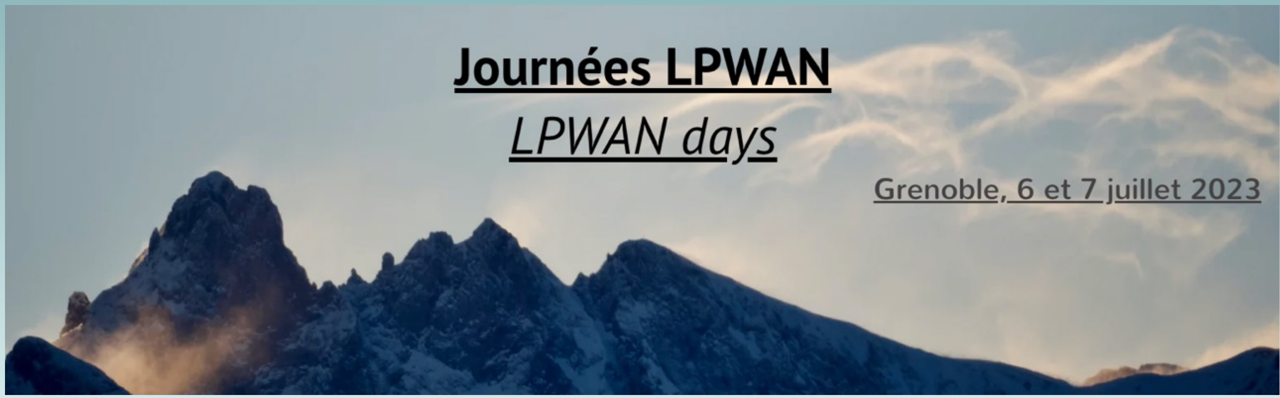
Collision Avoidance in Dense LoRa Networks

Guillaume Gaillard and Congduc Pham



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Channel access in LoRa

- LoRa's channel access is basically an ALOHA system: vulnerable time is 2xT_{pkt}, max efficiency at about 18%
- Frequency, SF & BW diversity can increase network scalability
- LoRa packet reception can benefit from capture effect so performance can be higher
- Advanced techniques for interference cancellation can help
- Collision resolution approaches are also very promising

Capture Effect
Interference Cancellation
Collision Resolution

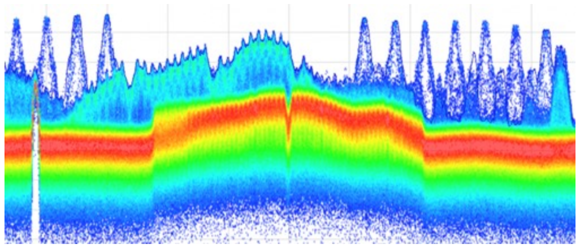
Dense LoRa networks

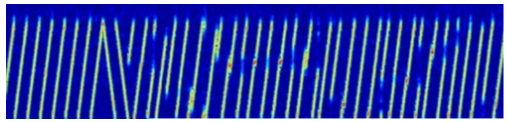
- More LoRa deployments mean more devices
- More devices mean more traffic, more interferences & collisions!
- 1 msg/20min = 3 msg/h. For 1000 devices = almost 1 msg/s!
- More gateways increases coverage & SF diversity on same frequency channel BUT there are still many devices on same collision domain!

Capture Effect
Interference Cancellation
Collision Resolution

?

- Advanced mechanism such as CE, IR & CR have limited benefits in dense environments





Capture Effect
Interference Cancellation
Collision Resolution

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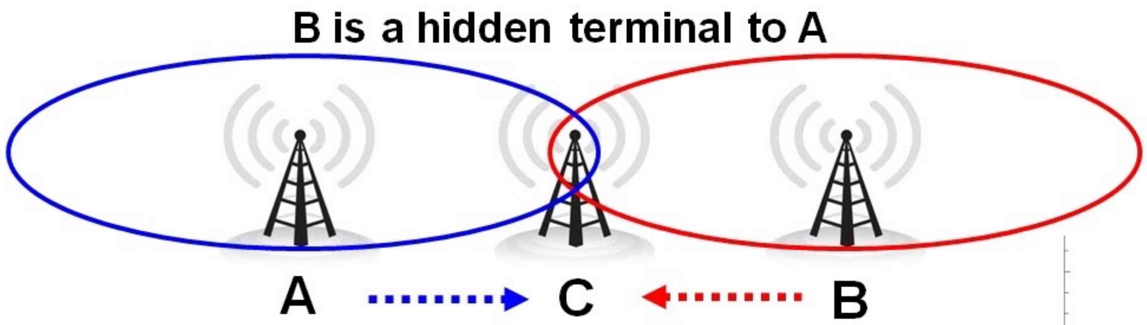
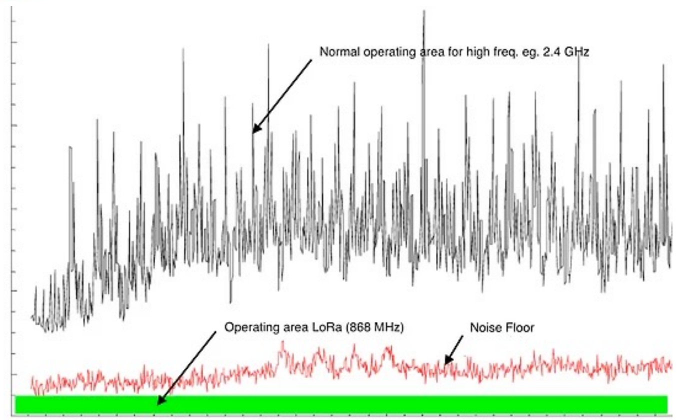
Collision Avoidance

- Prevent situation to become uncontrollable!
- **NEED** a reliable Clear Channel Assessment (CCA)
- Under fully reliable CCA, Collision Avoidance is optimal
- **BUT** reliable CCA is not easy thing: hidden terminal problem

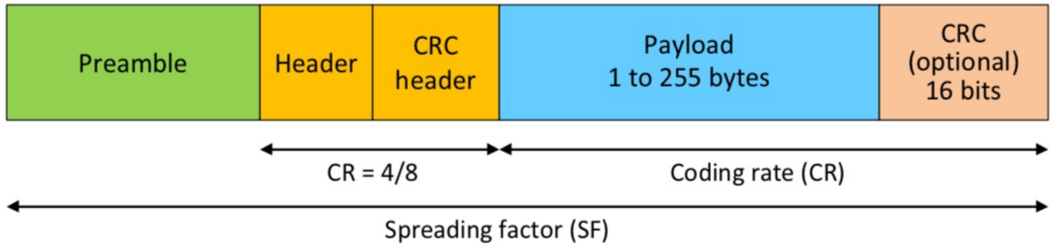


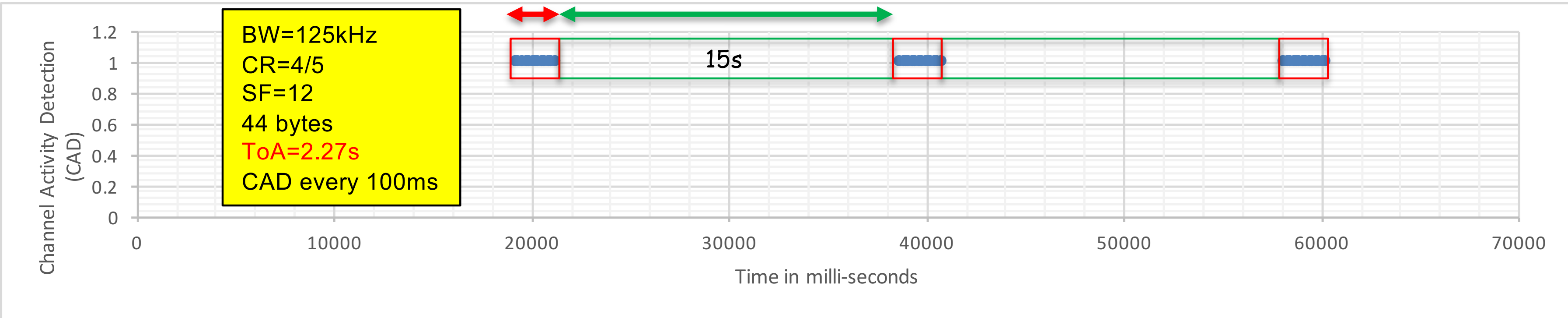
- For LoRa, it is even more difficult to detect transmission of a packet

