

Priority-based resource allocation in layering LoRaWAN

Vipin Balyan*

Department of Electrical,
Electronics, and Computer
Engineering, Cape Peninsula
University of Technology, Bellville,
Cape Town 7535, South Africa

*E-mail: vipin.balyan@rediffmail.com

Received for publication
May 26, 2024.

Abstract

Network applications for the Internet of Things (IoT) frequently use Long-Range (LoRa) technology. It allows tiny wireless devices to transmit data at low volumes. The idea behind LoRa networks, or Low-Power Wide Area Networks (LPWAN), is to use airborne data transmission from sensors with a transmission range of no more than 10 km. These sensors run on batteries and should not be connected to the electrical grid. Because of the benefits of Long-Range Wide Area Network (LoRaWAN) private networks, users have implemented various services in a single LoRaWAN system to realize a range of intelligent applications. LoRaWAN faces difficulties with multiservice coexistence as the number of applications grows because of insufficient channel resources, disorganized network configuration, and scalability problems. Creating a sensible plan for allocating resources is the best course of action. Nevertheless, current methods are inapplicable to LoRaWAN systems that support several services with varying criticalities. To coordinate multiservice networks, we therefore suggest a priority-based spreading factor (SF) allocation delay monitoring layered (DML) resource allocation scheme. The three primary categories of LoRaWAN application services—monitoring, control, and safety—are outlined in this paper. The suggested priority based resource allocation (PB-RA) scheme distributes SFs to end devices according to the highest priority parameter, taking into account the varying criticalities of these services. This increases throughput, lowers energy consumption, and increases packet delivery rate (PDR). The main advantage associated with using it is that priority is given to applications that require safety without introducing latency in other applications.

Keywords

Internet of things, LoRa, LoRaWAN, SF, mesh networks, packet delivery rate

I. Introduction

The Internet of Things (IoT) seeks to facilitate communication and cooperation between disparate devices so that they can offer users transparent smart services in various settings. Billions of IoT devices will be installed globally over the next several years, enabling smart systems for various applications [1]. These applications include smart farming, smart cities, manufacturing, transportation, and many other areas.

Wireless networks are necessary for these applications to cover a large area within a city, building, or farm [2, 3]. The wireless technologies utilized for this purpose, such as ZigBee, Wi-Fi, and Bluetooth, have a range of a few meters or tens of meters [4]. Mesh network structures can increase the coverage area by utilizing multihop communication [5].

Low-Power Wide Area Networks (LPWAN) were recently developed to offer a workable solution for applications that need energy efficiency and wide

area coverage [6]. In licensed bands, the most popular topologies are Long-Term Evolution for M2M (LTE-M) and Narrowband IoT (NB-IoT) [7] for LPWAN, and in unlicensed bands, Long-Range Wide Area Network (LoRaWAN) and SigFox are the most common topologies. Because it is possible to create private networks using unlicensed frequency bands (868 MHz in Europe and 915 MHz in the USA and Brazil), Long-Range (LoRa) communication is one of the most popular applications. LoRaWAN technology offers low data rates and low energy consumption for LoRa communication. According to certain tests, the technology can travel several kilometers in open spaces or rural areas. However, due to attenuation and fading effects, LoRaWAN's range is significantly reduced in situations with obstacles or inside buildings, leading to packet losses and errors.

Numerous obstructions in cities can deteriorate the signal, which also reduces the coverage area. The topography of the terrain has a significant impact on rural areas; for example, a mountain may produce a shadow area. A device operating in unfavorable conditions will need more power to transmit, which increases energy consumption and shortens the device's lifespan. The endpoints that make up the LoRaWAN network send data to gateways in the form of a star network topology. Only one hop between LoRa devices and the gateway is permitted by the specification [8]. However, multihop networks, which require less transmission power than single-hop networks, are well known for increasing coverage, improving energy efficiency, and extending battery life [9–11]. The scalability and network capacity of LoRaWAN networks are some open research issues.

