2022 5th Information Technology for Education and Development (ITED)

Development of Interference Mitigation Technique for Low Power Wide Area Network

Abdulwaheed Musa[1,2], Mojeed Adio[1] and Nasir Faruk[3]
[1]*Department of Electrical and Computer Engineering, Kwara State University, Malete, Nigeria*
[2]*Institute for Intelligent Systems, University of Johannesburg, South Africa*
[3]*Directorate of Information and Communication Technology, Sule Lamido University, Kafin Hausa, Jigawa State, Nigeria*
abdulwaheed.musa@kwasu.edu.ng; adio.mojeed@gmail.com; faruk.n@slu.edu.ng
https://orcid.org/0000-0001-8371-2465

***Abstract*— Evolution of technology has been rapid in recent years and with the wide acceptance of 5G/6G networks, Internet of Things (IoT), Machine Learning (ML), blockchain technologies, there must be a methodology of interconnecting them across large proximity or regions to centralized servers. Existing mobile technologies are not suitable to ensure communications between these devices, and this has necessitated the need to create Low Power Wide Area Network (LPWAN). The LPWAN, assuming a set of networks, is considered to have subsets including Sigfox, LoRaWAN, NB-IoT and others. For any real system, there is always collision between packets upon arrival, thereby subtracting and extracting the weaker ones. In this work, a Repetitive Interference Mitigation algorithm is proposed, with focus on power differences between User Equipment (UE) and guard subcarriers. This process ensures decryption of the packets that arrive at the same time. Usage of just one guard subcarriers and multiple iterations of the developed technique is suitable to ensure a very good system performance and has a throughput of 36% as compared with other methods.**

Keywords—LPWAN, NB-IoT, LoRaWAN, Interference, Sigfox, IoT, Machine Learning, machine-machine communication

I. INTRODUCTION

As at 2020, there is an estimated 50 billion connected devices according to Cisco. However, not all devices are connected to a Low Power Wide Area Network (LPWAN). Instead, some are connected to Local Area Networks (LAN's) such as Bluetooth low energy and Wi-Fi, in spite of the very significant potentials of LPWAN. Despite the issues with wireless standards, they still have several useful applications such as smart grid, electricity metering, control of city lighting and monitoring of agricultural produce. The potency of the network signals is determined by data rate, noise, interference, frequency of operation, receiver sensitivity, physical obstructions, transmit power, antenna gain and height.

With the advent of new technologies, mostly Internet of Things (IoT), 5G & 6G, and Artificial Intelligence, and an estimation of more than 75 billion to be built upon it by 2025, it is important that key considerations are taken into its design, management and maintenance of data, networks, and connections. For better and efficient design, it is important that they have LPWAN technologies embedded in their deployment [1]. The LPWAN scheme as an emerging technology can be used for a wide range of intelligent and smart applications, which include transportation, environment monitoring, smart cities and utilities, agriculture, industrial automation, health care, asset tracking and logistics. Although, they provide the needs for these IoT based devices, but there are challenges, such as interference, in some important aspects that need to be addressed.

With the daily increase in the number of end devices and 50 billion estimated devices [2] mostly connected via LPWANs, comprehending the scalability of such networks becomes significance before the deployment of end device. LPWAN, despite its widespread advantage has numerous subsets. In [3], the author explained how the important property of LPWAN, such as low power consumption and long-range communication, could be attained. The author in [4] considered various properties like modulation, mobility, multiplexing access scheme, battery lifetime (years) and security strength of the existing LPWAN's. These existing LPWANs includes LoRaWAN, NB-IoT, LTE, 5G, Sigfox – classifying them by infrastructure-based and infrastructure-less.

In one of the papers reviewed [5], the author accessed and compared signal activities in various locations. The method explained the measurement of the signal activity of band and power levels using five (5) different locations as reference points. The possible source of interference and its effect on LoRa and Sigfox were investigated. The Rohde & Schwarz TSMW radio network scanner was used for measurement from 863MHz to 870MHz using 7kHz bins and 200ms sampling time. LoRa uses spread spectrum modulation and Sigfox uses frequency hopping by transmitting same packet on three separate channels.

In another publication [6], the author used an inter-cell interference avoidance scheduling technique and Round-Robin algorithm. The interference avoidance scheduling technique optimizes application of limited NB-IoT radio resources in enhancing the total throughput. The technique depends on the application of a strategy between base stations by sharing the expected scheduling tables among them. The Round-Robin algorithm is then applied as a benchmark, after which simulations are carried out.

