Evaluation of LoRaWAN Class B efficiency for downlink traffic

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***Abstract*— The LoRaWAN technology is today the object of great interest in the Internet of Things context. It defines a simple network architecture offering a wide-area wireless coverage for low rate IoT applications with low power consumption for devices. The LoRaWan class A is designed for sensor networks with a focus on the uplink. LoRaWan defines an optional MAC operation, Class B, that provides the network server with the opportunities to initiate a downlink, which can be a real solution for actuators focus network. Today, Performances of Class B are not quantified and compared to default LoRaWAN class. In this paper, we propose an evaluation of Class B performance. We offer a set of realistic evaluation scenarios based on an NS-3 simulation module that we have developed for this purpose. Results show that Class B reduces the delivery delay of downlink traffic in comparison to Class A. Class B operation significantly reduces the percentage of packet loss for downlink traffic even in congested contexts. We conclude that a trade off should be made between having low access delay or packet loss. Both the NS-3 module and data are released as an open-source to the research community.**

Keywords— LoRaWAN, LoRaWan Class B, internet of things

I. Introduction

Low Power Wide Area Networks (LPWAN) are communication technologies introduced in the 2000s for IoT communication needs. They aim to offer long-range, low-power communications for low rate use cases and applications. They represent an extremely efficient alternative to cellular networks, ensuring wide-area coverage, low energy consumption for devices, and reducing the deployment costs. Several LPWAN technologies are today competing on the market: SigFox, Ingenu, LoRaWAN, Weightless… The LoRaWAN technology, in particular, is today the object of a great interest thanks to an open Business model, reduced deployment costs, and open standardization (network architecture and MAC protocols) [1].

The LoRaWAN technology is based on LoRa® Radio technology owned by Semtech. LoRa proposes a spread spectrum modulation for a low rate and long-range transmissions. The network architecture and MAC layer protocols are standardized by the LoRa® Alliance [2]. LoRaWAN specifies three classes of devices A, B, and C. Class

The technical and economic interest of LoRaWAN has resulted in scientific interest, with many research works studying the performances of this technology. Related research was mainly interested in Class A, which is the default class, and the one implemented today on LoRaWAN hardware. These studies have shown the number of limitations of Class A in terms of data transmission efficiency, particularly its vulnerability regarding collisions with the increase of the network load.

Class A has been the topic of many studies since it is relatively simple to implement. Evaluation of performance has been done on class A, and we now see much work on optimizing it.

Class B offers a synchronized downlink focused protocol which can be implemented in actuators and in sensors that require command interventions.

The implementation of class B on a simulator is relatively difficult. For now, there is only a simple implementation. It is very simplified, not maintained for two years now, and the module itself unstable and buggy [3].

In this work, we are interested in the evaluation of Class B performances based on realistic scenarios on the NS-3 module we developed. We go beyond the previous works by offering an in-depth study of Class B performances regarding delay and transmission efficiency for downlink traffic in comparison to Class A., and we offer our implementation for other researchers, and we hope to see future work improving class B performance[1].

This paper is organized as follows. Section I an introduction. Section II presents LoRaWAN technology. Section III gives an overview of previous work related to LoRaWAN. Section IV describes the LoRaWan module. Section IV presents the evaluation scenario and simulation settings. Section V details the evaluation results. Section VI concludes the paper.

II. LoRaWAN overview

Introduction

The LoRaWAN technology defines a star topology where a set of Gateways serves as wireless bridges that relay data exchange between the end-devices and a centralized network server: the NetServer. One gateway can offer up to 766 km of wireless coverage in open space.

The Semtech LoRa® is the base of the LoRaWAN physical layer. LoRa is based on a spread spectrum modulation technique. Spreading the spectrum makes the signal less sensitive to selective frequency fluctuations. Six orthogonal spreading factors (SF) are defined, ensuring non-concurrent simultaneous transmission on the same channel. Each SF results in different Data Rates (DR). The highest SF ensures better transmission robustness and the lower DR. The PHY throughput varies from 100 bps to 50 kbps.

Three classes of end-devices (A, B, and C) are specified by the MAC layer to fix the transmission opportunities offered to the network to transmit downlink (DL) data to devices. In the following, we detail the operations of these classes

In this paper, we will only talk only about class A and B because thus, two classes are battery-powered, class C is suitable for applications where continuous power is available.

A. Class A

Class A is the default class. It defines limited DL opportunities triggered by uplink (UL) transmissions.

