POPA was born in 1964. He received the M.Sc. degree in electronics and telecommunication and the Ph.D. degree in components, electronic devices and circuits from the Polytechnic Institute of Iasi, in 1989 and 1998, respectively. Since 2005, he has been a Full Professor and a Ph.D. Adviser with the Computers, Electronics and Automation Department, Stefan cel Mare University of Suceava, where he has also been the Rector, since 2012. He has authored or co-authored four books about his scientific achievement published in Romania, co-author four chapters, and over 100 scientific articles. His research interests include radio frequency identification (RFID), wireless data acquisition systems, and data information and transmission.