Studies in the literature have indicated that crowded networks with a higher number of devices can lead to decreased network performance, resulting in higher latencies and lower reliability. The LoRaWAN protocol utilizes ALOHA as the MAC protocol, which may not provide an efficient solution with increased traffic load or node density due to interference and packet collisions [12, 13]. Utilizing the multihop approaches can improve scalability, capacity, and reliability. Gupta et al. [14] focused on analyzing the number of collisions and their impact on the network; the study enhances the throughput of LoRa nodes while optimizing parameters such as energy harvesting (EH) duration, spreading factor (SF), and transmit power. A mathematical expression for packet collisions has been developed, and an algorithm is proposed to assign SFs to nodes depending upon collisions and distance. The study demonstrates

improved packet error rates (PER) and time on air (ToA) with fewer LoRa nodes using lower SFs compared to higher SFs through simulation results.

With $SF = 7$, nearly four times as many LoRa nodes can communicate as with $SF = 11$ while still maintaining a low PER. Additionally, $SF = 7$ sees a 20 ms increase in ToA when the coding rate is changed from 1 to 4, whereas $SF = 12$ experiences a 1,200 ms increase in ToA. Additionally, comparisons are made between the energy efficiency for various transmission powers and SFs. Six SFs are partially orthogonal to each other, and eight different uplink channels are orthogonal to each other, which allows a maximum of 48 messages to be sent without interference [15]. For shorter distances, lower SF and transmission powers are more appropriate, as they offer superior energy efficiency [16, 17].

The paper is organized as follows: Section 2 presents the work, Section 3 presents the results and simulations, and finally, the paper is concluded in Section 4.

II. Proposed Work

Consider the network with gateways $g_i, 1 \leq i \leq G$, the total number of LoRa nodes as $r, 1 \leq r \leq R, r_i$ and number of layers formed are denoted by $l, 1 \leq l \leq L$, where G, R , and L denote the maximum number of gateways, LoRa nodes, and layers formed respectively in the network. The proposed delay monitoring layered (DML) scheme considers the IoT applications listed as three main categories: delay sensitive, delay tolerant, and delay insensitive (DIS) [18]. The abbreviations used are listed in Table 1.

a. Delay-sensitive services (DSS)

This includes services used for the purpose of security and safety; their occurrence is random, and they require an urgent or timely response. They can be

Table 1: Parameters abbreviation

Parameter	Abbreviation
Spreading factor	SF
Delay-sensitive services	DSS
Delay-tolerant service	DTS
Delay insensitive	DIS
Offered load	OL

modeled as Class A uplink transmissions, which are nonperiodic in nature.

b. Delay-tolerant service (DTS)

These are basically control services that work on remote commands, and they can be modeled as downlink Class C transmissions, which are automated in nature.

c. DIS

These are periodic measurements of the sensors and basically used for monitoring, and these are periodic uplink transmissions, which can be modeled as Class A.

With a kilometer-level transmission range and microampere-level power consumption, LoRaWAN is one of the most widely used LPWA technologies. This leads to an increase in the number of LoRaWAN nodes to grow exponentially, resulting in increased interference and a higher rate of packet collisions. The scarcity of channel resources, due to the utilization of unlicensed bands, escalates the resource competition, which increases the probability of delayed information transfer for delay-sensitive applications and might lead to damage to life, property, etc. Therefore, the proposed DML scheme provides resource allocation based on the sensitivity of the application, i.e., the SFs are assigned to applications in each layer depending on their sensitivity. The order of their priority is DSS > DTS > DIS. A priority-based resource allocation scheme that prioritizes emergent packets and reduces overall packet collision is suggested as a solution to these problems.

As specified earlier, $7 \leq SF \leq 12$, which means we have six SFs per channel to select for fairness in terms of transmission range and data rate. The work uses the orthogonality nature of SF to reduce packet collision probability. By using algorithm stated in Ref. [19], the success probability of a packet for the LoRa nodes in the MAC layer using a SF can be determined as follows:

$$p(SF) = \left(1 - \frac{T_{OA}(SF)}{T}\right)^{(2n(SF)-1)} \quad (1)$$

where $n(SF)$ denotes the number of LoRa nodes using that SF, and T is the duration in minutes. The work considers that each LoRa node generates a packet of payload B bytes randomly at an instant of time and this is uniformly distributed with respect to

time period. This leads to an offered load (OL) [19] generated by a r^{th} LoRa nodes in bits per second equal to

$$OL_r = \frac{8(L \times B)}{T} \text{ bits/sec} \quad (2)$$

At this point, the priority factor used for LoRa nodes at each layer is introduced.

$$PF_m^{l_r} = \frac{OL_r \times m}{\sum_{r=1}^L OL_r} \quad (3)$$

Where $1 \leq m \leq 3$ integer value only; a higher value means higher priority. The flowchart of algorithms is shown in Figure 1.

