Performance Evaluation of LoRa and Sigfox LPWAN Technologies for IoT

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Abstract:

Internet of Things (IoT) is a system that connects computing devices including phones, sensor, mechanical machines and other items over a network allowing them to exchange data and perform tasks without human interaction. It has altered the means by which connected devices interact and communicate, facilitating smarter and more convenient applications. As a result of their technological specifications, these devices are considered power constrained, as they lack battery sources. Therefore, they require a suitable underlying technology that considers power constraints and fulfills other IoT application requirements including long-range communication and low cost. Low Power Wide Area Network (LPWAN) is a communication technology that is gaining increasing popularity, as it provides low-rate long-range communication suitable for IoT applications. This research uses simulation to evaluate the performance of LoRa and Sigfox as the leading LPWAN technologies. The simulation evaluates collision, packet error rate and spectrum using different values for channel bandwidth. It also examines the impact of the number of IoT devices on network performance. Results reveal that Sigfox has less collisions and packet error rate compared to LoRa. They also show that in general, increasing the number of devices leads to increasing collision and packet error rate. Utilizing larger bandwidth provides more available slots and therefore reducing collision.

Keywords: LoRa, NB-IoT, Packet Error Rate, Power Constrained Devices, Sigfox.

1. Introduction:

The number of Internet-connected devices has already exceeded that of non-connected devices worldwide. By 2025, the number of Internet of Things (IoT) connected devices is estimated at almost 40 billion devices (Statista, 2021). Due to their nature, IoT devices including phones, sensors and actuators are constrained by a number of factors and require a technology that suits their limitations. Since IoT devices do not have a battery source, they should not operate under high power consumption. In addition, IoT applications require long range communication to transmit relatively small amounts of data. All these requirements are expected to be fulfilled at affordable costs. Short-range networks such as Bluetooth not only lack the long-range communication criteria vital for IoT, they are also considered expensive. They are most popular for providing high data rates, a feature that is insignificant to IoT. On the other hand, even though cellular networks provide long-range communication, the high power consumption associated with this type of communication results in them not being a suitable candidate for IoT communication.

A Low Power Wide Area Network (LPWAN) provides long-range communication of up to 10-15 km in rural areas and 2-5 km in urban areas, and it is highly energy-efficient and inexpensive. These features have resulted in LPWAN becoming the most suitable communication technology for IoT. The most promising technologies among LPWANSs are LoRa and Sigfox.

Long Range (LoRa) is a physical layer wireless modulation technology for long-range low-power low-data-rate applications developed by Semtech. It utilizes unlicensed frequency bands and a spread spectrum technique to modulate signals in sub GHZ ISM bands. End devices are connected to gateways (base stations) using single-hop LoRa and gateways are connected to the network server using standard IP connections. Most traffic is in the uplink where multiple data rates can be used with no interference. The data rate is specified with respect to communication range, message duration and end device battery life and ranges from 0.3 kbps to 50 kbps (Raza et. al, 2017) (Lora Alliance, 2017).

Sigfox is an LPWAN technology that connects end devices to its base stations using an ultra-narrow band (100 Hz) sub-GHZ ISM band carrier. Similar to LoRa, Sigfox technology utilizes unlicensed ISM bands.

The maximum throughput is 100bps. Communications from the base station to end devices are responses to uplink messages which are limited to 140 messages per day and a size of 12 bytes. Messages received at base stations are transmitted to the cloud using a Virtual Private Network (VPN) tunnel for increased security. Sigfox benefits include low noise levels, low power consumption, higher receiver sensitivity, and low-cost antenna design (Gennaro et. al, 2018) (Ismail et. al, 2018).

In our work in (Osman & Abbas, 2018), we presented initial simulation results for the comparison between LoRa and Sigfox technologies. In this paper, we extend the results by considering additional number of connected IoT devices as well as variant channel bandwidth values under LoRa. A simulation is developed to evaluate the performance of an IoT network employing LoRa and Sigfox LPWAN technologies. The simulation considers different values for the number of IoT devices and channel bandwidth.

2. Research Objectives:

The objectives of this research are to:

1. Investigate the functionality of LoRa and Sigfox technologies and develop a simulation model accordingly.

2. Examine the influence of the number of IoT devices on network performance.

3. Evaluate the influence of channel bandwidth in LoRa technology on attained performance results.

4. Calculate the resultant collision and Packet Error Rate (PER) and demonstrate spectrum representation under considered LPWAN technologies.

3. Research Importance:

To date, there is still a need for full evaluation of LPWAN technologies in order to estimate network performance and the suitability of each technology for various IoT environments and applications. The comparative results attained by the simulation provide a valuable insight of the performance of the two considered technologies with respect to the number of IoT devices.

4. Related Work:

Previous literature in LPWAN can be classifies with respect to research orientation into three categories. The first group of related work reviews surveys in LPWAN which mostly present background information on LPWAN, features and challenges. They also provide comprehensive comparison between different LPWAN technologies. The work presented in the second group implements real-world LPWAN networks in specific environments. Their results are extracted from actual parameter measurements from deployed networks. A third category consists of related work that focuses on evaluating the suitability of LPWAN technologies for a certain application area. These works are either theoretical or involve an actual LPWAN network.

