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Towards More Energy Efficient MAC protocols for LoRaWAN Networks

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Résumé

The Internet of Things (IoT) is currently one of the most trending research topic. Many wireless network technologies, called LPWAN (low power wide area network), have been developed with low-power, long-range and low-throughput in mind. It is estimated that there will be over 50 billion connected devices in these LPWAN networks. This paper focuses on Medium Access Control (MAC) protocol of LPWAN networks to evaluate the scalability and energy consumption performances. More precisely, we compare the two well-known MAC protocols, namely pure Aloha and slotted Aloha. First, we define two performances indicators such as the Data Extraction Rate (DER) and the Network Energy Consumption (NEC). Then we simulate a typical LoRaWAN networks based on the LoRaSim simulator. The results show that the slotted Aloha protocol is more efficient than the pure Aloha protocol in terms of energy consumption.

1 Introduction

Low Power Wide-Area Network (LPWAN) is an emerging network dedicated to the Internet of Things (IoT). LPWAN refers to the type of networks on which IoT applications rely on to meet the communication requirements of the IoT. As a matter of fact, IoT applications require a high level of autonomy, a low power consumption and a low implementation complexity. Recently, several technologies such as LoRaWAN [1] and SigFox [2] have been developped to address these IoT challenges. LoRaWAN networks are supposed to be an energy-efficient wireless networks that target the deployment of a very large number of battery-powered and connected devices, called end-devices or nodes. LoRaWAN networks use unlicensed spectrum such as the ISM frequency bands and are composed of two layers : a physical layer using the Semtech LoRa modulation techniques ; and a Medium Access Control (MAC) layer protocol, namely LoRaWAN.

In unlicensed frequency bands, different networks can be deployed in a specific region using the same frequency bands. Even though there exist regulation rules to control the access to the physical radio channels, many radio transmissions may collide at the same place, time and frequency due to the nature of the unlicensed bands. These collisions may lead to an increase of the energy consumption of connected devices, and therefore reduces their battery lifetime [3].

For the past ten years, many works have been done on the MAC protocols in order to improve the network performances in terms of scalability and energy consumption. For instance, in [4] the authors use the simulator NS-3 to propose a simple enhancement of LoRaWAN based on a Carrier Sense Multiple Access (CSMA) MAC protocol that reduces the number of collisions. Nevertheless, the energy consumption is slightly increased. On the other hand, the authors of article [5] have evaluated the impact of the physical layer parameters on the performances and scalability of LoRaWAN networks. However, they only consider the pure Aloha MAC protocol to evaluate the network performances.

Therefore, we propose, in this paper, to evaluate the impact of MAC protocols in LoRaWAN networks. Our goal is to give a fair comparison of pure Aloha and slotted Aloha MAC protocols in terms of scalability and energy consumption.

The rest of this paper is organized as follows. Section 2 gives a brief overview of LoRa technology. Section 3 presents typical MAC protocols used in LPWAN networks. Section 4 defines two metrics to evaluate the performance of the MAC protocols in a LoRaWAN networks. In sections 5 and 6 we present the simulation scenario and give the results. Finally, section 7 concludes this paper.

2 LoRa

LoRa or Long Range, is a radio communications technology developed by Semtech that allows objects to communicate wirelessly over a long distance. LoRa mainly uses the 868 MHz frequency band in Europe [6] and employs spread spectrum modulation which offers excellent performance, a long range propagation distance with a robust signal and increased sensitivity on the receiver side. The throughput is relatively low, from 300 bps to 50 kbps [6] depending on the spreading factor SF. LoRa modulation uses a variant of the spread spectrum called Chirp Spread Spectrum to encode the information. A chirp is a sinusoidal signal whose frequency increases (upchirp) or decreases (downchirp) as a function of the time. This modulation is robust against narrowband, broadband and multipath fading disturbances.