[7] proposed an interference algorithm to enhance conformity between NB-IoT and LTE devices by allocating resource blocks (PRBs) to various IoT and LTE devices based on the network load. Three (3) operation modes were identified and described to make it possible. These include in-band operation, guard band operation as well as stand-alone operation. Decision feedback SIC algorithm was used in each of the iteration to recreate the interference of a system, remove it from the other, thereby enhancing detection of the signal.

978-1-6654-9370-3/22/$31.00 ©2022

In this paper, the main aim is to develop a mitigation protocol in reducing the effect of interference on LPWAN, using NB-IoT as a case study. The paper investigated LPWAN and its applications in IoT, developed an interference mitigation technique, simulated the interference mitigation algorithm and discussed the results.

II. Existing LPWAN technologies

This section gives an overview and comparison of available LPWAN technologies, including their operation ranges, modulation and multiplexing access scheme, etc. Table I gives a comparison of the LPWAN technologies.

TABLE I: COMPARISON OF LPWAN TECHNOLOGIES

Parameter	Sigfox	LoRaWAN	NB-IoT
Frequency band (in MHz)	862	869	900
Spectrum (in kHz)	200	1175	800
Sub-channel BW (in kHz)	100	250	200
Spacing (in kHz)	0	200	3.75
Modulation	DBPSK	FSS/CSS	OFDMA
Sensitivity of Receiver (in dBm)	164	154	150
Capacity of device per cell	100k	10k	40k
Payload of DL (in bytes)	8	14	125
Payload of UL (in bytes)	12	51	125
Data rate (in kbps)	0.1	1.76	50
Duty cycle per Tx restriction	140 msg per day	1%	-
Topology	Star	Star	Star

A. *LoRaWAN*

Long Range Wide Area Network is an LPWAN protocol built on top of the LoRa radio modulation scheme. It connects different devices to the internet and commands communication between network gateways and end-node devices wirelessly. It modulates in the unlicensed Sub-GHz band, using chirp spread spectrum (CSS) methods [8]. LoRaWAN uses a frequency band of 868MHz and spreading factors that allow an exchange between coverage area and bandwidth. The data rate could range from 300 bps to 50 kbps, depends on various spreading factors. It used FSS/CSS modulation technique and has 200kHz channel spacing [9].

B. *Sigfox*

Sigfox is a long range, low power and low data rate form of wireless communications and cellular style designed for wireless connectivity for M2M and IoT devices, such as remote sensors and actuators [10]. An end-to-end IoT and wireless connectivity solution, Sigfox makes use of binary phase-shift keying (BPSK) modulation in the ultra-narrow band, i.e. 100Hz, that produces low power consumption, low noise level, and high receiver sensitivity. It uses a frequency band of 868MHz and has 0 channel spacing [11].

C. *NB-IoT*

Narrow Band Internet of Things (NB-IoT) is a standard based LPWAN technology developed by 3GPP which enables wide range communication for IoT devices and M2M applications [12]. It provides better quality of service (QoS) and has the least latency in usage. With this technology, a novel radio is proposed to enhance the efficiency of the battery and extended coverage areas. Future application areas and services of NB-IoT will include localization and multicast.

III. Materials and Methods

The materials, methods, calculations, and procedures used to successfully carry out this research work are presented in this section. The building blocks showing how the work has been implemented is shown in Figure 1.

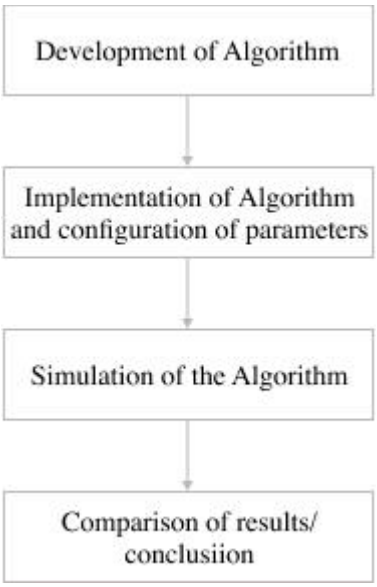


Fig 1. Block Diagram

Development of Algorithm: An algorithm, programmed and simulated using MATLAB, is developed. One of the approaches used in carrying out this work include reducing the power of the radio frequencies, integration of filters in the channel or transmitting at different frequencies and different time. When network density becomes high, the signal being sent along the communication channel is disrupted by unwanted signals generated in the channel itself or through external factors. This could lead to loss of data, thereby causing reliability issues.

