Performance Evaluation of Spreading Factors in LoRa Networks

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Abstract. LoRa Networks is one of the fast-growing and promising technologies to enable communications for the Internet of Things (IoT) devices on a large scale or long-range communication. Spreading Factors (SF) plays a significant role in enabling multiple long-range receptions of packets with every packet assigned a different spreading factor. Therefore, a change in SF is necessary for improving the data rate for transmission where the link is better and allow LoRa networks to adapt the range trade-off. This work uses FLoRa open source framework for carrying out end-to-end LoRa simulations network in the OMNET++ simulator. In this paper, we investigated the Adaptive Data Rate (ADR) and provided the behaviour of SF and data rate in LoRa wide Are network (LoRaWAN). Some of the findings includes the ability of transmitting data very fast possessed by the low SF no matter the size of the network and high amount of energy consumed by the high SF.

Keywords: Spreading factors · LoRa networks · IoT · Gateway · Simulation

1 Introduction

Recently Internet of Things (IoT) has gained momentum and opened up new challenges in the establishment of efficient networks. The establishment includes low energy consumption of IoT devices and transmitting a large amount of data through wireless communication. These IoT/smart devices can be deployed using short-range technologies such as Bluetooth, infrared and ZigBee, or long-range technologies such as Sigfox, NB-fi and LoRa. In addition, IoT devices have the capability of being located inside buildings, underwater or underground. A Low

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Smangaliso Mnguni is a Masters student in the Department of Computer Science at the University of Zululand. His research interest is under LoRa gateway placement in the Internet of Things (IoT) and Low Power Wide Area Networks (LPWAN).

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Power Wide Area (LPWAN) usually provides a long-range transmission, wireless connectivity (using a star topology) and increased power efficiency [10,13]. LoRaWAN is one of the technologies provided by LPWAN which has a lot of capabilities and promising features. LoRa devices use LoRaWAN standards for communication, and it can improve power efficiency. The choice of parameters used for radio resources and the number of gateways deployed such as transmission power, coding, spreading factors and bandwidth impacts the LoRaWAN network performance in terms of latency, robustness, and coverage. In the Chirp Spread Spectrum (CSS) wherein physical layer, a based ALOHA method consists of several SFs to pick from, in order to trade data rate for a long-range [5]. Therefore, higher SF allows more extended range at the expense of lower data rate, and vice versa. In different channels the transceivers can take control of receiving different data rates where the data rate is defined as time-on-air of the data transmitted [18].

A high packet error rate may occur as a result of letting nodes choose their power control and SFs, which cause an unfair network performance [17]. In this equation, for LoRa modulation BW as a parameter play a significant role such that a doubling of it automatically doubles the transmission rate. Furthermore, at a given SF the bit rate and symbol rate are directly proportional to the frequency bandwidth, SF bits of information can effectively be encoded by a symbol since there are chirps in a symbol [1]. Many studies have been trying to solve the gateway placement in LoRa networks by introducing different algorithms to achieve maximum coverage. However, many algorithms were a none success and the impact of SFs and data rate in the algorithms were not considered to improve them. This paper is solving the problem of SFs and data rate in LoRaWAN networks for the gateway to be optimally placed.

The rest of this paper is organized as follows. Section 2 provides an overview of LoRa/LoRaWAN. Section 3 provides the relevant and related work for the study, and Sect. 4 discusses the approached used in the study. Section 5 describes the framework for LoRa simulations, and Sect. 6 discusses the evaluation of performance in LoRa networks. Finally, Sect. 7 provides concluding remarks.

