SF-DS: A Slot-Free Decoding Scheme for Collided LoRa Transmissions

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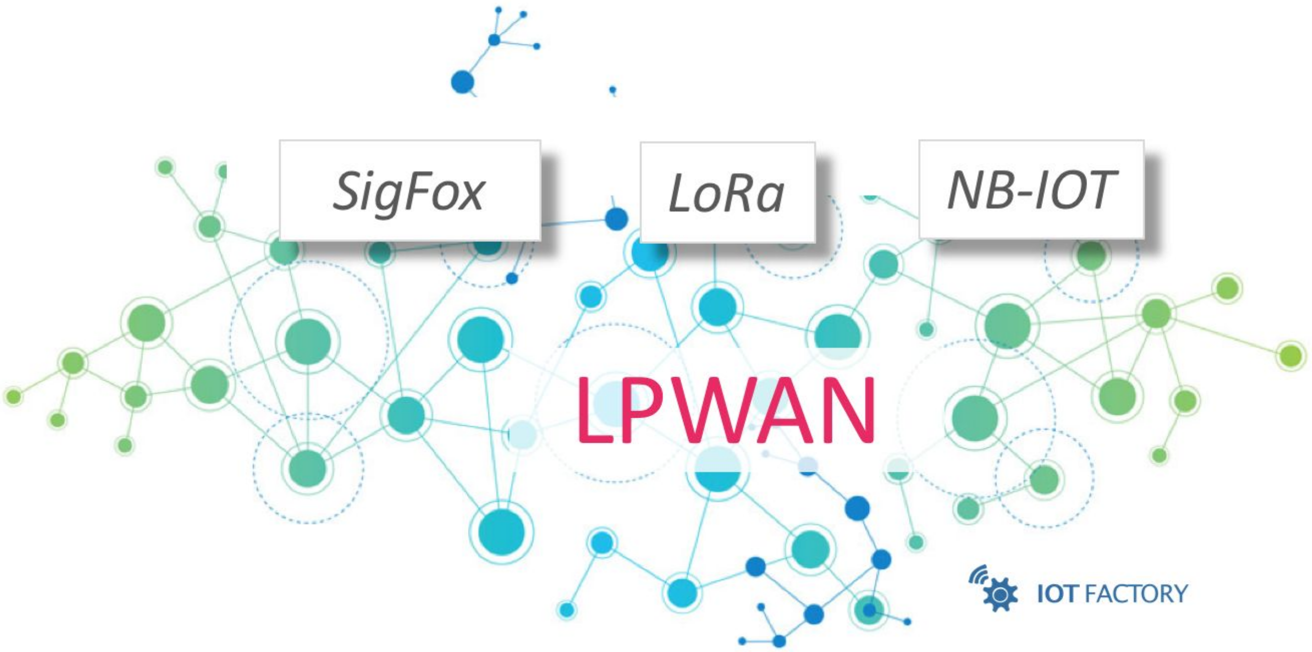
LIMOS

Outline

1. LoRa and LoRaWAN
2. Collided LoRa Transmission
    a. Collisions in LoRa network
    b. Power-based Decoding Algorithms
    c. Time-based Decoding Algorithms
3. SF-DS
4. Perspectives and conclusions

LoRa and LoRaWAN

LoRa in LPWAN



LPWAN: Low Power Wireless Area Network

Long range:

10 km and more

Battery lifetime:

up to 10 years

Data rates:

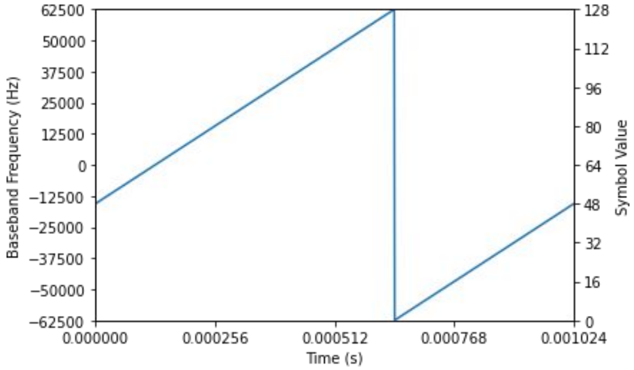
0.3-5.5kbps

LoRa technique

Physical layer - Chirp Spread Spectrum

LoRa uses a linear Chirp: a linear frequency sweep over a given bandwidth (BW).