Configuration of parameters: All simulations parameters are defined to suit the need of the algorithm. The parameters are reiterated until the satisfactory results are obtained. Parameters defined include User Equipment, subcarrier spacing, subframe, physical resource blocks, intercarrier spacing and constellation.

Simulation of Algorithm: After the implementation of the algorithm and configured using the appropriate parameters, simulation of the algorithm is then carried out also in MATLAB environment.

Comparison of result: The results obtained from the simulation are then evaluated and reiterated upon until the desired result is gotten.

Repetitive Interference Mitigation (RIM) algorithm is used. This technique is used in a wireless transmission system for decryption of multiple packets arriving at the same time in a receiver. The simultaneous arrival of the multiple packets causes a collision in regular system. The RIM technique is possible because the receiver is able to decrypt the stronger signal from the weaker one. This technique is widely used either when two transmitters are sending data to same receiver or different receiver.

To allow for low data cost, power consumption in IoT based devices, there is a challenge on existing cellular networks as IoT devices cannot handle heavy networks. This issue led to the creation of NB-IoT to ensure coexistence between IoT devices and existing LTE devices using the same PRB and a structure (frame) that is compatible. The standard specifies a network of access arranged for serving a high number of low throughputs, delay that are moderated and devices of low cost.

It is plausible to apply a common analog front-end to decrypt LTE and single-tone IoT signals in Base Stations (BSs). But the difference in the structure of the PRB affects the orthogonality and causes interference. This circumstance affects the LTE and NB-IoT coexistence. This cannot be addressed easily because of the large signal spectral leakage. The interference of LTE over IoT is higher and more damaging since NB-IoT are power constrained devices.

IV. SYSTEM MODEL

The situation of a BS serving many LTE and IoT User Equipment (UEs) simultaneously was analysed. The BSs assign physical resource blocks (PRBs) to various IoT or LTE devices based on the load of the network. Three (3) operation modes, including in-band operation, guard band operation and stand-alone operation are highlighted for NB-IoT.

In this paper, the focus is on the in-band operation because of its most suitability in handling high number of devices. Also, it is the most challenging in the area of interference and managing it. The NB-IoT nodes uses the following LTE numerology, which are a subcarrier spacing of $1/T_L$ = 15kHz and a subframe of 1ms made by two (2) slots of seven (7) OFDM symbols. Besides, LTE PRB is made during a slot by M_L = 12 contiguous subcarriers.

Using Time Division Duplexing in offering network to the systems in the mode of 3.75 kHz makes the Base Station (BS) scheduler to avoid the interference it would have imposed on it. A problem with this, however, is that NB-IoT UEs must always be active while the Base Station receives suitable channel access request to add to the frame, and thereby increase the power consumed. The other option is using the Frequency Division Duplexing (FDD), regardless of the lack of orthogonality, i.e. being at 90º, between the systems using it.

The pseudocode of the Repetitive Interference Mitigation Algorithm is shown below:

