2020 9th International Conference on Modern Circuits and Systems Technologies (MOCAST)

A Novel LoRaWAN Scheduling Scheme for Improving Reliability and Collision Avoidance

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***Abstract*—The employment of Low-Power Wide Area Networks (LPWANs) has proven quite beneficial to the advancement of the Internet of Things (IoT) paradigm. The utilization of low power but long range communication links of the LoRaWAN technology promises low energy consumption, while ensuring sufficient throughput. However, due to LoRa's original scheduling process there is a high chance of packet collisions, compromising the technology's reliability. In this paper, we propose a new Medium Access Control (MAC) protocol, entitled the RCA-LoRa towards improving reliability and collision avoidance in LoRa wide-area networks. The novel scheduling process that is introduced is based on the broadcasting of beacon frames by the network's gateway in order to synchronize communication with end devices. Our results demonstrate the benefits of RCA-LoRa over an enhanced version of the legacy LoRaWAN employing the ALOHA protocol and an advanced adaptive rate mechanism, in terms of throughput and collision avoidance. Indicatively, in a single cell scenario with 600 nodes, RCA-LoRa can increase throughput by nearly 50**

***Index Terms*—Low-Power Wide Area Networks, Internet of Things, Medium Access Control, Collision Avoidance**

I. Introduction

TOday, the Internet of Things (IoT) technology grows into a need for modern society, integrating a variety of communication technologies through wireless battery driven sensor nodes and networks. The selection of appropriate communication technologies helps to manage and to maintain the quality of service in the IoT platform based on limited resources. A qualified networking technology should be scaleable enough, reliable in terms of throughput with minimum delays and last but not least, promote energy conservation and data privacy [1]. In order to satisfy these requirements, another range of protocols and technologies have emerged, known as Low-Power Wide Area Networks (LPWAN). A LPWAN can provide radio coverage over a very large area at a low bit rate. These specific characteristics distinguish a LPWAN from a wireless WAN, that is intended to connect users or businesses, and carry more data, using more power. Low power networking technologies have already become very popular, especially in smart city applications on environmental parameters monitoring, road traffic management, precision agriculture, smart parking, and home automation [2].

Our study is focused on the LoRaWAN technology. LoRa stands for Long Range and has been adopted by the European countries and the USA, operating on the 868/915-MHz ISM bands, available worldwide. This technology has the ability to transmit at data rate of up to 50 Kbps using an advertised radio range of up to 15-30 kilometers in rural areas, while providing battery life of about 10 years. However, based on recent studies, LoRa has been shown to face several challenges, due to its regulatory constraint on duty-cycle, which disables a device from sending data packets at will [2]. The utilization of low power but long range communication links of the LoRaWAN technology promises low energy consumption, while resulting in sufficient throughput. Nevertheless, due to LoRa′s original scheduling process, there is a high chance of packet collisions, compromising the technology's reliability. The employment of high spreading factors (SFs) in LoRa′s physical layer and random access in shared channels leads to an increase in packet transmission time and consequently to a higher chance of collision. Our contribution lies upon the design of a new MAC layer, named RCA-LoRa, towards improving reliability and collision avoidance in LoRa wide-area networks. The introduced novel scheduling process is based on the broadcasting of beacon frames by the network's gateway in order to synchronize communication with end devices. Transmission parameters on each channel are dynamically specified, while the CSMA-CA algorithm is also utilized in order to avoid collisions during up-link communications. Nodes are guided to transmit randomly according to the scheduling information acquired by the beacon frames, by utilizing different SFs in the available channels so as to increase the reliability of the network. Through the proposed scheduling process, downlink transmissions are safeguarded, collisions are significantly decreased, high channel utilization is achieved, and throughput increases.