The initial frequency of a Chirp is shifted to encode the symbols:



Symbol value:

2^{SF}, Spreading Factor (SF)

Symbol Duration:

$SD = 2^{SF} / BW$

LoRa demodulation:

- synchronization on each symbol;
- multiplication by a downchirp;
- FFT and find the argmax of the strongest peak.

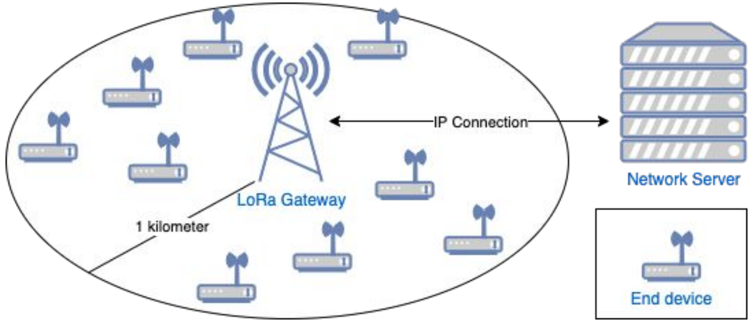
LoRaWAN

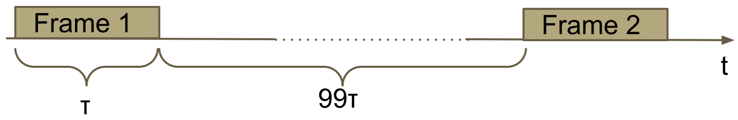
MAC layer protocol based on LoRa.

ALOHA random access for uplink (from node to gateway). Opening two short listening windows for downlink (from gateway to node).

Operating at ISM band, in EU868:

- Data Rate (DR) from 0 to 5;
- Spreading Factor (SF) from 12 to 7;
- Coding Rate (CR) from 1 to 4 (redundancy);
- 1% duty cycle (or 10%).

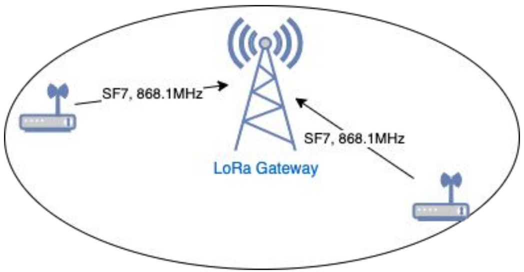




Collided LoRa Transmission

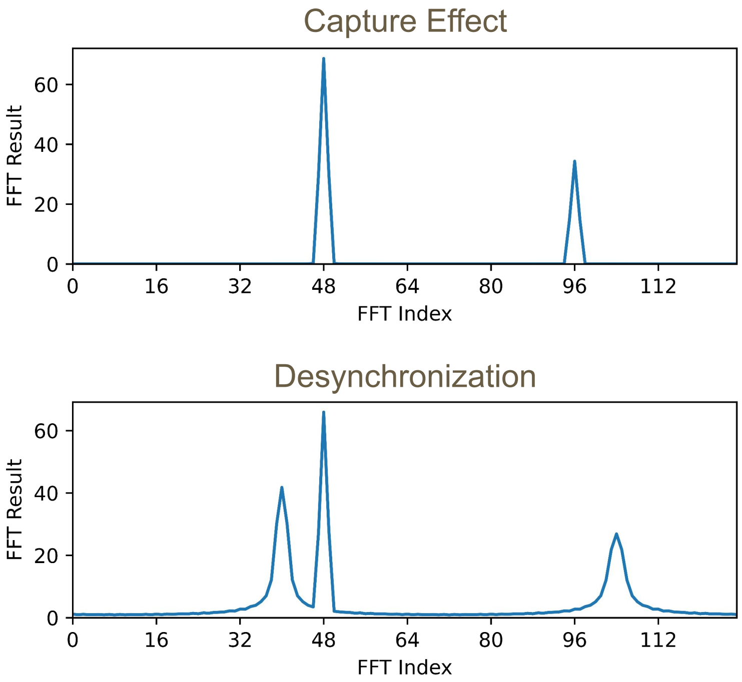
Collisions in LoRa network

Collisions in LoRa: simultaneous frames on the same channel, with the same SF.



