CAPÍTULO 03

CSMA PROTOCOL PERFORMANCE WITH DYNAMIC SPREADING FACTOR IN LPWAN NETWORKS WITH LORA RF TRANSCEIVERS

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ABSTRACT: Long Range (LoRa) is a spread spectrum modulation technology designed for Low- Power Wide-Area Networking (LPWAN) with a growing application in Internet of Things (IoT), which plays an important role in the global digitalization process. The expansion of LORAWAN networks demands careful circuit, system and network design to improve energy efficiency and quality of service. To support this task, advanced CAD tools can offer reliable network simulations results, where the effects of building blocks can be found. LoRaSim, one of the most popular simulators available for LoRa and LoraWan, had solely implemented an ALOHA access model protocol, which is not the most common protocol in real life scenarios. To mitigate this limitation and taking advantage of the open-source nature of both LoRaWAN and LoRaSim, it is proposed a Carrier Sense Multiple Access/ Collision Avoidance (CSMA/CA) protocol extension, as well as active adaptive parameters selection to cope with collisions. To demonstrate the effectiveness of these additions to the base solution, a comparison between both on different scenarios and their simulated performance key indicators will be presented.

KEYWORDS: IoT; LPWAN; LoRaWAN; LoRa; Spreading Factor; LoRaSim; CSMA/CA.

RESUMO: Long Range (LoRa) é uma tecnologia de modulação de espectro espalhado projetada para Low-Power Wide-Area Networking (LPWAN) com uma aplicação crescente na Internet das Coisas (IoT), que desempenha um papel importante no processo de digitalização global. A expansão das redes LORAWAN exige um projeto cuidadoso de circuitos, sistemas e redes para melhorar a eficiência energética e a qualidade do serviço. Para apoiar essa tarefa, ferramentas CAD avançadas podem oferecer resultados confiáveis de simulações de rede, onde os efeitos dos blocos de construção podem ser encontrados. O LoRaSim, um dos simuladores mais populares disponíveis para LoRa e LoraWan, implementou apenas um protocolo de modelo de acesso ALOHA, que não é o protocolo mais comum em cenários reais. Para atenuar essa limitação e aproveitar a natureza de código aberto do LoRaWAN e do LoRaSim, é proposta uma extensão do protocolo Carrier Sense Multiple Access/ Collision Avoidance (CSMA/CA), bem como a seleção de parâmetros adaptativos ativos para lidar com colisões. Para demonstrar a eficácia desses acréscimos à solução básica, será apresentada uma comparação entre ambos em diferentes cenários e seus indicadores-chave de desempenho simulados.

PALAVRAS-CHAVE: IoT; LPWAN; LoRaWAN; LoRa; Fator de Espalhamento;

LoRaSim; CSMA/CA.

1. INTRODUCTION

This study intends to demonstrate the difference between two of the most popular random-access protocols. It will also present the key parameters that define how the protocol will behave in each scenario. The theoretical analysis is accompanied by graphs extracted from the LoRaSim simulator [1], the most popular simulator for LoRa/LoRaWAN, which has been extended with development to allow a second, more efficient protocol to be simulated, as well as an adaptative Spreading Factor (SF) and timing management features.

In this paper, we use LoRaSim simulator to study the impact of the different medium access protocols (ALOHA and CSMA) and develop a new algorithm for a dynamic attribution of SF using CSMA/CA protocol for LoRa/LoRaWAN Radio Interface. We first show (section 2) the main contributions to the main theme of the conference. In section 3, we summarize LoRa and LoRaWAN Network. In section 4, we describe our purpose of this work – the new algorithm developed, and the new extension implemented in LoRaSim original. Section 5 presents results and draw the conclusions.

