Time Slotted Lora for Industrial IOT Applications

Anumula Sneha[1], Sribhashyam Rithvik[2]

[1,2]*Dept of Electronics and Communication, Jawaharlal Nehru Technological University, Hyderabad.*

Abstract – *As the technology is growing, the deployment of a large number of wireless sensor devices in industrial environments also increasing. All these devices have to be connected via reliable, low-latency, low-power, and low operating-cost networks. Although LORAWAN provides a Low power Network technology, its present ALOHA-based MAC protocol limits scalability. One of the best practices to solve this issue is through the use of time-slotted communications. Allowing these overheads is not straight through the LORAWAN restrictions on the radio duty cycle. Therefore, in this paper, we propose Time slotted Lora which allows devices to self-organize and determine their slot positions in a given time frame autonomously.*

Key Words: LORAWAN, Time slotted Lora

1. INTRODUCTION

The main aim of industries is the automation of a large number of processors by sensors. The arrangements of such devices require high packet to delivery ratio, and low latency and low power. Present Industrial **IoT (IIoT)** communications involve protocols such as Wireless HART. However, some of these protocols are wired with high installation cost and hence cannot support mobility. In contrast, with the above limitations of IIOT protocols, a long-range technology such as LORA has been introduced. Lora is a spread spectrum modulation technique developed by Semtech which trades data rate with sensitivity using multiple spreading factors. The higher the spreading factors, the longer the transmission range but the lower the data rate.

1.1 Disadvantages of LoRaWan

However, LoRaWAN's development has been focused on longer battery duration, longer distance mechanisms to communicate between nodes and gateway. Moreover, as the consequence, the ALOHA-based MAC-layer cannot guarantee typical IIoT requirements which can be as higher than 99% packet delivery ratio and low delay. The major drawback is unlicensed spectrum in which strict radio duty cycle regulations are applied for most of the bands. These restrictions set a lower bound on time between successive transmissions.

If 1% duty cycle is applied, a node is allowed to transmit only for 36s per hour and stay inactive for rest of period. The same type of restriction holds for gateways. If gateway receives multiple data packets within a short amount of time, it will not be able to acknowledge all of them.

1.2 Alternative Approach

There should be an approach, where an efficient design needs to be adopted for a reliable communication service where received packets are acknowledged without violating the regional duty cycle rules which was set by Lora wan. The time –slotted approach would be a good alternative to the Lora WAN standard ALOHA-based MAC. By using the time-slotted communications, the collision rate will be significantly reduced, which enhances the scalability of network. As gateways run on a restricted duty cycle, spreading the schedule represents the main issue in using time-slotted approach in LoRaWAN.

2. Towards Time Slotted- LORA Communications

2.1 Time Slots, Frames and Synchronization:

Time Slotted Lora is a time slotted protocol which uses Lora as the physical layer of the network. According to this, the time is divided into repeated frames where each frame consists of a number of time slots. Each time slot will accommodate the transmission of one node of data to gateway. Assume that packet of same size and the transmission time increases with higher SF's.

2.2 Scheduling:

The schedule consists of series of frames which consists of slots from all nodes in network. Nodes are accommodated in one or more slots. TS-Lora does not perform any scheduling since nodes are serially placed into slots. Scheduling is part of the resource allocation mechanism, which is a fundamental mechanism for every TDMA-based system. The main job of this mechanism is to reserve the number of slots in a frame for every node in-network and can use them to perform transmissions without interfering with other nodes.

Scheduling can be performed by using either centralized way or distributed way which depends on the nature of the network. Despite this, a LoRa gateway would require several minutes to spread a schedule of a few kilobytes to all the nodes given a 10% duty cycle and the lowest Spreading Factor. The nodes joining and leaving the network at random times would require often re-computation and re-spreading of the schedule. The other example of cellular networks where nodes request slots on demand would not work either for similar reasons. In a time-slotted environment, the time is divided into repeated frames and several slots are accommodated in each frame. By Assuming a slot can be allocated to only a pair of nodes (transmitter and receiver), we say that the number of slots in the frame has to be equal to the number of pairs. Moreover, due to the duty cycle restriction, empty slots may need to be added to the schedule to follow the duty cycle rules.

3. Time Slotted LoRa

The LoRa based system consists of set of nodes and the gateways with sensing and communication information. A gateway which collects data transmitted from the nodes. In general here, we assume a traditional 1-hop star network topology where the nodes transmissions can be collected at the gate way.In LoRaWan, the procedure is divided into 2 phases, the Joining Phase and the data transmission phase. During the joining phase, the nodes first register with the gateway by exchanging a set of keys that are initially used and later to facilitate the encryption of data. The nodes wake-up periodically and transmit a data packet over a secure channel which is established using exchange keys. In TS-LoRa in order to avoid collisions, transmissions are performed generally during specific time-slots using time division mechanism. However, TS-LoRa introduces last phase where synchronisation and transmission of acknowledgements taking place.