4.1 Theoretical Surveys:

A number of previous studies have surveyed LPWAN technologies considering theoretical insights (Raza et al., 2017) (Ismail et al., 2018) (Sinha et al., 2017) (Mikhaylov et al., 2016) (Chaudhari et al., 2020). The survey in (Raza et al., 2017) explains the design goals of LPWAN and surveys major LPWAN technologies including LoRa, Sigfox, Ingenu and Telensa. In addition, it explains LPWAN technical specifications and standards grouped by their developing organizations. The survey indicates that existing standards focus on the physical layer, while challenges in upper layers yet remain.

A second survey presented in (Ismail et al., 2018) provides a comparative study on Sigfox, LoRa, Narrow Band IoT (NB-IoT) and Long Term Evolution for Machines LTE-M. It reviews technical features, deployment aspects as well as advantages and disadvantages of each technology. Moreover, it associates different applications to the best technology based on connectivity aspects. Paper (Sinha et al., 2017) surveyed the suitability of LoRa and NB-IoT for IoT applications. The survey focused on their advantages and disadvantages in terms of technological features. The paper suggests employing LoRa for low cost applications while NB-IoT is more compatible with high quality low latency IoT applications.

The study in (Mikhaylov et al., 2016) analyzed LoRaWAN performance and scalability under European frequency regulations for a number of application scenarios. It stated that a single base station can accommodate several millions of devices, but with uplink data rates not more than 2kbit/s. The study recommended that end devices requiring additional uplink data rates should be located close to the base station.

The authors of (Chaudhari et al., 2020) identified the features of a wide range of IoT applications and converted these characteristics into design requirements. They also surveyed the design considerations, topologies and architectures of various LPWAN technologies including LoRaWAN, Sigfox, NB-IoT, LTE-M and others. Moreover, they explained the relevance of 5G technology to future IoT. The authors stated that 5G is expected to cater for future IoT applications alongside LPWAN targeting applications that require high data rates. Hybrid cellular-low power WAN architectures are possible solutions.

4.2 Experimental Environments:

The work in (Mekkia et al., 2017) 0(Petal & Won, 2017) (Benny et al., 2017) (Neumann et al., 2016) (Petrić et al., 2016)0 (Lauridsen et al., 2017) (Prando et al., 2019) deployed real-world LPWAN networks for evaluating various technologies. In (Mekkia et al., 2017), Sigfox, LoRa, and NB-IoT are compared with respect to IoT factors. The comparison indicated that NB-IoT outperforms other technologies in terms of scalability, battery life, latency, Quality-of-Service (QoS) and payload length. Sigfox and LoRa showed resemblance in many factors, however, Sigfox proved to have the best range and coverage among all.

The study reported in (Petal & Won, 2017) investigates the impact of mobility on the performance of LPWAN in mobile IoT networks. Results indicated that even low mobility considerably influences the LPWAN network, and the impact of mobility depends on factors such as speed, the distance from the gateway and the surrounding environment. The study in (Benny et al., 2017) compares SigFox, LoRa, General Packet Radio Service (GPRS), and NB-IoT in terms of network coverage and capacity under a real network implementation. Indoor and outdoor scenarios are considered, and the performance of uplink and downlink communication is evaluated. The results revealed that even though all technologies provide high performance communication for outdoor users, GPRS is unable to accommodate 40% of indoor users. LoRa maintains low blocking probability but suffers high uplink collisions. In addition, it outperforms Sigfox in downlink communication performance. In general, NB-IoT outperformed other technologies due to utilizing link adaptation.

The case study presented in (Neumann et al., 2016) evaluated the performance of LoRaWAN in an indoor environment. It examined the size of data, signal quality, coverage and data rate. The experimental results showed that channels have a maximum daily transmitted data.

In addition, signal quality degradation was noticed in the basement of the building, and therefore this type of network might not be suitable for underground applications such as car parking monitoring. Moreover, the distance of the end device from the gateway influenced the maximum achievable data rate. The authors of (Petrić et al., 2016) implemented an experiment to evaluate the performance of a LoRa star topology network with IoT communication. They performed range and fixed point measurements for PER, Received Signal Strength Indicator (RSSI) and Signal to Noise Ratio (SNR). Their finding implied that the factors that influence network performance include antenna type, base station elevation and communication environment. They highlighted the inefficiency of the network since end devices communicate with all base stations in range simultaneously. Experiment results also found no correlation between RSSI and PER.

The interference of an IoT network employing LoRa and Sigfox is evaluated in (Lauridsen et al., 2017) considering five different environments. The objective is to examine signals interfering with the European Industrial, Scientific and Medical band 863-870MHz, as interference is a major parameter influencing network coverage and capacity and therefore restricting IoT deployment. Measurements revealed that there is a 22-33% probability of interfering signals in the shopping area and business park, and less than 3% in the industrial and residential areas. In residential areas, interfering channels are mainly Radio Frequency Identification (RFID). The experiment conducted in (Prando et al., 2019) contrasted the performance of LoRa against IEEE 802.15.4g for IoT environments, namely sensitivity and PER. Measurements indicated that the LoRa showed better performance due to the wide bandwidth it offers. However, this wider bandwidth might conflict with laws of regulator organizations. The documentation of IEEE 802.15.4g is fully and thoroughly documented..