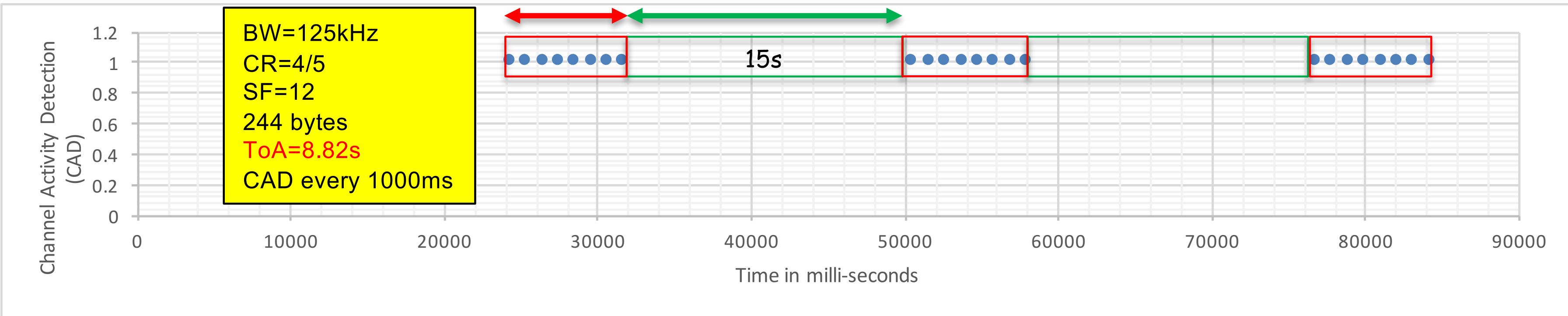


CCA with LoRa

- LoRa's Channel Activity Detection (CAD)
- Low overhead, low power

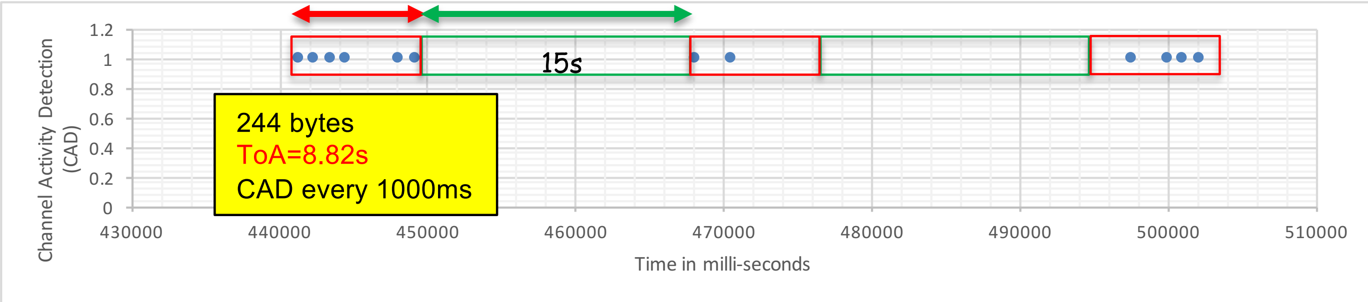




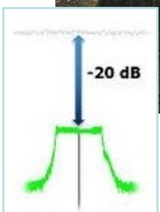


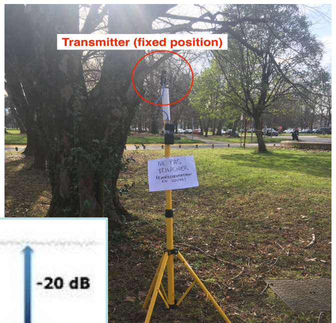
CAD reliability?

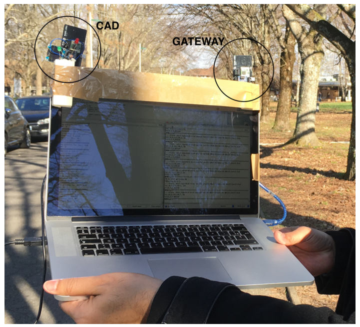
- CAD reliability decreases as distance increases
  - A CAD returning false does not mean that there is no activity!
  - Similar to <u>hidden terminal issue</u>

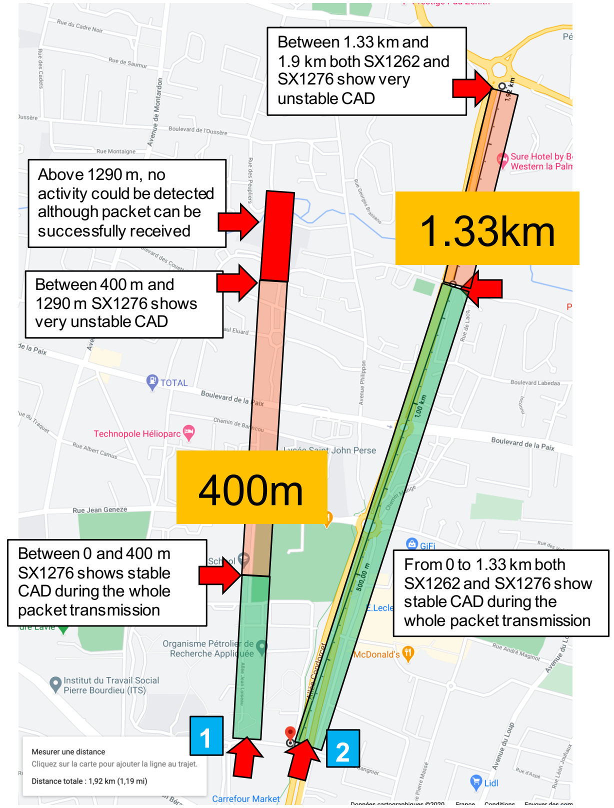


- CAD sensitivity not as good as full reception sensitivity!
- CAD returns "no activity" but packet can be received!
- Because LoRa can receive below noise flow!