2. TECHNOLOGICAL INNOVATION FOR IOT

The nature of some of Internet of Things (IoT) services encourages operators to be particularly flexible and agile during the service-delivery and operation phases. Some capabilities, such as firewall, that are needed to create, deliver, and maintain a feature of an IoT service may be hosted in various platforms typically located in a cloud infrastructure. Other capabilities, such as traffic forwarding and Quality of Service (QoS), may be supported by in-network nodes such as dedicated service cards or devices with dedicated hardware. Selection of capabilities needed to dynamically orchestrate and deliver an IoT service therefore benefits from the flexibility of cloud-hosted service platforms and applications coupled with Software-Defined Network (SDN) techniques [2] that include dynamic service-inferred IoT resource allocation and policy enforcementas well as assurance. Recently, the application of SDN to IoT networking has been investigated [3]-[4]. However, the focus has primarily been on dynamically enforcing a traffic-forwarding policy within an IoT network infrastructure according to abstract models and virtualized functions. SDN combined with Network Function Virtualization (NFV) and mass data analytics is a promising option for introducing high-degree automation into the overall IoT service-delivery procedure (from dynamic exposure and negotiation of IoT service parameters to resource allocation, policy enforcement, and service fulfillment and assurance). An SDN platform can be used to manage one or moreIoT services. SDN can significantly help customize involved nodes at large to accommodate the design requirements of an IoT service portfolio, from smart home automation to advanced e-health or energy distribution services.

3. LORA AND LORAWAN NETWORK

LoRa network is a spectrum modulation technology developed by the company Semtech Corporation [5], and its own devices and modulation have come to be recognizedas standard in the IoT area. Within LoRa Technology: there are two operating frequencies.The 433 MHz band is inserted in the free and theoretically a wave higher than the 868 MHz frequency will have greater range, and therefore also greater resistance to interference and greater ability to penetrate objects. The 433 MHz frequency is more popular by other technologies and as features that do not first give an advantage to the use of the 868 MHz frequency end up becoming reality additionally, as the applications for LoRa are now better compared to 868 MHz.

This modulation derives from Chirp Spread Spectrum (CSS) technology. Frequency Modulation (FM) more resilient than simple FM. chirp is a bandwidth scan assigned to this technology (typically 125 kHz and 250 kHz in Europe and 500 kHz in other continents) and "done in the +/- direction if it is a bit at 1" This scan is also a large amount of a "rhythm", one between the highest scanning rhythm and greatest information difficulty (especially taking in length the interferences of the medium as practical counts.) In Europe six sweeping rhythms or SF are used.

LoRaWAN that allows the creation of a range link, and establishment of communication between stations as a communication protocol. This open-source protocolhas opened a huge number of private initiatives since the implementation of the protocol, such as the development of ancillary solutions (both at the application layer and at the application layer level), expanding the range of solutions even further. Possibilities and catapulting the development of IoT networks, like, CMOS transceivers that uses lowpower techniques such as parametric amplifications [6].

3.1 CSS and spreading factor

LoRa is a CSS modulation, based on chirps and spread. The transmitted data, in the form of symbols, which will be represented in the form of chirps comprised between a minimum and maximum frequency. In LoRa modulation we can configure the symbol by changing the scattering factor and bandwidth, according to [7] a symbol will have a transmission time duration of Ts seconds, which is a function between bandwidth (BW) and SF, represented below:

$$T_S = \frac{2^{SF}}{BW} \tag{1}$$

When studying the modulation used in LoRa (CSS) it is important to mention the importance of the Orthogonal Variable Spreading Factor (OVSF). An encoding that assigns a “user” code to each station (orthogonal to each other), this scheme is representedin the form of a tree. Since the CSS uses chirps as a form of modulation, and these chirps are limited by the available bandwidth and therefore strongly linked to the SF used, we end up having a compromise between two inversely proportional variables that are the number of stations active at the same time and the bandwidth available for each of these stations to transmit their data. The OVSF codes can be represented by a tree [8].