While transmitting a UL frame, a class A End-Device (ED) has to select a channel randomly and start transmitting. Then, the ED opens two reception windows RX1 and RX2. RX1 is opened w-RX1 seconds after the end of the transmission. The end-device has to listen to the channel during the Receive window waiting for a possible transmission from the gateway. If a DL transmission starts during RX1, the end-device continues to listen until the reception of the entire frame. If no DL transmission starts during RX1, the end-device opens the second Receive window w-RX2 seconds after the end of the transmission with the same behaviour as in RX1.

The parameters of the physical layer (channel frequency and DR) used during RX1 are the same as the related uplink transmission. During RX2, fixed physical parameters are used. The default settings for the European region are 869,525 Mhz and DR0 (SF12, 125Khz).

B. Class B

Class B is an optional mode that offers an additional DL opportunity independent from UL transmissions. Its goal is to offer to the NetServer to send data to end-devices without waiting for UL transmissions. The Uplink transmissions are managed identically to Class A.

Class B mode is based on a synchronization mechanism between the network (gateway, NetServer) and the end-devices on a specific channel. The synchronization mechanism is based on a beacon broadcasted periodically by the gateways on this channel. Based on the time reference offered by the beacon, end devices periodically open receiving windows referred to as *ping Slots*, which may be used by the NetServer to initiate a downlink communication. related to the readiness of end-devices to receives downlink transmissions

Class B proposes periodic DL transmissions opportunities that offer the possibility to bound the latency for DL transmissions without increase excessively the power consumption due to DL listening. This class fits battery-powered EDs with high autonomy and applications having periodic DL transmissions.

The class B beacon is broadcasted every 128s during a *Beacon_reserved* period of 2.12 seconds. The time between two successive beacons is named *Beacon period*. The latter is divided into 4096 (2^{12}) *PingSlots* and a guard time interval where no ping slot can be placed. *PingSlots* are indexed from 0 to 4095 and with a duration of 30 ms, each with a beacon_guard of 3 seconds.

At each beacon period, the end-device and the NetServer compute a new PingOffset equal to Rand modulo pingPeriod separately. *Rand* is a pseudo-random number computed using the AES encryption method *aes128_encrypt,* considering as inputs the reference time indicated by the beacon *BeaconTime* and the physical address of the ED *DevAddr* [1].

[1] https://github.com/houssembsir/lorawan

Every 128, a beacon is broadcasted in the class B channel to all EDs in range. Each ED computes its *Pingslots,* and the NetServer computes *Pingslots* for all EDs. If the NetServer has DL transmission for a specific ED. It selects one of the end-device *Pingslots*.

LoRaWAN specifies that end-devices have to start their operations as class A end-devices. An ED can negotiate with the NetServer the switch to Class B mode. This change can be triggered by the applications using the end-device.

It is highly relevant to mention technology specification does give any information about the performances of the different classes. Particularly, the contributions of classes B and C compared to class A with regard to downlink traffic is not quantified.

III. RELATED WORK

The performances of LoRaWAN Technology has been studied in many studies. The majority of these works have focused on Class A, which is the only class implemented today on hardware and available on actual deployments. Performance studies have considered the question of the scalability of the technology (with class A) regarding network load. The latter is considered in terms of connected end-devices and generated Uplink traffic [4] [5] [6] [7]. The results have shown high sensitivity of the LoRaWan network to the increase of the network load, with results in the decrease of the packet delivery ratio (PDR) and the increase of the network load (retransmissions) because of the collisions between competing transmissions.

Other studies have investigated the effect of downlink traffic on the performances of a Class A [8] [9] [10]. The results have shown that the increase of acknowledgements decreases network performances. Also, the number of end-devices that can be supported by a gateway in acceptable conditions decreases significantly. These studies have also shown that the increase of the downlink traffic quickly results in a blockage of the gateway because of the limitation of the duty cycle.

In [11] , Phui *al* studied the power consumption of every class and, in particular, class A. They concluded that class A could work with a battery for up to ten years. Their work does not count for the power consumption for the data analysis and the main microcontroller.

Few research works have investigated the Class B performances.

In [9], authors have focused on the evaluation of the data transmission efficiency of class B in congested conditions. Evaluations have shown exciting results for the delay and several limitations regarding the packet delivery ratio. Unfortunately, these works do not provide a comparison under the same conditions with class A performances and do not propose an in-depth study of class B limits. The only exciting results are that if the gateway used all the duty cycle on the g3 band, it would not be able to send the beacon, and the LoRaWan protocol must address this.