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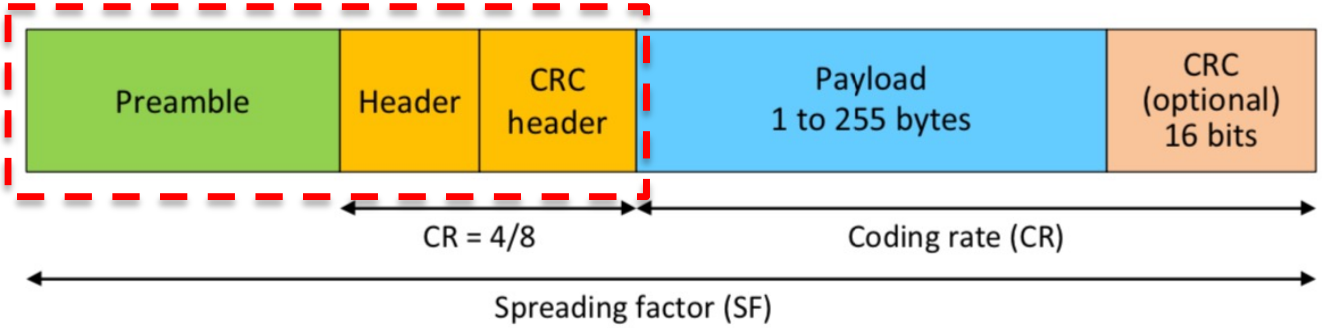
CCA without CAD?

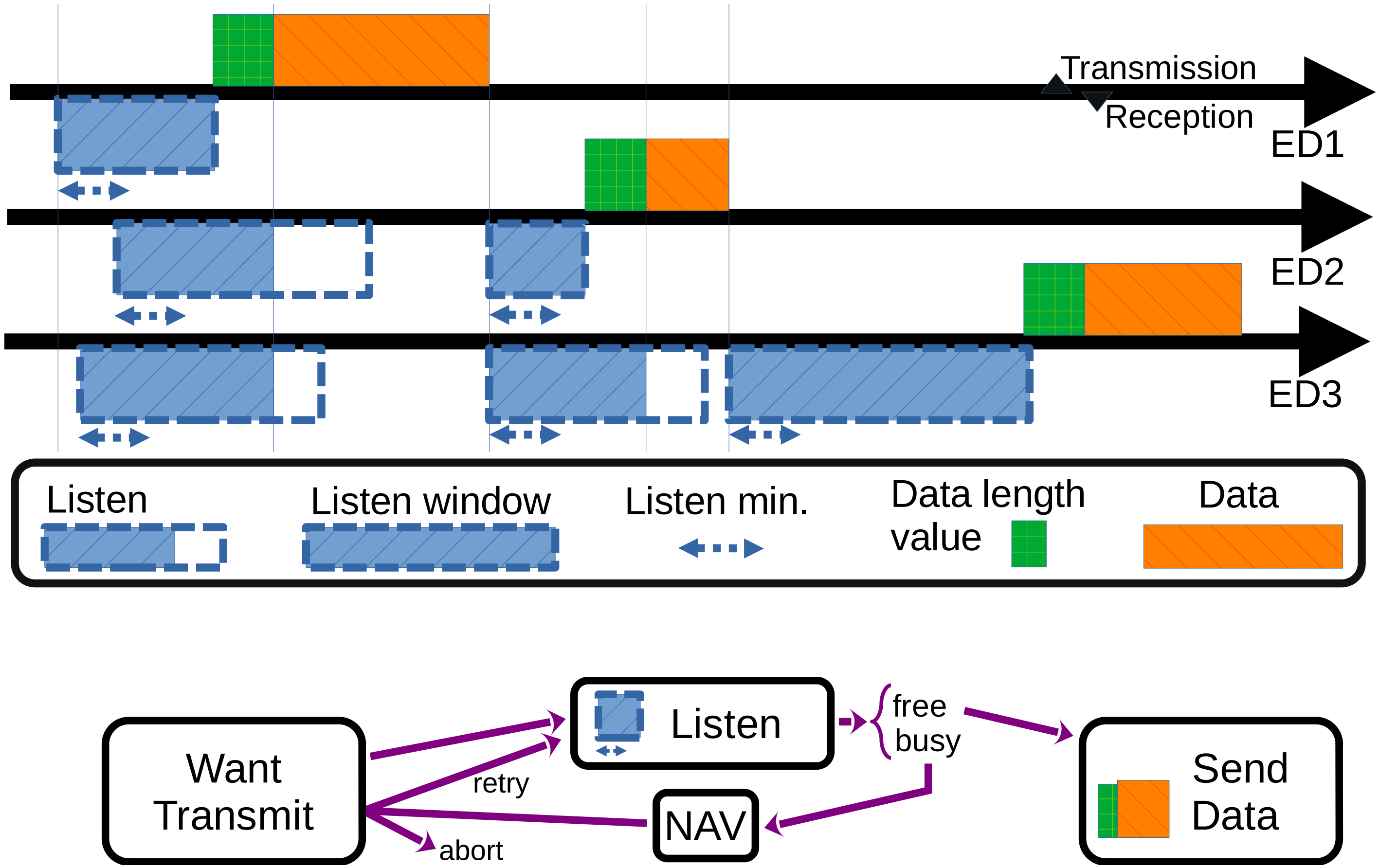
- CAD sensitivity not as good as full reception sensitivity!
- So, let's use the LoRa radio in packet reception mode!

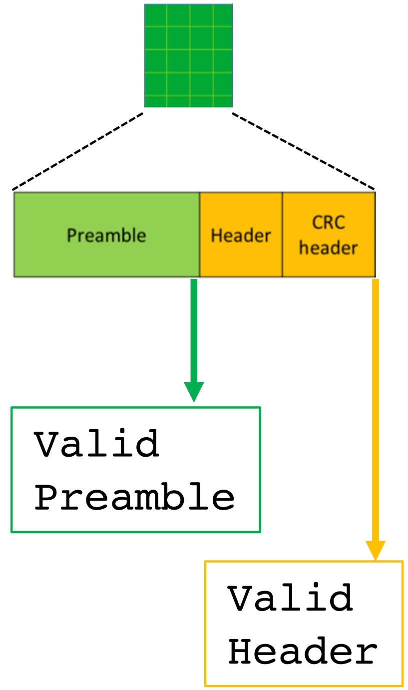


- Once synchronization on Preamble is realized, the packet header with the Payload length can be received
- Then, transmission can be deferred by the corresponding time-on-air duration

CANL approach

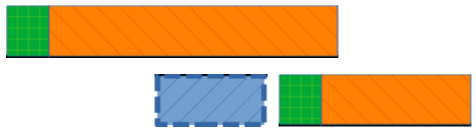
- CANL LoRa: Collision Avoidance by Neighbor Listening





Not perfect neither!

