Exploring Standard-Compliant Channel Access Enhancements for dense LoRaWAN

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LoRaWAN : The Next Step in IoT Evolution

Massive IoT → Energy-efficient, Long-range scalable networks → **LPWAN** technologies → **LoRaWAN**




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LoRaWAN : Free (ISM bands), open, cost-effective, flexible, and scalable connectivity.

LoRaWAN in a Nutshell

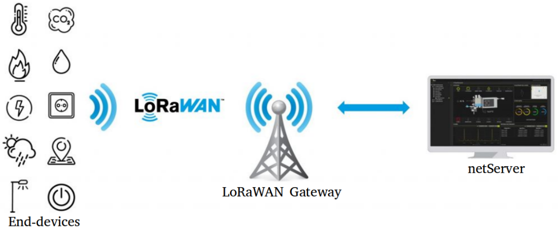

Figure 1 – LoRaWAN architecture

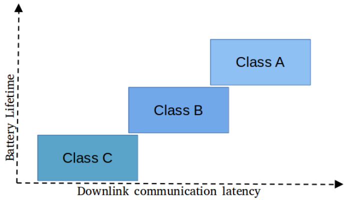

Figure 2 – LoRaWAN classes

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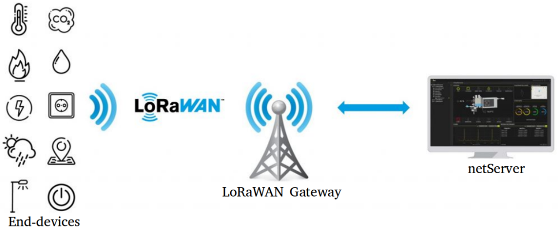

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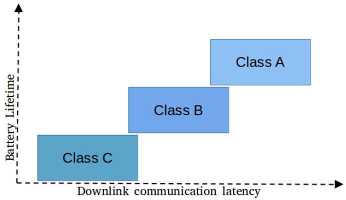
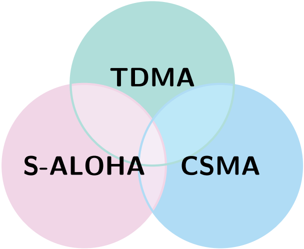


Figure 2 – LoRaWAN classes

- **LoRaWAN Challenge :** Regardless of end-device class, LoRaWAN's pure ALOHA mechanism results in high collision rates and limited scalability in dense networks.

Problem Statement & Research Questions

- **Conventional Enhancements :**



- Contradictory results on the effectiveness of existing enhancements.

- **Open issue :** Lack of standard-compliant (interoperable) and experimentally validated solutions.

- **Research Questions :**

1. Can S-ALOHA, CSMA/S-ALOHA, and TDMA be implemented while fully comply with LoRaWAN ?

2. How do these schemes perform under dense deployments (up to 1000 nodes) and confirmed traffic ?

Objective of the Contribution

Objective : Address the practical validity of channel enhancements –S-ALOHA, CSMA/S-ALOHA, and TDMA– through Packet Success Rate PSR and Energy consumption E_c evaluation in a dense deployment.

Practical Validity

Full Compliance with the Standard

- Use built-in Class B synchronization.
- Do not modify the standard downlink.
- Preserve beacon message structure & timing.

Realistic LoRa PHY conditions

- Default channels & spreading factors (SF).
- Realistic path loss/ Duty-cycle constraints.

Plan

Related works

Related works

Study	TDMA	S-ALOHA	CSMA	CSMA/ S-ALOHA	Scale	Interoperability / Compliance
[1]	×	✓	×	×	small	×
[2]	×	✓	✓	×	large	×
[3]	✓	×	×	×	large	×
[4]	✓	×	×	×	large	-
[5, 6]	×	×	✓	×	medium	✓
our work	✓	✓	×	✓	large	✓

Existing Solutions :

- Often about small scale or not standard-compliant.
- Few studies combine CSMA with S-ALOHA.
  $\rightarrow$ Need for standard-compliant evaluation under realistic conditions.