In [12], authors have studied the effects of class B parameters on delay to confirmed downlink messages. They studied the effect of ping number on delay performance using a mathematic model presenting many simplifications, and They concluded that a higher ping number generates a low latency and estimates that this will be at the cost of power efficiency.

In [13], Chekra *et al* proposed a new Uplink Synchronization scheme for LoRaWAN Class B. They proposed a new class derived from class B. the goal is to have a synchronized uplink like the synchronized downlink. Their results show a 10% to 20% increase in the probability of success transmission.

In [14], Alenzi et al worked on a new approach to use machine learning to reduce collisions and delay for uplink in class A.

Unfortunately, these works do not provide a comparison under the same conditions with class A performances and do not propose an in-depth study of class B limits.

Considering the available research, several questions remain open concerning the performances that class B can offer. Mainly, it would be interesting to understand in detail the causes of the data loss in loaded conditions and to quantify the delays offered by class B to downlink traffic in comparison with class A.

We conclude that none in-depth investigation of class B is done despite the potential performance offered by a synchronized network.

IV. LORAWAN CLASS B NS3 MODULE

A. Module description

In this work, we propose a study of the Class B performances regarding delays and transmissions efficiency in comparison to Class A.

We developed for this purpose, a simulation module enabling realistic evaluation scenarios. In this section, we describe the simulation module and the scenario settings.

For the implementation of the LoRaWan Class B simulation module, we considered an already existing NS-3 Class A LoRaWAN module proposed by Magrin *et al* [7]. In this module, the physical layer implementation is based on LoRa© specifications defined by Semtech.

This module implements end devices based on three essential layers: the physical layer, the MAC layer, and the application layer. It proposes one node implementing the gateway and the NetServer operations. This node is also including the physical layer, the MAC layer, and the application layer. To support class B, we create a new MAC layer for the end-devices and the gateway. This MAC layer supports the beacon-based operations of the DL Class B channel. It implements the periodic beacon broadcast for the gateway and all the ping allocation mechanism for the gateway and the end-devices.

B. *LoRaWan Class B assumption*

While developing the new class for the LoRaWan module, we face some problems.

Conflicts between Class A RX2, and Class B Pingslots: The LoRaWAN specification does not forbid an end-device to transmit during the beacon transmission of the gateway (Class A end-devices are not aware of the timing of the beacons) or during the ping slots.

This will not result in collusion because downlink data (beacon and data on ping slots) uses a different sub-band then uplink data.

After an uplink, the end device open RX1 and RX2 to receive downlink data even if there is a ping slot in place of RX1 or RX2.

From the network server perspective, when it generates a packet as a downlink data for a specific end device, and schedule it in the ping slot properly, the information is then passed to the gateway, even an uplink happens before the ping slot, and there is an opportunity RX1 and RX2, the network server cannot use them.

The spreading factor (SF) is assigned to every end device depending on position and distance from the gateway.

C. *SCENARIO AND SIMULATION SETTINGS*

We consider a network architecture with one NetServer serving a set of end-devices through a unique Gateway. End-devices are placed in a 2-dimensions space with a maximum distance from the gateway equal to 8km.

To simulate the behave of the LoRaWAN network, first, we must fix the traffic charge, for that we looked back to the previewers work on evaluation and choose a configuration for data exchanged by the ED and gateway applications layer with different amount of downlink traffic. [9] [10] [4]

We propose unconfirmed uplink messages in addition to unconfirmed downlink messages equivalent to 20% of uplink data. The configuration can be described as the lightest network charge, there is no confirmed uplink, and therefore no ACK from the network server, the only data in the downlink are date generated from the application layer of the network server. The inter-packet time between downlinks is 5000 seconds.

In these scenarios, we increase the number of end devices to evaluate its effect on the overall performance of the network. The duration of the scenario execution is 24 hours. For class B evaluations, we change the ping number to be 4, 8, and 16 to understand its impact on performance.

V. PERFORMANCE EVALUATION

A. *Class A vs Class B*

We first evaluate the packet loss defined as all packet loss in the network, from uplink and downlink traffic and taking into consideration internal collision in the network server. Then we evaluate the downlink link access defined as the time between a packet is generated in the network server application and the time its passer to the gateway physical layer to be transmited.

1) *packet loss*

We carried out simulations to evaluate the performance of class B and class A in terms of DL packet loss. We used the network configuration to show a lightly loaded LoRaWAN network load with low uplink and unconfirmed data. Figure 1 presents the percentage of packets lost in the hole network accounting for uplink and downlink data for class A and B as a function of the number of end-devices.