Root gateway sends the available message to all the gateways.

Algorithm 1: Gateways and LoRa nodes discovery

- 1 Broadcast message to all gateways for discovery of gateways.
- 2 Broadcast message received by the i^{th} gateway in layer 1 is denoted as g_i^1 . It sends acknowledgment to the root gateway and introduces itself as g_i^1 .
- 3 $\forall g_i^1$ broadcast to all gateways and LoRa nodes.
- 4 $\forall g_i^1$ gets connected to LoRa nodes in its coverage area denoted by r_i^1 , meaning $r_i^1 \in g_i^1$ for connection to root gateway.
- 5 For $2 \leq l \leq L$
- 6 Broadcast message to all gateways for discovery of gateways.
- 7 Broadcast message received by i^{th} gateway in layer l is denoted as g_i^l . It sends acknowledgment to the gateway in layer $(l + 1)$ and introduces itself as $g_i^{(l+1)}$.
- 8 $\forall g_i^{l+1}$ broadcast to all gateways and LoRa nodes.
- 9 $\forall g_i^{l+1}$ gets connected to LoRa nodes in its coverage area denoted by r_i^{l+1} , meaning $r_i^{l+1} \in g_i^{l+1}$ for connection to the l^{th} gateway.

Algorithm 2: SF assignment

- 1 Find LoRa nodes with $\max_m PF_m^{l_r}$, let the number of LoRa nodes are n_r .
- 2 If $nr \leq n(SF = 6)$
- 3 Assign $SF = 6$ to all n_r nodes.
- 4 Else
- 5 Assign $SF = 7$ to all $(n_r - n(SF = 6))$ nodes.
- 6 End