The OVSF code tree is a binary tree with K layer, where each node represents a channelization code (k,m), k=0,1,…,K, m=1,…,2k. The lowest layer is the leaf layer andthe highest layer is the root layer. The data rate that a code can be support is called its capacity. Let the capacity of the leaf codes (in layer K) be R. Then the capacity of the codes in layer (K-1),(K-2),…,0,1 are 2R,4R,…,2K-1 R,2K R respectively. Layer K has 2K codes and they sequentially labeled from left to right, starting from one. The mth codein layer K is referred to as code (k,m). The total capacity of all the codes in each layer is 2KR, irrespective of the layer number. We also define the maximum SF

Nmax=2K as the total number of codes in layer K. All lower layer codes spanned from a higher layer code are defined as descendent codes [8]. All codes in each layer are mutually orthogonal. Furthermore, any two codes of different layers are also orthogonal expect for the case when one of the two codes is the mother code of the other. The chirp signal spectral width BW can vary between 125 kHz, 250 kHz, and 500 kHz, which along with the SF, the chirp signal duration, and the coding efficiency, lends itself to calculating the bit rate, Rb [9]. Calculation performed for various combinations of BW and SF with extreme values of have been provided in [9]. In [9] we can be concluded that the spread data stream in LoRa is sent at a chip rate equal to the channel bandwidth, BW.

To keep the complexity of the network low, LoRa relies on a star topology in which end devices directly communicate with a few Gateway (GW) in a single-hop manner. GWs in turn forward data received from end devices to a central network server. GWs and end devices communicate with each other using different data rates, where the selection of a particular data rate provides a trade-off between communication range and message duration. In the PHY layer, LoRa implements CSS with integrated Forward Error Correction (FEC) [10]. Different data rates can be selected in the developed algorithm by changing the SF, which can be one of {7, 9, 12}. LoRa uses orthogonal SFs, which allows packets with different SFs to be transmitted concurrently without collisions. Using higher SFs results in higher noise immunity, thus longer communication range; however, it will result in longer packet air times, increasing the chance of collisions with other packets.

In a LoRa network, end devices transmit their packets in a broadcast manner, while GWs listen for transmissions on all available channels and all possible SFs. An end device's transmission is received successfully at a GW if the received signal power at the GW is higher than a minimum required Received Signal Strength Indicator (RSSI). The minimum required RSSIs for successful reception at different SFs are provided [9]. The GW, in turn, send the decoded packets to a central network server using broadband Internet connections, where duplicate packets are detected and removed. An advantage of broadcast transmissions is that, while a packet might not be decoded successfully by one gateway, e.g., due to collisions, there is still a chance that it may be decoded by another gateway, resulting in more successful receptions [10]. The number of GW that can hear an end device's transmission depends on the communication range of the end device, which in turn is directly related to the transmission power and the SF used by theend device. The link layer of LoRa networks is referred to as LoRaWAN. The channel access mechanism in LoRaWAN is pure ALOHA [10], in which end devices access the channel as soon as they have packets ready for transmission. Our proposal is using LoRaSim simulator, implement a new algorithm of CSMA/CA (original LoRaSim simulator only include pure ALOHA) and implement a dynamic SF attribution (new implementation in LoRaSim simulator).

4. DYNAMIC SPREADING FACTOR ALGORITHM FOR LORA/LORAWAN

The simulation environment used to emulate the operating conditions of LoRa communication was the LoRaSim simulator, developed at Lancaster University [10]. TheLoRaSim extension presented is based on the original LoRaSim platform. It differs essentially on the following aspects.