The spectrum spreading is achieved by the generation of a linear chirp signal whose frequency varies continuously according to the spreading factor SF. LoRa defines the spread spectrum factor (SF) by the following formula.

$$SF = \log_2 \left(\frac{R_c}{R_s} \right). \quad (1)$$

Where R_c is the bit rate of the transmitted message (Chirp) and R_s is the bit rate of the symbol to be transmitted. In LoRa modulation, a symbol is encoded by 2^{SF} chirps. Semtech documentation provides the following relationship between the modulation rate R_b, the spreading factor SF, the bandwidth BW and the performance of the error correction coding rate CR [6].

$$R_b = SF \times CR \times \left(\frac{BW}{2^{SF}} \right) \ bits/sec. \quad (2)$$

The range of a LoRa communication is determined by its bandwidth BW, the transmission power of the signal and the spreading factor SF. Therefore, increasing the spreading factor of the signal increases its range. However, it reduces the throughput as the transmission time becomes longer. A long transmission time leads to a higher power consumption and as a result a reduction of the battery lifetime.

3 MAC : Pure Aloha and slotted Aloha

3.1 Pure Aloha

Pure Aloha is a well-known and simple random MAC protocol. Indeed, in pure Aloha when a node has a packet to send it transmits it without waiting or checking if the radio channel is available. This means that nodes do not care about the state of the channel. However, after a certain predefined delay, if the node does not receive an acknowledgment of receipt, it transmits the same packet with same parameters after a randomly chosen waiting period. Beyond a certain number of attempts if no acknowledgment has been received, then the transmission fails. Finally, when several nodes try to send their packets at the same time on the same channel, the packets will collide, then the transmission fails.

LoRaWAN networks is based on pure Aloha MAC protocol which is mandatory. However, other MAC protocols such as slotted Aloha can be used to improve its performances.

3.2 Slotted Aloha

The goal of slotted Aloha MAC protocol is to improve the performances of pure ALOHA MAC protocol by reducing the energy consumption and the number of collisions. In slotted Aloha, the time is divided into time intervals of a fixed duration called slots. Thus, the nodes can only transmit their data at the beginning of the slots. Therefore, collisions can occur when two packet transmissions take place in the same slot. However in this case, the number of collisions is reduced and the throughput is improved. In contrast to pure Aloha, nodes in slotted Aloha cannot transmit as soon as they want. They are only allowed to initiate a transmission at the beginning of a slot. For example, when a node has a packet to send at a time between the beginning of slot n and $n+1$, the end-device will have to delay the transmission until the beginning of slot $n+1$.

4 Performance Metrics

To compare then evaluate the performances of MAC protocols, we propose to use two performances indicator as defined in [5] : the Data Extraction Rate (DER) and the Network Energy Consumption (NEC).

4.1 Data Extraction Rate (DER)

The DER allow us to investigate the scalability of a deployed LoRaWAN network. Actually, in an effective LoRa deployment, all transmitted data must be correctly received by the receiver. Thus, the authors of article [5] define the data extraction rate (DER) as the ratio of the number of messages correctly received to the number of messages transmitted over a given period of time. The value of the DER depends on several parameters such as the location, number and physical layer parameters of the nodes. An analytical expression of the DER metrics is given in [5] as :

$$DER = \exp\left(-2 \times N \times T_{air} \times \lambda\right). \quad (3)$$

Where N represents the number of transmitters, T_{air} the time on air (or the packet transmission time) and λ the transmission frequency of the nodes. The value of the DER is between 0 and 1, and the closer this value is to 1, the more effective the deployment of LoRa is. Obviously, in an ideal deployment, one would expect a $DER = 1$.

4.2 Network Energy Consumption (NEC)

As nodes will be deployed in many scenarios on batteries which should last for at least ten years, it is essential to limit the energy consumption for transmissions as much as possible. The NEC is defined as the energy consumed by the network to successfully extract the messages sent by all nodes in the network. In most cases, the energy consumption of a LoRa node will depend mainly on the power consumption of the transceiver.

$$NEC = \sum_{i=1}^{N} \sum_{p=1}^{N_p^i} Pc_p^i. \quad (4)$$

where N is the number of nodes, N_p^i refers to the number of transmitted packets by node i and Pc_p^i the power consumption of a transmitted packets. Note that the power consumption of a transmitted packet depends on the transmission power T_p and the transmission time T_{air} of node i, which depends on the physical layer parameters such as the SF, BW and CR. According to (4), the NEC also depends on the MAC protocol used in the network, since the number of transmitted packets depends on the MAC protocols. As a matter of fact, the lower the value of the NEC metric is, the more effective the LoRaWAN network deployment is since the battery life of the nodes will last longer.

