

Resource Management for Cognitive Radio-Based LoRaWAN

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Abstract

The use of internet of thing (IoT) unbinds the race for wireless communication. The LoRaWAN can address the requirement generated by IoT devices in terms of long distance and power efficiency. Due to these reasons, network administrators are looking for unleashed unlicensed band to be utilized for the purpose of communication of long range (LoRa) nodes as secondary users (SUs) without affecting the licensed band (primary users [PUs]). In this paper, the unlicensed band is utilized while adopting slotted ALOHA to provide access to LoRa nodes. The LoRa nodes are in a cluster and each cluster has a gateway(s) that provides services to LoRa nodes in that area by assigning frequency, with the spreading factor (SF) depending upon their distance from the gateway. The network is aware of the spectrum map and can adapt itself when LoRa nodes join and leave the network dynamically. The simulation and results indicate that LoRaWAN performs better than a static network when used in a cognitive radio (CR) environment with knowledge of spectrum.

Keywords

IoT, Spectrum aware, cognitive radio, primary users, secondary users, LPWAN, LoRa

I. Introduction

Interconnection and data exchange characterize the internet of things (IoT) among several other network sensor nodes or devices. IoT applications are gaining attention in many sectors such as smart cities, smart homes, businesses, wearable technologies, and industries as well as healthcare and agriculture. Nonetheless, these applications look toward IoT as a solution due to its ability to provide services at lower cost, lower energy consumption, and lower data rate while operating for long distances. Some of the most used IoT-based technologies such as Bluetooth, ZigBee, or WiMAX are not able to integrate with networks that require longer distance transmission. The disadvantage associated with these technologies made way for utilization of low-power wide area

networks (LPWANs) [1–3]. LPWAN has integrated with many technologies such as NOMA and LiFi for the effective utilization of spectrum.

The use of LPWAN-enabled wireless devices can operate and provide coverage in remote areas at low power. LPWANs lead to the development of IoT. LPWAN technology, which is a solution for IoT, is Long Range (LoRa) or any other long-range wide area network (LPWAN). These LoRa nodes interact with gateways that are connected to the internet and act as bridges and transfer information to LoRa network servers over radio links [4–7]. For the purpose of long-distance networking, industrial scientific medical (ISM) band spectrum is used and sharing of spectrum is done for cognitive radio networks (CRNs). This is implemented using spectrum sensing, in which the silence of primary users (PUs) is considered as

an opportunity to use spectrum by secondary users (SUs). CRN users are grouped wireless users that have access to spectrum dynamically. CRN refers to a group of wireless users that have dynamic spectrum access and advanced cognitive radio capabilities. In the beginning, the issue of spectrum shortage and congestion in network was addressed by CRN users by utilizing the spectrum holes of PUs. Intelligent CR devices are implemented according to the realities of spectrum scarcity, thus enabling CR users called SUs.

The PU cannot bear the interference caused by an SU in this sharing [5, 8, 9]. Random varying and uncorrelated geometry models are used as a tool to construct a LoRa model for performance evaluation of multiple devices [10–12]. The proposed solution assumes that the network is the only noise contributor. However, these approaches do not do well with a shared spectrum that is shared for IoT systems such as LoRa, which experience significant mismatches in terms of signal strength between bands and mobile broadband technologies. Similarly, this program does not lay the basis for network planning. Therefore, instead of paying much more for expensive LoRa receivers, SDRs might be used in GNU radio applications employing LoRa modulation and encoding technique [13]. However, these programs do not provide an infrastructure for developing networks. If there is a range of spreading factors (SFs) employed to separate channels, when both the receiver and transmitter use the same SF, packets could still be received even though another node might be trying to block data transmission [14]. Allowing different SFs to separate channels within a single frequency band can mitigate interference [15]. Additionally, an assessment of the possibility of using carrier activity spectrum sensing has been provided.