Node(n) and GW placement assumes a pseudo-random distribution. For consistency's sake the distribution of nodes was reprogrammed to the following:

$$n = -0.008 \cdot (x - 80)^2 + 100, \ \ 1 \le n \le 75 \tag{2}$$

$$n = 0.008 \cdot (x - 80)^2 - 100, \ \ 76 \le n \le 150 \tag{3}$$

$$GW = -(0.08 \cdot (x - 80))^2 + 60, \ \ 1 \le GW \le 12 \tag{4}$$

$$GW = (0.08 \cdot (x - 80))^2 - 60, \ \ 13 \le GW \le 24 \tag{5}$$

LoRaSim tool disposes of frequency, SF and timing collision functions. On these last two, a parameter was added to accommodate the new features. The *sfCollision* variable, now receives *p1*, *p2* (both packets) and *sfcounter*, so that if *p1* and *p2* collide the properties, *p1* changes its SF value and retransmits. *sfCounter* has a value of 3 (reconfigurable) which allows for it to sweep the values of SF=7, SF=9 and SF=12, and is decremented each time the packets collide. After which if it fails a 4th time, collision is deemed unavoidable. The *timmingCollision* variable, also receives now *p1*, *p2* and *botcounter* (value set to 3, but configurable), working the same way as *sfcounter*, botcounter allows for the backoff time before packet is transmitted to be randomized up to 3 times. This backoff time is chosen between 5 milliseconds and 3 seconds.

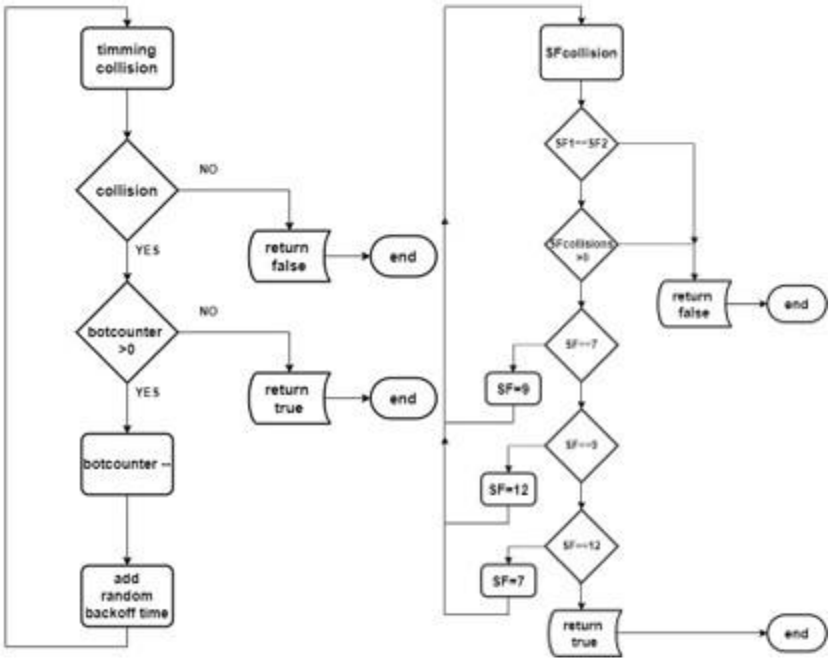
LoRaSim tool implements only the pure ALOHA technique, which allowed to perform about half of the simulations, however the scope of this study is the performance of both techniques, side by side to draw conclusions with an empirical basis. Thus, to design a CSMA/CA implementation, it was necessary to identify a collision, draw a backoff time and perform a retransmission.

In the field of collisions, the simulator has four different collision detections: collision in frequency, collision in SF, collision in time and collision in power. As far as collision in time is concerned, the function present in the simulator compares two packetsat a time, and analyzes their presence in time, checking if the beginning of a *p2* packet has a temporal signature after or before a *p1* packet. The solution found was the introduction of a *botcounter* variable (backoff time) which because it was not possible to define globally, led to a recursive implementation. The *botcounter* variable indicates howmany retransmissions are allowed, if there is a collision and if this value is 0 the code runs normally, otherwise it will add a random value in milliseconds between 5 and 3000to the values under analysis and call the function again with the values of the updated parameters. As for the implementation of an ability to adjust the SF when a collision is detected, the approach was like the previous one. The original function validated whether the SFs of the packages in question were the same or not: which opens the possibility, ifthey are the same, to change the SF so that it does not collide with the same package, the *sfcounter* variable is then limited to the value 3, allowing 3 exchanges of SF of 7, 9 or 12. Figure 2, presents in left side: CSMA/CA algorithm and right side: dynamic SF algorithm.