System Model : Design of LoRaWAN standard-compliant channel access enhancements

Class B Synchronization for Time-Slotted LoRaWAN

- **LoRaWAN class B beacon window 'BW' :** 2048 time slots.
- **Time slot length** $=$ Uplink packet time-on-air (ToA), accommodating one uplink transmission (28-byte payload with SF7).
- **Vulnerability period** T_{BcVln} **:** Prevents overlap between uplink transmissions and beacon reception (guard $+$ reserved intervals).
- **Downlink periodicity=7** : Beacon periods are reserved for uplink transmissions.

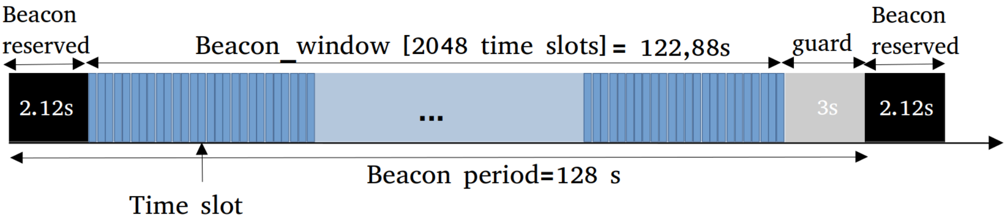
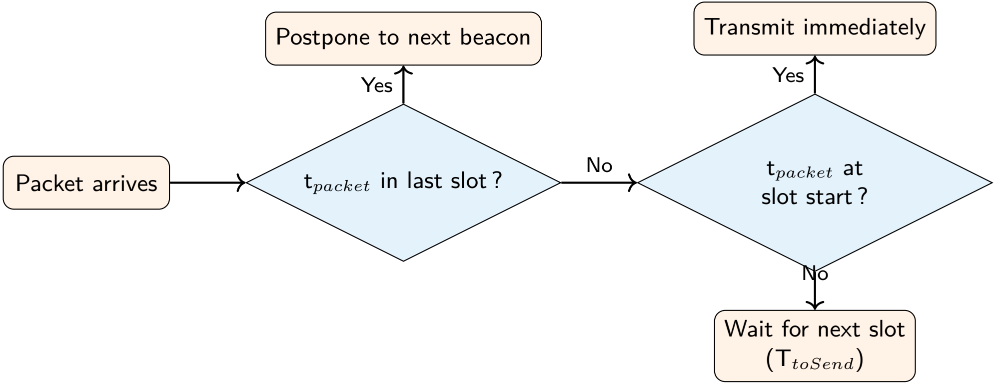


Figure 3 – Beacon timing structure for uplink communications.

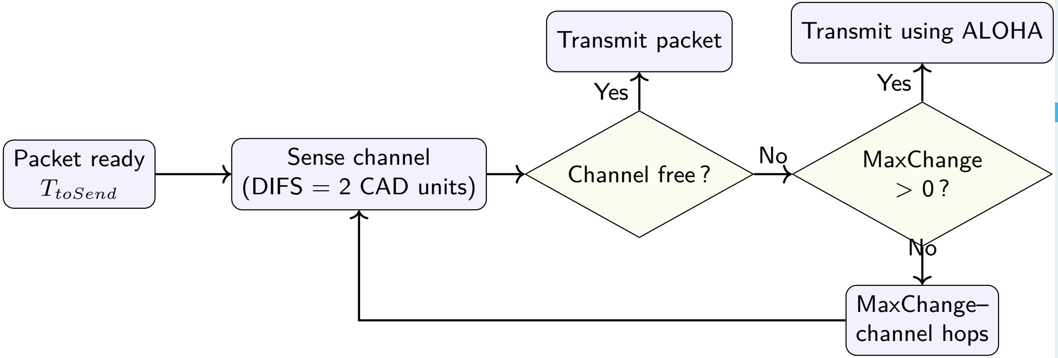
S-ALOHA over LoRaWAN Class B

- A packet arriving at t_{packet} is sent in the next slot start time T_{toSend}. If it arrives after the last slot, transmission is postponed to the next BW.



