SF*l*x*M*: Flexible LoRa Modulations for Elastic Resource Allocation
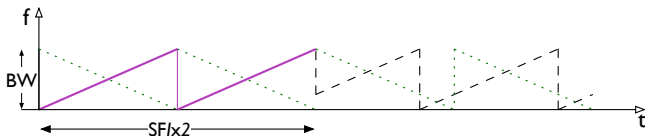
Martin **Heusse**[†], Ghislaine Maury[⋆], Christelle Caillouet[△†]
† Univ. Grenoble Alpes, LIG
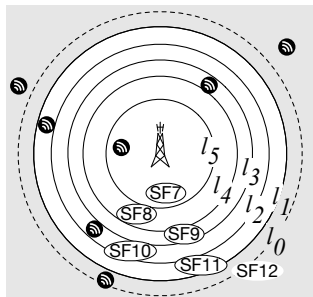⋆ Univ. Grenoble Alpes, CROMA
△ Université Côte d'Azur, I3S

Motivation

- The LoRa modulation offers quasi-orthogonal channels
  - ✓ SF12 mostly insensitive to lower SFs (23+ dB rejection)[1]
  - ✓ SF7 a little weaker in front of SF8, SF9…(8 to 9 dB rejection) etc.
    But SF7 nodes are near the GW…
- If all nodes are near the GW, SF8 to SF12 doubles (approx.) the capacity of **SF7 alone**;
- If the nodes are far from the GW, some SF values are unusable!
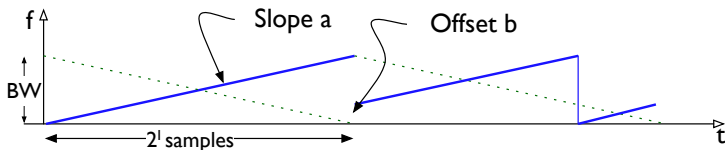- In all cases, the SF sensitivity steps are not generally aligned with traffic demand

What can we do?

- Use LR-FHSS?
- mioty?
- ⇒ Those come at a cost!
  (Software radio gateways)

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[1]Croce et al. « Impact of LoRa Imperfect Orthogonality: Analysis of Link-Level Performance »
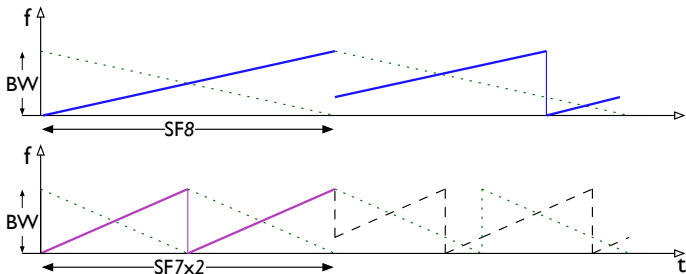
Quick tutorial on LoRa (de)modulation

1. $e^{2\pi j t [f_0 + (at+b) \bmod BW]} \times e^{-2\pi j t [f_0 + (at) \bmod BW]}$
   $= e^{2\pi j t [b \bmod BW]}$

   N.B. : $a = \frac{BW^2}{2^l} \rightarrow$ so it takes a time $\frac{2^l}{BW}$ to sweep BW

2. **Sample** at frequency BW (typically 125kHz) and use an **FFT** to find b

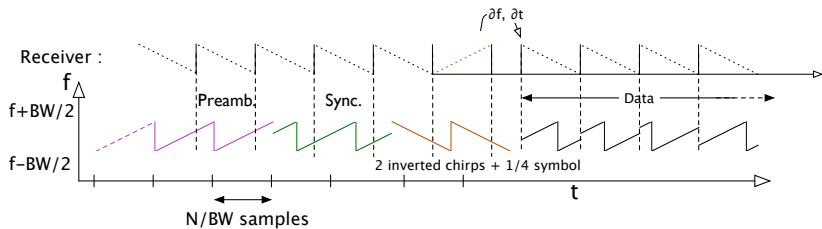3. That's it!