4.3 Application Implementations:

In order to investigate the suitability of LPWAN technologies for particular application types, LPWAN specifications and characteristics are compared with respect to application requirements. In addition, the performance of LPWAN networks is evaluated under the specific application (Gennaro et al., 2018) (Roque & Padilla, 2020) (Wang et al., 2020) (Santa et al., 2019) (Islam et al., 2020) (Singh et al., 2020) (Rubio-Aparicio et al., 2019) (Thoen et al., 2019).

A water monitoring system was developed and implemented in (Gennaro et al., 2018) which gathered readings related to water quality such as PH, temperature and turbidity employing Sigfox. The proposed system costed only 10% of traditional solutions and used solar power to provide energy, which was already reduced due to significant reductions in the duty cycle. The authors of (Roque & Padilla, 2020) presented a low-power prototype for a fire detection system employing Sigfox. They assessed the time from the moment a fire starts until the system reaction with respect to the distance between sensors. They recommend placing sensors 25 meters apart which results in 16 minutes response time, a huge improvement over satellite-based monitoring systems.

The study presented in (Wang et al., 2020) allows specifying a weight for each performance matric with respect to application requirements and then calculate a weight for each LPWAN technology accordingly. It considers LORAWAN, Sigfox and NB-IoT with the objective of pinpointing the most suitable technology for the considered application type. The proposed method was applied to a parking detection system and calculations found that LoRaWAN was the most suitable technology for car parking applications. A network interface for vehicle monitoring using LPWAN was developed and implemented in (Santa et al., 2019). The system deployed LoRaWAN technology to connect vehicles moving in a ring with a 1km radius, and the performance of the system was evaluated. Attained results proved the suitability of LoRaWAN for such applications with a Packet Delivery Ratio (PDR) of 95%. Results also recommended direct line of sight with the gateway to maximize signal strength.

A smart farming system is designed and implemented in (Islam et al., 2020) employing three LPWAN technologies: LoRaWAN, Sigfox and NB-IoT. The objective was to compare the performance of the three technologies in remote communication IoT applications. Moister sensors were installed in the farm to provide data for the sprinkler system, and weather conditions including temperature, humidity and wind were measured for more accurate irrigation decisions. Results stated that NB-IoT had better performance in terms of QoS, latency and scalability whereas Sigfox provided the best coverage by far. Results also showed that end devices of LoRaWAN and Sigfox consumed less energy compared to NB-IoT, though LoRaWAN performed best under high mobility of end devices.

Another experiment implemented in a farming system is presented in (Singh et al., 2020) where the energy efficiency of LoRaWAN, DASH7, Sigfox and NB-IoT end devices installed in a greenhouse was evaluated. The evaluation considered different battery capacities and message transmission rates. Results revealed that the major factors influencing end device lifetime were message transmission power and current idle power. In addition, LoRaWAN and DASH7 proved to be more energy-efficient compare to NB-IoT and Sigfox.

The authors of (Rubio-Aparicio et al., 2019) designed and implemented a water meter monitoring system employing a mixed LoRa-Sigfox network architecture. The aim was to take advantage of LoRa base stations to reach areas of poor coverage, and then transfer signals to the Sigfox gateway. For areas with reception rates of 75% and lower, the mixed architecture provided 100% coverage, since the areas conventionally not covered by the Sigfox gateway became reachable using LoRa sites. In areas with high received signals, it was ideally more effective to only maintain the Sigfox architecture. The authors of (Thoen et al., 2019) design an open-source low-cost low-energy LPWAN platform for IoT applications. Cost efficiency was realized by eliminating the modem, whereas energy efficiency was achieved by significantly reducing sleep power. The proposed design was implemented and verified in a tree health monitoring system. The expected lifetime of the proposed system was up to 2 years in contrast to at most 0.2 years for the LoRaWAN architecture.

5. LoRa and Sigfox Network Architectures:

LPWAN technologies have emerged introducing features that were not previously offered by existing wireless networks. The network design of LPWAN technologies has a common architecture with some components which are specific to a certain technology. Figure.1 shows the LPWAN common architecture with main components.

Network end devices access the network through one or several base stations using single-hop radio frequency communication. They broadcast messages with respect to their type and application settings. Any base station that detects the message will forward it to the Network Server without any data processing (Santa et al., 2019). Base stations are connected to the Network Server (or the Cloud) via secured standard IP connections. Network Servers are in charge of authentication, access control, mobility and data traffic management.

A secure link, generally Hypertext Transfer Protocol (HTTP) over Transport Layer Security, connects Network Servers to Application Servers that provide the platform for application data storage and processing (Gennaro et al., 2018).