2 Overview of LoRa/LoRaWAN

There are two components a LoRa network relies on, namely LoRa and LoRaWAN. In a protocol stack, each of these components corresponds with a different layer. The LoRa Alliance, on the other hand, describe LoRaWAN as an open standard, Semtech developed the LoRa physical layer, which however remains the sole LoRa integrated circuit producer [11]. The relation between the spreading factor (SF), bandwidth (BW), bit rate ($\mathrm{R_b}$) and symbol rate ($\mathrm{R_s}$) is summarized in the form of Eq. (1) [18].

$$R_b = \frac{BW \times SF}{2^{SF}} = (SF)R_s \tag{1}$$

LoRaWAN is the system architecture and ALOHA based communication protocol for a network using the LoRa physical layer. LoRa wireless, with the option for different bandwidth and spreading factor (SF) uses CSS modulation for optimization of modulation to meet data and the long-range requirements. LoRaWAN can communicate over the air with a gateway and involves protocol stack with LoRa wireless; usually, network servers communicate with the gateways, and LoRa Physical layer creates communication between LoRa nodes and the gateway [21]. Chirp modulator passes through the data for binary chirp modulation in a waveform:

$$s(t) = \sqrt{\frac{2E_s}{T_s}} cos\left[2\pi f_c t \pm \pi \left(u\left(\frac{t}{T_s}\right) - w\left(\frac{t}{T_s}\right)^2\right)\right] \tag{2}$$

where *s(t)* is function respect to time, E_s represents the energy of *s(t)* in the symbol duration T_s. Carrier frequency is denoted by f_c, the sweep width and peak-to-peak frequency deviation are presented by constant w and u respectively, both normalized by symbol rate. Adaptive Data Rate (ADR) enables the trade-off between energy consumption, robustness, and network throughput through the support of LoRa while the bandwidth is fixed.

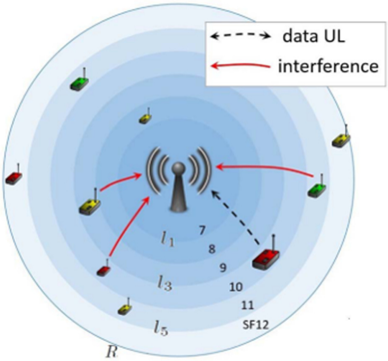

Fig. 1. Uplink (UL) system architecture consisting of several LoRa nodes and one gateway located uniformly in a certain R km radius [7].

In Fig. 1. ALOHA is used by the LoRa devices for a random transmission in the UL and satisfy an additional maximum $p0 = 1\%$ duty cycling policy. According to this cycling policy, LoRa nodes with higher SFs transmit less often as compared to those with lower SFs, for a simplicity BW = 125 kHz is kept constant for every transmission. However, packet loss may still occur if concurrently received signal of the same SF and frequency interfere at the same gateway regardless of simplification. Furthermore, $l_1, l_2 ..., l_n$ denotes Euclidean range between gateway and LoRa nodes [7,8]. Finally, for a system model or settings a cell of radius R was considered with one or two gateways centered for a different scenarios and LoRa nodes were randomly distributed within the cell, another factor for data transmission is the distance which determines which SF and channel a packet to be transmitted into.

3 Related Work

Since LoRaWAN is an actively studied protocol, other researchers have been working around this area. In [12] authors evaluated the LoRaWAN based protocol using the permanent outdoor testbed, In their evaluation metrics like packet delivery ratio, payload length and link checks were taken into consideration focusing on Adaptive Data Rate (ADR) impact. They revealed that regardless of distance, the ADR schemes assign either the slowest data rate (SF12: BW125) or the fastest (SF7: BW250) primarily.

Another author in [2] evaluated the LoRa transmission parameter selection to ensure reliable and efficient communication amongst the Low Power Wide Area Network (LPWAN) devices. Communication reliability and energy consumption matrices were included in the study, and it was observed that more than 6720 possible settings are available for LoRa device configuration with the use of bandwidth setting, transmission powers, code rate and spreading factors. However, it is still a challenge to determine the required communication performance with minimal energy transmission cost.