5 Simulation scenario and parameters

The scenario we have simulated is to vary the number of nodes from 100 to 1600 nodes by a step of a 100 nodes. These nodes are placed at a random distance from a single gateway in an area of 3.8 ha. Each node transmits a 20 bytes packet every 10^6 ms on a randomly chosen frequency in between the three available frequencies (868.1 MHz, 868.1 MHz, 868.1 MHz). The packets are transmitted with the same parameters ($SF12$, $BW125$, $CR4/8$). To obtain the results presented in section 6, we have simulated the scenario over a period of 58 days using the LoRaSim simulator [5]. The input parameters to run a simulation are summarized in Table 1.

TABLE 1. LoRaSim simulation parameters.

Parameters	Values
Experiment	1
Transmission frequency (λ)	10^6
Nodes	from 0 to 1600
Simulation time in days	58
Collision	0

6 Simulation Results and Discussion

6.1 Comparison of pure Aloha and slotted Aloha

We performed simulations of pure Aloha and slotted Aloha (for a slot time of 5 s) in order to compare the performances of these different methods of access to the radio medium. The results obtained are shown in Figures 1 and 2.

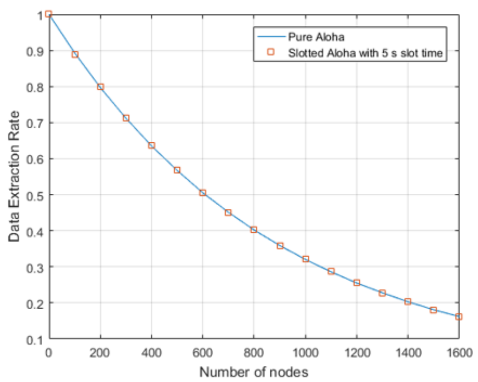

FIGURE 1. DER variation depending on the number of nodes for pure Aloha and Aloha slotted at 5 sec.

Figure 1 shows the evolution of the DER as a function of the number of nodes. The results are presented for the Aloha and Slotted Aloha Medium Access Control (MAC) protocols. As shown in Figure 1, the DER metric decreases as the number of nodes in the network increases. Moreover, it is also shown that both MAC protocols, namely pure Aloha and Slotted Aloha, lead to the same performances in terms DER. The results show almost identical values of the DER obtained with pure Aloha and slotted Aloha (slot time used 5 s), this is materialized by a superposition of the curves of variation of the DER according to the number of nodes with pure Aloha and slotted Aloha (Figure 1). We can deduce that the two access methods Pure Aloha and Slotted Aloha (with a slot time of 5 s) have the same impact on the DER. Which is not completely in line with the literature because from the point of view of the functioning of the two protocols, Aloha slotted should present better performances in terms of DER.

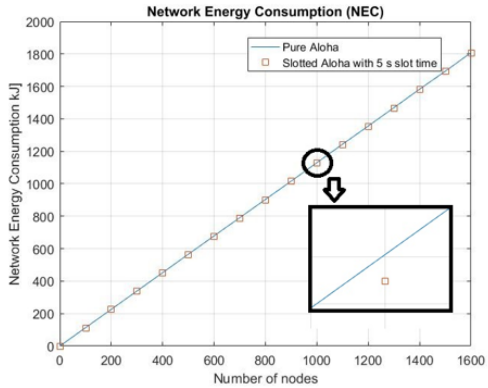

FIGURE 2. NEC variation depending on the number of nodes for pure Aloha and Aloha slotted at 5 sec.

Figure 2 shows the evolution of the NEC as a function of the number of nodes for the pure Aloha access methods and slotted Aloha. However, the results show the opposite with regard to NEC (Network Energy Consumption). Indeed, the access method has an impact on the NEC, i.e. with slotted Aloha we note a decrease in the network energy consumption (NEC) compared to pure Aloha, for a network or a simulation with the same capacity (the same number of nodes). Thus, the NEC goes from 113 kJ and 1808 kJ with pure Aloha to 112 kJ and 1805 kJ with slotted Aloha, i.e. a slight decrease from 1 kJ to 3 kJ for network simulations of 100 and 1600 nodes respectively. Over the years, this difference in the NEC of the Aloha and slotted Aloha access methods can become very significant or even very important. From this point of view, it has been demonstrated, as announced in the literature that the slotted Aloha access method is more efficient than the pure Aloha access method in terms of NEC.