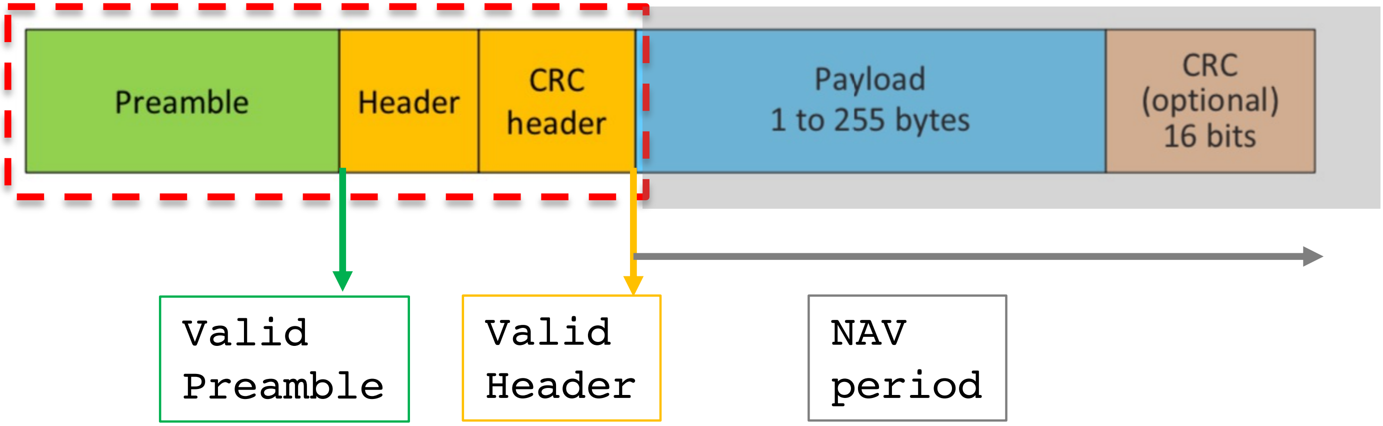
- Higher energy consumption due to full reception mode
  - But we do not need to receive the entire packet
- Collisions & interferences can dramatically impair the detection of Preamble -> transmission cannot be identified as packet
  - Maybe a simplified Collision Resolution approach can help detecting only preamble+header?
- Low probability to detect a long packet



  - Split a long packet into 2 smaller packets (tradeoff w.r.t. overhead)
- Hidden Terminal problem is still an issue
  - Not really possible to solve this issue as downlink (e.g. CTS) from gateway is not tractable due to duty cycle
- Device-Device transmission are usually of "lower quality"
  - Lower cost hardware leading to lower sensitivity
  - Device & antenna placement, higher attenuation, bad Fresnel zone,…

Abort reception as soon as possible?

- It is not necessary, and not advised, to receive the full packet!
- We didn't succeed in reading the payload size from the header



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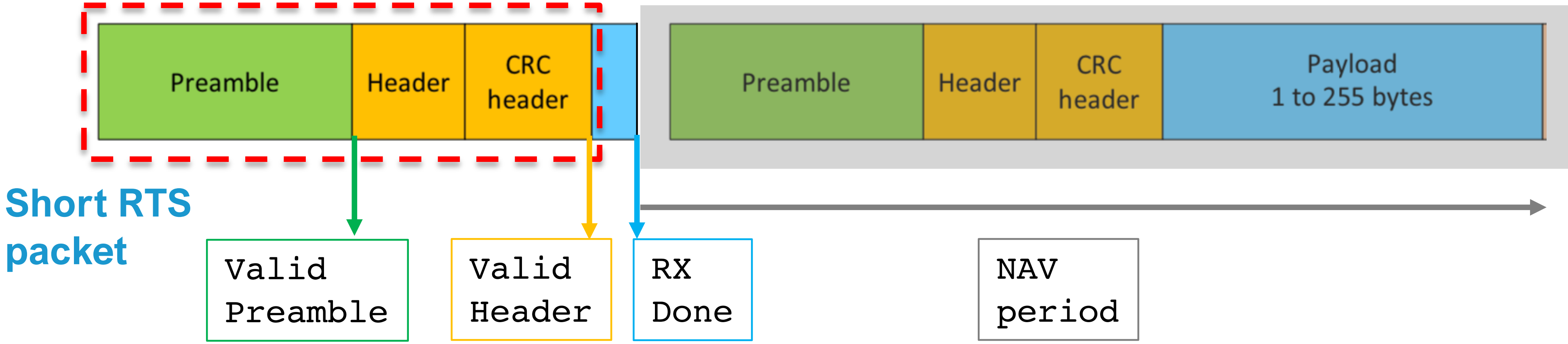


- Implementation solution: transmit a short "RTS" packet
  - 1 byte of payload in RTS packet indicates the size of the next DATA
  - Only a few bytes needs to be received then device can go to NAV
- Referred to as CANL-RTS

Simulation

- Based on LoRaSim (Python)
- Improved with many advanced features
  - Higher reproducibility (topology is generated separately)
  - Capture Effect with more than 2 transmitters
  - IDEAL and CAD+Backoff in addition to ALOHA for comparison
  - More accurate energy model
  - More accurate channel modelisation (noise, Rayleigh)
  - End-Device-End-Device communications (ED-ED)
  - Specific sensibility, path-loss and collision model for ED-ED
- https://github.com/Guillaumegaillard/CANL-LoRa
- G. Gaillard and C. Pham. CANL LoRa: Collision Avoidance by Neighbor Listening for Dense LoRa Networks. *In ISCC 2023, July 2023*.