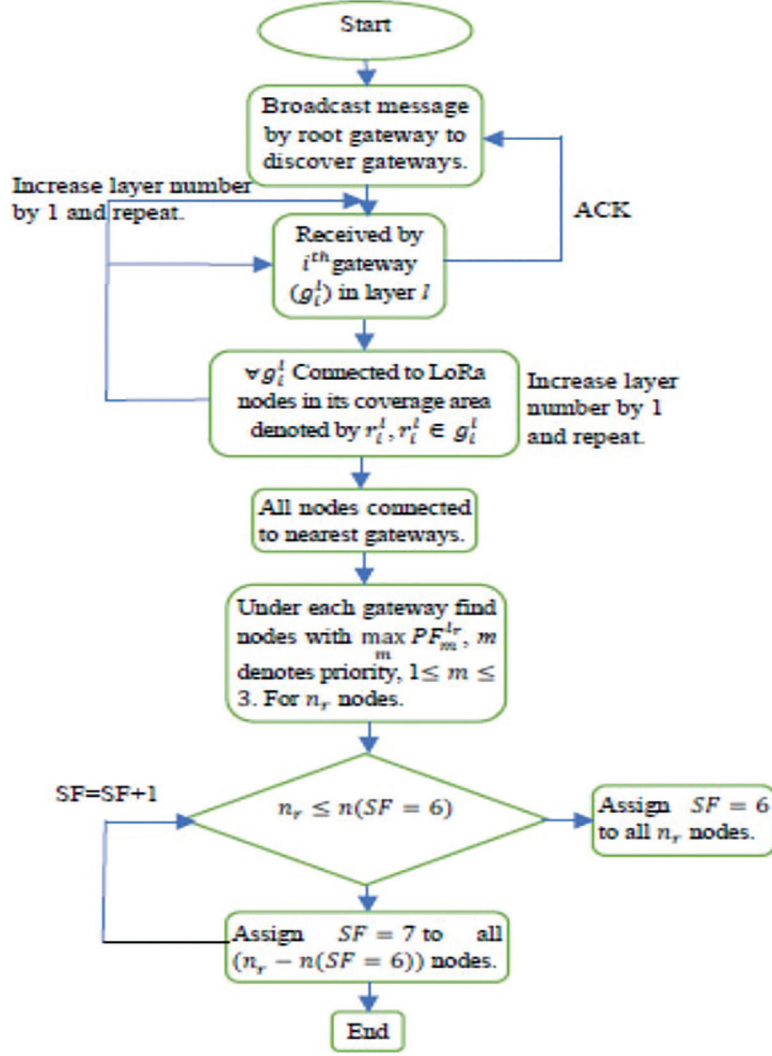


Figure 1: Flowchart of algorithms.

- 7 Repeat step 1–6 for next $m = 2, 1$ and $SF = SF + 1$ when required.

III. Results and Simulations

The simulations are done on an Intel Core i7 series processor with 32 GB of RAM using LoRaSim [20]. The simulation parameters are given in Table 2. In Figure 2, the packet delivery rate (PDR) of the proposed work is plotted for nodes increasing from 40 to 100. When priority is used, the average PDR is lower than when DML is used without priority due to preference given to some applications over others, which slows down the overall performance of the setup. In Figure 3, energy consumed is plotted and compared

Table 2: Simulation parameters

Parameters	Value
Frequency	125 kHz
SF	6–12
Data rate	250 bps
Payload	59
Coding rate	4/5
LoRa nodes	40–100
Number of layers	1–15
Number of gateways	20

LoRa, long-range; SF, spreading factor.

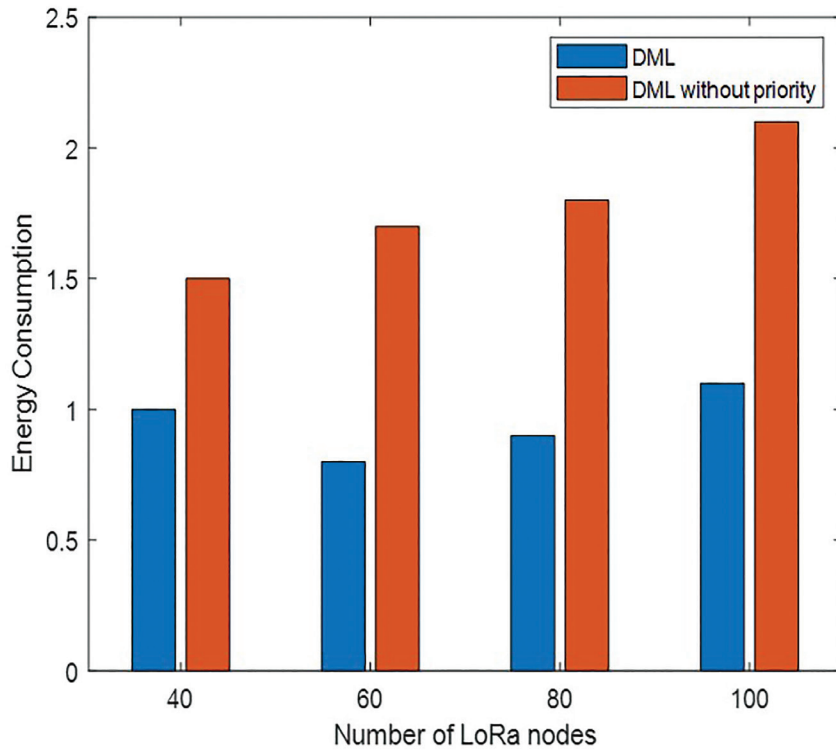


Figure 2: Energy consumption versus number of nodes. DML, delay-monitoring layered.