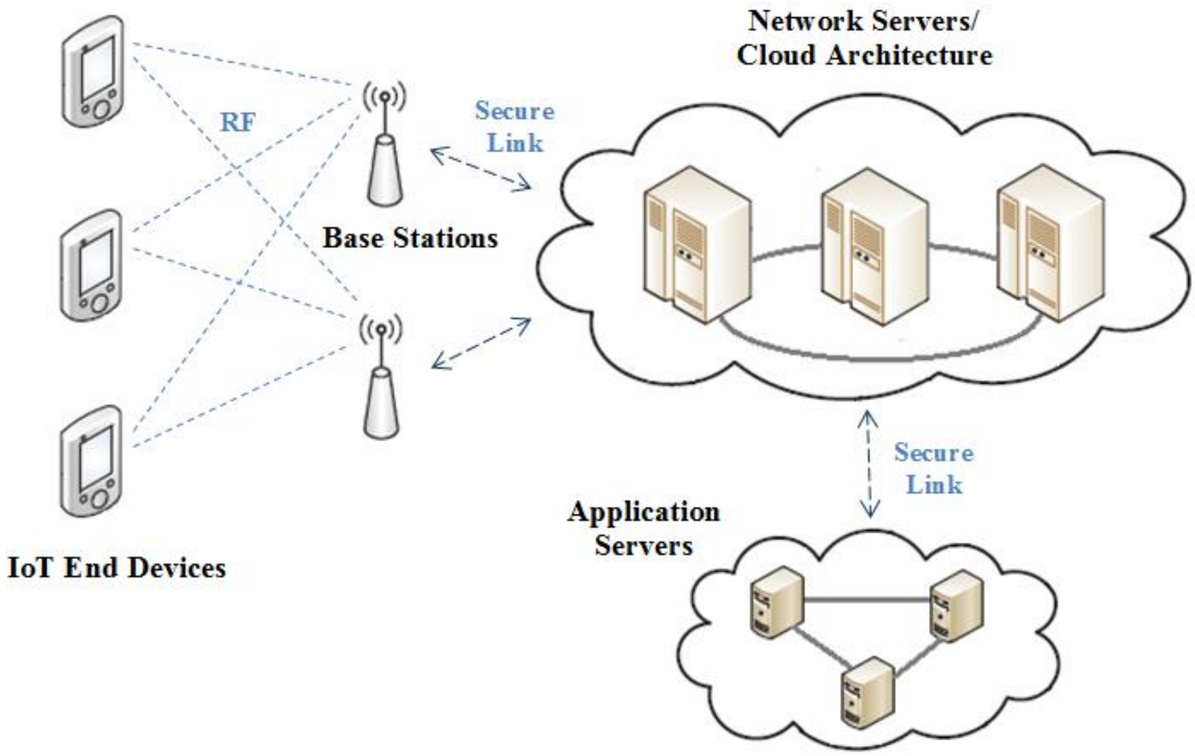


Figure.1 LPWAN Network Architecture

6. Simulation Model:

In this work, a simulation is developed to evaluate the performance of LoRa and Sigfox technologies under different input parameters. Following we reveal the simulation inputs, performance evaluation parameters and describe the simulation.

6.1 Simulation Inputs:

The inputs of the simulation are:

1. LPWAN technology:

There are two LPWA technologies that have been considered in the model which are: LoRa and Sigfox. The technology type must be determined at the start of the simulation, to consider communication differences between them.

2. Bandwidth:

There are three bandwidths specified for LoRa (125, 250, and 500 kHz). Sigfox uses 200 kHz which is defined for 868.7 - 869.2 MHz frequencyband.

3. Maximum number of devices:

The value of the maximum number of devices is selected to evaluate the network performance and investigate its influence on performance metrics.

6.2 Simulation Outputs:

The outputs of the model are:

1. Collision:

When two or more devices attempt to transmit a packet across thenetwork at the same time, a packet collision will take place. Collision is considered a concerning issue in LPWAN as it influences network performance. The output of the evaluation here is the number of collisions that occurred during the simulation process.

2. Packet Error Rate (PER):

PER is the ratio, in percent, of the number of packets not successfullyreceived to the number of packets sent by end devices. This value influences network performance and can have a toll on the quality of received data.

3. Spectrum representation:

The spectrum is a mapping operation (i.e. visualizing) of the packets performance. It is expressed in the form of a matrix; the rows represent the number of slots, and the columns represent the number of channels.

6.3 Simulation Description:

The evaluation carried out in this paper is achieved using a simulation which adheres to the following steps:

- Initialization of all variables.
- Selecting the desired LPWAN technology (LoRa or Sigfox), as well as bandwidth and maximum number of devices.
- If the selected technology is LoRa, it randomly generates the spreading factor according

to the number of channels.

- Generation of specific packet duration values according to each technology specification.
- Calculating the number of time slots according to Equation (1):

$$Number\ of\ slots = \frac{simulation\ time}{time\ interval} \quad (1)$$

- Time offset values are randomly generated as shown in equation (2). The time offset is generated for all simulated devices which represents offset between each device packet transmission, each device considered to send one message or packet. The simulation will check if there is an available slot in the current channel in order to continue. In this case the packet is transmitted and the simulation continues transferring packets. Otherwise, a collision occurs and the packet transmission fails.

$$Time\ offset = No.of\ slots - \frac{(packet\ duration \times no.\ of\ packets)}{time\ interval} \quad (2)$$

- The simulation terminates when the maximum number of devices is reached, and the PER is calculated using equation (3):

$$PER = \frac{no.\ of\ collisions}{total\ packets} \quad (3)$$

At the end of the simulation, the evaluation parameters (PER, collision and spectrum representation) are displayed.

7. LoRa and Sigfox Performance Evaluation:

In this section, we demonstrate by results the outcomes of the comparison between LoRa and Sigfox LPWAN technologies in terms of PER, collision and spectrum representation. The simulation is implemented using MATLAB, and input values are shown in Table I. The simulation assumes random access to six channels specified inside the specified bandwidth, so random spreading factors are generated in the range from 6-12. It randomly generates the spreading factor according to the number of channels.