Calculate $Y_{I,p}(k)$ and $Y_{L,l}(k)$

Set $G_{I,l}(k) = 0$

for** $s = 1$ to N_{rim} **do

$V_{l(k)} = \mathcal{D}[\frac{Y_{L,l}(k) - G_{I,l}(k)}{H_l(k)}]$

Calculate v_n

Calculate $G_L(k + pM_I)$

$X_{p(k)} = \mathcal{D}[\frac{Y_{I,p}(k) - G_L(k+pM_I)}{H_{k,p}(k)}]$

Calculate $x_{k,p}(n)$

Calculate $G_{I,l}(k)$

End for

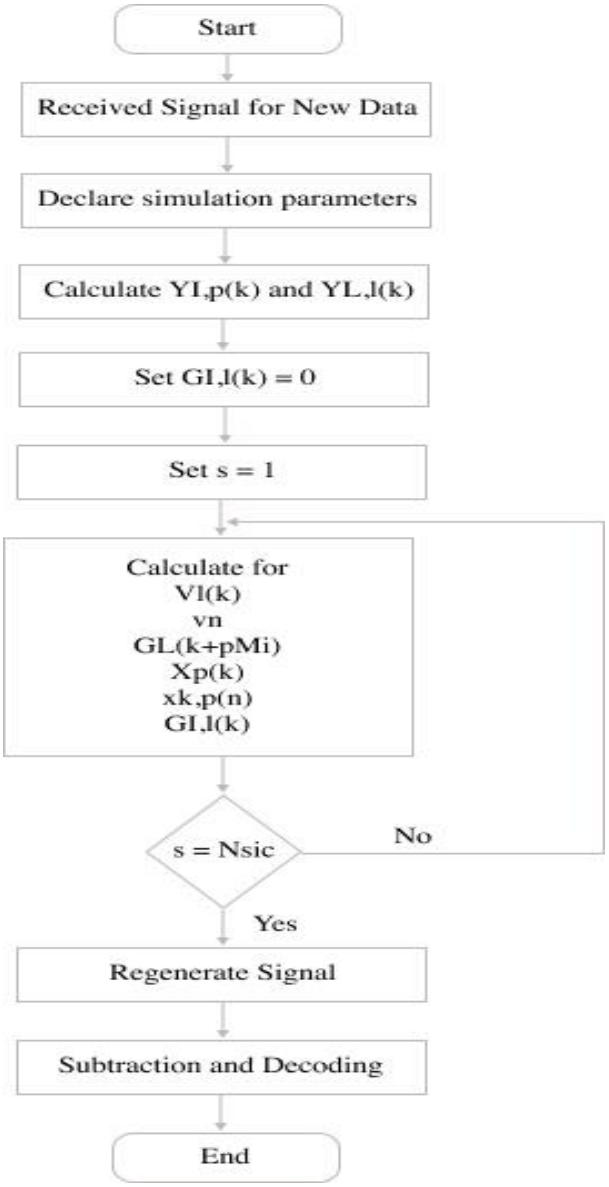


Fig 2. Flow chart of Repetitive Interference Mitigation Algorithm

The algorithm's results $V_l(k)$ and $X_p(k)$ are estimations of the symbols being transmitted.

$Y_{I,p}(k)$ is the NB-IoT received signal while $Y_{L,l}(k)$ is the LTE received signal

$$Y_{I,p}(k) = \sum_{n=0}^{N_I-1} y(n) e^{(\frac{-j2\pi n}{N_I}(k+pM_I))}$$

$$Y_{L,l}(k) = \sum_{n=0}^{N_I-1} y(n - l(N_{cpL} + N_l)) e^{(\frac{-j2\pi nk}{N_L})}$$

The flowchart for implementing the algorithm is presented in Figure 2.

V. Results and Discussion

Results are presented and discussed under this sub-section. Measuring the LTE interference across the NB-IoT receiver have been included. The required number of guard subcarriers and the iterations of the RIM technique are found through simulation. Finally, the effect of system's power difference on the robustness of the RIM technique is also shown.

It is imperative to understand the challenges, such as high data rate and delay intolerance, that cellular networks pose on IoT. LPWAN serves as an alternative and solves the issues associated with previous networks by ensuring conformation and interoperability between the network paradigms. As such, network interference must be accounted for in both LTE and NB-IoT, technologies used in this technique.

The system parameters are defined and presented in Table II. Parameters, including the User Equipment, subcarrier spacing, subframe, physical resource blocks (PRB) size, intercarrier spacing and constellation, cyclic prefix (CP) are defined for LTE and NB-IoT respectively.

TABLE II: SIMULATION PARAMETER

Parameter	LTE	Value
Subcarriers	$N_L = 64$	$N_I = 256$
CP	$N_{cpL} = 8$	$N_{cpI} = 32$
PRB Size	$M_L = 12$	$M_I = 48$
Intercarrier spacing	$1/T_L = 15$ kHz	$1/T_I = 3.75$ kHz
Constellation	64-QAM	QPSK

The parameters are required for the simulations. The network applied in the simulation has three (3) cells and four (4) users per cell that are uniformly shared within a cell. The cyclic prefix used acts as buffer to protect incoming signals from interference. The more they exist, the more the guard region or interval available. In this work, the NR 5G network is simulated using cell radius, noise power density, and base station transmitting power as parameters and in line with the standard of 3GPP.

Figure 3. shows the Bit Error Rate performance of the RIM algorithm, with and with-out interference using various number of guard subcarriers, N_g. The subcarriers ensure the transmission of separate signals into a single transmission line fed into the receiver. The iteration is performed using three (3) distinct values for the carriers, i.e., no carrier, one carrier and two carriers, all maintaining a N_{rim} value of three (3). The results from the simulations show that the network ensures its maximum throughput when just a guard subcarrier is used.