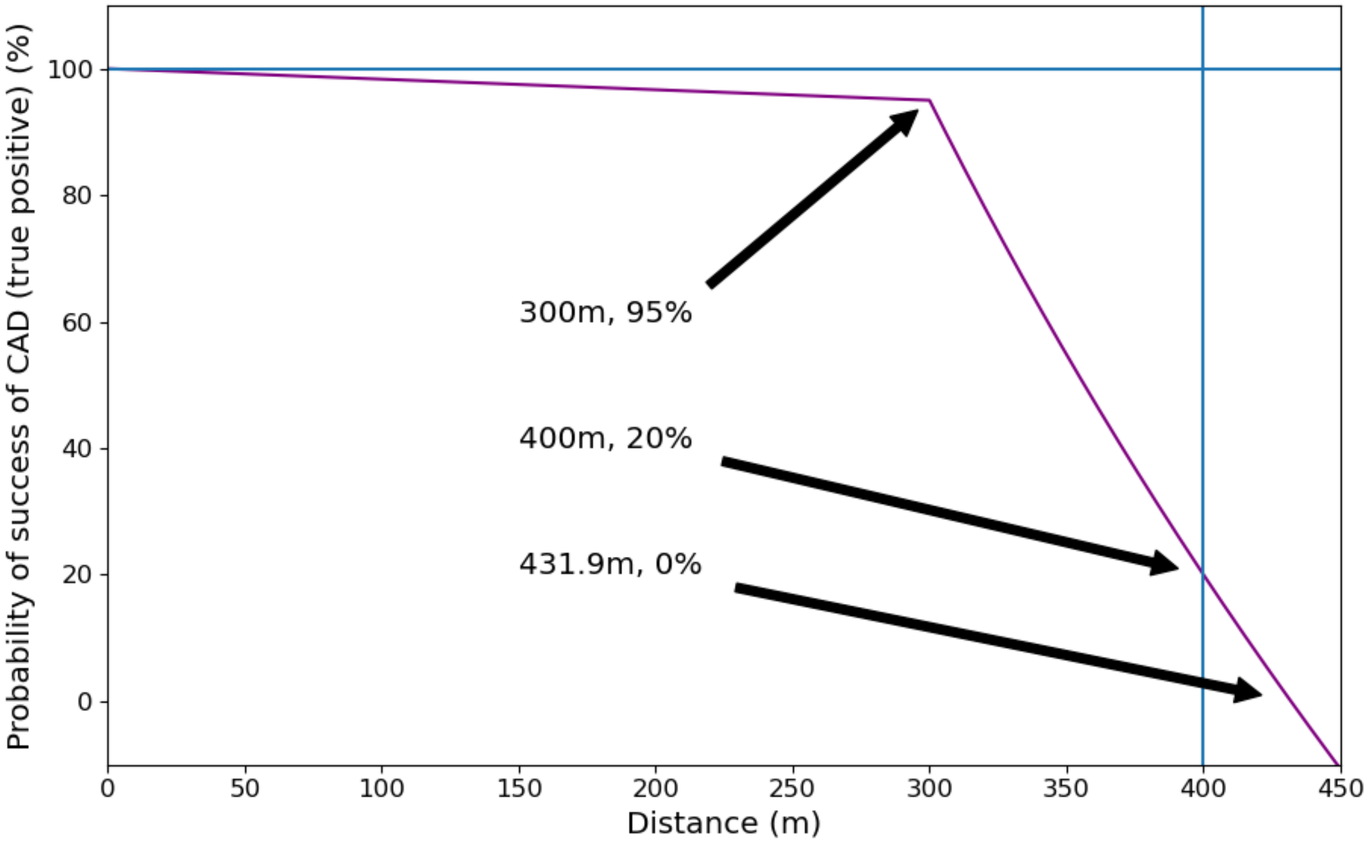
Simulation parameters

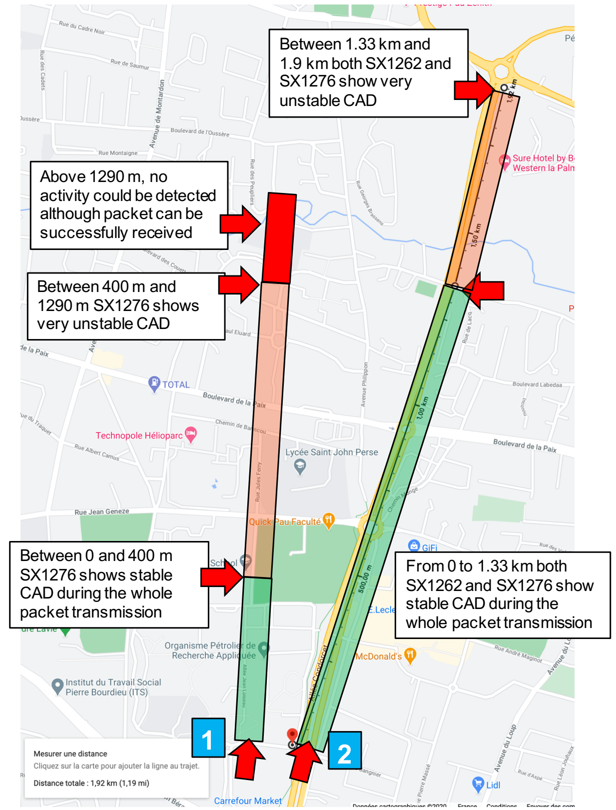
$$P^{dB}_{RX} = P^{dB}_{TX} + G - Lpld0 - \gamma 10 log_{10}(\frac{d}{d0}) - n - r$$

Setting Category:	Description:		
Reference traffic	exponential distribution, no buffering	mean inter frame generation time:	3200 s each ED, 6.4 s network-wise
Reference payload sizes	normal distribution, clipped into [0,max]	mean 60 B, std. dev. 10 B, max. 150 B	in short: (60 B, 10 B, [0 B, 150 B])
Reference ED distribution	uniform 2D locations, spread on disk around GW	maximum radius: 2500 m	minimum inter ED distance: 40 cm
LoRa PHY parameters	SF12, BW125, CR4/5, frequency 868 MHz	data with explicit header	preamble duration: 12.25 symbols
Times on air	symbol: 32.8 ms; preamble: 401 ms	RTS: 827 ms; data (10 B): 991 ms	data 60 B: 2630 ms; 150 B: 5579 ms
ED log-distance model	Tx: 14 dBm; PLE: 3; Lpl-d0: 83 at 40 m; Gains: 0 dB	normal noise: (3 dB, 3 dB, [0 dB, 6 dB])	unbiased Rayleigh fading average: 4 dB
GW log-distance model	PLE: 2.95; Lpl-d0: 83 at 40 m; Gains: 1.5 dB	normal noise: (3 dB, 3 dB, [0 dB, 6 dB])	unbiased Rayleigh fading average: 4 dB
Receiver sensitivity	ED: -133.25 dBm, GW: -138 dBm	preamble detection:	minimum 3 symbols to detect a preamble
Capture power threshold	linear w.r.t. the h channel competitors	margin over other frames:	$\mathcal{M}_h = 6 + 2 \times (h - 2)$ dB
ED energy consumption	voltage supply: 3.3 V	TX, RX current: 45 mA, 5.3 mA	power in CAD: 169.54 nAh [12], [19]
CANL listen parameters	Listen window: uniform size in [4,20] preambles	fair reduction factor $\mathcal{F}$, retries:	4 preambles/retry, maximum 5 times
CANL_RTS parameters	fixed length: 5 B (4 header, 1 data length)	with implicit LoRa PHY header	RTS only for data payloads $\geq$ 12 B
CAD parameters	CAD sampling duration:	4 active symbols (131 ms)	backoff and retry at most 5 times
CAD reliability model	uniform success probability w.r.t distance	0 m: 100%; linear, down to 300 m: 95%	then log. decrease, 400 m: 20%, 420 m: 0%
Backoff parameters	uniform; minimum duration: 1 preamble	initial value 2^3 preambles	maximum exponent: 6, i.e. 2^6 preambles

- Of course, it is still simulation model, but impacts are global allowing quite realistic comparisons