Table I. Simulation parameters

Parameter	Value
Spreading factor	6-12

Frequency band	868.7 - 869.2 MHz
LoRa channel bandwidth	125, 250, and 500 kHz
Sigfox channel bandwidth	200 kHz
Payload size	25 bytes
Maximum number of devices	500/1000
Frequency interval	100 Hz
Time interval	10 ms
Simulation time	60 seconds

7.1 LoRa Performance Evaluation:

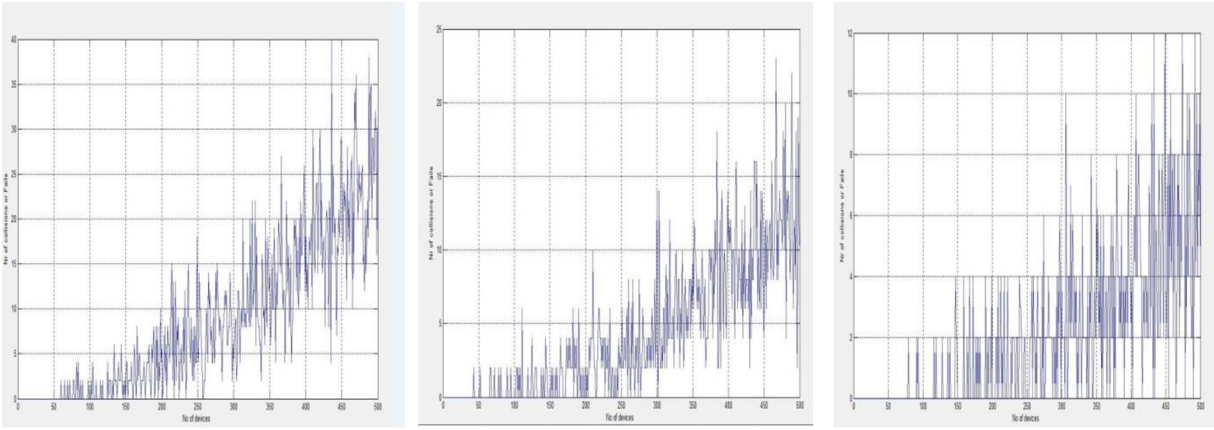
The simulation is run when LoRa technology is selected under considered maximum number of devices and bandwidth. Simulation results are demonstrated according to the performance metrics (PER, collision and spectrum).

7.1.1 Collision:

The upcoming figures (Figure. 2 throughout Figure. 4) illustrate packet collision of LoRa technology for maximum number of devices 500 and1000.

A. Maximum number of devices = 500:

In the case of 500 devices, the collision of packets is evaluated considering a bandwidth of 125, 250 and 500 kHz and the result in shown in Figure.2. The collision under the three considered bandwidths experiences similar influence by number of devices. Increasing the number of devices results in more collisions. By comparing the three figures, when the bandwidth is increased, collision decreases, as additional bandwidth allows for more successful packets transmission.

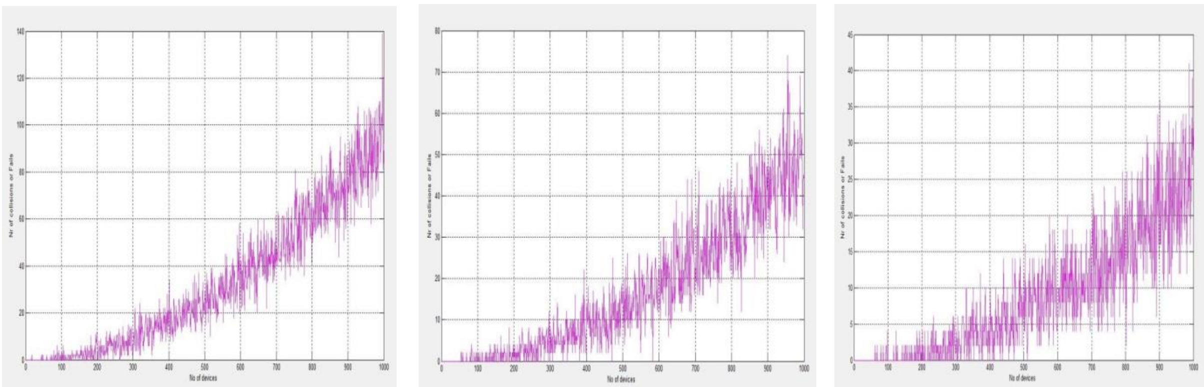


(a) (b) (c)

Figure.2 Collision of packets (500 devices) in (a) 125kHz, (b) 250kHz and (c) 500kHz

B. Maximum number of devices = 1000:

The same evaluation is carried out under 1000 devices. Figure.3 depicts packet collisions considering LoRa bandwidths of 125, 250 and 500 kHz. Similarly, increasing the bandwidth results in fewer collisions. In addition, increasing the number of devices has a subsequent increase in packet collisions.



