LoRaSync: energy efficient synchronization for scalable LoRaWAN

LPWAN Days 2022

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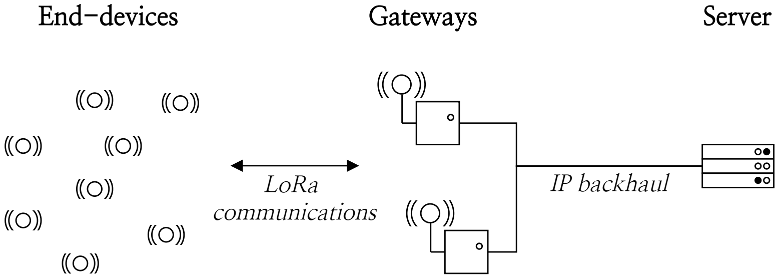
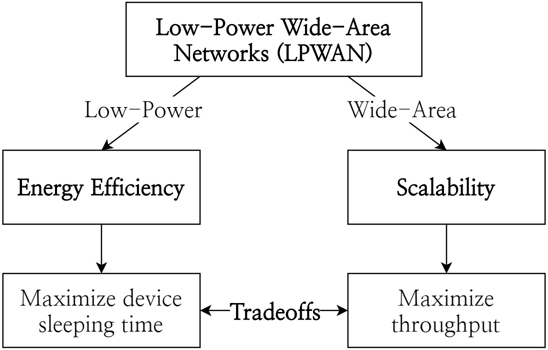
Background about my thesis

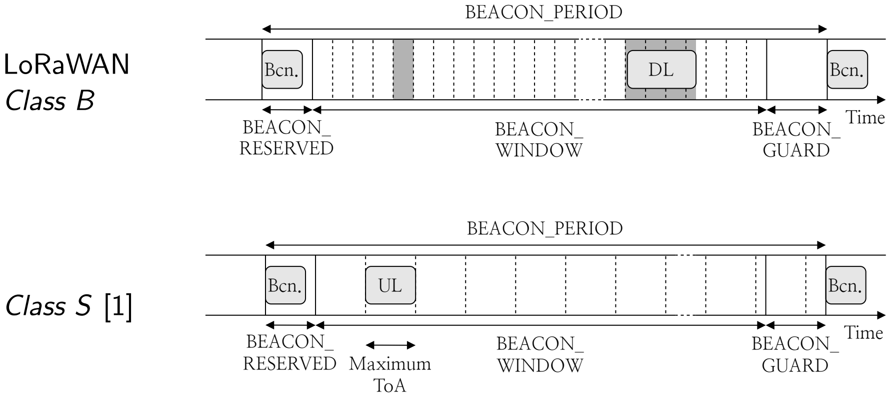
LoRaWAN architecture



General problematic

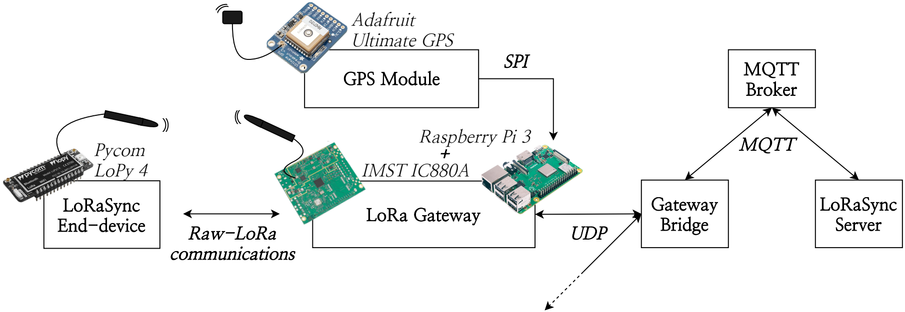


From *Class B* to *Class S*



Design of the synchronization mechanism

Testbed infrastructure



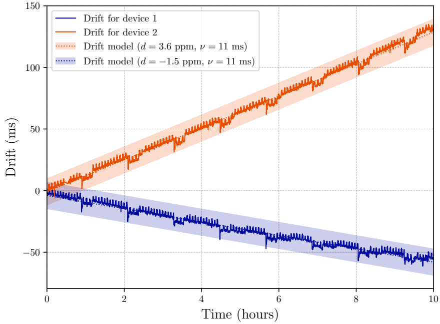
Measuring and modeling the device clock drift

Literature [2, 3, 4] → Simple Skew Model (SKM) [5], linear model at constant temperature.