The researchers in [14,15] studied the LPWANs coverage in channel attenuation model and range evaluation for LoRa technology. The intention was to see the impact of distance and channel attenuation in IoT networks, and the nodes were placed in different places such as water (attached in the radio mast of a boat) or ground (attached on a roof rack of a car) for measurements in different scenarios in an area called Oulu, Finland. They reported that for a node operating in the 868 MHz ISM band with power transmission of 14 dBm and a maximum of spreading factor resulted in a maximum communication range of 30km and 15 km on water and ground respectively. However, the model was not tested in bidirectional communication. At around 40 km/h speed they revealed, because of the duration of the LoRa-modulated communication performance get worse. The extensive research around ADR scheme has resulted in authors to propose another algorithm for modification and addition in order to extend LoRa performance by a suitable allocation of spreading factors. Through the simulation results, EXPLoRa showed much-improved performance compared to the ADR scheme. However, the algorithm selects the spreading factor based on the number of devices deployed in a network [6].

However, it is still necessary to conduct more experiments in a different environment such as testbed to verify the results and find different aspect as to how the SFs and data rate impacts the LoRa networks.

4 Simulation Setup

Network deployment plays a significant role in network throughput, an impact of range on performance can be provided by deploying gateways at a fixed distance without even a need for that gateway(s) to be continuously relocated. Furthermore, simultaneous data collection is possible through permanently deploying nodes at a fixed range. We used an end-to-end simulation-based to test the algorithm enhanced with the support of FLoRa which allows bi-directional communication.

4.1 Design and Layout

The LoRa simulation consists of two network scenarios, one with 100 nodes and the other with 20 nodes, in both scenarios gateway(s) were varied from one to two. All experiments were simulation-based which runs on virtual machine ubuntu 18.10 environment, the simulator integrated inet-4.1.1 with omnetpp v5.5.1. The simulator is written in C++ programming language. The gateway(s) in both network scenarios were placed central in the simulation area and LoRa devices distributed around them, as shown in Fig. 2 and Fig. 3. The gateway is responsible for facilitating communication in the network, and it is connected to a network server.

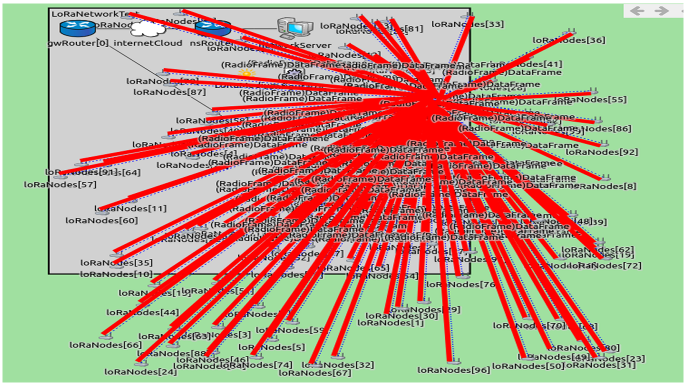

Fig. 2. Example of the first scenario with 100 nodes.

4.2 Topology and LoRa Devices

A star-of-stars topology approach was followed in this study, in which LoRa devices send/receive packets through the channel to/from one or more gateway. The gateway act as a middle man between the LoRa devices and network server by forwarding packets via high throughput and reliable link. It is assumed that at least one gateway will receive the packet and forward them to the network server after end devices have sent them as illustrated in Fig. 4.

4.3 LoRa Simulations a Framework

This section discusses LoRa simulations in details, including the configuration of LoRa devices deployed and together with their parameters. Framework for

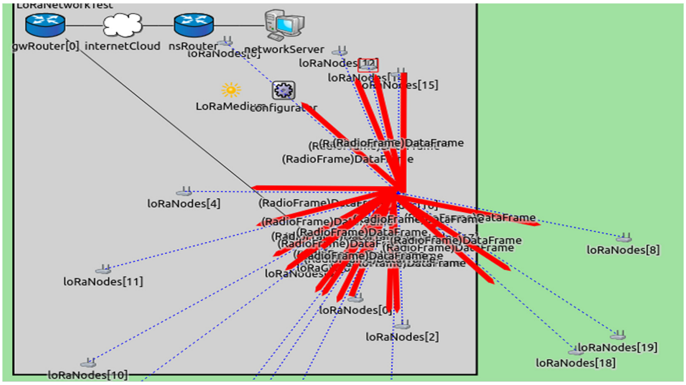

Fig. 3. Example of the second scenario with 20 nodes.