The bit error rate (BER) parameter compares the performance degrees of the LoRa modulation and the frequency shift keying (FSK) modulation [16]. From the results, it is visible that the overall performance degree of LoRa modulation increases when an additive white Gaussian noise (AWGN) channel is applied. The work of Liao et al. [17] measured the effect of LoRa nodes transmitting simultaneously. It allows other nodes to transmit packets concurrently having the same SF at the same time. This approach will lead to faster processing of the packets in quick succession, which leads to improvement in network performance. The work of Khan et al. [18] performed cooperative detection and spectrum selection in steps using coefficient vectors that are weighted. Sector evaluation inside the cognitive network

is used, while sufficient performance standards were no longer taken into consideration within the simulations.

The work of Chen et al. [19] proposed a particle swarm optimization (PSO), a primarily based collaborative spectrum detection approach. In this method, more than one cell is deployed over the network and they cooperate in spectrum sensing instead of SUs. All agent nodes act consistent with the state-of-the-art international optimum retailers of the target PUs related to the health function constructed with the aid of the superior PSO. The proposed work of Hossain and Miah [20] is a system mastering-based malicious consumer and spectrum sensing technique for a CRN-IoT that uses a support vector system (SVM) algorithm to discover and classify malicious CR-IoT users.

The work in this paper uses a cluster and zones for allocating the gateways to LoRa nodes for assignment of SF, frequency that depends upon their distance from gateway. The work is mainly focused on resolving the spectrum scarcity for SUs.

The remainder of the paper is organized as follows: problem statement and proposed implementation are discussed in Section 2, results and simulation are given in Section 3, and the conclusions are drawn in Section 4.

II. Problem Statement and Proposed Implementation

The considered problem is improvement in throughput of the secondary network, which in turn improves the total throughput of the network.

LoRa nodes usually look for the opportunity of sending a packet when it has a packet to send, and it randomly picks the available channel for transmission. In this work, a slotted ALOHA is used in which transmission can take place only at the start of the time slot. This leads to reduced collisions. The slotted ALOHA is used, keeping in mind its ability to reduce collisions to half and efficiency to double, as compared with pure ALOHA. At this stage, successful frames transmission rate and throughput are required. If G is the average number of packets generated by LoRa nodes in a frame time that jointly represents an independent Poisson source with an average packet generation rate of λ packets per second, then $G = \lambda T$. Then the probability of successful transmission of a packet using slotted ALOHA is

$$P = e^{-G}. \quad (1)$$

With normalized throughput

$$P_n = Ge^{-G} . \quad (2)$$

The considered configuration is very close to the real configuration of LoRaWAN, which works without an acknowledgment from the gateway for the uplink transmission. Due to this reason, the nodes emit packets independently without retransmissions. The work in the literature uses pure ALOHA for transmission, in which throughput is restricted due to concurrent transmissions, which has been improved by using slotted ALOHA. The collision still exists due to bandwidth (BW), carrier frequency (CF), and same SF. This can be improved by using different SFs for concurrent transmissions while using the same BW and CF to decode successfully.

The configured gateways in this network in conjunction with the network of cognitive radio enable sensors to assign available frequencies in each cluster and classify the traffic generated depending upon their distance from the gateways. The work assumes that LoRa nodes at a similar distance from the gateway will use the same SF proportional to distance from the gateway. The SF decides the ToA; a smaller SF has a smaller frame time and vice versa, which means LoRa nodes take a longer time to send data when larger SFs are used. The work in this paper optimizes available frequencies and SF distribution depending on the generated traffic.

The number of clusters are denoted by $1 \leq c \leq C$, and SF as $7 \leq SF \leq 12$. LoRa nodes that exist with PUs in each cluster can use only those frequencies for uplink transmission that do not cause interference to PUs; the available frequencies are denoted as $1 \leq n \leq N$. Only one SF will be used for transmission by the LoRa nodes, depending upon its distance from the gateway. Without loss of generality, the time on air will depend upon the selected SF, coding rate, and frequency.