Model for CAD reliability

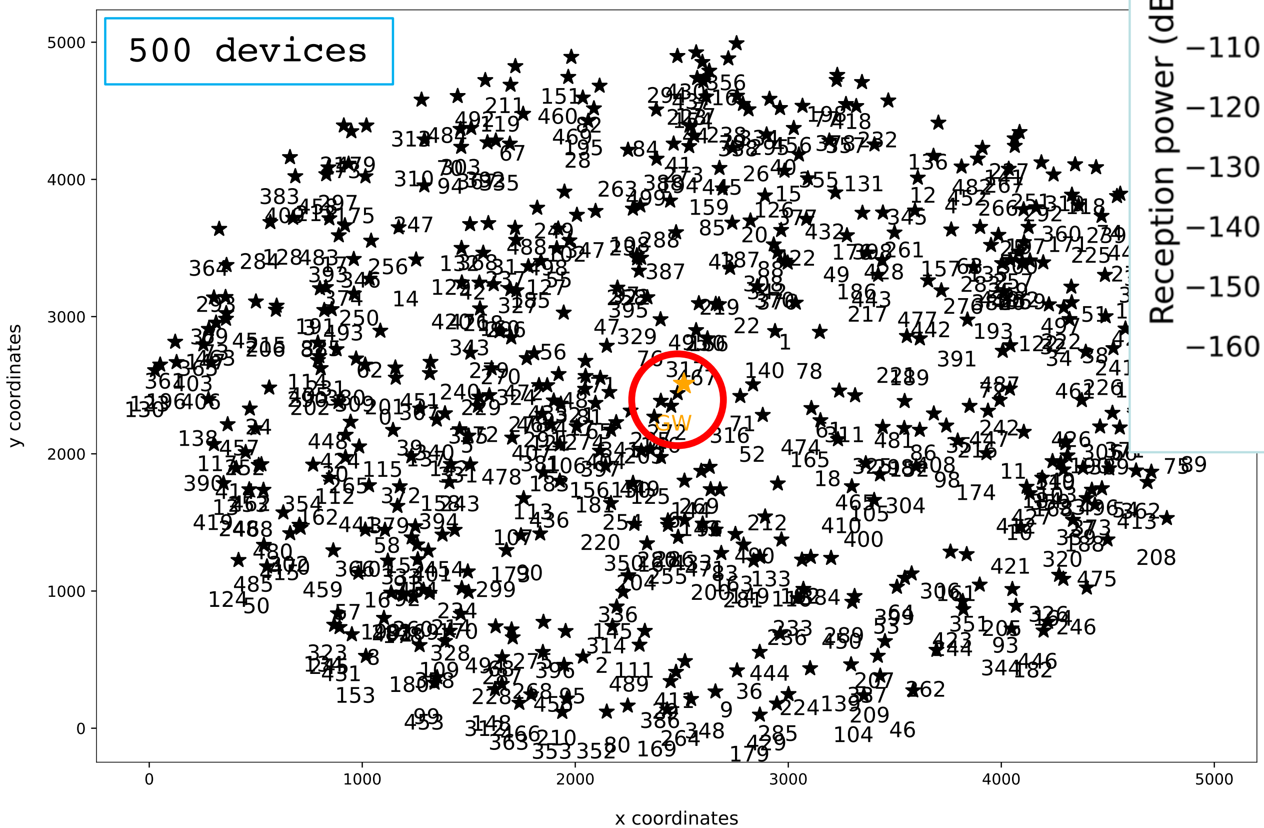


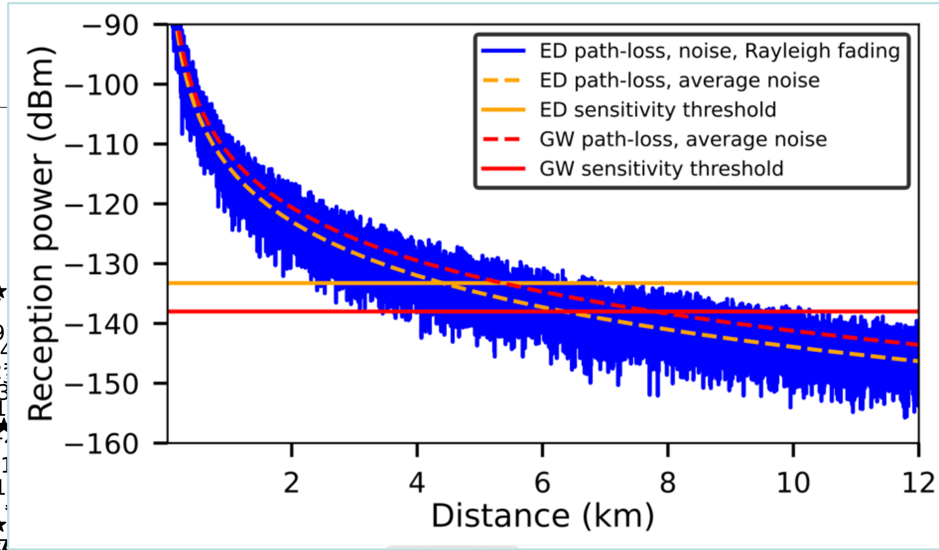


Topology

- 500 & 1000 devices, disk radius of 2.5km
- ED: 1 packet every 3200s

$$P_{RX}^{dB} = P_{TX}^{dB} + G - Lpld0 - \gamma 10log_{10}(\frac{d}{d0}) - n - r$$



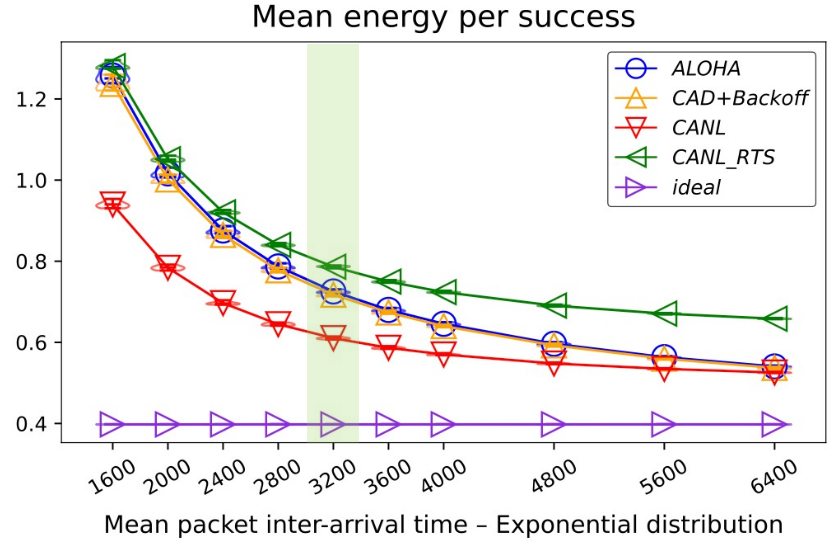


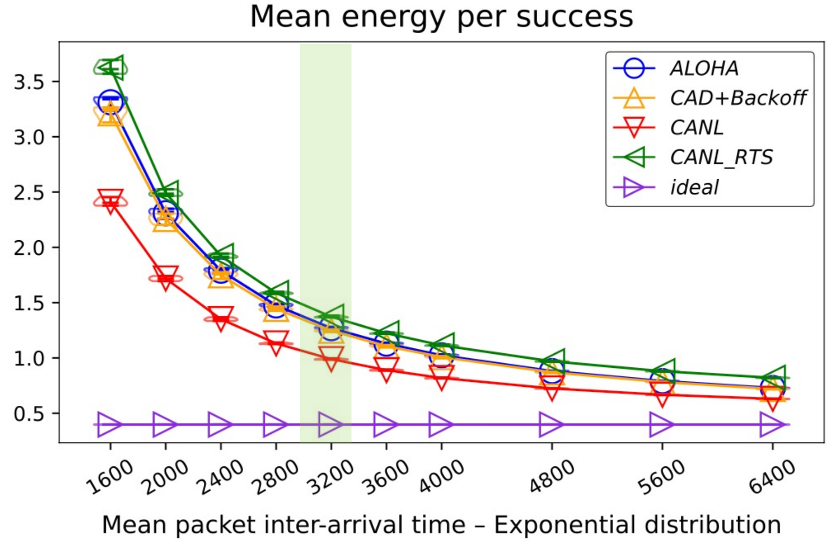
A GW receives around half the signals at a distance of 7.8 km whereas an ED hardly detects any signal after 6.5 km