Results show that class B offers a better performance in terms of packets loss. The probability of proper reception of a packet by the terminals decreases with the number of terminals due to collisions due to the use of ALOHA. If during a downlink transmission, a terminal starts an uplink transmission using the same channel and the same SF, it will cause a collision.

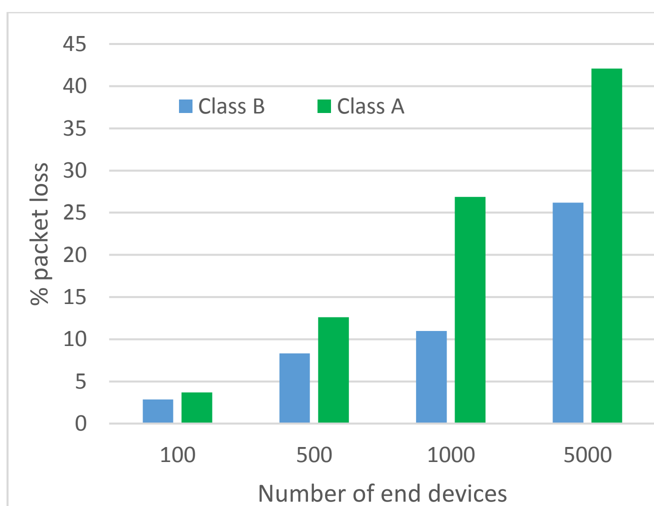

Figure 1 Percentage of packets lost for class A and B

2) Link access delay for downlink traffic

In the second evaluation, we investigate the link access delay for downlink traffic offered by class A and B.

We define the link access delay as the duration between the packet generation time (in the network server) and the time the physical layer sends it. a DL packet can be sent in RX1 or RX2 following a UL transmission, in class A operations. It can be sent in one of the *pingSlots* synchronized between the NetServer and the end-device, in class B operations. Figures 2 presents the link access delay for class A and B as a function of the number of end-devices, respectively.

Downlink link access delay start with 312 seconds, and it reaches its maximal value of 923 seconds with 5000 devices for class A, and link access delay remains less than 52 seconds for class B. In this configuration, we have unconfirmed uplink data. For each uplink, the end device only opens RX1 and RX2, which limits the possibilities of downlinks with class A. If the network server decides to send downlink traffic, it should wait until an upcoming uplink. Downlink data is generated randomly every in 5000 seconds, and we have a downlink possibility every 1000s. Class B offers a downlink opportunity each 42-second (Considering *pingNB*=8) approximately, and with some opportunity missed, we end up with a 52-second average.

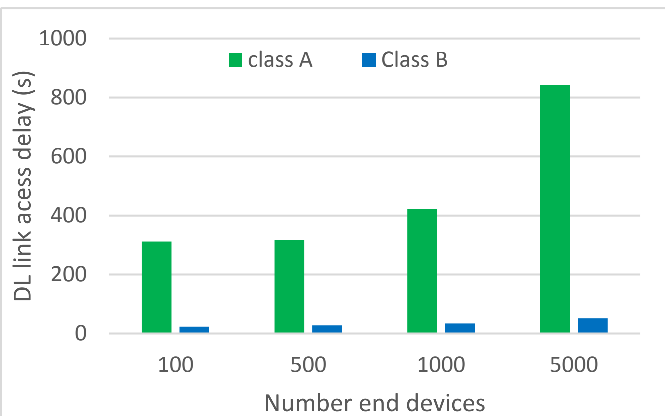

Figure 2 DL Link access delay

Results show clearly the benefits of class B for the minimization of the link access delay for downlink traffic compared to Class A.

This is due to the growth of uplink transmissions for end-devices, which results in intersection phenomena between RX1 and RX2 and downlink packets scheduled class B ping slots. In class B, if an end device sends an uplink, it opens RX1 and RX2 and ignores the pings slots in that time, and the network server does the same. If a downlink packet was previously scheduled in a ping slot during this period, this packet will not be transmitted and will be delayed to a ping slot after the two RX windows.

Based on the previous results, it is clear that class B offers better performance in terms of packet loss and link access delay for downlink transmissions, particularly in highly loaded conditions. Nevertheless, we notice that there is a significant percentage of packet loss. We propose in the next subsection to investigate the causes of these packet losses.

B. Performance evaluation of Class B

We first evaluate the packet loss, then we evaluate the downlink link access in the class B in function of the ping number parameter.