If an arrival rate in a cluster c is denoted by λ_c it is further convenient to define the set λ_i , which indicates the packet arrival rate in zone i . The network providers are usually aware of the information regarding clusters and available frequencies, which makes them aware of λ_c . The overall traffic generated in all clusters is

$$G_{n,SF} = \sum_{c=1}^C \lambda_c T_{SF} . \quad (3)$$

Using Eqs. (2) and (3), the throughput is

$$S_{n,SF} = \sum_{n=1}^N \sum_{SF=7}^{12} \left(\sum_{c=1}^C \lambda_c T_{SF} \right) \times e^{-\left(\sum_{c=1}^C \lambda_c T_{SF} \right)} . \quad (4)$$

For any communication network, the main performance parameter is throughput. Therefore, the throughput given in Eq. (4) must be maximized.

In Eq. (4), λ_c and T_{SF} are variables that affect the overall throughput. From network point of view, reducing λ_c will not improve network performance as it generates traffic. The only solution is to minimize T_{SF} , which depends on the SF used by the node for the transmission in a cluster at a particular frequency. The work in this paper assigns in each cluster the minimum available SF to nodes depending on their distance from the gateway(s); assigning the minimum SF will lead to minimum T_{SF} , which will maximize Eq. (4).

III. Results and Simulations

The parameters used are given in Table 1. Three parameters are considered for checking the performance of the work signal to noise ratio (SNR), receiving signal strength indicator (RSSI), and received power. The work uses two combinations of gateway(s) (i.e., single gateway and two gateways) for performance checking for all LoRa nodes in a cluster. The SNR is measured at LoRa nodes placed at different distances using different SFs for gateway(s). The SNR of a j^{th} node in cluster c is defined as

$$SNR_{c,j} = RD_{c,j} \text{ (dBW)} - \text{Noise}RD_{c,j} \text{ (dBW)} \quad (5)$$

where RD denotes the received power and NoiseRD denotes the noise. The RSSI is the intensity of the signal intensity, which is identified by LoRa nodes at the time of communication with gateway(s). The work is evaluated for higher number of gateways also, but it will result in complex selection and increase cost.

Looking at the SNR, the single gateway rejects more packets while using lower SFs as compared with when two gateways are used, as shown in Figure 1. The problem is twofold when clusters are near. The utilization of a higher number of gateways can further enhance the performance; however, it will make the

Table 1: Notations

Parameters	Value
G	Average number of packets.
$\lambda, \lambda_c, \lambda_i$	Arrival rates (packets/sec), in cluster c , and zone i .
P, P_n	Probability of successful transmission of packets without and with normalized.
T_{SF}	Time on air for an SF.