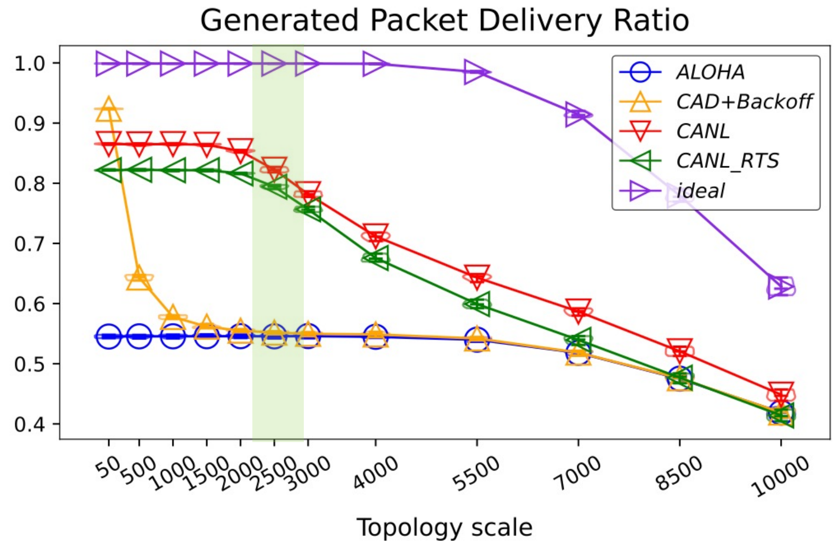
Main results

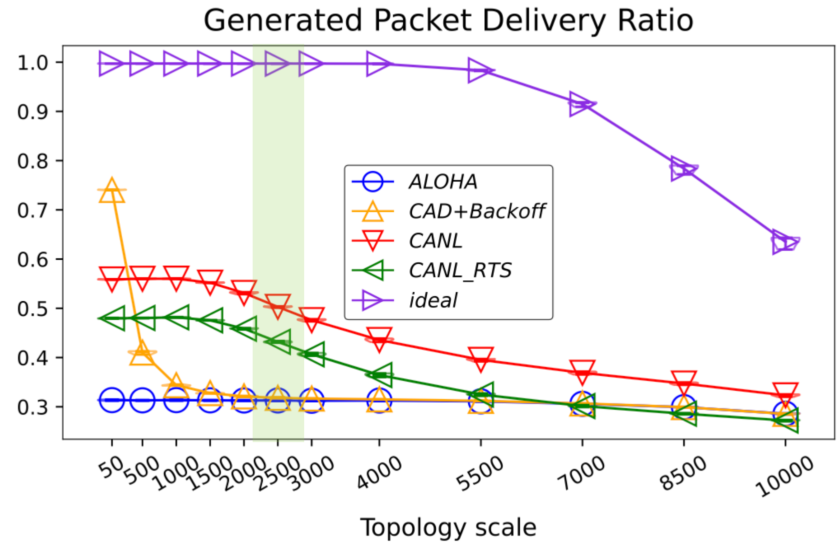
500 devices

1000 devices



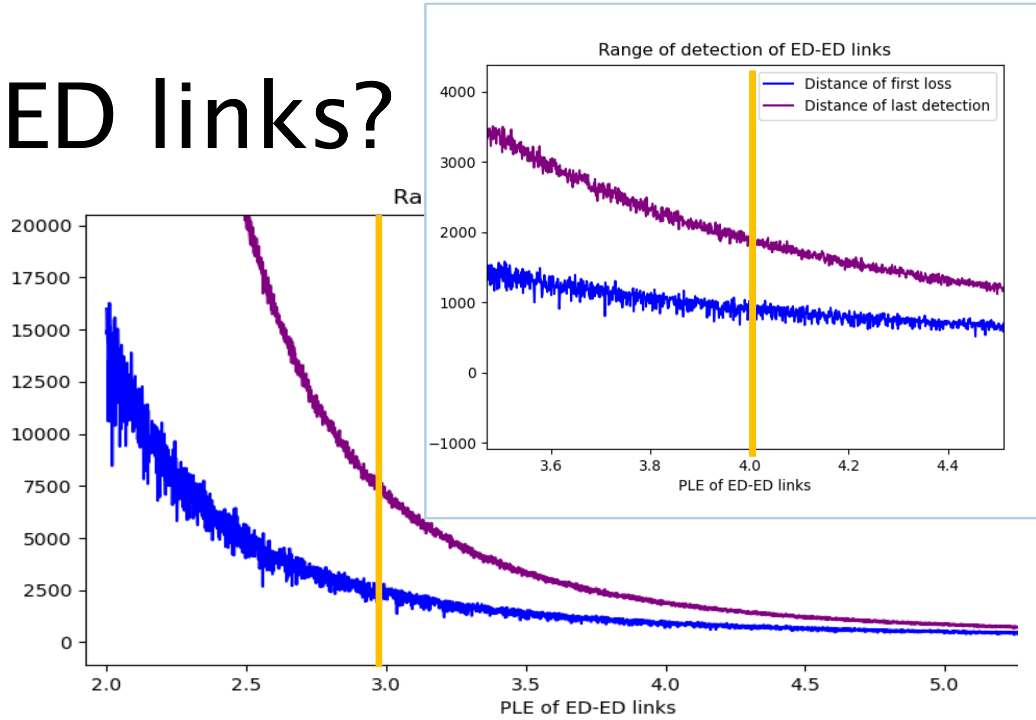


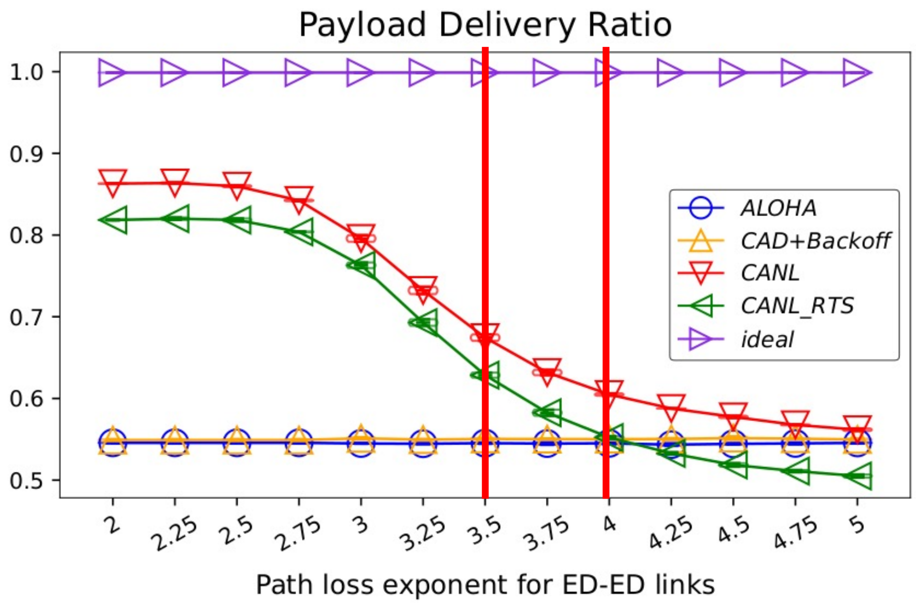


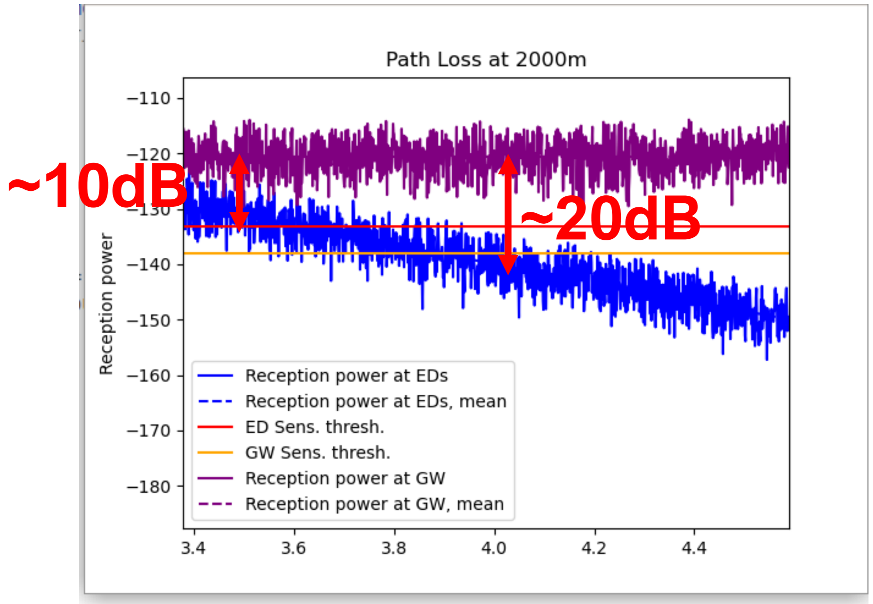


More realistic: ED-ED links?