5. RESULTS

A basic LoRaWAN network is comprised of a node, a GW which later communicates with a server. The extension of our tests allows for up to 24 GWs and 150 nodes. Typically, the distribution of nodes and their connection to the GWs assumes a star-like topology however, since an automated approach was taken, the distribution of nodes and GWs follows a second-degree polynomial expression. Within the simulation environment and the parameters presented above, the objective in this phase was to verifythe performance of each one of the techniques against the different parameterizations of nodes, GW, SF and BW.

Figure 2. CSMA/CA algorithm and Dynamic SF algorithm.



More than 260 simulations were carried out between ALOHA and CSMA/CA with the variation of the number of nodes between 1 and 30 for ALOHA and 1 and 150 for CSMA/CA with dynamic algorithm The initial conditions were the same for ALOHA and CSMA, for the sake of data consistency. Figures 3-5 presents the results with CSMA/CA algorithm.

Figure 3. Successful transmission with CSMA/CD algorithm changing SF.

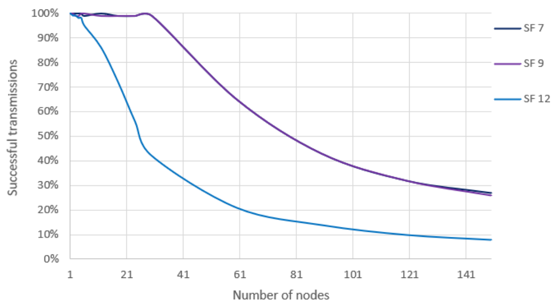


Figure 4. Successful transmission with CSMA/CA algorithm changing BW.

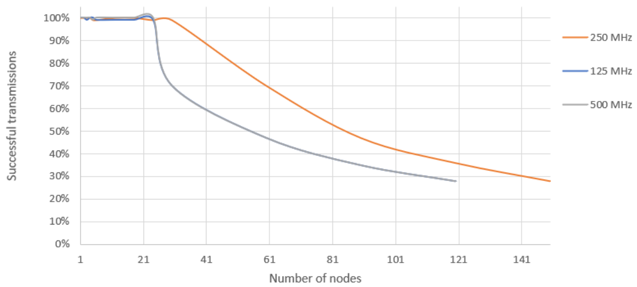
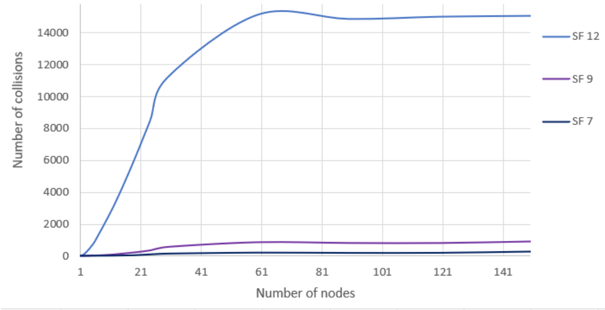


Figure 5. Number of collisions with CSMA/CA algorithm changing SF.



Figures 6-8, shows the results with CSMA/CA with dynamic SF compared with ALOHA.

Figure 6. Collisions and successful transmission: CSMA/CA and ALOHA.