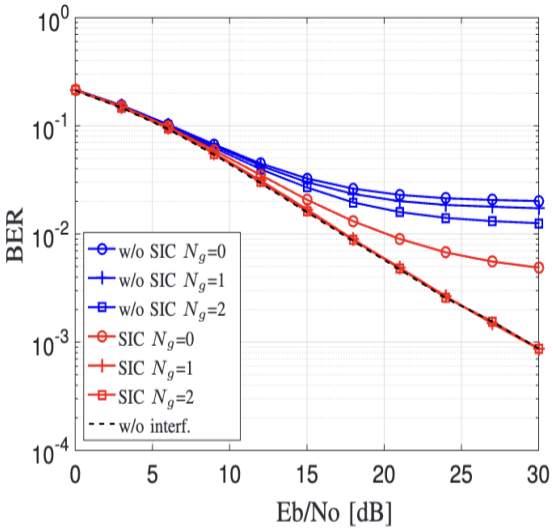


Fig 3. BER performance of NB-IoT with or without RIM technique to include guard subcarrier

Since it was discovered, in the above simulation, that one guard subcarrier gives the best result without interference, it then becomes necessary to determine the number of iterations to be performed on the algorithm to obtain maximum delivery of signals.

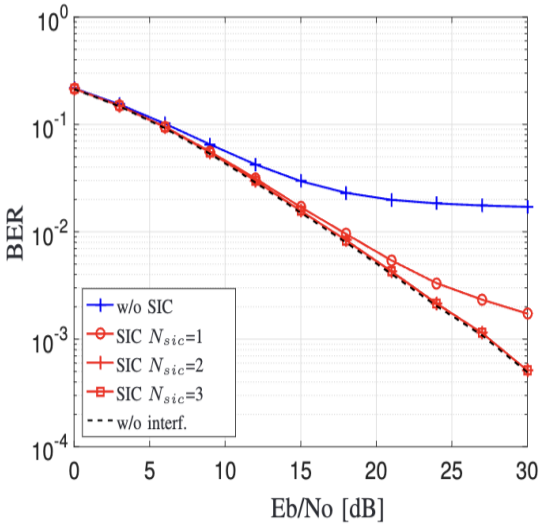


Fig 4. BER performance of NB-IoT for various iteration numbers in the RIM technique

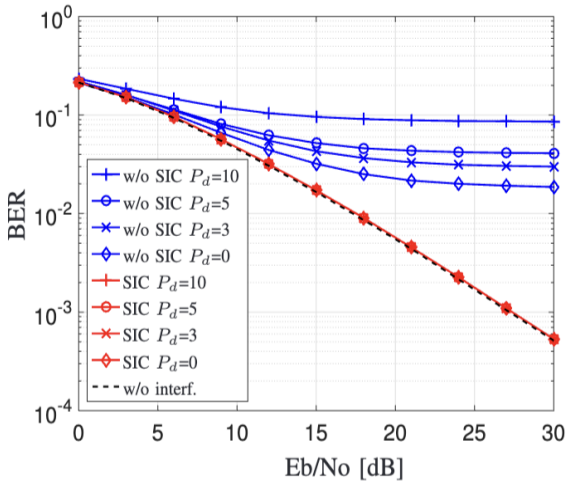


Fig 5. BER performance of NB-IoT considering the difference in power of LTE and NB-IoT received signals

In Figure 4, the Bit Error Rate of the NB-IoT system is recorded for multiple iterations of the RIM algorithm. The performance of the system for N_g = 1 and N_{rim} = 1, 2 and 3 is shown and it is discovered that only 2 iterations is enough to ensure the system's peak performance without interference.

The first two simulation processes already give two (2) important parameters of this technique. To ensure the interoperability of LTE and NB-IoT, another important factor to be put into consideration is power difference. The characteristics of LPWAN are such that they are to be operated using low power. Conventional cellular networks in their operation does not account for power. It is therefore important to ensure that there is compatibility in these networks.

Figure 5 shows the Bit Error Rate performance of the system considering the massive difference in the power of NB-IoT and LTE received signals. The chart indicates the graphs for a power difference P_d = 0dB, 3dB, 5dB and 10dB, N_g = 1 and N_{rim} = 2. It is deduced that despite the huge power difference between LTE (high) and NB-IoT (low), the algorithm is still compatible and does not affect the results of the first two simulations.