1) packet loss in class B

We carried out simulations to evaluate the performance of class B in terms of packet loss with the same configuration and traffic used to evaluate class A in [10] , and we observe the effect of ping number on packet loss. Figure 3 presents the percentage of packet lost in the hole network caused by collusion, duty cycle limitation, or systematic collusion accounting for uplink and downlink data for class B as a function of the number of end-devices.

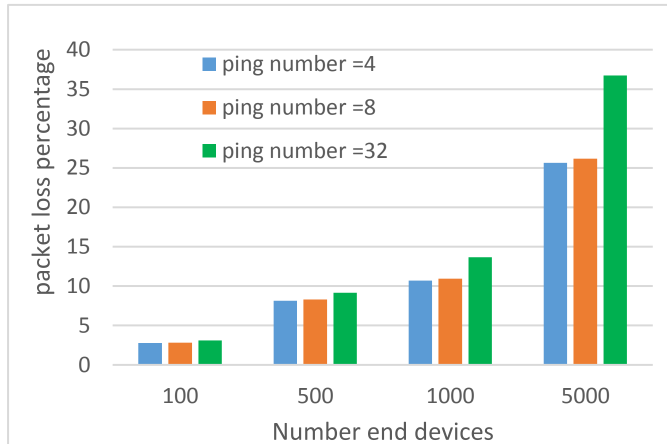

Figure 3 Percentage of packet loss for class B

Results show that class B offers a better performance in terms of packet loss then class A from previous work [4] [15] [6] [10]. The probability of proper reception of a packet by the terminals decreases with the number of terminals due to collisions due to the use of ALOHA. Ping number also can be a cause of packet loss, so a deep dive into the causes of packet loss is necessary to understand this behavior.

2) Link access delay for downlink traffic

we investigate the link access delay for downlink traffic offered by class B. We define the link access delay as the duration between the packet generation time (in the network server) and the time the physical layer sends it. A DL packet can be sent in RX1 or RX2 following a UL transmission, in class A operations. It can be sent in one of the *ping Slots* synchronized between the NetServer and the end-device, in class B operations.

Figures 4 presents the link access delay for class B as a function of the number EDs.

ping number can significantly reduce link delay access and can remain around 50 s with a high number of end devices in the network

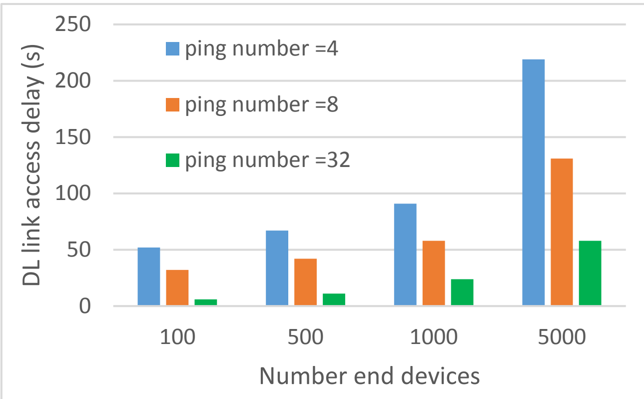

Figure 4 Link access delay

Results show that for a low charged network, a high ping number is beneficial, but with a highly charged network with many retransmissions, a higher ping number can be a problem and causes link access delay to rises.

Based on the previous results, it is clear that class B offers better performance in terms of packet loss and link access delay for downlink transmissions, particularly in highly loaded conditions. Nevertheless, we notice that there is a significant percentage of packet loss that increases with ping number and retransmissions.

Overall, Class B offers better performances than class A for downlink transmissions regarding data transmission efficiency and link access delay. Class B ensures a packet loss around 26 % and a link access delay around 44 seconds while with class A the packet loss is higher than 42% and a link access delay around 842 seconds.

VI. CONCLUSION

In this paper, we have proposed an evaluation of performances offered by the LoRaWAN technology class B. Our goal was to go beyond previous work by offering an in-depth study of Class B performance in terms of link access delay and transmission efficiency for downlink traffic on the function of ping number and compared the results to Class A. To do this; we have considered realistic simulation scenarios based on an NS-3 extension that we developed. Results showed that class B significantly improves performances compared to class A in terms of data transmission efficiency and link access delay.

Regarding data transmission efficiency, results show class B packet loss and access delay depends on the ping number parameter, a trade off should be made between having low access delay or low packet loss.

As part of ongoing work, we are studying the effect of the number of Ping Slots per device on Class B power consumption in a real-life scenario. As future work, we are interested in implementing the machine learning algorithms on the network server for better optimization.

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