6.2 Impact of slot time duration

In the previous simulations we used a slot time of 5 *s* which we will now modify in order to study (evaluate) the impact of the slot time on the performance of the slotted Aloha access method.

Figure 3 shows the evolution of the DER as a function of

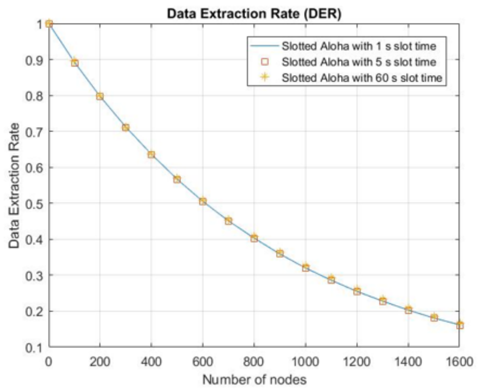

FIGURE 3. DER variation curves with slotted Aloha as a function of the number of nodes for slot times (ST) of 1 s, 5 s and 60 s.

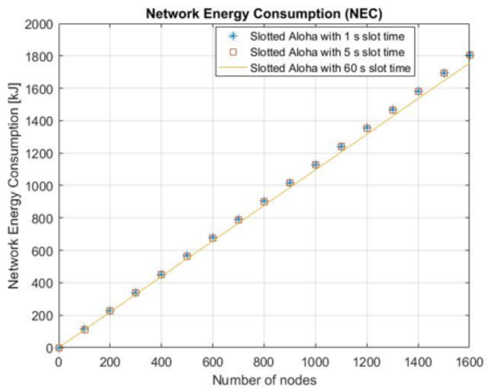

FIGURE 4. NEC variation curves with slotted Aloha as a function of the number of nodes for slot times (ST) of 1 s, 5 s and 60 s.

the number of nodes for the slotted Aloha method with different slot times of 1 s, 5 s and 60 s.

Figure 4 shows the evolution of the NEC as a function of the number of nodes for the slotted Aloha method with different slot times of 1 s, 5 s and 60 s.

The results of the simulation of the DER and the NEC with slotted Aloha for slot times (ST) of 1 s, 5 s and 60 s have enabled us to draw the curves in Figures 3 and 4 to show the impact of the slot time on the two performance criteria of the access method, i.e. the DER and the NEC. We note that even if the DER (very random variation with almost identical values with two digits after the decimal point) does not depend too much on the slot time, it still increases very slightly with the latter. However, even if we can neglect the impact of the slot-time on the DER, its impact on the NEC is worth considering. As the curves in Figure 4 show, the NEC decreases as the slot time increases. Thus, for a LoRaWAN network with a capacity of 100 nodes, the NEC go from 113 kJ for a slot-time of 1 s to approximately 112 kJ and 109 kJ for slot times of 5 s and 60 s respectively, i.e. a maximum gain of 4 kJ with these three different configurations. For maintaining a network of 1600 nodes (the maximum size of the network used in our simulations), the NEC go from 1807 kJ for a slot-time of 1 s to approximately 1805 kJ and 1755 kJ for slot times of 5 s and 60 s respectively, i.e. a maximum gain of 52 kJ. This gain will be greater as the slot-time increases and over the years (we recall that the simulations are carried out for 58 days). Hence the impact of the slot-time on the performance criteria of Aloha slotted in particular the NEC.

7 Conclusion

In this paper we focused on Internet of Things (IoT) applications using LoRa technology and the LoRaWAN protocol, which also defines the name of the network. Our goal was to evaluate the performance of MAC protocols by comparing at first pure Aloha and slotted Aloha MAC protocols. Both MAC protocols can be used in a LoRaWAN network. Based on the LoRaSim simulation tool in which we have added the slotted Aloha MAC protocols, we have simulated a typical LoRaWAN networks and evaluate the performances of the network in terms of DER and NEC. The results showed that slotted Aloha outperforms pure Aloha in terms of energy consumption. However, no gain was observed in terms of DER.

In our future works, we will improve the NEC metric to take into account the energy consumption due to the several state of the nodes namely the sleeping and the synchronization state specially for slotted Aloha MAC protocol.

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