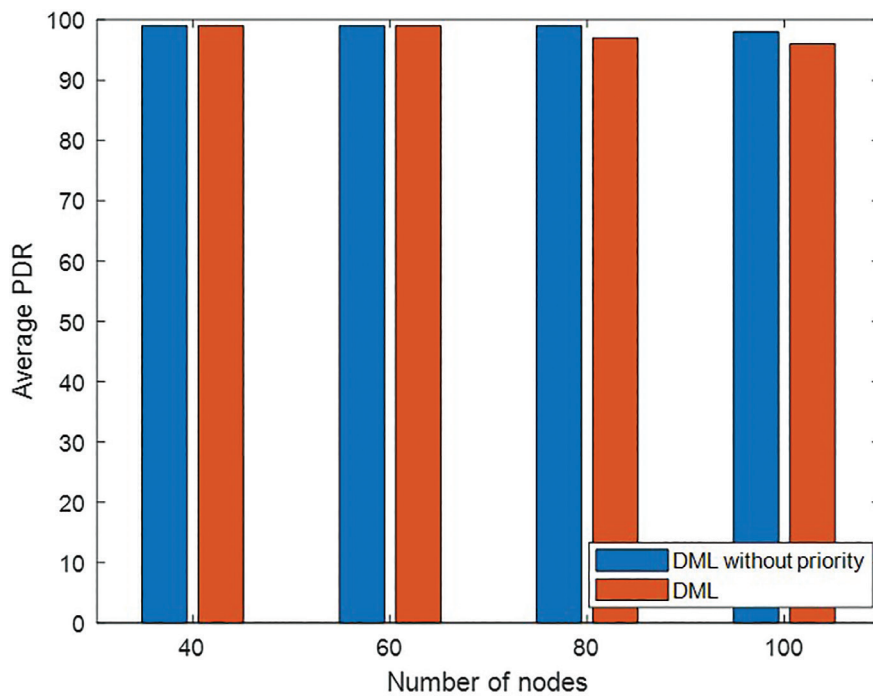


Figure 3: Average packet delivery ratio versus number of nodes. DML, delay-monitoring layered; PDR, packet delivery rate.

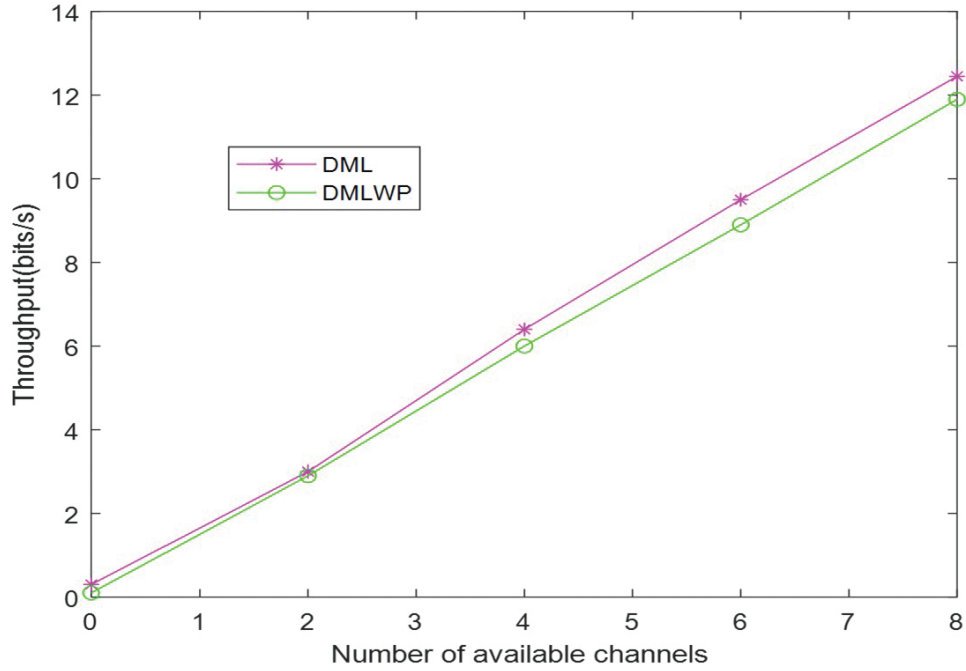


Figure 4: Throughput of the proposed DML schemes versus number of nodes. DML, delay-monitoring layered.