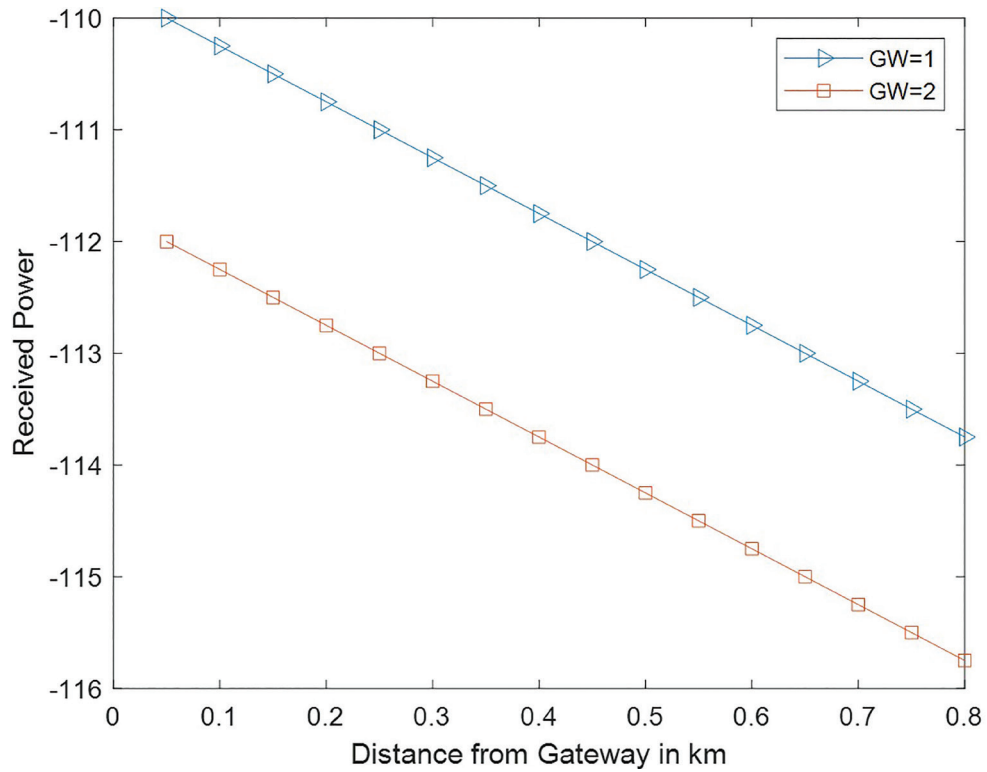


Figure 1: SNR versus number of nodes distance from Gateway when 1 and 2 gateways are used. SNR, signal to noise ratio.

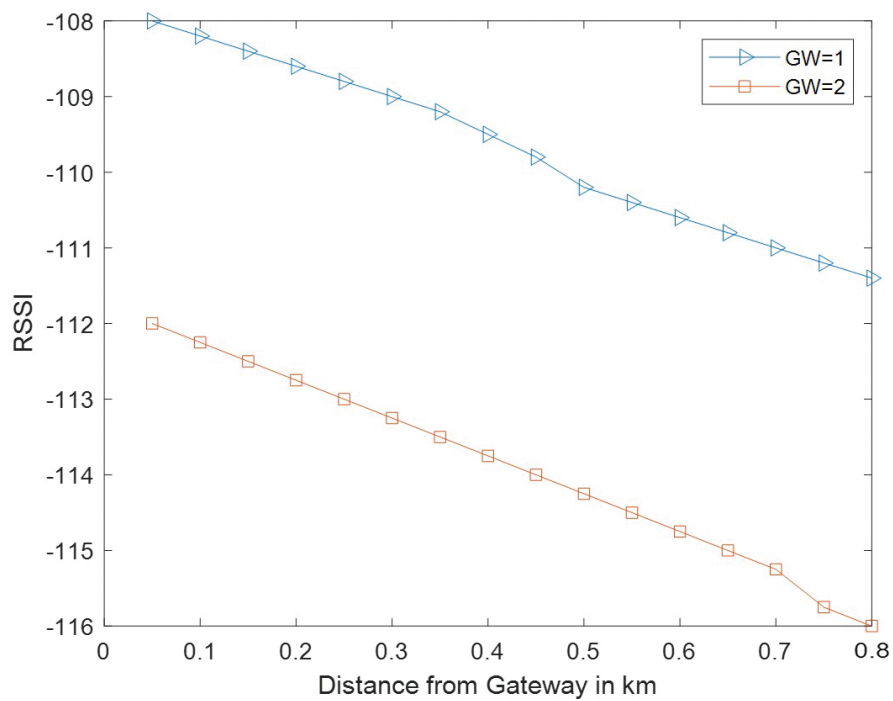


Figure 2: RSSI versus number of nodes distance from Gateway when 1 and 2 gateways are used. RSSI, receiving signal strength indicator.