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II. BACKGROUND

A. LoRaWAN Architecture

LoRaWAN is an open standard specification for LPWANs defining the operational structure of the system and network implementation protocols for resource constrained devices. A basic LoRaWAN scenario may involve multiple sensor nodes or end nodes guided to transmit data packets to an according gateway. Each node typically includes various sensors, a LoRa transponder for signal transmissions and optionally a micro-controller. Gateways can cover hundreds of square kilometers in range and are responsible for forwarding incoming transmissions to a specific network server by utilizing a back-haul network such as 4G or Ethernet. An application server is also involved, communicating with the network server via TCP/IP connection. In order to safeguard data privacy in radio transmissions, the LoRaWAN protocol adopts the technique of symmetric cryptography by utilizing session keys extracted from the device's root keys [3].

LoRa has proven to be quite useful in numerous IoT applications. However, the low data rate restricts LoRa′s employment in applications which produce low amounts of data traffic. Depending on the application scenario, LoRaWAN nodes can be of three different types utilizing bi-directional traffic: *a) class A nodes*, that randomly transmit data packets to the gateway and then wait for a short period to receive their pending messages from the gateway, *b) class B nodes*, which send messages on demand, but also schedule specific receive windows for the gateway to answer, and *c) class C nodes*, which are always listening to the channel, keeping almost continuous receive windows so as to check for messages from the gateway. In LoRaWAN, device-to-device communications are not enabled. Packets are only allowed to be transmitted from an end-device to the gateway and further on to the network server, or backwards.

B. The LoRa Physical Layer

The physical layer of LoRa consists of a specific type of spread spectrum modulation technique, which uses frequency chirps with a linear variation of frequency over time in order to encode information. LoRa modulation is characterized by the utilized *Bandwidth (BW), Spreading Factor (SF) and Code Rate (CR)* parameters. This technology requires encoding each symbol with 2^{SF} chirps, where SF takes a value between 7 to 12. SFs can greatly impact the communication range. Since, the chirp rate defines the bandwidth (one chirp per second per Hertz of bandwidth) utilizing a higher value of SF will lead to a longer time for each symbol transmission and yield a longer communication range. Furthermore, LoRa modulation involves the addition of error correction bits in every data transmission, known as *forward error correction (FEC)*. Regarding the definition of the *CR* parameter, it indicates the percentage of bits being transmitted that actually carry information. An increase in the CR value impacts the duration of the transmission, leading to a decrease in battery life.

LoRaWAN is scheduled to function on different ISM bands, depending on the network deployment areas, as presented in [4]. There are various combinations of frequency channels and data rates for establishing communication between LoRa end-devices and gateways [3]. The minimum LoRa data rate is 0.3 kbps and can reach up to 50 kbps. The data rate selection depends on the messages′s duration and the required communication range. In addition, towards maximizing the end devices′ battery life and overall network capacity, LoRa utilizes an Adaptive Data Rate (ADR) scheme for each end-device individually. For Europe, the 863-870MHz ISM band is used, involving a bandwidth of 125 KHz, a data rate of 250 bps, three frequency channels around 868.10MHz, 868.30MHz and 868.50MHz, and a less than one percent duty cycle specification. Regarding the *duty-cycle* definition, it is referred to as the required amount of time that an end-device needs to wait before the next data transmission. Towards reducing collisions as well as increasing channel utilization by different transmitters, LoRa requires a limit to be set for every end-device regarding the maximum duty-cycle. Based on this assumption, the duty-cycle limit guides the LoRa end-device to use another channel for the next data transmission, until a specific period of silence has passed. This wait timer is something that applies to all LoRaWAN transmitters, including the gateways.

C. The LoRa MAC Layer

LoRa′s MAC layer defines the process of end-devices accessing the wireless medium in order to communicate with LoRa gateways. LoRaWAN utilizes an ALOHA-based MAC protocol [5], able to reduce the complexity of end-devices. Its basic operation lies upon the ability of end-devices to transmit information to the LoRa gateway whenever they are ready. Each LoRa gateway listens to a specific sub-band and is responsible of forwarding the packets received from end-devices to the network server. For an up-link transmission to occur, a LoRa end-device must select an available frequency channel, the bandwidth and an SF value for the according data rate. Up-link messages can be either confirmed or unconfirmed. A confirmed message triggers the gateway to provide an acknowledgment. The acknowledgements sent by the gateway may not be necessary, however, they promote a proper working connection between the end-node and the rest of the network, especially due to the operational circumstances of the ALOHA protocol. Based on confirmation receptions, the MAC layer can better manage the selection of SFs and bandwidth towards increasing throughput. If an acknowledgment is requested, after each up link transmission, the gateway has to choose between two down link slots at fixed time instances, so as to provide an answer to the corresponding end-device. The first slot opens after the transmission, lasting for at least one second, while the second slot lasts exactly one second after the first one. According to the agreement made between the end-device and the gateway, different communication parameters regarding this slot can be selected.