(a) (b) (c)

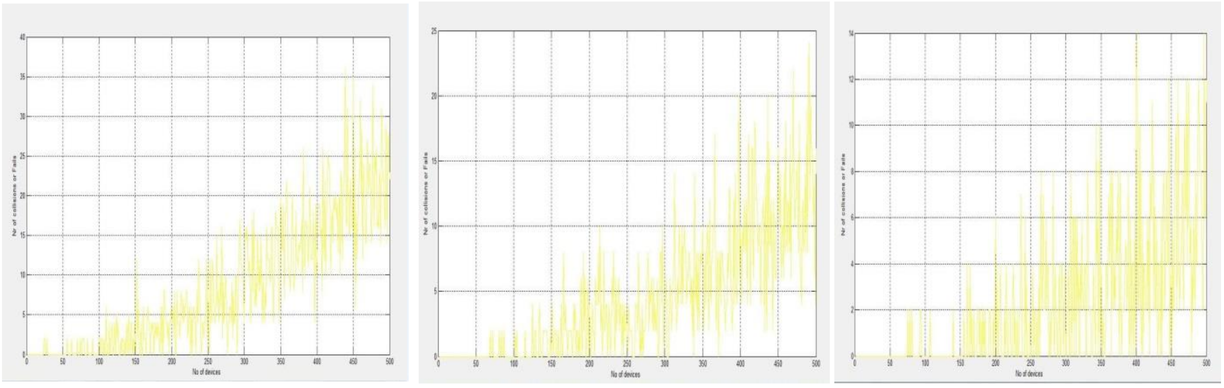
Figure.3 Collision of packets (1000 devices) in (a) 125kHz, (b) 250kHz and (c) 500kHz

7.1.2 Packet Error Rate (PER):

The PER of LoRa technology for a total number of 500 and 1000 devices under 125, 250 and 500 kHz bandwidths is evaluated and illustrated in Figure.4 and Figure.5.

A. Maximum number of devices = 500:

In the case of 500 devices, the increase in the number of devices results in increasing the number of packet collisions which consequently implies a growing PER. Having a higher bandwidth reduces PER. This can be observed in Figure.4.

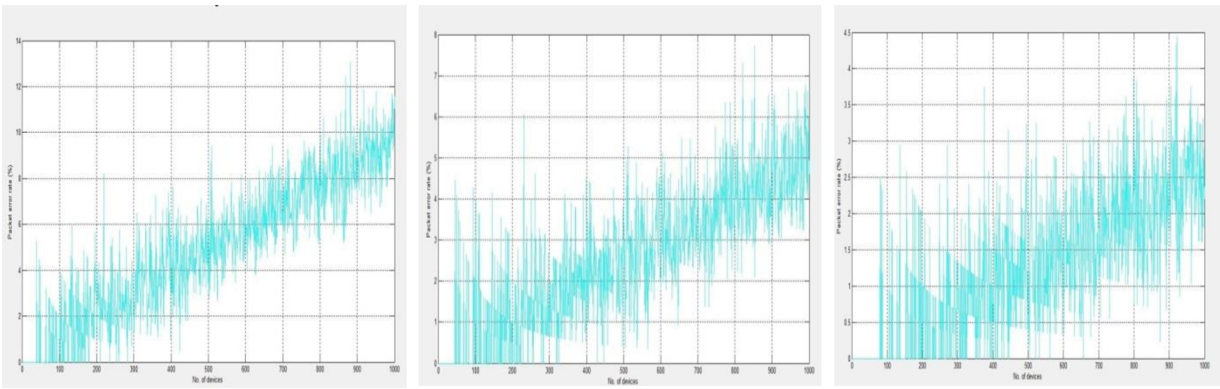


(a) (b) (c)

Figure.4 PER (500 devices) in (a) 125kHz, (b) 250kHz and (c) 500kHz

B. Maximum number of devices = 1000:

Here, the PER is evaluated under 1000 devices considering the three bandwidths of LoRa technology. As seen in Figure.5, the PER decreases when the bandwidth is increased. But the PER is higher comparedto having 500 devices; which means that in general PER increases when increasing the number of devices.



(a) (b) (c)

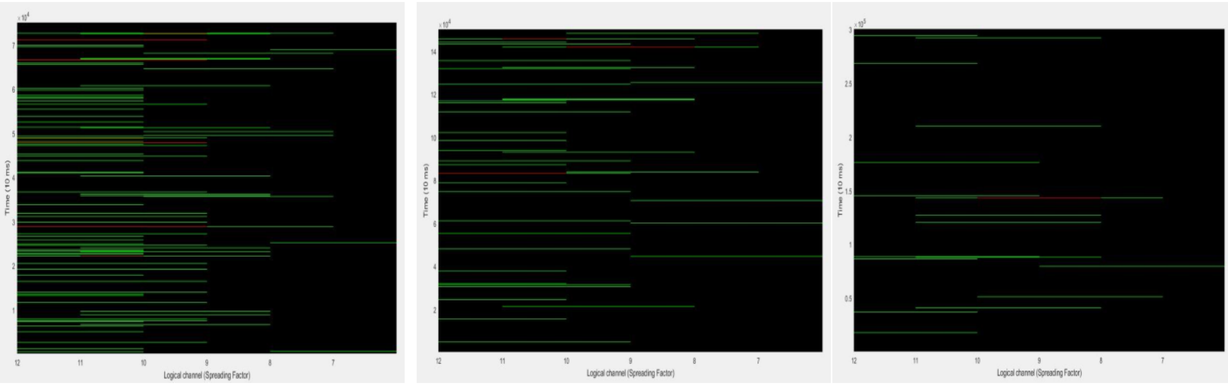
Figure.5 PER (1000 devices) in (a) 125kHz, (b) 250kHz and (c) 500kHz 125 kHz

7.1.3 Spectrum:

Figure.6 and Figure.7 illustrate the spectrum representation of LoRa technology for a total of 500 and 1000 devices. In this evaluation, green lines represent used slots, black lines are the available slots and red lines exemplify collisions.