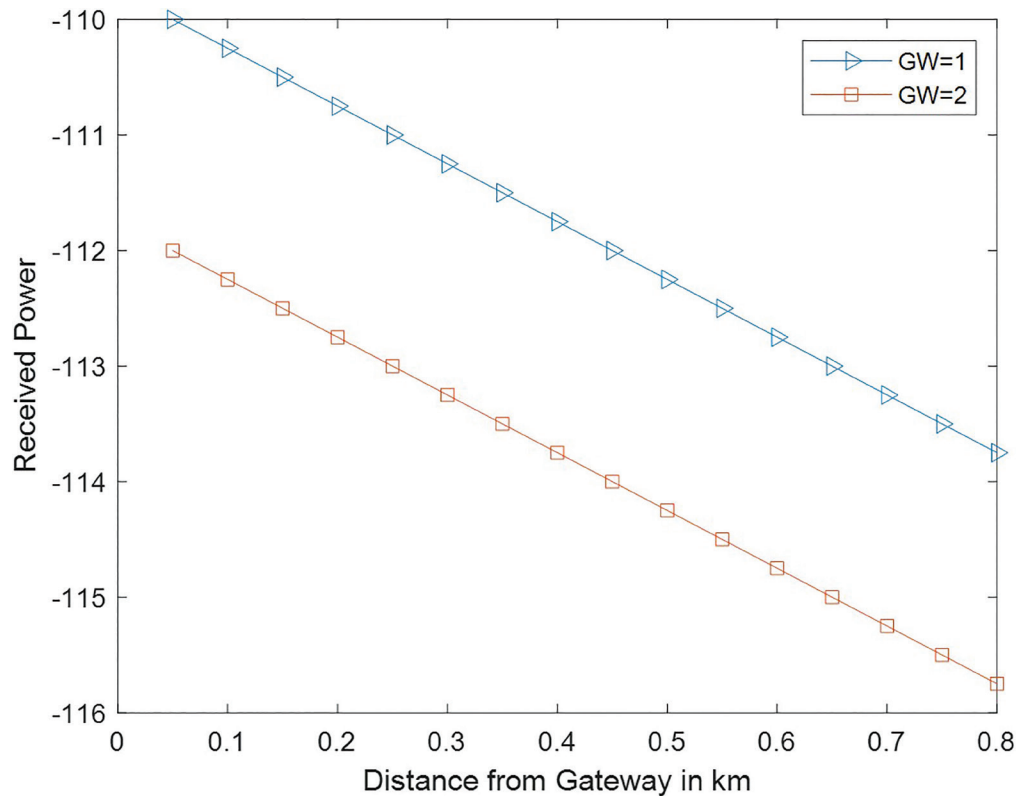


Figure 3: Received power versus number of nodes distance from Gateway when 1 and 2 gateways are used.

selection of gateways more complex. The RSSI indicates how easily a gateway signal can be picked up by LoRa nodes; the value of RSSI is the best way to know whether a wireless connection is good enough or not. In Figure 2, RSSI at different LoRa nodes is shown for different distances from gateway(s), while using one gateway and two gateways.

In Figure 3, the received power at different LoRa nodes is compared for single gateway and two gateways. The power is in decibels and closer to zero is better. The results show different received powers with varied distance from gateways.

IV. Conclusion

The work in this paper uses slotted ALOHA for low payloads. The LoRa nodes (SUs) use unlicensed band in a cluster; the gateway(s) assigns SF, with frequency to LoRa nodes depending upon their distance from itself. Utilization of two gateways significantly improved SNR, RSSI, and received power of LoRa nodes; varying SF also improves the

utilization of available spectrum and improves the overall performance of the network. Utilization of ISM band is gaining a lot of attention from researchers, and using this band in the presence of PUs has a lot of scope for future research. The work in the future will focus on using an algorithm that will do change in frequencies, which is assigned to the user in a particular instant of time.

References

- [1] K. Mekki, E. Bajic, F. Chaxel, and F. Meyer, "A comparative study of LPWAN technologies for large-scale IoT deployment," *ICT Express*, vol. 5, no. 1, 2019, doi: 10.1016/j.icte.2017.12.005.
- [2] F. Sanchez-Sutil and A. Cano-Ortega, "Smart regulation and efficiency energy system for street lighting with LoRa LPWAN," *Sustain Cities Soc*, vol. 70, 2021, doi: 10.1016/j.scs.2021.102912.
- [3] 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.