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Furthermore, due to the ALOHA protocol scheme, it is quite possible for two end-devices to attempt to communicate with the same gateway, at the same time. In such a case, if both end-devices use the same channel and also modulate their data with the same SF, interference will be caused, leading to packet collision. The introduction of Slotted ALOHA could help eliminate partial collisions, since it utilizes time-slots for data transmission. Each node is allowed to send a packet only at the beginning of a time-slot. However, access in the medium remains uncontrolled. The occurrence of a collision depends on the decision of more than one end-devices to transmit a packet simultaneously. The lack of coordination and the absence of scheduling in packet transmissions are the main reasons that a real-time poor performance is caused for both pure and slotted ALOHA.

III. The Proposed Scheme

The proposed RCA-LoRa scheme was developed on OMNeT++ [6] discrete event simulator by using the FLoRa (Framework for LoRa) simulation tool [7] and the INET framework [8]. FLoRa is an open source tool implementing various modules of the LoRaWAN network, including the LoRa physical layer and the legacy LoRaWAN MAC protocol operations. RCA-LoRa requires the definition of synchronous up-link and down-link channels for the whole available bandwidth. We assume there are three available channels (868.10MHz, 868.30MHz and 868.50MHz), all arranged in units of superframes, which use a specific structure and duration. Each superframe is initiated by a beacon frame transmitted by the gateway and followed by a Beacon Period (BP), defined as the interval between the start of two successive beacons. Each BP is further divided into a Beacon Reserved (BR) time interval, a Beacon Guard (BG) time interval and a Beacon Window (BW) time including time slots during which nodes can transmit their packets. Each beacon transmission is aligned with the beginning of the BR time interval. Then, follows the BW time interval including time slots for data transmissions from the end of the BR time interval to the beginning of the next BG interval. Each BG time interval depends on the transmission time of the longest allowed packet frame in LoRaWAN, in order to insure the completion of all down-link transmissions initiated during a time slot and avoid collision with the beacon transmission.

Beacon frames include information regarding the utilization of up-link/down-link slots in each corresponding superframe. Beacons contain information regarding packet type identification and communication parameters, as presented in Figure 1. In the first 4-bit field, *Packet Type*, the type of the respective packet is provided. Then, follows the 16-bit *Gateway ID* field and the 8-bit *Superframe ID* field, giving nodes information about the timing in the LoRa network. Next, the 8-bit *Gateway Cycle ID* field contains information regarding the utilization of the current channel for beacon transmissions. The length of the current beacon is specified in field *Length* that takes 8 bits. The following 32-bit field, *BW End Time* informs the end-device regarding the timing in the according BP. A 6-bit field *SF selected* specifies the value of SF chosen by the gateway for this transmission. The remaining two fields, a variable *List of Channels* and a 6-bit *Length of Channel* list the available frequency channels for the current LoRaWAN. All this information helps end-devices to more efficiently schedule their transmissions to the gateway by utilizing the appropriate frequency channel so as to avoid packet collisions. LoRa end-devices listen to the latest beacon broadcasted by the gateway in order to synchronize their clocks.

