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Improving LoRaWAN Performance Using Reservation ALOHA

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Abstract

LoRaWAN is one of the new and updated standards for IoT applications. However, the expected high density of peripheral devices for each gateway, and the absence of an operative synchronization mechanism between the gateway and peripherals, all of which challenges the networks scalability. In this paper, we propose to normalize the communication of LoRaWAN networks using a Reservation-ALOHA (R-ALOHA) instead of the standard ALOHA approach used by LoRa. The implementation is a library package placed on top of the standard LoRaWAN; thus, no modification in pre-existing LoRaWAN structure and libraries is required. Our proposed approach is based on a distributed synchronization service that is suitable for low-cost IoT end-nodes. R-ALOHA LoRaWAN gives better performance in comparison with the previous models; Pure-ALOHA LoRaWAN, Slotted-ALOHA LoRaWAN, and TDMA LoRaWAN. It significantly improves the performance of network regarding the probability of collision, the maximum throughput, and the maximum duty cycle.

Keywords: Wireless networks, LoRaWAN; Reservation ALOHA, Synchronization.

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Introduction

LoRaWAN protocol is relatively new and became the motivation of several research centers across the world. It is considered to be one most promising IoT technologies due to the data rate adaptation expertise. In addition to, LoRa (Long Range) is a modulation technique that enables the long-range transfer of information with a low transfer rate and low-cost power consumption (Ibrahim, 2019), (Nolan et al., 2016). The LoRa modulation has been patented by Semtech Corporation (Alliancem, 2016).

Currently, one of the major issues that LoRaWAN used to increase its salacity is the use of ALOHA protocol especially the random-access Medium Access Control (MAC). In ALOHA protocol, the number of nodes can be increased with a limit bandwidth, moreover, its ability in reducing transmitter and receiver capacity and protocol complexity by avoiding carrier sensing. In general, multiple access protocols can be divided into three categories (Khater & Ibrahim, 2019). The first category is the random-access protocols in which all the nodes have the same superiority without fixed time for sending data like pure ALOHA and carrier sense multiple access (CSMA). The second category is the controlled access protocols in which the data can be sent by that node which is approved by all the other nodes like Reservation. The third category is the channelization protocol where the available bandwidth of the communication link is shared in frequency, in time, and in code to multiple nodes for accessing that channel simultaneously like Time Division Multiple Access (TDMA), Frequency Division Multiple Access (FDMA), and Code Division Multiple Access (CDMA) (Frenzel, 2013).

In this paper, we demonstrated that LoRaWAN network performance can be improved by using one of the multiple access protocols which is Reservation ALOHA (R-ALOHA) protocol. R-ALOHA allows a large number of stations with irregular traffic to reserve slots to transmit their frames in future cycles. Each cycle has mini-slots allocated for making reservations. Stations use slotted ALOHA during mini-slots to request slots (Rahman & Tepe, 2012).

The rest of this paper is organized as follows: after this introductory section, Section 2 presents a literature review on LoRaWAN networks and its models. In Section 3, the Proposed Reservation-Aloha (R-Aloha) LoRaWAN model is illustrated, while Section 4, clarifies the experimental results and discussions. Finally, Section 5 draws the comments and conclusions in addition to future work.

Literature Review on LoRaWAN Networking Models

In the literature, we have found three different models that used with LoRaWAN networks Pure-ALOHA (P-ALOHA) LoRaWAN, Slotted-ALOHA (S-ALOHA) LoRaWAN, and

TDMA LoRaWAN. In P-ALOHA LoRaWAN, each node can send a data frame anytime whenever it has a data ready to be sent. It depends on receiving an acknowledgement from the receiver within a predefined time interval. After time-out period if the acknowledgement dose not arrived the node resend its data. It is important to recognize the maximum propagation time required to transfer the data between the widely separated nodes (Bouguera et al., 2017). As well known, P-ALOHA protocol could generate large inefficiencies when the number of nodes in a network increase significantly. The disadvantages of P-ALOHA are low throughput under heavy loads and low channel utilization. In addition to, the presence of collisions and the need of retransmitting the packet after a collision decrease the capacity of the communication channel (Khater & Ibrahim, 2019).