A. Maximum number of devices = 500:

In the case of 500 devices the spectrum visualization is evaluated considering the three bandwidths of LoRa technology. From Figure.6, it can be observed that when the bandwidth is increased the available slots increase and at the same time collision decreases.



(a) (b) (c)

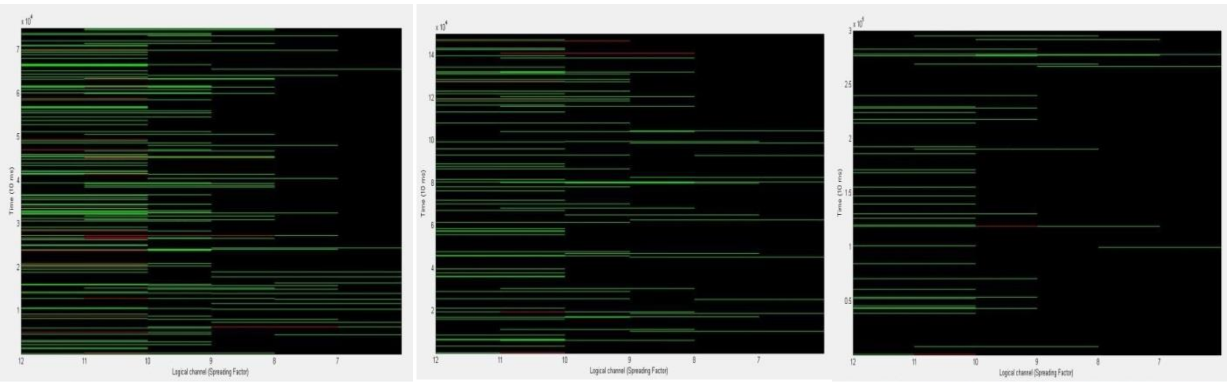
Figure.6 Spectrum (500 devices) in (a) 125kHz, (b) 250kHz and (c) 500kHz 125 kHz

B. Maximum number of devices = 1000:

In the case of 1000 devices and as can be seen in Figure.7, the trend of available slots and collision follows that of 500 devices. Compared to 500 devices, when having 1000 devices, used slots are more and packet collision is higher.

7.2 Sigfox Performance Evaluation:

Similar to LoRa, in the second scenario we simulate Sigfox technology according to the performance metrics (collision, PER and Spectrum).

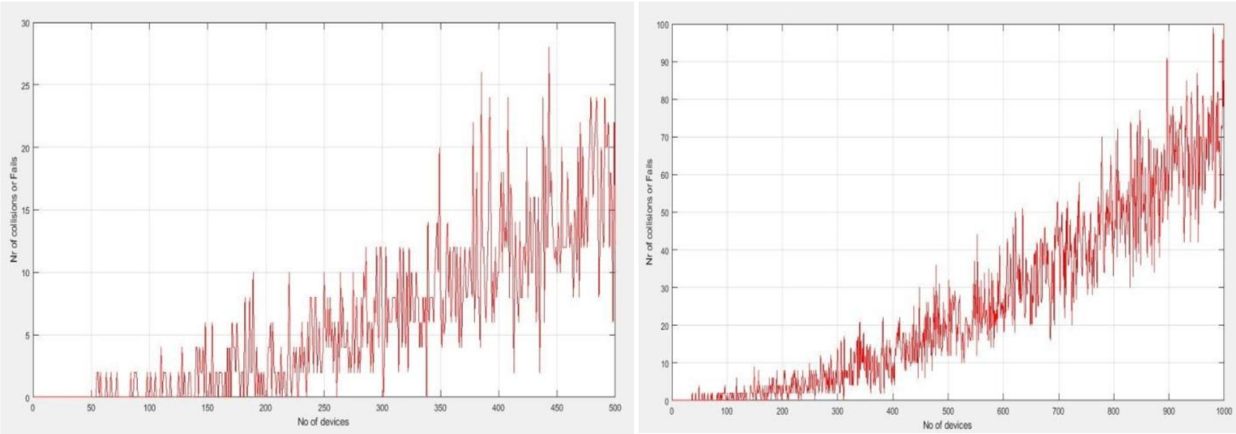


(a) (b) (c)

Figure.6 Spectrum (1000 devices) in (a) 125kHz, (b) 250kHz and (c) 500kHz 125 kHz

7.2.1 Collision:

Figure.7 (a) and (b) illustrates the packet collision of Sigfox technology for a maximum number of 500 and 1000 devices, respectively. In this evaluationwe choose a bandwidth of 200 kHz. As can be seen in figure.7 the collision intensifies when the number of devices increases.