Let's build other modulations!
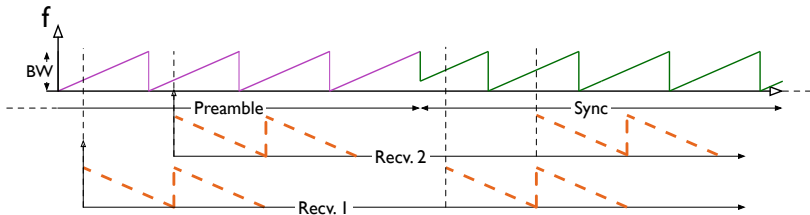# Concatenating *M* identical chirps

- 2 (ou 4, 8 …) assembled **identical** *chirps* correspond to $M = 2$ times (4 times) more time samples
- Equivalent to à SF$l + 1$ ($l + 2$…) ; same orthogonality characteristics…
- Demodulation using 2 (4…) inverted *chirps*…

Things are not this simple… (and this presentation is not over)

LoRa Synchronisation quick tutorial

There is an alignment problem!

- Which of the M=2 (or 4, 8…) chirps are we sync'ed with?
- We need to add an alignment preamble!

Alignment preamble of $2M - 1$ staggered *chirps*
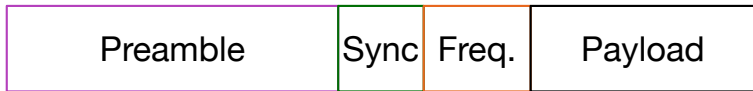… demodulated by M staggered chirps
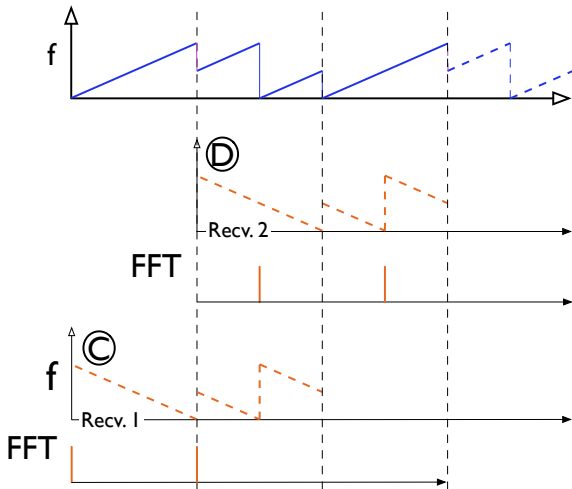
SF*l*x*M* Frame format

LoRa:

	10		2	2.25	
	Preamble		Sync	Freq.	Payload

SF*l*x*M:*

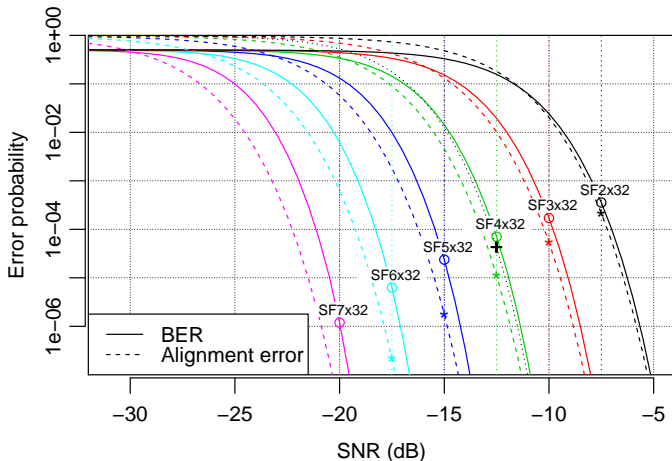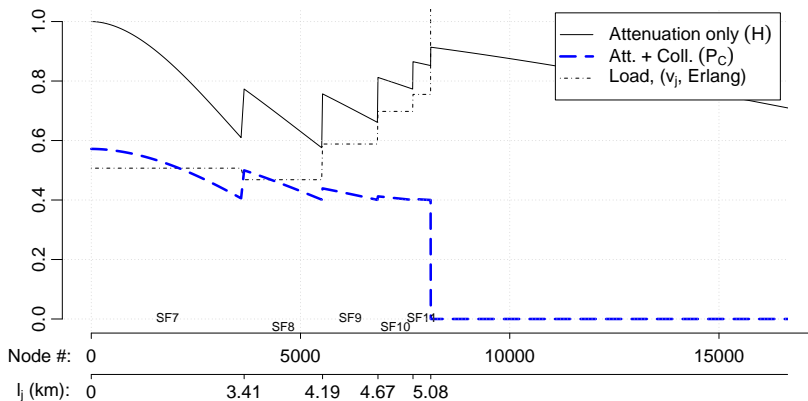|	10M		2M	2.25M	2M-1	
	Preamble		Sync	Freq.	Align	Payload