In S-ALOHA systems, that is used widely in local wireless communications, the channel actual time is divided into slots, and each terminal is permitted to transmit packets only at the start of a slot (Polonelli et al., 2018). Each time slot is consisting of two parts: transmission time and the confidence interval. If two or more nodes transmit their packets at the same time, a collision occurs and no data are successfully transmitted; otherwise no collision is generated, and the data are properly sent (Casares-Giner et al., 2019). Nodes with new arriving data: transmit at the start of the next slot. If collision occurs, resend data frame in future slots with probability, until successful. The advantages of Slotted-ALOHA are: Single action can continuously transmit at full rate of channel and highly reorganized within only slots having nodes need to be in simple synchronization. While the disadvantages are: wasting slots, collision, idle slots, and clock synchronization (Polonelli et al., 2019).

For TDMA LoRaWAN, all the nodes that has data ready to be sent have to be synchronized and the transmission can only start at the beginning of each time slot. But still eee access ff eeeee eeee s oo each rrrrr rr ss ttt caaaaaaaaaa (Piyare et al., 2018). The disadvantages of TDMA LoRaWAN are: few numbers of nodes can communicate in idle channel, the occurrence of multipath interference that effects on the quality of the connection, and high synchronization overhead. (Lavric & Petrariu, 2018)

LoRaWAN communication protocol original stack consists of three main layers; the physical layer, the MAC layer, and the application layer (Sanchez-Iborra et al., 2018), (Muzammir et al., 2019), (Adelantado et al., 2017). The physical layer uses the concept of LoRa modulation while in the MAC layer, defined on top of the physical layer, it contains the LoRa MAC, MAC options, and the LoRaWAN classes A, B, and C that used for the end-devices, as illustrated in Figure 1 (Augustin et al., 2016), (Trüb, & Thiele, 2018).

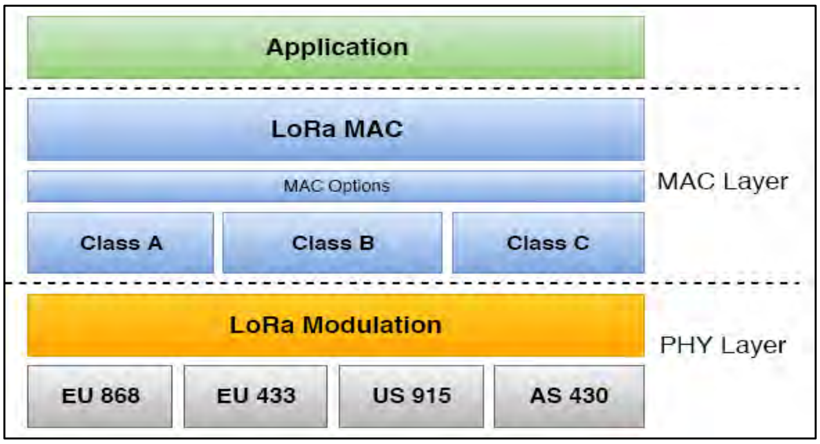

Figure 1. LoRaWAN original stack

The Proposed Reservation-Aloha (R-Aloha) LoRaWAN model

The main idea of R-ALOHA is allowing any node needs to transmit data to make a reservation before sending that data. Actually, there are two types of periods in R-ALOHA; the first is reservation interval with fixed time length and the second is data transmission period with variable frames (Petrovic & Thomas, 2006). As illustrated in Figure 2, if there are five nodes then the reservation interval will be divided five slots, and each node has only one slot. Assume if Node 1 has a data frame to send, it transmits 1 bit during the slot 1. No other node is permitted to transmit during this slot. In the first interval, only nodes 1, 3, and 4 have made reservations. In the second interval, only Node 1 has made a reservation. This means that, nodes can reserve future slots in transmission period (Rahman, & Tepe, 2012).