(a) (b)

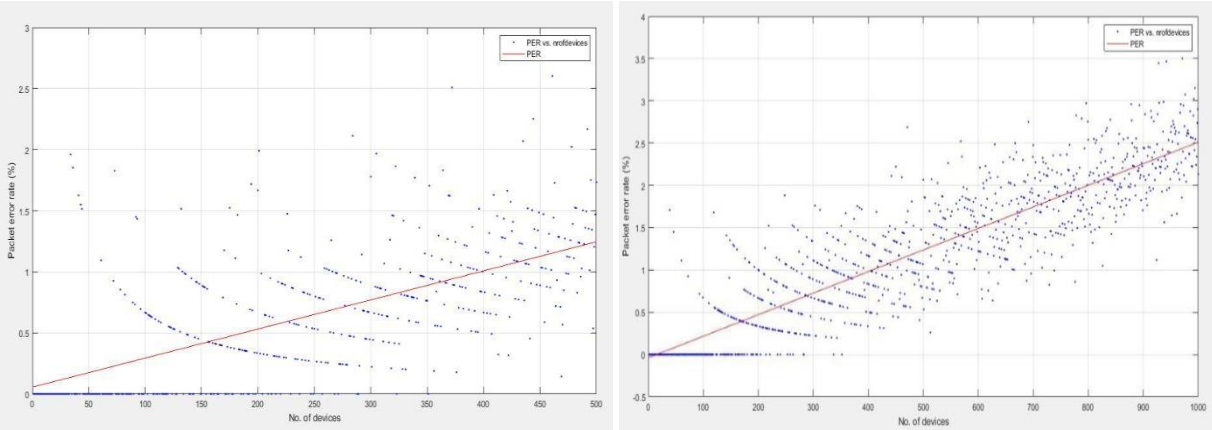
Figure.7 Collision of packets in 200 kHz bandwidth: (a) 500 and (b) 1000 devices

7.2.2 Packet Error Rate (PER):

The PER of Sigfox technology is evaluated for a maximum of 500 and 1000 devices under 200 kHz. Figure.8 (a) and (b) illustrates PER having 500 and 1000 devices, respectively. Observing figure.8, the PER is higher compared to having 500 devices; which means that in general PER increases whenincreasing the number of devices.

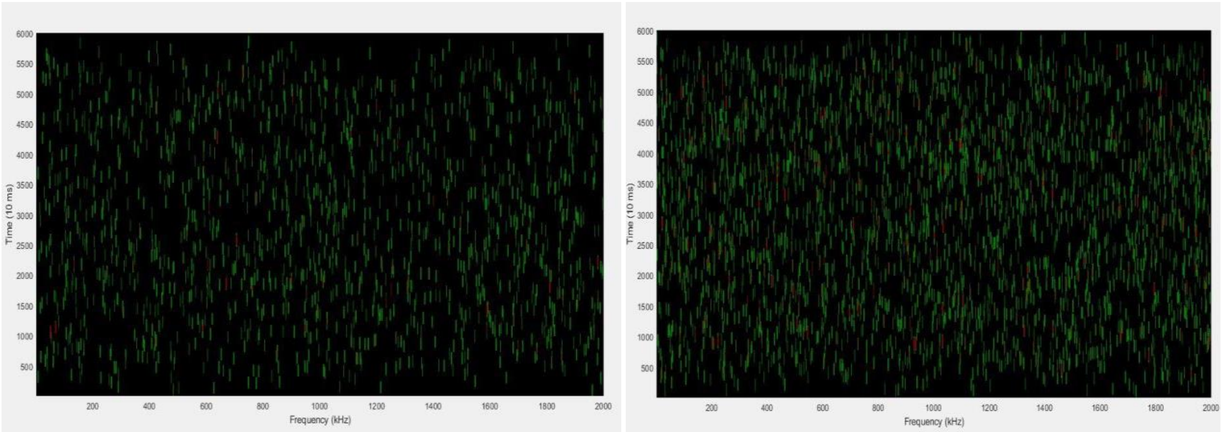
7.2.3 Spectrum:

Figure.9 (a) and (b) illustrates the spectrum representation of Sigfox technology for a maximum 500 and 1000 devices, respectively. The figure clearly shows that when the number of devices increases, the occupied slots increase. It also shows that packet collision is higher compared to having 500 devices.



(a) (b)

Figure.8 PER in 200 kHz bandwidth: (a) 500 and (b) 1000 devices



(a) (b)

Figure.9 Spectrum in 200 kHz bandwidth: (a) 500 and (b) 1000 devices

Attained results can be summarized as follows:

1- Packet collision increases with the increase in the number of devicesunder both LoRa and Sigfox and decreases when utilizing higher bandwidth (LoRa).

2- Increasing the number of devices leads to increasing PER using bothtechnologies.

3- The bandwidth flexibility offered by LoRa results in allowing for more available channels under high bandwidth (500kHz). This leads to less collision.

4- Spectrum representation is slightly different between the two technologies (when the bandwidth is increased the available slots also increase).

8. Conclusions:

This paper has evaluated LoRa and Sigfox as promising LPWAN technologies for IoT applications. A simulation model that implements LPWAN network architecture is developed using MATLAB environment. The simulation evaluates the influence of the number of devices and bandwidth on collision, PER and spectrum. Attained results have shown that increasing the number of devices leads to increasing collision and PER. They have also demonstrated that using higher bandwidth increases available channels which reduces packet collision. The future work involves extending the evaluation by considering device mobility and distance from the base station.

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