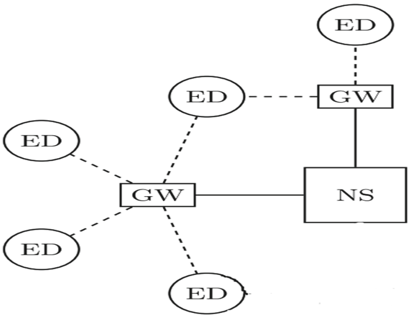

Fig. 4. Example of LoRa network star-of-stars topology.

LoRa (FLoRa) carries out end-to-end simulations for LoRa network. The framework is based on a simulator called OMNET++ and takes advantage of INET framework components, with modules from a network server, gateway(s) and LoRa nodes FloRa allows the creation of LoRa networks. Adaptive Data Rate (ADR) helps in dynamic management of parameters configuration with the support of LoRa nodes and network server. Finally, for every LoRa node present in the network energy consumption statistic is collected, and LoRa physical layer characterization is described [20].

4.4 LoRa Links

In the LoRa physical layer transmission parameters are configured through the support of FLoRa such parameters include transmission power, code rate, bandwidth, center frequency and spreading factor. These parameters influence the occurrence of collision and transmission range. In example, suppose the receiver sensitivity is less than received power the LoRa transmission is successful. The long-distance path loss equation below was used to model the transmission range, received power and receiver sensitivity by determining path loss based on a distance between receiver and transmitter:

$$PL(d) = \overline{PL}(d_0) + 10n\log(\frac{d}{d_0}) + X_\sigma \quad (3)$$

Where the mean path loss for distance d_0 is denoted by $\overline{PL}(d_0)$, $X\sigma$ and n represents zero-mean Gaussian distributed random variable and path loss exponent respectively. A transmission is regarded as successful if no interference occurred during LoRa transmission of packets. Furthermore, the assumption is made two transmissions in an orthogonal channel (meaning transmission of different SFs) do not collide not unless otherwise. Lastly, the transmission power is calculated as: TP = 2 dBm + 3 dBm ×intuniform (0,4) and communication model was validated against the results [19].

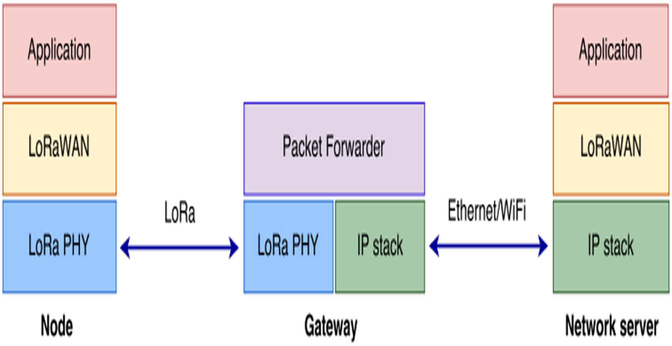

Fig. 5. Corresponding protocol stack and available FLoRa modules [19].

The protocol stack of nodes, gateways and network server is shown in Fig. 5. Gateway is responsible for forwarding messages between the nodes and network server, whereas nodes and network server have an application layer.

4.5 Energy Consumption Module

In a particular state, the amount of time spent by LoRa radio determines the energy consumed. State-based energy consumer module is used to model energy expenditure. Sleep, receive and transmit all form three primary state of LoRa radio after receiving or transmitting a frame the radio is switched to sleep mode. Level of transmission power always controls the energy consumed in the transmit state [3,4,9].

5 Evaluation of Performance

Initially, the adaptive communication is evaluated in LoRa networks through simulations. Firstly, the simulation setup is described, followed by obtained results. Finally, the experimental simulation is the summary of findings.