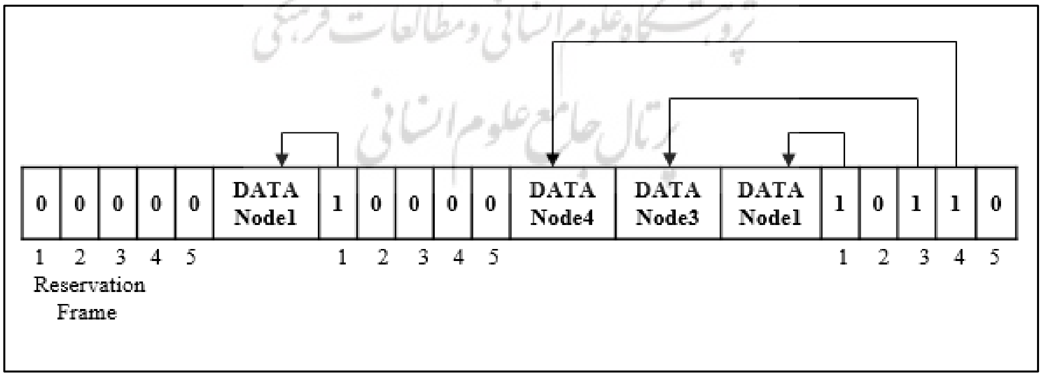

Figure 2. Situation of five nodes and five slot reservation frames

Our proposed model aimed to normalize and improve the communication of LoRaWAN networks using R-ALOHA instead of the standard ALOHA approach used by LoRa. The implementation of our model is done by using a library package placed on top of the standard LoRaWAN; thus, no modification in pre-existing LoRaWAN structure and libraries is required. The proposed model with R-ALOHA is shown in Figure 3. By applying R-ALOHA on LoRaWAN networks the communication between the nodes will take two modes: (1) the ALOHA mode that is responsible for slots reservation. (2) the reserved mode which accountable for data transmission through the reserved slot successfully. It is very important to keep the list of reserved slots for the nodes to be consistent at any time and, consequently, all the nodes have to synchronize every once in a while. This proposed R-ALOHA model allows a large number of nodes with infrequent traffic flow to reserve slots for transmitting their data frames in the upcoming cycles. This will lead to increase the network throughput under heavy loads.

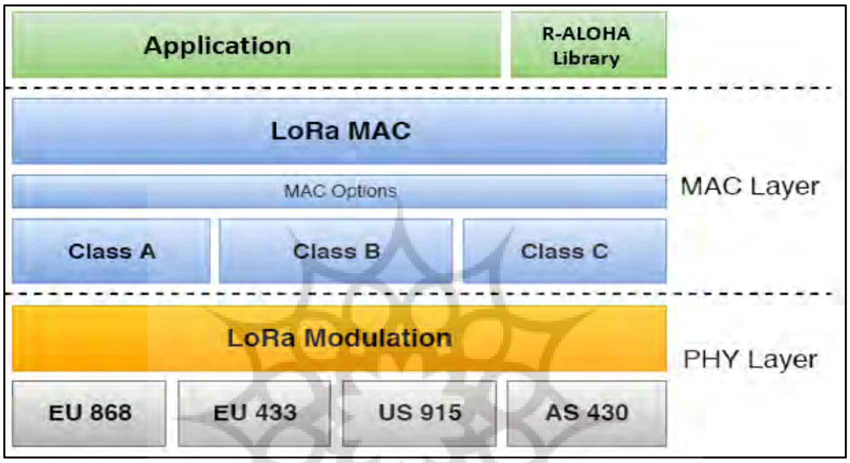

Figure 3. The Proposed LoRaWAN stack with R-ALOHA Library

Experimental Results and Discussions

The LoRaWAN network model using R-ALOHA has been built and compared with the previous models: P-ALOHA, S-ALOHA, and TDMA LoRaWANs. We rebuild these three models with the same parameters as our own model. We measure the performance of the models using three different metrics: the probability of collision, the maximum throughput, and the maximum duty cycle. The probability of collision is defined as the ratio of the cross-section of a particular type of collision between two nodes to the total cross-section of all types of the collision between nodes. The maximum throughput is the maximum rate of successful packets delivered over a communication network. The maximum duty cycle means the maximum channel time allowed for every wireless node (Polonelli et al., 2018).