Impacts of collisions in LoRa/LoRaWAN: worse throughput, higher delay and higher power consumption.

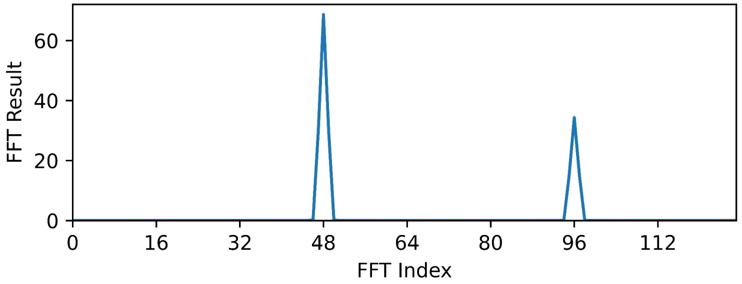
Resistance to the collision: capture effect and desynchronization.



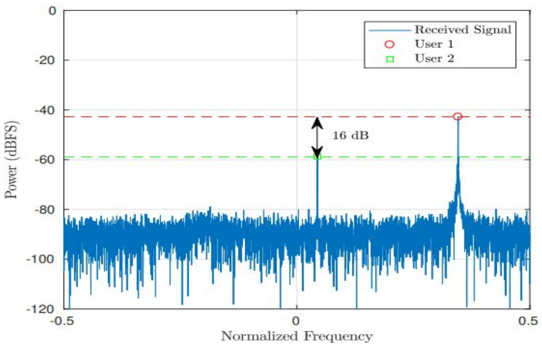
Power-based Decoding Algorithms

Use the relative power level to distinguish the frames in collision:

- Frame 1: 48
- Frame 2: 96



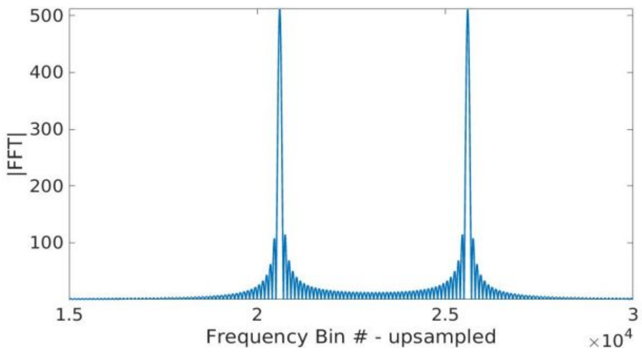
Successive interference cancellation (SIC): reconstructing and removing the captured signal. Requires a difference of power[1] varying from 6 dB for SF7 to 20 dB for SF12.



[1] B. Laporte-Fauret, M. A. Ben Temim, G. Ferre, D. Dallet, B. Minger, and L. Fuche. An Enhanced LoRa-Like Receiver for the Simultaneous Reception of Two Interfering Signals. In Proceedings of Annual International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC), September 2019.

Time-based Decoding Algorithms

CHOIR[2]: separation based on hardware frequency offsets.



FTrack[3]: sliding FFT window over each symbol to distinguish the symbol edge.

SCLoRa[4]: several sliding FFT windows over each symbol, to extract features for symbol classification (SC).

GS-MAC[5]: Slotted MAC protocol with several sub-slots.

[2] R. Eletreby, D. Zhang, S. Kumar, and O. Yagan. Empowering Low-Power Wide Area Networks in Urban Settings. In Proceedings of the Conference of the ACM Special Interest Group on Data Communication, SIGCOMM ’17, August 2017.
[3] X. Xia, Y. Zheng, and T. Gu. FTrack: Parallel Decoding for LoRa Transmissions. In Proceedings of the ACM 17th Conference on Embedded Networked Sensor Systems, New York, November 2019.
[4] B. Hu, Z. Yin, S. Wang, Z. Xu, and T. He. SCLoRa: Leveraging Multi-Dimensionality in Decoding Collided LoRa Transmissions. In Proceedings of the IEEE 28th International Conference on Network Protocols (ICNP), 2020.
[5] N. El Rachkidy, A. Guitton, and M. Kaneko. Generalized Slotted MAC Protocol Exploiting LoRa Signal Collisions. In Proceedings of the IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC), September 2020.