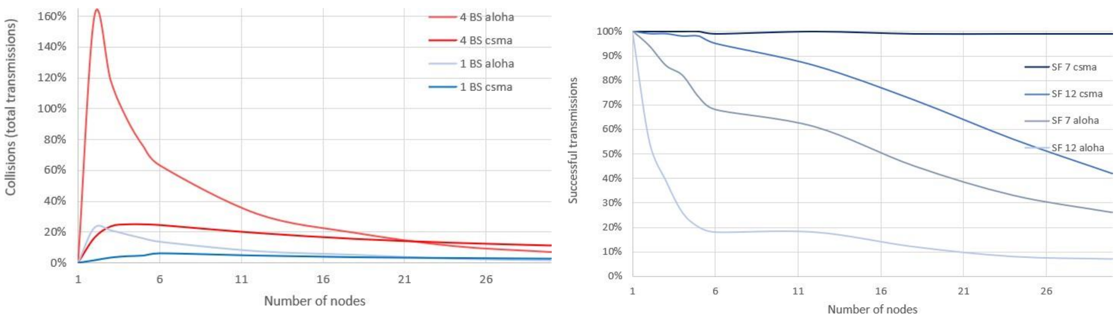


Figure 7. Successful transmission and changing BW: CSMA/CA and ALOHA.

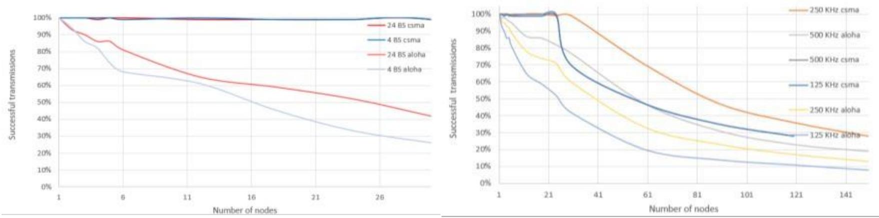
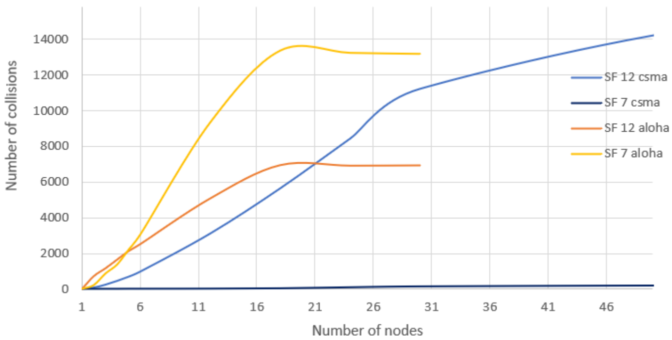


Figure 8. Number of collisions: CSMA/CA and ALOHA.



6. CONCLUSION

With SF of 7, it appears that up to 30 nodes the SF reduction increased the efficiency, stabilizing it close to 100%. From this point onwards we see a polynomial trend descent, which indicates the ability to maintain efficiency between 15%-30% with moderate increase in nodes. When we change SF, is possible to observe the drastic way as the effectiveness of the communication improved with the use of SF 7 and 9. Arrivingto have an improvement of 55% to 41% we gradually diminishing the difference until 20%. It is also relevant how the SF 12 starts to lose efficiency after just a few knots, whilethe SF 7 and 9 hold their efficiency up to around 30 nodes. It is important to mention this point because the dynamic SF capacity of the model allows the adaptation of the communication according to the existing conditions. The difference in performance of the SF 12 compared to the SF 7 and 9 is notorious, which not only increase the number of collisions to a much lesser extent, but for the extension of the simulations carried out, they kept this value below 1000. Which constitutes a very significant improvement of themodel compared to the original ALOHA setting in the simulator. For the defined conditions it showed a clearly superior performance with SF 7 followed by BW, which indicates that for this experiment it benefited from short transmission times, with high packet rate, and a BW of 250 MHz, using CSMA/CA, in terms of the variation of nodes, GW, BW and SF [12]. The dynamic SF component proved to be effective in increasing efficiency for higher node numbers.

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