We compared the channel access probability of collisions between P-ALOHA, S-ALOHA, TDMA within our deployment R-ALOHA using different number of end-devices starting with 50 till 300 end-devices. Figure 4 presents the probability of collision with the increasing of the number of end node devices. The results for the models demonstrate that the proposed R-ALOHA LoRaWAN network model gives the best and lowest results with value averaged with 0.029% in comparison with P-ALOHA, S-ALOHA, and TDMA that gives averaged values 1.7%, 0.54%, 0.09%, respectively.

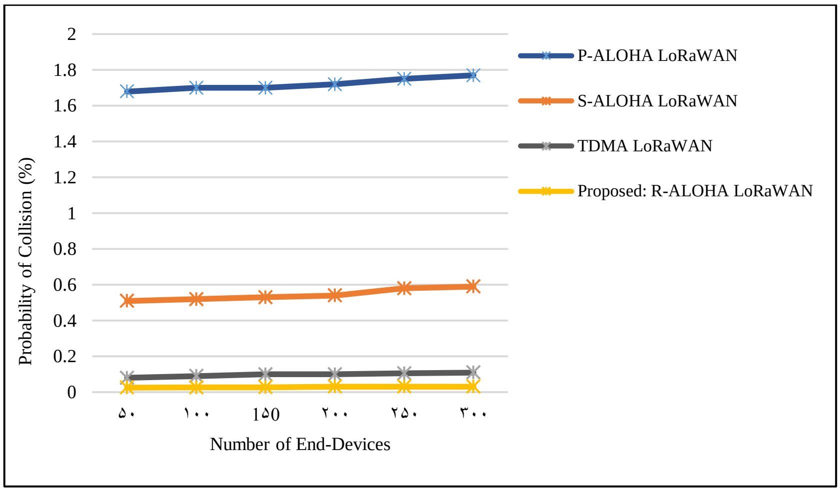

Figure 4. Probability of collision vs. number of end-devices

Figure 5 presents results for the R-ALOHA network models that measure the maximum throughput with the increasing of the number of nodes. The results show that our proposed R-ALOHA LoRaWAN model achieves maximum throughput is approximately 78% average, while the P-ALOHA model gives an average value of 18%, S-ALOHA model reaches about 36% average, and TDMA model has 65.6% average throughput.