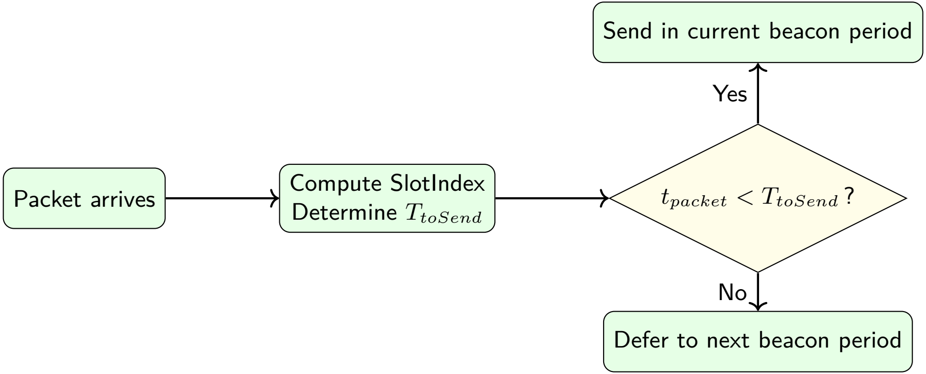
CSMA/S-ALOHA over LoRaWAN Class B

- Devices sense the channel (DIFS phase) before T_{toSend}. If channel is busy→ hop up to **MaxChange** ; if no free channel & **MaxChange=0** → ALOHA.
- Back-off phase is disabled : only 3 channels ; busy ones occupy entire slots.



TDMA over LoRaWAN Class B

- Each end-device i transmits in slot i, with $i \in 0..N_{ed} - 1$.
- If a packet arrives after its slot start (T_{toSend}), it is deferred to the next beacon period.



Simulation Results

scenario and settings

- Extending ns-3 module by implementing class B functionalites.
- Implementing S-ALOHA, CSMA/S-ALOHA, and TDMA on top of Class B.

Parameter	**Value / Description**
Number of end-devices (N_{ed})	200 – 1000 (uniformly distributed)
Cell radius (R)	2.5 km around gateway
Path loss model	Log-distance, exponent $=$ 3.76
Uplink packets periodicity (T_{app})	15 minutes
Spreading factor / Bandwidth	SF7 / 125 kHz
Time-on-air : uplink / ACK$_{RX1}$ / ACK$_{RX2}$	0.06 s / 0.04 s / 0.10 s
Retransmissions (confirmed)	Enabled, N_{bret} $=$ 7
Current consumption (I_{tx}, I_{rx}, I_s)	(25.5 / 4.2 / 0.0012) mA
(V, P_{out})	(3.3 V, 13 dbm)
Simulation time	S=24h

Table 1 – Simulation parameters.

Unconfirmed traffic— Observations and main conclusions :

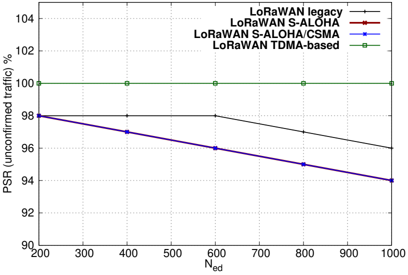


Figure 4 – PSR as a function of N_{ed} (unconfirmed traffic).

Key Observations :

- TDMA achieves 100% PSR.
- With strict compliance to Class B synchronization : Pure-ALOHA outperforms S-ALOHA and CSMA/S-ALOHA. T_{BcVln} $\rightarrow$ collisions+ sub-band under-utilization.
- No CSMA gain over S-ALOHA $\rightarrow$ CAD sensing becomes unreliable beyond 1.29 km (due to fading, low SNR))$\rightarrow$ hidden terminal problem.