Test results → noise on low-cost devices.

$$\text{drift} \in (d \cdot t) \pm \nu \qquad (1)$$

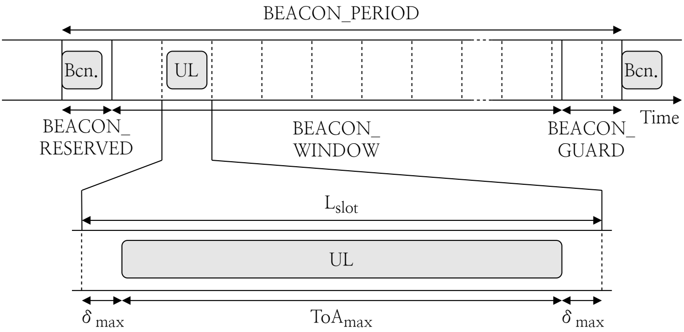
- d drift coefficient in ppm.
- ν noise margin in seconds
- t elapsed time since last synchronization in seconds



Internal clock drift and model for two devices.

LoRaSync: a robust and energy efficient synchronization mechanism

Class S over *LoRaSync*



Beacon-skipping mechanism to save power → n_{skip} is defined as the biggest $k \in \mathbb{N}$ that fits (using worst-case d and ν values):

$$(k+1) \cdot BEACON\_PERIOD \cdot d + \nu \leq \delta_{max} \quad (2)$$

Performance modeling and protocol optimization

Throughput modeling

Pure ALOHA (*Class A*) [6]

$$p = 1 - e^{-\lambda} \quad (3)$$

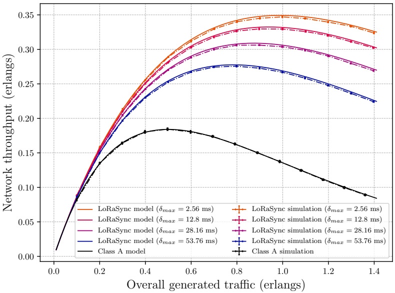
$$T_p = np(1-p)^{2(n-1)} \quad (4)$$

Slotted-ALOHA over *LoRaSync/Class S*

$$q = 1 - e^{-\lambda \frac{L_{slot}}{ToA_{max}}} \quad (5)$$

$$k_s = \frac{n_{slots} \cdot ToA_{max}}{BEACON\_PERIOD} \quad (6)$$

$$T_s = k_s nq(1-q)^{n-1} \quad (7)$$



Throughput models validation with simulation results

Energy efficiency modeling

Pure ALOHA (*Class A*)

$$P_p = \left[\lambda P_{\text{TX}} + \rho_s P_{\text{RX}} + (1 - \lambda - \rho_s) P_{\text{SLEEP}}\right] \cdot n \quad (8)$$

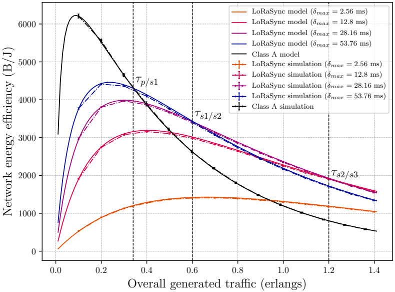
$$E_p = \frac{T_p}{P_p} \cdot \frac{bytes_{\text{pkt}}}{ToA_{\text{pkt}}} \quad (9)$$