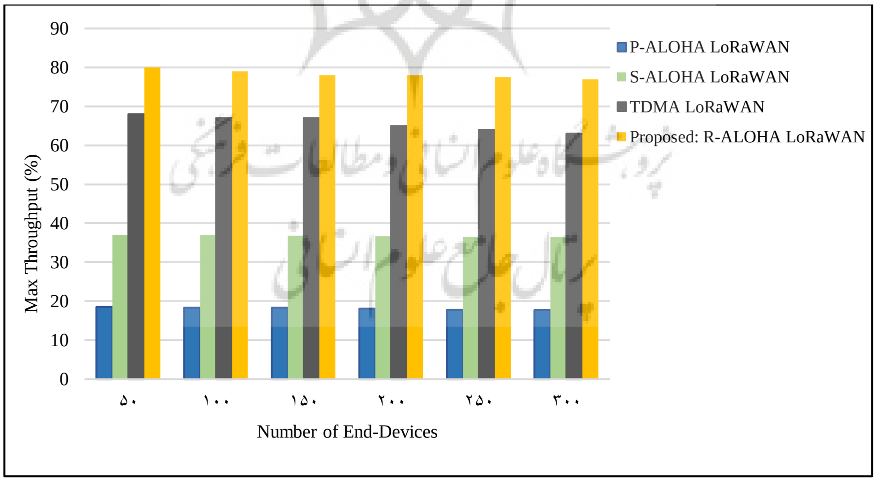

Figure 5. Maximum throughput vs. number of end-devices

The maximum channel time which known as maximum duty cycle allow for every wireless end-device as a function of the number of end-devices as represented in Figure 6. We choose our test line when the number of nodes is 50 end-devices. The projection of the proposed R-ALOHA curve and the curves of the other models up to the test line allows the verification of the proposed R-ALOHA improvement. For the P-ALOHA, we found that the network keeping constant with only 15 end node devices, the S-ALOHA keeping persistent with about 38 end node devices, and the TDMA model keeping stable with near to 66 end-node devices. While our proposed R-ALOHA model can sustain more than 78 end node devices. Table 1 summarizes all the results with the averaging values between our proposed R-ALOHA LoRaWAN model and the previous ones.

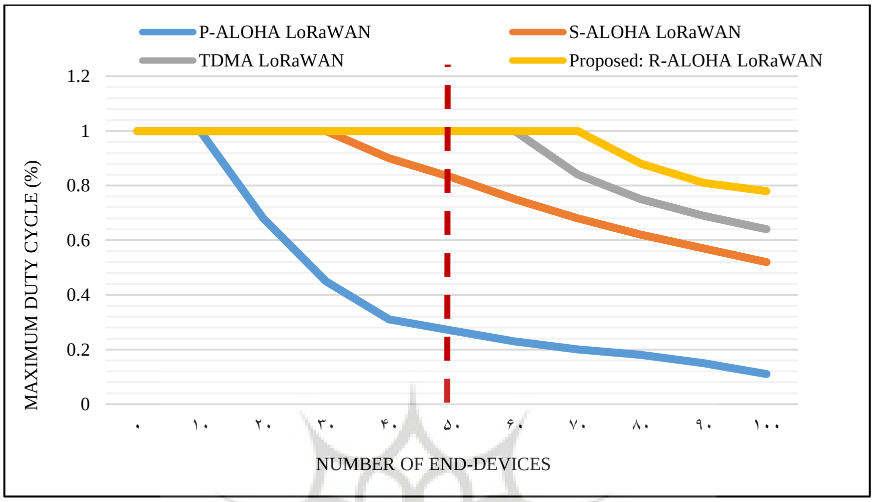

Figure 6. Maximum duty cycle vs. number of end-devices

Table 1. Comparison between R-ALOHA LoRaWAN and previous work

Performance Metric	P-ALOHA LoRaWAN	S-ALOHA LoRaWAN	TDMA LoRaWAN	R-ALOHA LoRaWAN (Proposed)
Avg Prob of Collision	1.72 %	0.54 %	0.1 %	**0.029 %**
Avg Throughput	18.15%	36.73%	65.67%	**78.25%**
Maximum Duty Lifecycle	15	38	66	**78**

Conclusion

LoRaWAN is considered to be one of the current important issues deals with the IoT applications. However, network scalability faces some challenges like: end-devices density predicted for each gateway is high in addition to the lack of an active synchronization system between end-devices and gateway. In this paper, we propose to normalize the communication of LoRaWAN networks using a Reservation-ALOHA (R-ALOHA) instead of the standard ALOHA approach used by LoRa. The implementation is a library package placed on top of the standard LoRaWAN; thus, no modification in pre-existing LoRaWAN structure and libraries is required. Our proposed approach is based on a distributed synchronization service that is suitable for low-cost IoT end-nodes. R-ALOHA LoRaWAN gives better performance in comparison with the previous models; Pure-ALOHA LoRaWAN, Slotted-ALOHA LoRaWAN, and TDMA LoRaWAN. It significantly improves the performance of network regarding the probability of collision, maximum throughput, and the maximum duty cycle.

As a future work, some modifications can be done on the Lora MAC layer with additional experiments related to the MAC layer classes A, B, and C.

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