5.1 Parameters of the Simulation

The performance of LoRa networks was evaluated with the help of FloRa. Two simulation experiments conducted, in the first one, a network of 100 nodes was created varied from 100 to 700 in steps of 100. For both experiments, the number of LoRa gateway(s) varied from one to two, and for LoRa physical layer European environmental parameters were used as explained in Table 1. The second simulation consists of a 20 nodes network with different gateways, where every LoRa node deployed pick an arbitrary transmission power and spreading factor distributed within a permissible range.

INET framework played a significant role in modelling the backhaul network with a transmission power of 10 ms and no packet loss. In the simulation, a typical sensing application was considered. After distribution time, each LoRa nodes sent a 20-byte packet with a mean of 1,000 s. The size of the deployment area was set to 500 m by 500 m for the first scenario, 10000 m by 10000 m for the second scenario. All the deployed LoRa devices were located within the square region to communicate with the gateway(s), and nodes were randomly placed. The simulated time for both experiments lasted one day, and ten iterations run for accuracy of the results. LoRa networks performance was evaluated with and without Adaptive Data Rate (ADR). Both at the network server and the nodes mechanisms is disabled in networks with no ADR, ADR-node ran on all variants of ADR and nodes at the network server when ADR was enabled.

Table 1. Parameters for simulation

Parameters	Value(s)
Transmission power	2 dBm to 14 dBm
Spreading factor	7 to 12
Code rate	4/8
Bandwidth	125 kHz
Carrier frequency	868 MHz

Performance of the network evaluated with LoRa devices of different densities, in the deployment area, the number of nodes were varied from 100 to 700 with the steps of 100. Lastly, below performance matrices were considered in the simulation process:

- Energy consumption per successful transmission, LoRa nodes total energy divided by the total number of messages received by the network server.
- Delivery ratio, as the number of messages correctly received by the network server divided by the total number of messages sent by the end nodes.

6 Simulation Results

Initially, the performance of networks with ADR was evaluated than followed by the analysis impact of the algorithm implemented for spreading factor allocation. Next, we compare the performance of the algorithm if the network has one gateway or two gateways. Finally, the evaluation of energy efficiency in the algorithm.

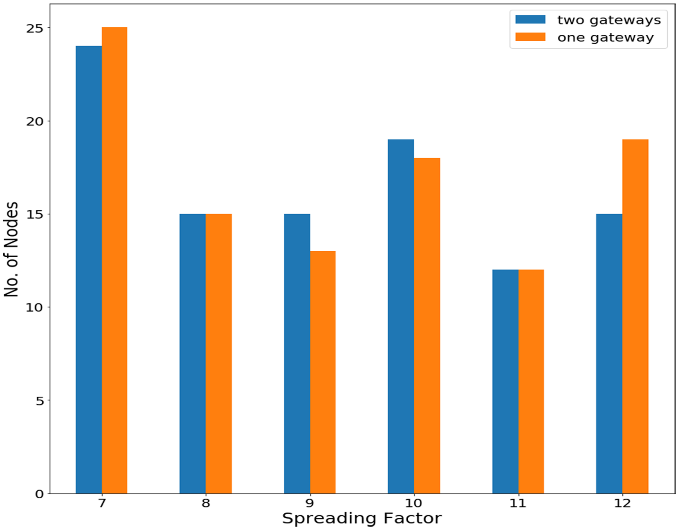

Fig. 6. Comparison of the number of nodes of each spreading factor.

Figure 6 shows the average number of nodes for both scenarios allocated to each spreading factors in different networks, and Each network consists of 100 nodes with one and two gateway(s) respectively. It is observed that most nodes were assigned to the lowest spreading factor number 7 in both scenarios, meaning most nodes were close to the gateway(s). A spreading factor of 7 allows nodes to take as less as possible to communicate with the gateway(s). However, the possibility of collision between the packets is more likely to increase when the number of nodes with the same spreading factor increases drastically. The same number of nodes were observed in spreading factors of 8 and 11 for both scenarios, respectively. The transmission power was kept constant throughout the simulation. However, in certain areas, it is observed that gateway and nodes can only communicate if transmission occurs at a high spreading factor and high transmission power.