SF*I*x*M* Alignment Preamble

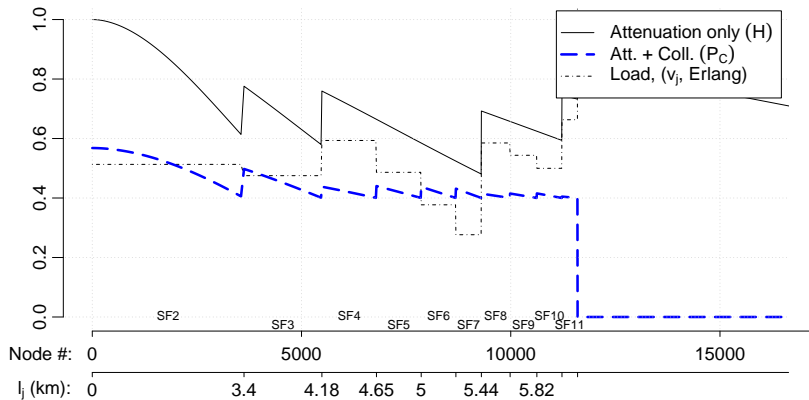# How often alignment will fail?

Very rarely

Capacity gains with SF*l*x*M*

If only SF12 is usable, capacity increases 600% with SF*l*x*M*

(SF7x32, SF8x16…)
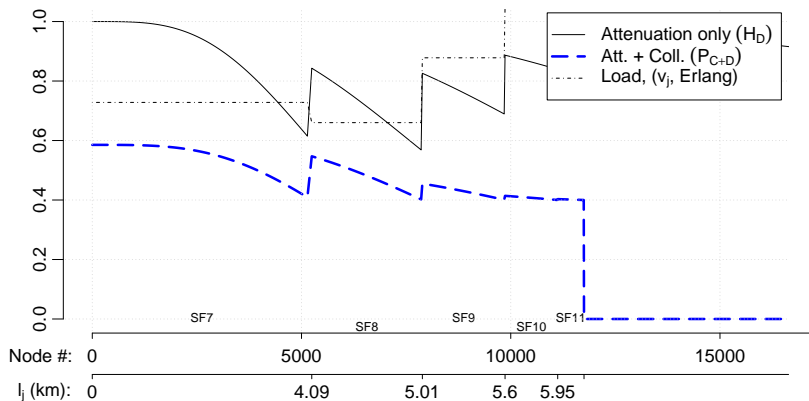
(Here: target success rate of individual transmission 40%)

LoRa only

Capacity gains with SF*lxM*

Node #: 0 — 5000 — 10000 — 15000

l_j (km): 0 — 3.4 — 4.18 — 4.65 — 5 — 5.44 — 5.82

Legend:
- Attenuation only (H)
- Att. + Coll. (P_C)
- Load, (v_j, Erlang)

SF2, SF3, SF4, SF5, SF6, SF7, SF8, SF9, SF10, SF11
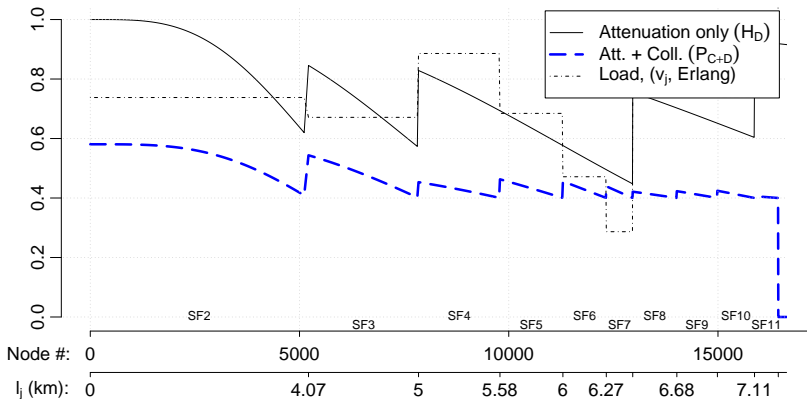
LoRa and SF*lxM*

SF*lxM* is (not) as good as adding a 2^d GW!

LoRa only with diversity

But you can use SF*l*x*M* **and** diversity 😁

SF2x32, SF3x32, SF4x32, SF5x16, SF6x8, SF8x4, SF8x4, SF9x2, SF10, SF11, SF12

LoRa and SF*l*x*M* with receiver diversity

Conclusion

- New modulation based on CSS, **with lower data rate**
- Requires a new alignment preamble – we evaluated the loss probability for that
- Significant capacity gains

  (May be combined with diversity)

- The ADR will need to take the M parameter into account

> Thank you