Confirmed traffic— Observations and main conclusions :

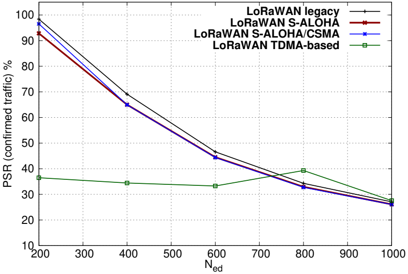


Figure 5 – PSR as a function of N_{ed} (confirmed traffic).

Key Observations :

- ACK traffic severely degrades ALOHA-based schemes ; Class A remains slightly superior.
- CSMA/S-ALOHA helps only at low densities ($N_{ed} < 400$).
- TDMA suffers from unscheduled ACKs colliding with uplinks $\rightarrow$ repeated retransmissions in fixed slots.
- With TDMA, PSR slightly improves at high densities ($N_{ed} > 750$)$\rightarrow$ retransmission delays reduce overall traffic, lowering collisions.

Confirmed traffic— Observations and main conclusions :

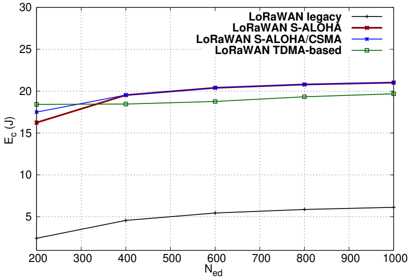


Figure 6 – E_c as a function of N_{ed} (confirmed traffic).

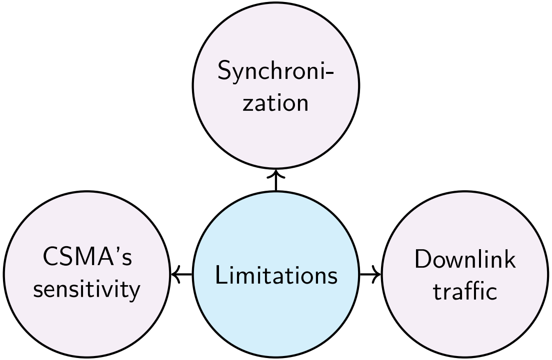
Key Observations :

- Class A is the most energy-efficient, followed by S-ALOHA, CSMA/S-ALOHA, and TDMA.
- When $\mathrm{N}_{ed} > 300$: S-ALOHA and CSMA/S-ALOHA converge in energy efficiency $\rightarrow$ balanced retransmissions and sensing costs.
- TDMA's overall energy drops due to the decrease of the total number of delivered packets.

Conclusion and Perspectives

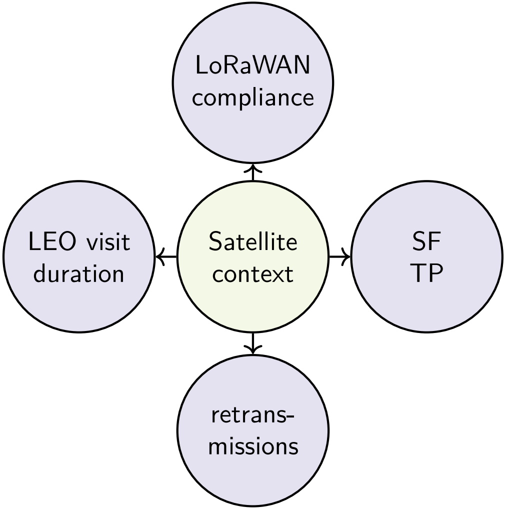
Key findings

- Limited gains with S-ALOHA, CSMA/S-ALOHA, and TDMA enhancements :
  $\rightarrow$ strict LoRaWAN Class B compliance constriants.



What's Next

- Applying our analysis to LEO satellite networks.



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