Figure 7 shows the energy consumed by nodes transmitting data in different spreading factors. As expected, the spreading factor of 12 has the highest amount of energy consumption in both cases. Bandwidth channel was set to 125 kHz throughout the simulation, nodes assigned to spreading factor of 12

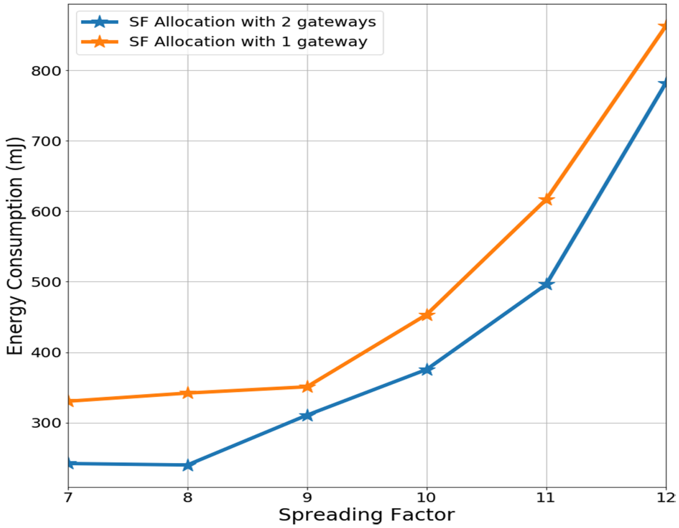

Fig. 7. Energy consumed by nodes in each spreading factors.

consumed a high amount of energy due to transmission distance the higher the spreading factor, the more time taken to transmit a packet which results to high energy consumption during the process. The increase of packet transmission is influenced by the increasing number of encoding bits, which allows radio module to consume more power. The spreading factor with one gateway consumed more energy compare to spreading factor with two gateways, energy consumed in both scenarios increased as the spreading factor increases. It is due to the lack of available gateways to transmit in a network with one gateway.

Figure 8 represents the energy consumed at different spreading factors as a function of the payload useful bits. It is observed that with the increase of useful bits in the network the energy consumption decreases, the energy consumed depends on the number of spreading factor, i.e. if a node uses a spreading factor of 12 to transmit packets the time-on-air will increase since the longer the distance, the more time it takes to transmit which results to the increase of energy consumption. If the node is closer to the gateway spreading factor of 7 will be picked for packet transmission depending on how near it is, in that case, less time will be taken on air due to short distance to travel which decreases the energy consumption as the useful payload bits increases. It is noted that energy consumed and the time-on-air increased with the decrease of the coding rate, where the code rate denotes a useful number of bits or transmission bits.

Figure 9 shows how time-on-air, payload and spreading factors have strongly impacted the packet transmission from nodes to the gateway(s). It is observed that time-on-air increases as the number of spreading factor increase, spreading factor of 12 have the highest amount of time-on-air due to distance between nodes and the gateways. There was a minor difference time-on-air between the

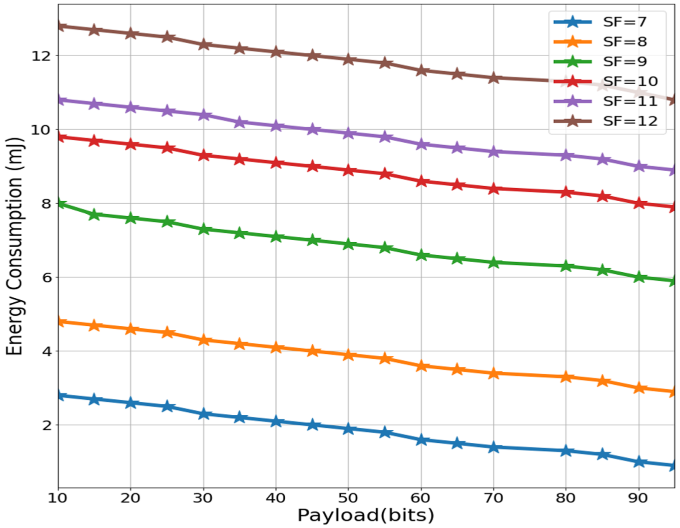

Fig. 8. Energy consumed per payload bits at different spreading factors.