SF-DS

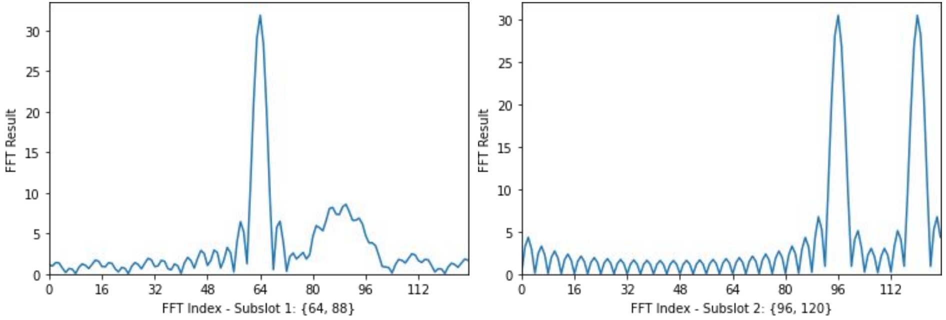
Removing synchronization

In SF-DS, the receiver constantly checks for preambles:

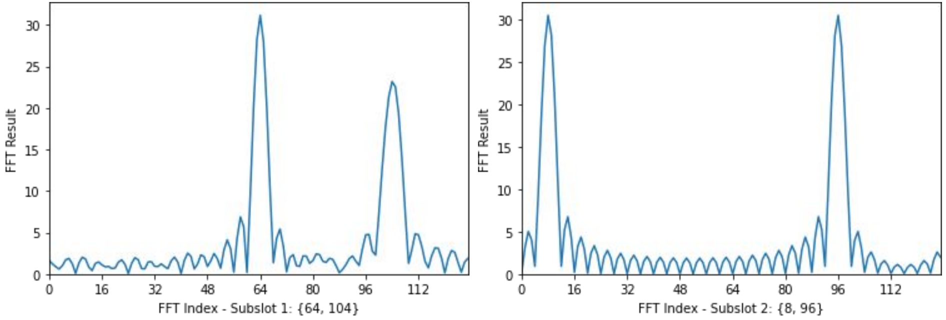
- The first detected preamble becomes the reference preamble, and enables the receiver to be synchronized;
- When new preambles are detected, the receiver stores the relative delay.

The following frames are allocated to the nearest subslot (rounding rule).

Two frames allocated to subslot 1 and subslot 2



Two frames allocated to subslot 1

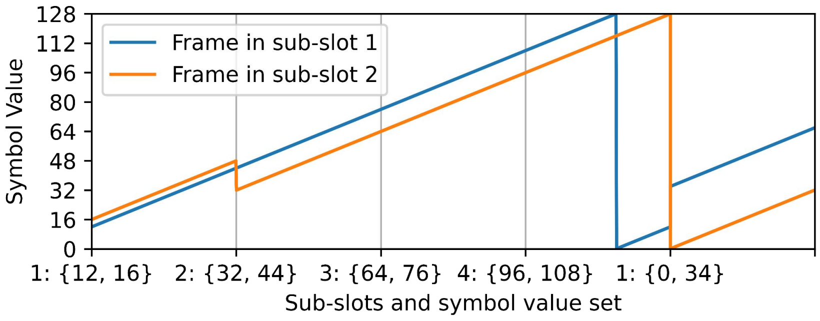


Core decoding scheme

Steps:

- Dividing each SD into x virtual subslots;
- Multiplying the samples in each subslot by downchirp;
- Performing FFT in each subslot to obtain the constant frequency components;
- Intersecting the set of frequencies to find the new arriving symbols.

Most frames can be decoded in different sub-slots.



