Poster: DSME-LoRa – A Flexible MAC for LoRa

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***Abstract*—LoRa is a popular technology that enables long-range wireless communication (kilometers) at low energy consumption. The transmission exhibits low throughput and underlies duty cycle restrictions. Long on-air times (up to seconds) and range are susceptible to interference. In parallel, common LoRa-devices are battery driven and should mainly sleep. LoRaWAN is the system that defines the LoRa PHY, MAC, and a complete vertical stack. To deal with the above limitations, LoRaWAN imposes rigorous constraints, namely, a centralized network architecture that organizes media access, and heavily reduced downlink capacity. This makes it unusable for many deployments, control systems in particular. In this work, we combine IEEE 802.15.4 DSME and LoRa to facilitate node-to-node communication. We present a DSME-LoRa mapping scheme and contribute a simulation model for validating new LoRa use-cases. Our results show 100% packet delivery and predictable latencies irrespective of network size.**

I. Introduction

LoRaWAN provides access to constrained Endnodes (ENs) over long distances. It specifies a complete vertical stack to access ENs, through dumb Gateways (GWs), and centralized Network Servers (NSs) which organize all communication, including PHY configurations, and MAC schedules. Application Servers (ASs) are the interface to control logic, allowing to interconnect LoRa ENs. The LoRaWAN architecture prevents peer-to-peer networks among LoRa devices. This makes it unusable for large scale automation and control use cases (Fig. 1a). Two constraints are worth noting: (*i*) LoRaWAN establishes star topologies around GWs that blindly forward packets between ENs and the NS, through an infrastructure network. Consequently, intermittent GW connectivity stops data retrieval from and between ENs, even if those are in wireless reach. In addition, node-to-node communication through a GW burdens its duty cycle which is heavily regulated in the ISM frequency band. (*ii*) Data flow is triggered by uplink packets from ENs (class A) but lacks MAC addresses, which prevents accessing neighbors directly. Downlink traffic is scheduled by the NS and sent in return to an uplink, within two subsequent receive slots of the EN. Consequently, node-to-node communication has to be mediated through NS and the AS, while the receiving node has to poll. This exhibits unpredictable behavior and very long latencies. Alternatively, class C leaves the EN always receive-able, but is not an option due to high energy consumption. Class B adds periodic downlink slots, allowing for intermittent device sleep, but

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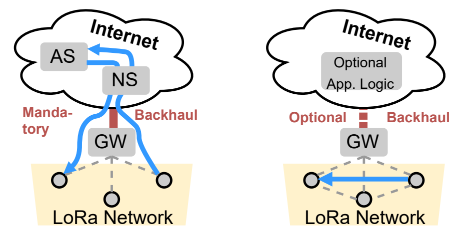

(a) LoRaWAN (b) DSME-LoRa

Fig. 1: Node-to-node traffic in LoRaWAN and DSME-LoRa.

it still prevents node-to-node communication as transmission slots are organized centrally.

We argue for replacing the LoRa MAC to overcome LoRaWAN limitations (Fig. 1b). Haubro *et al.* [1] present an approach for IEEE 802.15.4e TSCH mode (Time Slotted Channel Hopping) over LoRa which suggests performance potentials of a scheduled MAC for long-range radios. We argue that IEEE 802.15.4e DSME mode (Deterministic and Synchronous Multi-Channel Extension) is a better MAC for LoRa. Similarly to TSCH, DSME comprises time- and frequency division,however, two built-in features make it an appealing candidate for LoRa: (*i*) DSME initiates a superframe structure that consists of a beacon period, a contention-access period (CAP), and a contention-free period (CFP). The CAP provides room for node association handshakes during bootstrap, and CFP negotiation, which can take particularly long due to long on-air times. Furthermore, CAP utilization increases with the number of nodes. TSCH, in contrast, only preserves a single time slot for bootstrap traffic which increases collisions and join time. The CAP further allows for sporadic traffic, or can be omitted (*CAP reduction*, Sect. II-A) to increase the amount of CFP slots. The CFP provides deterministic and exclusive transmission resources. DSME creates CFP schedules natively in a decentralized manner which reduces management overhead and is an enabler for mesh and multi-hop topologies. In contrast, scheduling is out-of-band in TSCH. (*ii*) DSME resolves beacon collisions of overlapping coordinators by assigning unique beacon slots. Similarly, duplicate CFP allocations of nodes in wireless reach are resolved, to prevent collisions during CFP. TSCH lacks comparable features.