Unlike previous works, this method considers the NB-IoT devices UE, power differences and guard subcarriers. Extensive simulations are performed for analysis of performance improvements of this method. It is also recorded that this algorithm could guarantee a throughput improvement up to 37% when compared against Cooperative Interference Avoidance Scheduler and Round-Robin approach. This technique majorly accounted for power difference, guard subcarriers and number of iterations to be performed so as to mitigate interference in a LPWAN technology.

In comparison with Channel Equalization and Interference Analysis method, which also considers power differences between NB-IoT and LTE, this algorithm gives proper consideration for power differences between the two technologies and compensations between them.

VI. CONCLUSION

This paper used a Repetitive Interference Mitigation Algorithm to mitigate the effects of interference on Low Power Wide Area Network (LPWAN), laying more emphasis on the Narrow Band – Internet of Things (NB-IoT) technology using Frequency Division Duplexing (FDD) mode and an inter-carrier spacing of 3.75 kHz.

The conclusion drawn is that only a guard subcarrier and two (2) iterations of the Repetitive Interference Mitigation Algorithm is enough to attain a peak performance of NB-IoT equipment with limited effect of interference. The solution is also compatible with different received power of such equipment.

A recommendation is that Frequency Division Duplexing should be used against Time Division Duplexing because TDD requires the system to be always awake, thereby increasing power consumption and as such, violating the essence of LPWANs, low power. Also, more sophisticated means should be adopted in reducing the massive difference between the powers of the receiving signals.

REFERENCES

[1] B. S. Chaudhari, M. Zennaro, and S. Borkar, "LPWAN Technologies: Emerging Application Characteristics, Requirements, and Design Considerations," *Future Internet*, vol. 12, no. 3, pp. 46 - 52, 2020.

[2] D. Evans, "The Internet of Things: How the Next Evolution of the Internet is Changing Everything" *Cisco Internet Business Solutions Group: San Jose, CA, USA*, 2011.

[3] U. Raza, P. Kulkarni, M. Sooriyabandara "Low Power Wide Area Networks: An Overview," *IEEE Communications Surveys & Tutorials*, pp. 855 - 873, 2017.

[4] D. Ismail, M. Rahman, A. Saifullah, "Low-power wide-area networks. Proceedings of the Workshop Program of the 19th International Conference on Distributed Computing and Networking," *Workshops ICDCN*, 2018.

[5] M. Lauridsen, B. Vejlgaard, I. Z. Kovacs, H. Nguyen, and P. Mogensen, "Interference Measurements in the European 868 MHz ISM Band with Focus on LoRa and SigFox," *EEE Wireless Communications and Networking Conference (WCNC)*, 2017.

[6] C. B. Mwakwata, M. M. Alam, Y. Le Moullec, H. Malik, and S. Parand, "Cooperative Interference Avoidance Scheduler for Radio Resource Management in NB-IoT Systems," *European Conference on Networks and Communications (EuCNC)*, 2020.

[7] J. Gustavo, H. Fernando, and C. Juan, "Successive Interference Cancellation for the NB-IoT Uplink Multiple Access,", 2020.

[8] A. Khalifeh, K. A. Aldahdouh, K. A. Darabkh, and W. Al-Sit, "A Survey of 5G Emerging Wireless Technologies Featuring LoRaWAN, Sigfox, NB-IoT and LTE-M," *2019 International Conference on Wireless Communications Signal Processing and Networking (WiSPNET)*, 2019.

[9] M. Aernouts, B. Bellekens, R. Berkvens, and M. Weyn, "A Comparison of Signal Strength Localization Methods with Sigfox," *2018 15th Workshop on Positioning, Navigation and Communications (WPNC)*, 2018.

[10] A. Lavric, A. I. Petrariu, and V. Popa, "SigFox Communication Protocol: The New Era of IoT?," *2019 International Conference on Sensing and Instrumentation in IoT Era (ISSI)*, 2019.

[11] P. Adrian, and L. Alexandru, "Sigfox Wireless Communication Enhancement for Internet of Things: A study," 2021.

[12] B. Collins, E. Osama, L. Yannick, M. Muhammad, P. Sven, and A. Ivan, "Inter-cell Interference Reduction Scheme for Uplink Transmission in NB-IoT Systems," *International Wireless Communications and Mobile Computing (IWCMC)*, 2019.