[4] 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.

[5] J. Peña Queralta, T. N. Gia, Z. Zou, H. Tenhunen, and T. Westerlund, “Comparative study of LPWAN technologies on unlicensed bands for M2M communication in the IoT: Beyond Lora and Lorawan,” in *Procedia Computer Science*, 2019, doi: 10.1016/j.procs.2019.08.049.

[6] 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.

[7] 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.

[8] A. J. Onumanyi, A. M. Abu-Mahfouz, and G. P. Hancke, “Low power wide area network, cognitive radio and the internet of things: Potentials for integration,” *Sensors (Switzerland)*, vol. 20, no. 23, 2020, doi: 10.3390/s20236837.

[9] A. C. Sumathi, R. Vidhyapriya, C. Vivekanandan, and A. K. Sangaiah, “Enhancing 4G Co-existence with Wi-Fi/IoT using cognitive radio,” *Cluster Comput*, vol. 22, 2019, doi: 10.1007/s10586-017-1383-5.

[10] L. Beltramelli, A. Mahmood, M. Gidlund, P. Osterberg, and U. Jennehag, “Interference Modelling in a Multi-Cell LoRa System,” in *International Conference on Wireless and Mobile Computing, Networking and Communications*, 2018, doi: 10.1109/WiMOB.2018.8589100.

[11] D. Magrin, M. Centenaro, and L. Vangelista, “Performance evaluation of LoRa networks in a smart city scenario,” in *IEEE International Conference on Communications*, 2017, doi: 10.1109/ICC.2017.7996384.

[12] 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.

[13] P. Robyns, P. Quax, W. Lamotte, and W. Thenaers, “A multi-channel software decoder for the LoRa modulation scheme,” in *IoTBDs 2018 - Proceedings of the 3rd International Conference on Internet of Things, Big Data and Security*, 2018, doi: 10.5220/0006668400410051.

[14] M. Bor, J. Vidler, and U. Roedig, “Lora for the internet of things,” in *International Conference on Embedded Wireless Systems and Networks*, 2016.

[15] J. Petäjäjärvi, K. Mikhaylov, M. Pettissalo, J. Janhunen, and J. Linatti, “Performance of a low-power wide-area network based on lora technology: Doppler robustness, scalability, and coverage,” *Int J Distrib Sens Netw*, vol. 13, no. 3, 2017, doi: 10.1177/1550147717699412.

[16] L. Vangelista, “Frequency Shift Chirp Modulation: The LoRa Modulation,” *IEEE Signal Process Lett*, vol. 24, no. 12, 2017, doi: 10.1109/LSP.2017.2762960.

[17] C. H. Liao, G. Zhu, D. Kuwabara, M. Suzuki, and H. Morikawa, “Multi-Hop LoRa Networks Enabled by Concurrent Transmission,” *IEEE Access*, vol. 5, 2017, doi: 10.1109/ACCESS.2017.2755858.

[18] M. S. Khan, S. M. Kim, E. H. Lee, and J. Kim, “Genetic Algorithm Based Cooperative Spectrum Sensing Optimization in the Presence of Malicious Users in Cognitive Radio Networks,” in *ICTC 2019 - 10th International Conference on ICT Convergence: ICT Convergence Leading the Autonomous Future*, 2019, doi: 10.1109/ICTC46691.2019.8939859.

[19] J. Chen, S. Huang, H. Li, X. Lv, and Y. Cai, “PSO-Based Agent Cooperative Spectrum Sensing in Cognitive Radio Networks,” *IEEE Access*, vol. 7, 2019, doi: 10.1109/ACCESS.2019.2944227.

[20] M. S. Hossain and M. S. Miah, “Machine learning-based malicious user detection for reliable cooperative radio spectrum sensing in Cognitive Radio-Internet of Things,” *Machine Learning with Applications*, vol. 5, 2021, doi: 10.1016/j.mlwa.2021.100052.