Slotted-ALOHA over *LoRaSync/Class S*

$$P_s = \left[(\rho_s + \rho_b) P_{\text{RX}} + \lambda P_{\text{TX}} + (1 - \rho_s - \rho_b - \lambda) P_{\text{SLEEP}}\right] \cdot n \quad (10)$$

$$E_s = \frac{T_s}{P_s} \cdot \frac{bytes_{\text{pkt}}}{ToA_{\text{pkt}}} \quad (11)$$

- ρ_s is the RX slot rate
- ρ_b is the beacon RX rate
- P_{XX} is the device power consumption in state XX

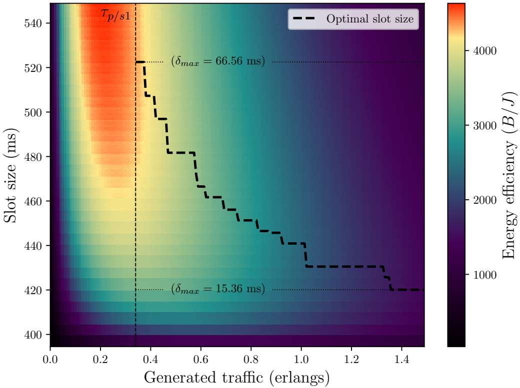


Energy efficiency models validation

How to choose the slot size?

Energy efficiency model with:

- 2000 devices
- $d = 20$ ppm.
- $\nu = 11$ ms.
- $ToA_{\max} = 389.376$ ms.
- $\delta_{\max} \in [2.56, 80]$ ms.

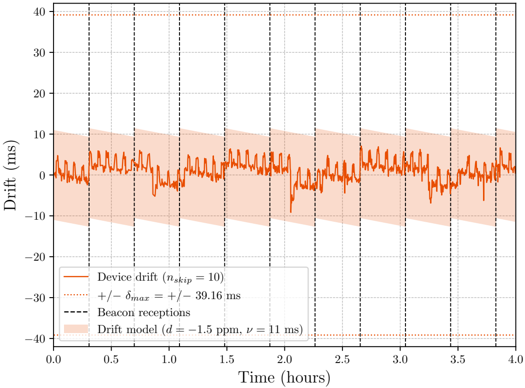


Proof of concept

Clock correction demonstration

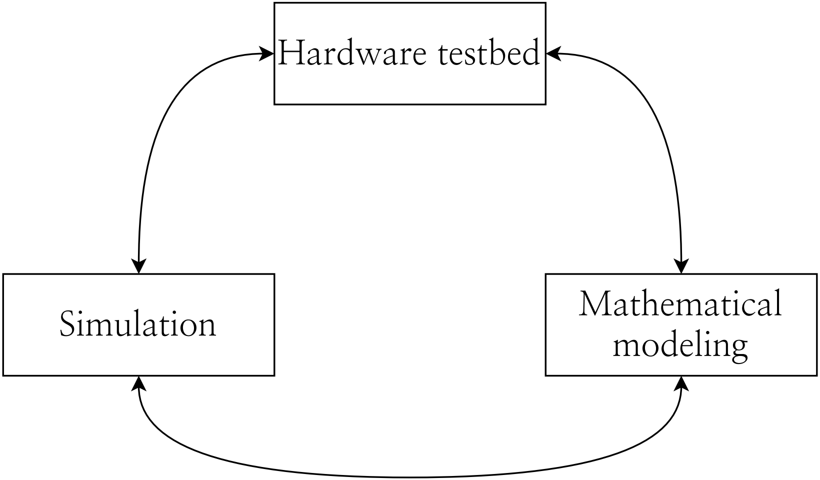
Measured on the testbed with:

- $\delta_{\max} = 39.16$
- $d = 20$ ppm. (worst-case)
- $d = -1.5$ ppm. (observed)
- $\nu = 11$ ms.



Conclusion

Conclusion



References

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References II

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Thank you very much!