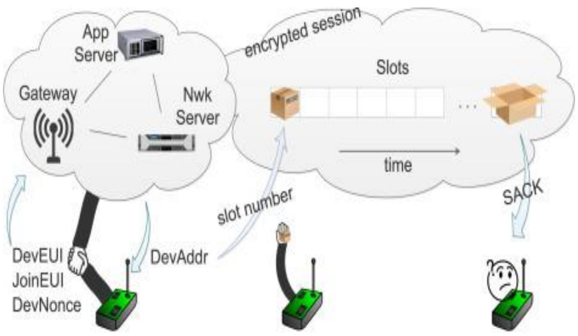

Fig -1: Phases of TS-LoRa:network registration,data transmission and Synchronisation/ACKnowledgements(SACK).

Registration & slot allocation mechanism

In the specification of Lora, a node can join a Lora WAN network using Over The Air Activation (OTAA) as follows: The node of Lora sends a join request of the form:

join-request1 = [JoinEUI|DevEUI|DevNonce1]

The node's unique identifier: DevEUI

Random application id: JoinEUI

DevNonce1 :2-octet nonce.

Joinaccept1=[JoinNonce|NetID|DevAddr1|DLSettings|RxDelay_1]

Where Join Nonce is device specific counter of Lora Net ID is network identifier. DevAddr1 is end-device address of Lora. The only difference that TS-Lora introduces takes place on network server side and related to the generation process of end device address (DevAddr). In TS-LoRa, every time when the gateway receives a join request, a time-slot must be associated with joining node. The gateway keeps track of number of reserved slots (per SF) starting from slot 0 and the maximum slots can be given by s. The slot associated could be directly communicated to the node. To keep the Lora WAN Protocol existing on the node end side, TS-LoRa generally uses DevAddr1 generation process. It generates a 32-bit DevAddr1 and checks with the below equation if it is satisfied. If not satisfied, a new DevAddr1 is chosen at random until the desired slot number is produced.

Slot = [int(crypto hash(DevAddr1))]%s

This modification will not affect underlying security services since replacing a random DevAddr1 with new one will not affect key generation.

3.1 Data transmissions of Lora:

The time is divided into frames where each frame is divided into slots and each slot is used to set one node with transmission. Guard times which are added at the beginning and at the end of each slot to tolerate small de-synchronizations between nodes and gateway.

A data slot has length equal to Tdata+2g where Tdata is the packet transmission time for given Spread Frequency, Channel BW and g is guard time.

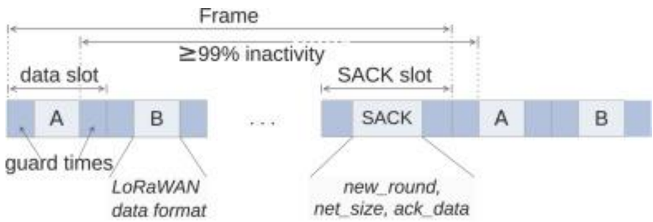

Fig -2: Frame structure depicting two data slots (A, B) and a Synchronization/Acknowledgements (SACK) slot.

Frame structure depicting two data slots A and B and a Synchronization/Acknowledgements (SACK) slot.

Network synchronization and data acknowledgements:

Network synchronization and data acknowledgements are the two operations in which the gateway handles by using a single packet called "SACK".

Acknowledgement data:

The gateway keeps track of the data bits received from data packet and associates each received bit with binary flag 1. A ‘0’ flag is indicated that either nothing was received in the respective slot. The gate way builds a sequence of ones and zeros whose positions in the sequence depend on the slot of each registered node. For example, if it consists of 5 nodes and the data in the first slot was received, the gateway will produce ACK binary sequence of ‘10000’.The node that receives a SACK packets , extracts the ACK information and checks if the i^{th} position of sequence is zero or one, where I is its slot number.If it is zero, the same packet will be repeated for next round.The length of the SACK slot may increase since more nodes of same SF may be added to network.The gate way cannot transmit another SACK packet unless a time duration of at least 99 times of the previous SACK packet has passes.

If T sack is the transmission time of last SACK packet,

$$99TSACK \leq frame\_size - TSACK$$

$$frame\_size = \begin{cases} 100T_{data}, & \text{if } n \leq \left\lfloor \dfrac{100T_{data}}{T_{data} + 2g} \right\rfloor, \\ n(T_{data} + 2g) + T_{SACK}, & \text{if } n > \left\lfloor \dfrac{100T_{data}}{T_{data} + 2g} \right\rfloor, \end{cases}$$

Where n is the number of nodes in the Lora,

Tdata : the data transmission time, g: guard time.

The SACK slot has maximum duration which mainly depends on transmission time of ACK data and guard time.