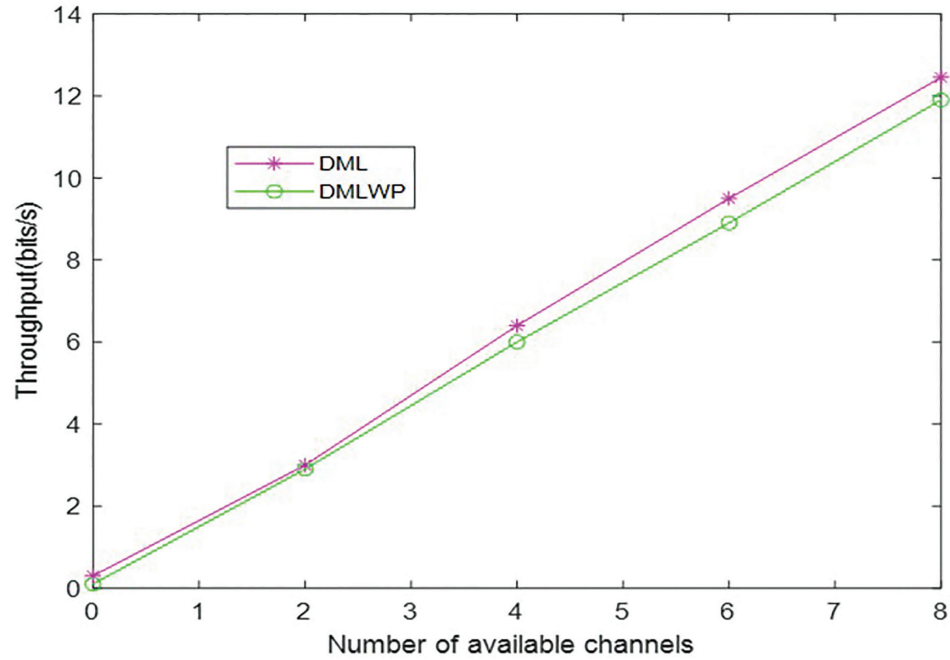


Figure 5: Throughput of the proposed DML schemes versus number of available channels. DML, delay-monitoring layered.

for DML with and without priority. DML with priority consumes less energy as the priority applications use lesser SF, which reduces their ToA. The result shows

that the number of messages sent for both schemes is the same, and it depends on the number of layers to be formed, which gives clarity that adding priority

does not provide added complexity and can be used for the purpose of scaling.

The throughput DML and DML without priority is compared as a function of the varying number of LoRa nodes in the network in Figure 4. An increase in number of LoRa nodes adds offered traffic, and throughput improves with increased load. Given the high PDR, the throughput of DML scheme and the DML without priority scheme perform close to each other.

In Figure 5, the throughput of the network when 200 LoRa nodes are present versus varying numbers of available channels in the network is compared; the work indicates the effect of the number of available channels on the proposed scheme. From the result, it is clear that the number of channels improves the throughput of the network, or, in other words, the proposed schemes.

IV. Conclusion

This article introduces a low-power system utilizing LoRa technology. Many applications based on LoRaWAN have been developed due to its benefits of long range, low power usage, and private network deployment. However, as the number of LoRaWAN applications increases, packet collisions have become a more significant issue due to limited resources. This article categorizes LoRaWAN application services into safety, control, and monitoring, each with varying levels of importance. To address this, the DML scheme was created to allocate SFs based on the highest priority parameter, ultimately enhancing average PDR, energy efficiency, and throughput.