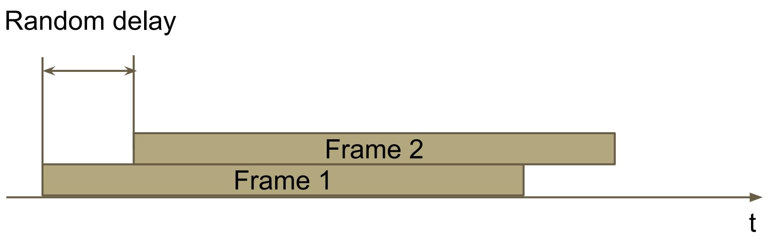
Example:
Subslot 1/4: {12, 16}   Subslot 2/4: {32, 44}
Expected Subslot 1/4: {32 - 32 = 0, 44 - 32 = 12}

By intersecting, only 12 remaining:
{12, 16} ∩ {0, 12} = {12}

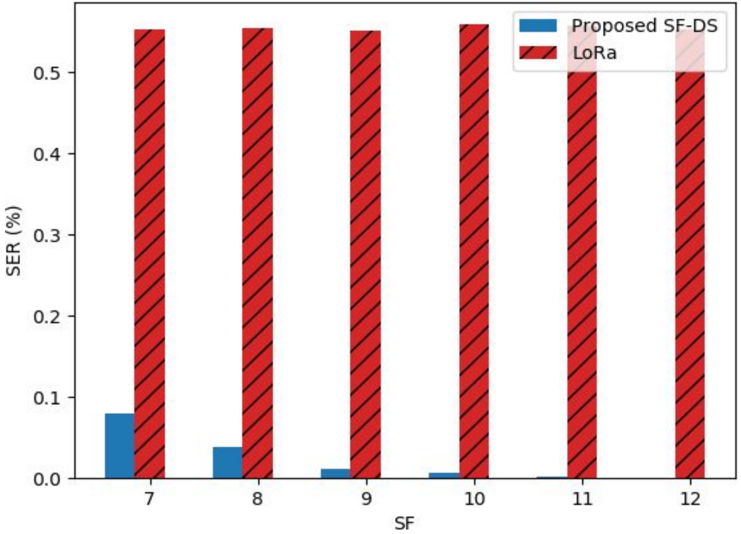
Simulation - simple scenario

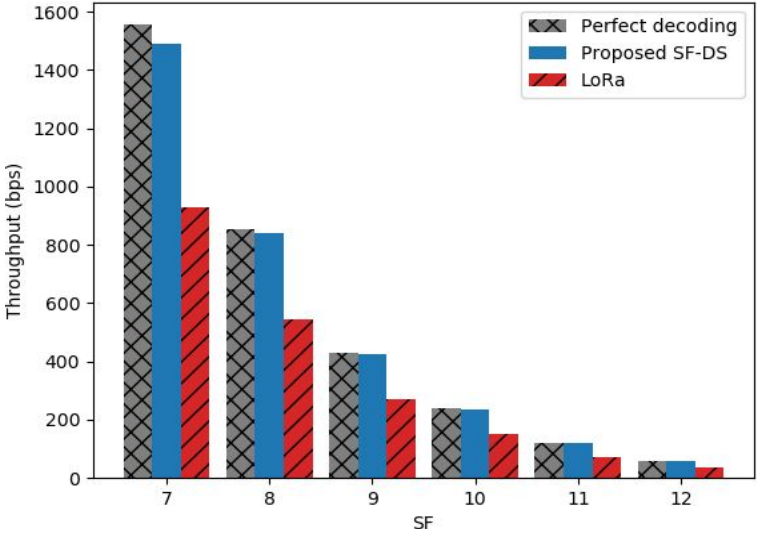
Only two colliding frames with similar power: the second frame starts with a random delay between 0 and the duration of the first frame.

We compare the **Symbol Error Rate (SER)** and the **throughput**.



Simulation result - simple scenario





LoRa: unable to decode the symbols of the second frames.