4. Performance guarantees of TS-Lora:

4.1 Reliability of TS-Lora:

TS-LoRa can achieve high reliability because of avoidance of interference and acknowledgment mechanism between nodes and gateway. Interference in LoRa will be intra and inter SF interference. Intra-SF interference occurs when transmissions of same SF will overlap. In TS-Lora, there is no intra-SF interference because transmissions of the same SF are accommodated in different slots.

4.2 Delays in Lora:

Lora consists of two types of delay. The first type of delay due to the transmission time of the data packet, which is most commonly called airtime. The second type is the delay which is caused due to the radio duty cycle. For TS-Lora, the duty cycle regulations should be set as minimum as possible according to the allowed frame size. By adding several nodes if it does not reach the limit of frame size, to satisfy duty cycle rules empty slots should be added. If once the duty cycle frame size limit has reached, additional nodes can be accommodated by Increasing the frame size. The higher the number of nodes in a plane, the larger the delay. The issue can be partially solved by moving some nodes to higher frequencies, but this is not always achievable. Some elements of control will be required to deal with this problem, but this is out of the scope of the current paper.

Table showing Features of TSL Implementation

FEATURES OF CURRENT TSL IMPLEMENTATIONS

	Property	TS-LoRa	TSCH-over-LoRa	Synchronous LoRa Mesh	LoRaBlink	Multi-Hop LoRa
Features	Collision-Free	Yes	Depends on schedule	Yes	No	Yes
	Acknowledgements	Yes	Yes	Yes	Optional	No
	Topology	Star	Mesh	Mesh	Tree	Tree
	Multiple Gateways	Multiple 1-channel	Yes	Yes	No	N/A
	Addressing	LoRaWAN-based	IPv6	Fixed	Fixed	Fixed
	Routing	N/A	RPL, Static	Flooding	Flooding	Custom
	Security	LoRaWAN-based	802.15.4, TinyDTLS	No	No	No
	Compatibility	N/A	UDP, CoAP, MQTT	N/A	N/A	N/A
	Protocol Overhead	Low	Very high	High	Medium	High
	Scalability	Medium to High	Medium	Low	Low	Medium
	Timeslot Size	Fixed per SF	Fixed	Fixed	Fixed	Fixed
	Channel Hopping	No	Yes	No	No	No
	Joining / Registration	Slow	Slow	Medium	Slow	N/A
Code	Open Source	Yes*	Yes†	Yes**	Yes‡	No
	License	GNUv3	BSD-3	GPL-3.0	EPL-v1.0	N/A
	Radio Supported	SX1276	SX1272	SX1276	SX1272/76	SX1272
	OS / SDK	Pycom SDK	Contiki-NG	FreeRTOS	IBM LMiC	Mbed OS
	Reference	[6]	[7]	[8]	[9]	[10]

*https://github.com/deltazita/ts-lora
†https://github.com/dtu-ese/contiki-ng-lora
**https://github.com/Eawag-SWW/loramesh
‡https://www.lancaster.ac.uk/scc/sites/lora/lorablinkkit.html

5. CONCLUSIONS:

In this paper, we proposed a TS-LoRa an unusual time-slotted approach. TS-Lora enables nodes to self-organize the time-slot schedule with in the frames. In TS-Lora, the information that the server has to send is the frame length. As this is the same piece of information to be shared for all nodes, the network server broad cast all its nodes at the same time. This is one of the best approaches to increase the scalability of the devices.

REFERENCES

[1] "TS-LoRa: Time-slotted LoRaWAN for the Industrial Internet of Things" Computer Communications, Volume 153,1March14,2020 https://www.sciencedirect.com/science/article/pii/S0140366419314677

[2] Bharat S. SChaudhari and Marco Zenna, "LPWAN Technologies for IoT and M2M Applications"

[3] Dimitrios Zorbas 'Design Considerations for Time-Slotted LoRa(WAN)' https://www.ewsn.org/file-repository/ewsn2020/271_276_zorbas.pdf

[4] Quy lam hoang, Woo-Sung Jung, Taehyon Noon, Daeseung Yoo, and Hoon Oh "A Real-Time Lora Protocol for Industrial Monitoring and Control Systems".

[5] Dimitrios Zorbas, Christelle Caillouet, Khaled Abdelfadeel Hasaan "Optical Data Collection Time in Lora Networks- A Time Slotted Approach"

[6] Alexandru Lavric, "LoRa (Long-Range) High-Density Sensors for Internet of Things", *Journal of Sensors*, vol. 2019, Article ID 3502987, 2019.

[7] Dongkyun Kim Sensors 2016, *16*(9), 1466; "A Study of Lora: Long Range and low power networks".

[8] Kun Wang 'Application of Wireless Sensor Network based on LoRa in City Gas Meter Reading'.