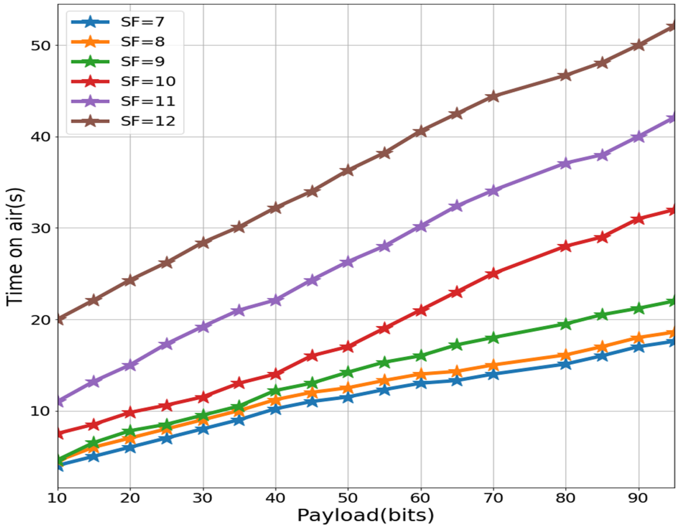

Fig. 9. Time on air vs payload at a different spreading factor.

nodes used a spreading factor of 7 and 8 which means the distance between those two spreading factors to the gateway was almost equal for every channel picked up. For every step up in spreading factor doubles the time-on-air for the same amount of data to be transmitted, the longer the time-on-air results in fewer data transmitted per unit of time with the same bandwidth [16].

7 Discussion

Whist the simulation results showed some key findings, solutions for the challenges in LoRa networks are highlighted and discussed. According to the algorithm implemented transmission power can increase the spreading factor until the packets from nodes are successfully transmitted to the network server via link budget. However, Adaptive Data Rate of nodes can only allow the increase of spreading factor while transmission power remains constant. From the observation of the results, it is not deniable that in some cases, nodes can be a secure link with the gateway if it transmits at a high spreading factor and high transmission power.

8 Conclusion

In this paper, the evaluation of LoRa network performance has been conducted with the use of adaptive communications. FLoRa was used to carry out end-to-end simulations which were integrated to OMNet++ and INET framework. Our results showed that most nodes picked up a spreading factor of 7 in both scenarios as the results of most nodes in the network not being far away from the gateway(s). If nodes are closer to the gateway, less energy consumed for packet transmission. However, there are high chances of packet collision due to congestion in the channels. The spreading factor has an enormous impact on network coverage, energy consumption and latency, as does the data rate. Appropriate choosing the transmission power and spreading factor automatically improves the link budget.

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References

1. Augustin, A., Yi, J., Clausen, T., Townsley, W.M.: A study of LoRa: long range & low power networks for the Internet of Things. Sensors **16**(9), 1466 (2016)
2. Bor, M., Roedig, U.: LoRa transmission parameter selection. In: 2017 13th International Conference on Distributed Computing in Sensor Systems (DCOSS), pp. 27–34. IEEE (2017)
3. Bor, M.C., Roedig, U., Voigt, T., Alonso, J.M.: Do LoRa low-power wide-area networks scale? In: Proceedings of the 19th ACM International Conference on Modeling, Analysis and Simulation of Wireless and Mobile Systems, pp. 59–67 (2016)
4. Bouguera, T., Diouris, J.F., Chaillout, J.J., Jaouadi, R., Andrieux, G.: Energy consumption model for sensor nodes based on LoRa and LoRaWAN. Sensors **18**(7), 2104 (2018)