In this poster, we present a DSME-LoRa mapping scheme (§II-A) and contribute a simulation model in a common network simulation environment (§II-B). We provide evaluations (§II-C) that demonstrate the applicability of node-to-node

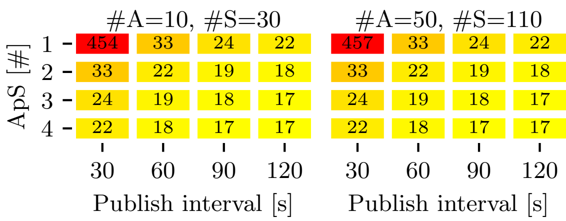

Fig. 2: Average time to completion [s] for varying numbers of actuators (A), sensors (S), and assigned actuators per sensor (ApS) at different publish intervals.

communication using DSME-LoRa, without the need for an infrastructure backhaul (unlike LoRaWAN).

II. DSME over LoRa

A. Low Layer Mappings

On the PHY we define an adaptation layer to operate LoRa radios below the DSME MAC. In agreement with [1] we configure: spreading factor 7, 125 kHz bandwidth, and code rate 4/5, which results in a PHY bitrate of ≈5.5 kbps, a symbol time of 1.024 ms and a theoretical transmission range of 2 km. These parameters align well with LoRaWAN default settings and provide a balanced tradeoff between on-air times and range. We assign 16 frequencies with 1 %-restriction onto DSME channels (for the CFP), and a 10 %-restriction band as common channel (for beacons and CAP).

On the MAC we configure a beacon order of 7, which results in a beacon interval of ≈ 125.82 s. This is aligned to the beacon interval of 128 s in LoRaWAN class B. Following the IEEE 802.15.4e standard, we set four superframes per multi-superframe which results in $28 \cdot 16 = 448$ unique and collision free CFP slots that repeat every ≈ 31 s, or 832 slots using CAP reduction. It noteworthy, however, that a single node can only operate on a single channel during one time slot. To avoid collisions during CAP, DSME applies the CSMA/CA protocol. We utilize channel activity detection, which is available on common LoRa devices, to assess a clear channel during CSMA/CA send attempts.

B. Simulation Environment

Our simulator is implemented in OMNeT++ and the INET framework and combines existing implementations *openDSME* [2] and *FLoRa* [3] via our novel DSME-LoRa layer. We assign CFP cells statically to analyze the performance of a steady-state network. DSME-LoRa replaces the radio access layer of *openDSME* by our LoRa adaptation that connects to the *FLoRa* radio. Wireless propagation operates on a sub-GHz channel model. Networks are configured through regular `.ini` files which set the number of sensors, actuators, and packet rate of the `Ipvx` INET traffic generator.

C. Evaluation

We simulate two networks with different numbers of LoRa sensors (S) and actuators (A). Thereby, we vary the number of actuators per sensor (ApS). For example, in a scenario with four sensors, two actuators, and an ApS of one, each actuator serves two sensors, whereas the assignment is randomized. Each sensor transmits 127 Byte control packets to one or multiple actuators in a dedicated time slot during CFP, following a Poisson process, and we vary the average publish intervals. Fig. 2 depicts the average completion times. In both networks, fast publish intervals (*i.e.,* 30 s) to a single actuator reveal highest latencies (> 450 s) and losses of ≈ 5 %. This effect is caused by MAC layer queueing which delays transmission by multiples of a multi-superframe duration. *openDSME* queues up to 22 packets which degrades the completion time up to 692 s in the worst case. Increasing the ApS reduces stress in the MAC queue, since multiple transmissions can be scheduled directly within a single multi-superframe. This reduces the average latency to less than 33 s. Increasing the publish interval has a similar effect and reduces completion to less than ≈ 24 s. In relaxed scenarios, the average completion time converges to ≈ 16 s which reflects half of a multi-superframe duration.

Our simulations show that network size (Fig. 2 left vs right) does not affect completion times nor packet delivery (not displayed). It is noteworthy, however, that we operate the MAC within its deterministic boundaries. Hence, we limit the number of slot allocations in agreement with Sect. II-A and exhibit 100 % delivery ratio for networks with > 100 nodes.

All nodes comply with the EU 868 ISM band duty cycle regulations, even under more stressful conditions. This exhibits a real advantage over LoRaWAN: A comparable LoRaWAN network mediates all traffic through the gateway. This is particularly challenging for control commands (downlink) which quickly exceed the available time-on-air budget of the gateway. Note that *The Things Network*, one of the most used LoRaWAN community networks, therefore reduces the number of downlink packets to 10 per node and day.

III. Conclusions and Outlook

DSME-LoRa enables node-to-node communication for long-range networks, contrasting LoRaWAN. Our results show that this approach is applicable for > 100 nodes, without sacrificing reliability.

Our research agenda is twofold. First, we will adopt concepts by the IETF 6TiSCH working group to DSME-LoRa, taking advantage of built-in DSME scheduling features to enable multi-hop communication. Thereby, we will extend our simulator to enable IPv6 connectivity through LoRa gateways which connect local networks to the Internet. Second, we will implement the network stack and evaluate a deployment on real hardware. *openDSME* is our starting point, since its core implementation already suits common IoT nodes.

References

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