References

- [1] L. Atzori, A. Iera, and G. Morabito, "Understanding the Internet of Things: definition, potentials, and societal role of a fast evolving paradigm," *Ad Hoc Networks*, vol. 56, 2017, doi: 10.1016/j.adhoc.2016.12.004.
- [2] A. Al-Fuqaha, M. Guizani, M. Mohammadi, M. Aledhari, and M. Ayyash, "Internet of Things: A Survey on Enabling Technologies, Protocols, and Applications," *IEEE Communications Surveys and Tutorials*, 2015, doi: 10.1109/COMST.2015.2444095.
- [3] A. P. Duda, V. Balyan, and A. K. Raji, "Smart Irrigation System for Farm Application Using LoRa Technology," in *Lecture Notes in Networks and Systems*, 2023. doi: 10.1007/978-3-031-50327-6_10.
- [4] L. Atzori, A. Iera, and G. Morabito, "The Internet of Things: A survey," *Computer Networks*, vol. 54, no. 15, 2010, doi: 10.1016/j.comnet.2010.05.010.
- [5] A. Cilfone, L. Davoli, L. Belli, and G. Ferrari, "Wireless mesh networking: An IoT-oriented perspective survey on relevant technologies," *Future Internet*, vol. 11, no. 4, 2019. doi: 10.3390/fi11040099.
- [6] U. Raza, P. Kulkarni, and M. Sooriyabandara, "Low Power Wide Area Networks: An Overview," *IEEE Communications Surveys and Tutorials*, vol. 19, no. 2, 2017, doi: 10.1109/COMST.2017.2652320.
- [7] R. S. Sinha, Y. Wei, and S. H. Hwang, "A survey on LPWA technology: LoRa and NB-IoT," *ICT Express*, vol. 3, no. 1, 2017. doi: 10.1016/j.icte.2017.03.004.
- [8] J. P. Shanmuga Sundaram, W. Du, and Z. Zhao, "A Survey on LoRa Networking: Research Problems, Current Solutions, and Open Issues," *IEEE Communications Surveys and Tutorials*, vol. 22, no. 1, 2020, doi: 10.1109/COMST.2019.2949598.
- [9] E. De Poorter *et al.*, "Sub-GHz LPWAN Network Coexistence, Management and Virtualization: An Overview and Open Research Challenges," *Wirel Pers Commun*, vol. 95, no. 1, 2017, doi: 10.1007/s11277-017-4419-5.
- [10] K. Mikhaylov, J. Petäjäjärvi, and T. Hänninen, "Analysis of capacity and scalability of the LoRa low power wide area network technology," in *European Wireless Conference 2016, EW 2016*, 2016.
- [11] F. Adelantado, X. Vilajosana, P. Tuset-Peiro, B. Martinez, J. Melia-Segui, and T. Watteyne, "Understanding the Limits of LoRaWAN," *IEEE Communications Magazine*, vol. 55, no. 9, 2017, doi: 10.1109/MCOM.2017.1600613.
- [12] T. Adame, A. Bel, and B. Bellalta, "Increasing LPWAN Scalability by Means of Concurrent Multiband IoT Technologies: An Industry 4.0 Use Case," *IEEE Access*, vol. 7, 2019, doi: 10.1109/ACCESS.2019.2909408.
- [13] A. Laya, C. Kalalas, F. Vazquez-Gallego, L. Alonso, and J. Alonso-Zarate, "Goodbye, ALOHA!," *IEEE Access*, vol. 4, 2016, doi: 10.1109/ACCESS.2016.2557758.
- [14] G. Gupta, R. Van Zyl, and V. Balyan, "Evaluation of LoRa nodes for long-range communication," *Nonlinear Engineering*, vol. 11, no. 1, 2022, doi: 10.1515/nleng-2022-0236.

- [15] Thethingsnetwork, "LoRaWAN | The Things Network," The things network.
- [16] G. Gupta and R. Van Zyl, "NOMA-Based LPWA Networks," in *Lecture Notes in Networks and Systems*, 2022. doi: 10.1007/978-981-16-2126-0_42.
- [17] G. Gupta and R. Van Zyl, "Energy harvested end nodes and performance improvement of LoRa networks," *International Journal on Smart Sensing and Intelligent Systems*, vol. 14, no. 1, 2021, doi: 10.21307/IJSSIS-2021-002.
- [18] D. F. Carvalho, P. Ferrari, E. Sisinni, and A. Flammini, "Improving Redundancy in LoRaWAN for Mixed-Criticality Scenarios," *IEEE Syst J*, vol. 15, no. 3, 2021, doi: 10.1109/JSYST.2020.3015274.
- [19] R. Marini, W. Cerroni, and C. Buratti, "A Novel Collision-Aware Adaptive Data Rate Algorithm for LoRaWAN Networks," *IEEE Internet Things J*, vol. 8, no. 4, 2021, doi: 10.1109/JIOT.2020.3020189.
- [20] M. Bor, U. Roedig, T. Voigt, and J. M. Alonso, "Do LoRa low-power wide-area networks scale?," in *MSWiM 2016 - Proceedings of the 19th ACM International Conference on Modeling, Analysis and Simulation of Wireless and Mobile Systems*, 2016. doi: 10.1145/2988287.2989163.