5. Caillouet, C., Heusse, M., Rousseau, F.: Optimal SF allocation in LoRaWAN considering physical capture and imperfect orthogonality. In: 2019 IEEE Global Communications Conference (GLOBECOM), pp. 1–6. IEEE (2019)
6. Cuomo, F., et al.: Explora: extending the performance of lora by suitable spreading factor allocations. In: 2017 IEEE 13th International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob), pp. 1–8. IEEE (2017)
7. Georgiou, O., Raza, U.: Low power wide area network analysis: can LoRa scale? IEEE Wirel. Commun. Lett. **6**(2), 162–165 (2017)
8. Khutsoane, O., Isong, B., Abu-Mahfouz, A.M.: IoT devices and applications based on LoRa/LoRaWAN. In: IECON 2017–43rd Annual Conference of the IEEE Industrial Electronics Society, pp. 6107–6112. IEEE (2017)
9. Kim, D.H., Lim, J.Y., Kim, J.D.: Low-power, long-range, high-data transmission using Wi-Fi and LoRa. In: 2016 6th International Conference on IT Convergence and Security (ICITCS), pp. 1–3. IEEE (2016)
10. Magrin, D., Centenaro, M., Vangelista, L.: Performance evaluation of LoRa networks in a smart city scenario. In: 2017 IEEE International Conference on communications (ICC), pp. 1–7. IEEE (2017)
11. Marais, J.M., Malekian, R., Abu-Mahfouz, A.M.: LoRa and LoRaWAN testbeds: a review. In: 2017 IEEE Africon, pp. 1496–1501. IEEE (2017)
12. Marais, J.M., Malekian, R., Abu-Mahfouz, A.M.: Evaluating the LoRaWAN protocol using a permanent outdoor testbed. IEEE Sens. J. **19**(12), 4726–4733 (2019)
13. Mnguni, S., Abu-Mahfouz, A.M., Mudali, P., Adigun, M.O.: A review of gateway placement algorithms on Internet of Things. In: 2019 International Conference on Advances in Big Data, Computing and Data Communication Systems (icABCD), pp. 1–6. IEEE (2019)
14. Petäjäjärvi, J., Mikhaylov, K., Pettissalo, M., Janhunen, J., Iinatti, J.: Performance of a low-power wide-area network based on LoRa technology: doppler robustness, scalability, and coverage. Int. J. Distrib. Sens. Netw. **13**(3), 1550147717699412 (2017)
15. Petajajarvi, J., Mikhaylov, K., Roivainen, A., Hanninen, T., Pettissalo, M.: On the coverage of LPWANs: range evaluation and channel attenuation model for LoRa technology. In: 2015 14th International Conference on ITS Telecommunications (ITST), pp. 55–59. IEEE (2015)
16. Potéreau, M., Veyrac, Y., Ferre, G.: Leveraging LoRa spreading factor detection to enhance transmission efficiency. In: 2018 IEEE International Symposium on Circuits and Systems (ISCAS), pp. 1–5. IEEE (2018)
17. Reynders, B., Meert, W., Pollin, S.: Range and coexistence analysis of long range unlicensed communication. In: 2016 23rd International Conference on Telecommunications (ICT), pp. 1–6. IEEE (2016)
18. Reynders, B., Meert, W., Pollin, S.: Power and spreading factor control in low power wide area networks. In: 2017 IEEE International Conference on Communications (ICC), pp. 1–6. IEEE (2017)
19. Slabicki, M., Premsankar, G., Di Francesco, M.: Adaptive configuration of LoRa networks for dense IoT deployments. In: NOMS 2018–2018 IEEE/IFIP Network Operations and Management Symposium, pp. 1–9. IEEE (2018)
20. Sommer, C., German, R., Dressler, F.: Bidirectionally coupled network and road traffic simulation for improved IVC analysis. IEEE Trans. Mob. Comput. **10**(1), 3–15 (2010)
21. Wixted, A.J., et al.: Evaluation of LoRa and LoRaWAN for wireless sensor networks. In: 2016 IEEE SENSORS, pp. 1–3. IEEE (2016)