In RCA-LoRa, the gateway transmits its beacons on different channels so as increase reliability against collisions and by utilizing a specific SF, so as to safeguard reception probability for the involved end-devices. Nodes harness beacons′ scheduling information in order to choose a SF value for their data transmission in the channel by which the latest beacon was received. As a next step, nodes select a random time offset and transmit their packets based on the CSMA-CA algorithm. The adoption of the CSMA-CA model increases the chances of a successful transmission in the corresponding BP of a superframe, since many nodes may attempt to transmit in the same time period. In addition, every time a data transmission of an end-device is scheduled, an estimation is provided regarding the possibility of successfully reaching the gateway. If the transmission is estimated to be placed outside the BW of the specific superframe, it is canceled. In such a case, the end-device waits for the next beacon to transmit again. During a BW, multiple transmissions may occur by different end-devices. End-devices have the ability to transmit more than once in the same BW. Due to the proposed scheduling method, no acknowledgements are required and the gateway almost always successfully receives the transmitted packets, leading to a minimum number of collisions at the receiver.

IV. Simulation Experiments

In this section, we present a single cell simulation scenario in OMNeT++, so as to evaluate the performance of RCA-LoRa compared to an enhanced version of the legacy LoRaWAN as implemented in the FLoRa framework by Slabicki et. all [7].

For both LoRa models, the European regional parameters were used for the LoRa physical layer in a deployment area of 480 meters x 480 meters. The transmission power range was from 2 dBm to 14 dBm, the chosen CR was 4/8, bandwidth was 125 kHz, SFs ranging from 7 to 12, and carrier frequency was set to 868 MHz for the legacy LoRaWAN implementation, while RCA-LoRa utilized channels 868.10 MHz, 868.30 MHz and 868.50 MHz. Both implementations followed a less than one percent duty cycle specification. LoRa end-nodes were randomly distributed over the deployment area. The simulation scenario included a single LoRa gateway arbitrarily placed, close to the center, in the deployment area. The LoRa gateway maintained an Ethernet connection with a single network server and the respective networking entities, i.e., routers, a packet forwarder, and the Internet cloud. In order to implement the Internet cloud component, the INET framework was adopted. The ideal back-haul network was modelled to have zero packet loss and a transmission delay

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MAC	Fields	Packet Type	Gateway ID	Superframe ID	Gateway Cycle ID	Length	BW End Time	SF Selected	List of Channels	Length of Channels
	Length	4 bits	16 bits	8 bits	8 bits	8 bits	32 bits	6 bits	variable	6 bits

Fig. 1. Structure of Beacons in the RCA-LoRa scheme

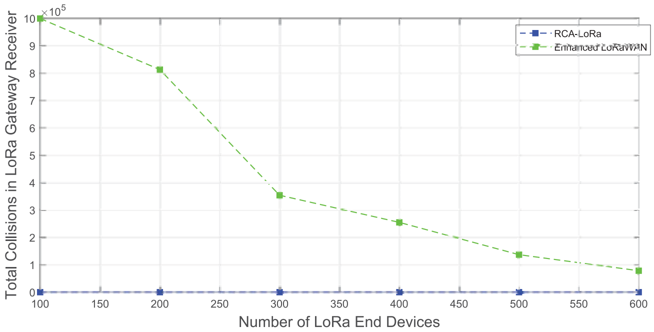

Fig. 2. Collision occurrences in a single cell LoRaWAN scenario

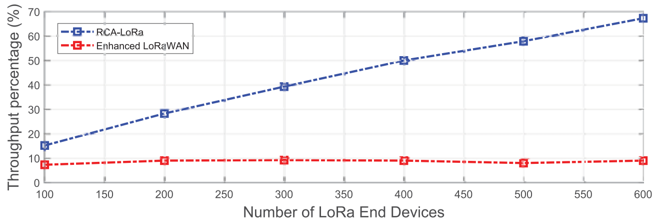

Fig. 3. Throughput evaluation in a single cell LoRaWAN scenario

of 10 milliseconds, while being based on Gigabit Ethernet links. The scenario was evaluated based on a variety of nodes from 100 to 600 in steps of 100 nodes, where each individual experiment lasted for 7 days, equally to 604.800 secs of simulated time.