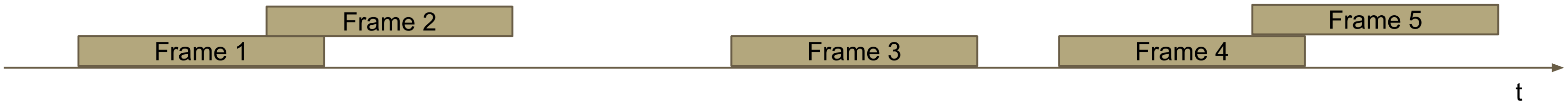
SF-DS: symbol errors arise only when there are two superposed symbols with similar values, e.g. 48 and 49.

Simulation - complex scenario

Configurations:

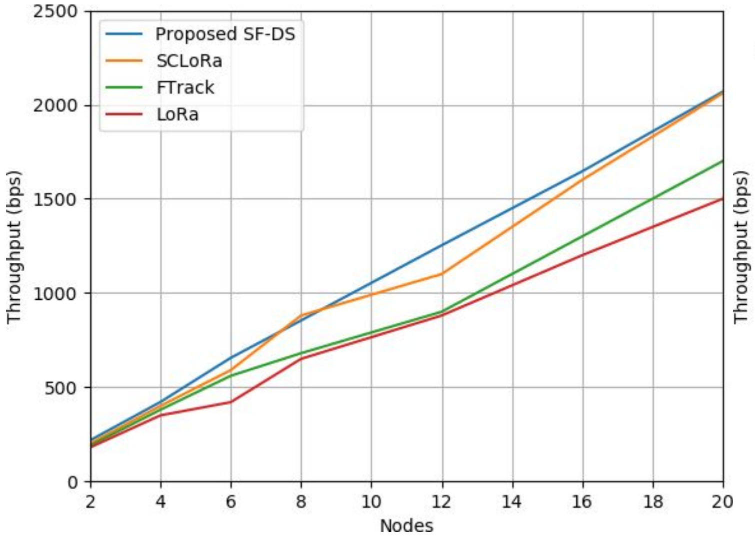
- Each node sends frames with an interval varying between 1000 ms and 2200 ms
- No duty-cycle limitations

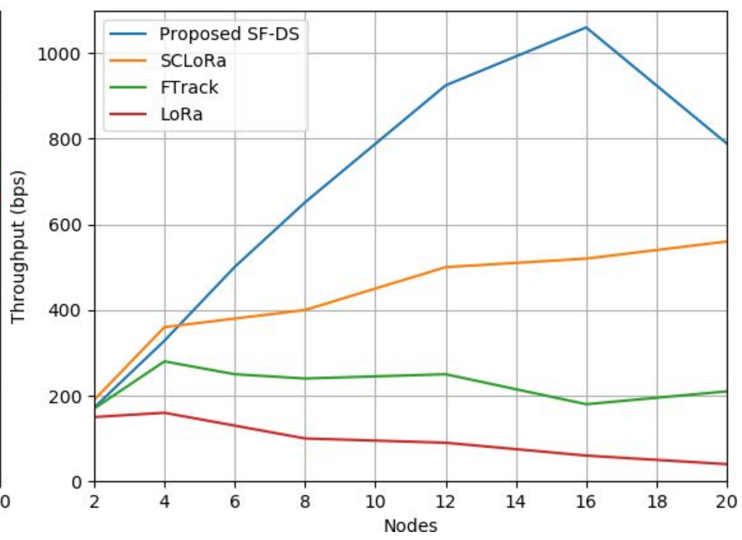
SF	Duration	Collision
8	103 ms	less
12	1480 ms	more



Simulation result - complex scenario

SF 8





SF 12

SF 8: the performance of SF-DS is similar to the one of SCLoRa (network not saturated).

SF 12: the best gain is about 103% at 16 nodes to the state-of-the-art SCLoRa.

Perspectives and conclusions

Our contributions:

1. No synchronization requirement between the LoRaWAN nodes;
2. Usage of the virtual sub-slots to regroup and track desynchronized signals;
3. Taking account of ambiguous FFT peaks and using the LoRa channel coding to resolve them.

In our future work, we plan to improve our algorithm to correct additional errors caused by the noise and carrier frequency offset (CFO).

Thanks for you attention!