- ED-ED links are usually of lower "quality"
- Increased PLE for ED-ED links







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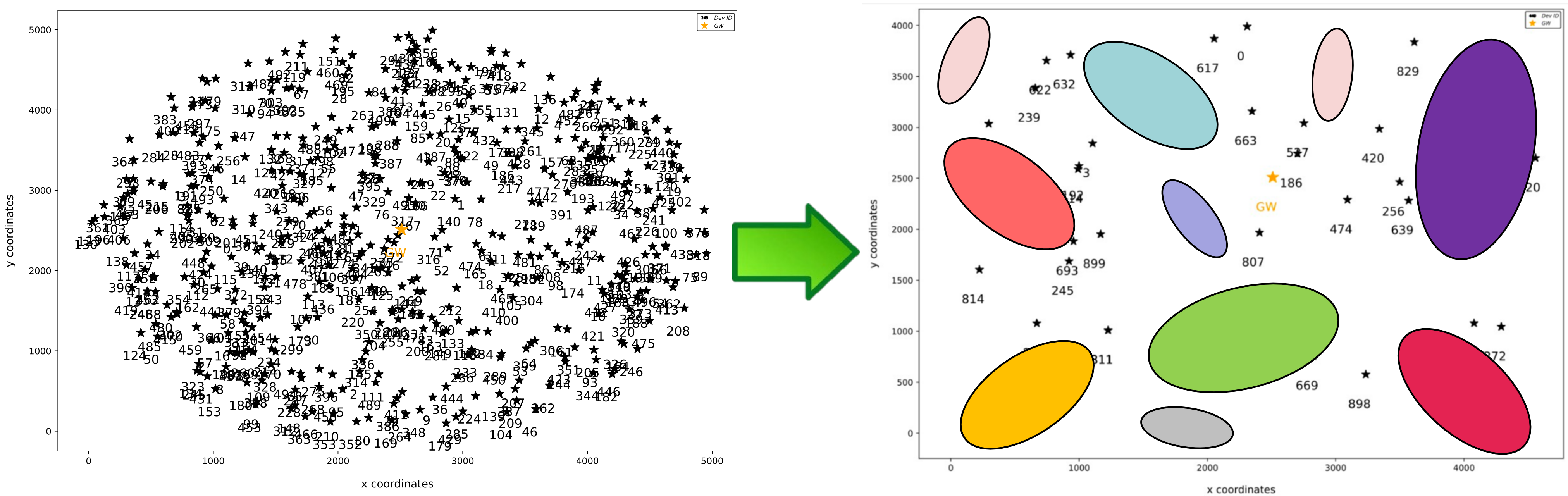
More realistic: better topologies?

- Uniform distribution may not be very realistic
- Uniform+Clustered distribution?
- This has an impact on CAD reliability and ED-ED links

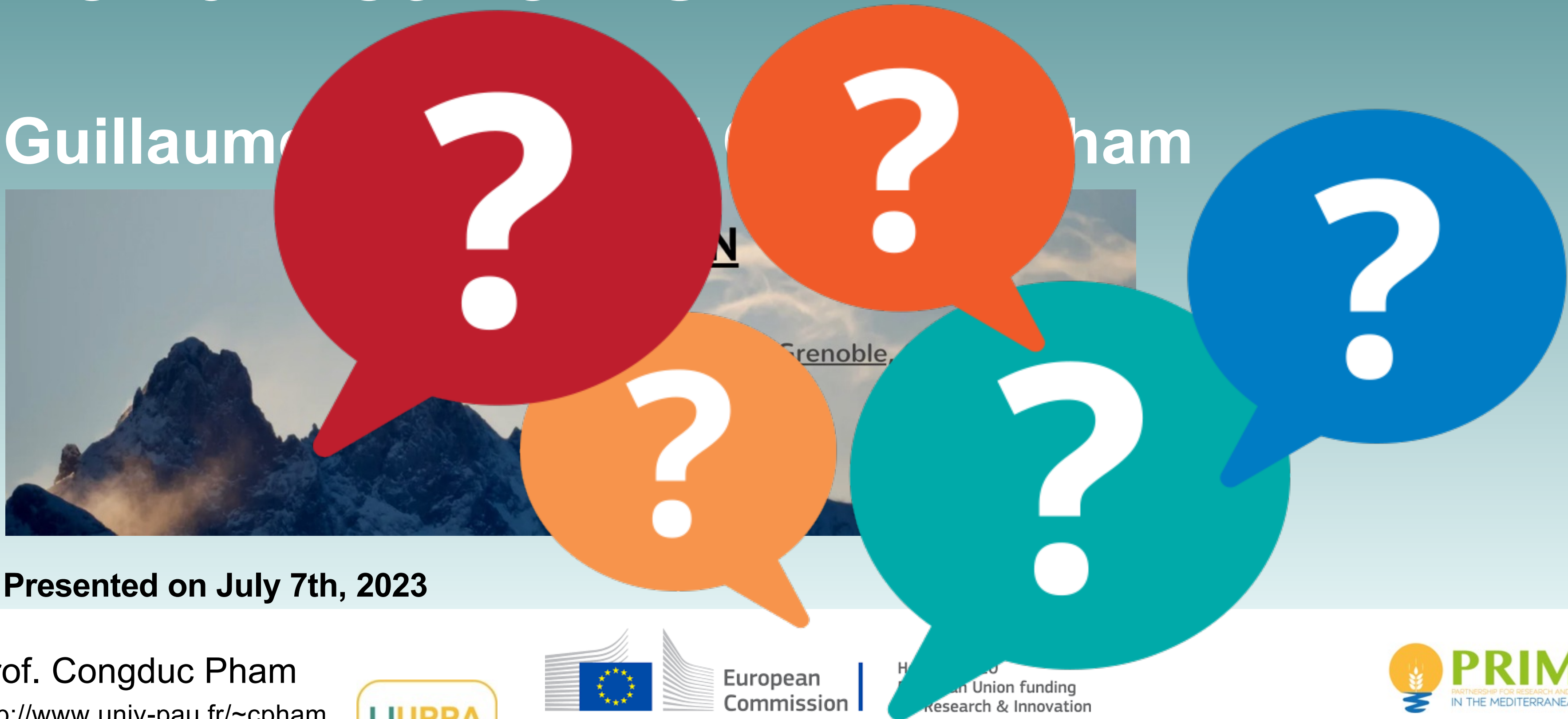


Conclusions & Future works

- Collision Avoidance is a preventive approach that should be considered!
- Using reception mode to detect on-going transmissions shows significant benefits
  - simplicity of implementation, readily deployable in LoRaWAN networks
  - Increased performances, smaller energy/success, …
- More realistic topologies such as cluster-based can be studied
- Take into account possible improvement thanks to Collision Resolution mechanisms
- See how some parameters (listening duration, …) could be determined based on traffic density
- Large-scale evaluation based on real implementation

Collision Avoidance in Dense LoRa Networks

Guillaum… ham



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