In both models, LoRa nodes were initially assigned a random SF value and a uniformly distributed transmission power level in order to cover all possible device configurations. The default SF for the LoRa Gateway was nine. According to the implemented scenario, the participating LoRa nodes send a 20 byte packet after a random period of time following an exponential distribution with a mean of 1000 seconds. Each LoRa node was instructed to transmit 1500 data packets to the gateway, without requesting acknowledgments. According to the RCA-LoRa model, node transmissions began only after the reception of a beacon by the gateway. The gateway must also acquire permission from the network server in order to initiate the beacon broadcasting. Regarding the Slabicki′s et. LoRaWAN model, an Adaptive Data Rate (ADR) mechanism is employed, which manages the transmission parameters for the communication links between LoRa nodes and the gateway in a dynamic way. The ADR mechanism is applied at LoRa end-nodes and at the network server asynchronously. Its basic contribution is the enhancement of the network′s performance under variable channel conditions.

The schemes′ evaluation was focused on the following performance metrics: 1) throughput, measured as the number of messages correctly received by the gateway divided by the total number of messages sent by the end nodes and 2) total number of collisions that occurred in the LoRa Gateway′s receiver regarding up-link transmissions. Figure 2 verifies the superiority of the RCA-LoRa scheduling method by eliminating packet collisions in the LoRa gateway receiver in contrast to Slabicki′s et. all scheduling method [7]. Additionally, Figure 3 presents a significant increase in throughput based on the RCA-LoRa scheduling method despite the scaling up of number of end-devices and the duty cycle restrictions.

V. Conclusions

In this paper we presented, implemented, and evaluated RCA-LoRa, a novel MAC protocol towards improving reliability and collision avoidance in LoRa wide-area networks. This novel scheduling process is based on the broadcasting of beacon frames by the network's gateway in order to synchronize communication with end-devices and the ability to optimize channel utilization by employing different SFs. As shown by our simulations in OMNeT++, RCA-LoRa upgardes the performance of the traditional LoRaWAN scheduling method in terms of throughput and collision avoidance. Going forward, we will study energy consumption parameters and further optimise network performance of the RCA-LoRa scheme for multiple gateway scenarios.

References

[1] A.Triantafyllou, P. Sarigiannidis, and T. D. Lagkas, “Network Protocols, Schemes, and Mechanisms for Internet of Things (IoT): Features, Open Challenges, and Trends,” Wireless Communications and Mobile Computing, vol. 2018, 24 pages, 2018, https://doi.org/10.1155/2018/5349894

[2] M. T. Islam, B. Islam and S. Nirjon, ”Duty-Cycle-Aware Real-Time Scheduling of Wireless Links in Low Power WANs,” 2018 14th International Conference on Distributed Computing in Sensor Systems (DCOSS), New York, NY, 2018, pp. 53-60, doi: 10.1109/DCOSS.2018.00015

[3] LoRa Alliance Inc., ”LoRaWAN™ 1.1 Specification,” 3855 SW 153rd Drive,Beaverton, OR 97003, 2017, Accessed 3rd of January 2020 in https://lora-alliance.org/resource-hub/lorawanr-specification-v11

[4] LoRa Alliance Inc., ”LoRaWAN 1.1 Regional Parameters,” 2400 Camino Ramon, Suite 375, San Ramon, CA 94583, 2017, Accessed on the 3rd of January 2020 in https://lora-alliance.org/resource-hub/lorawanr-regional-parameters-v11rb

[5] Polonelli T., Brunelli D., Marzocchi A., Benini L., ”Slotted ALOHA on LoRaWAN-Design, Analysis, and Deployment”, Sensors ,19(4):838,2019,doi:10.3390/s19040838

[6] A. Varga, “OMNeT++,” Modeling and tools for network simulation, pp. 35–59, 2010.

[7] M. Slabicki, G. Premsankar and M. Di Francesco, ”Adaptive configuration of lora networks for dense IoT deployments,”IEEE/IFIP Network Operations and Management Symposium, Taipei, 2018, pp. 1-9, doi: 10.1109/NOMS.2018.8406255

[8] “INET Framework,” https://inet.omnetpp.org/.

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