Institut Mines-Télécom

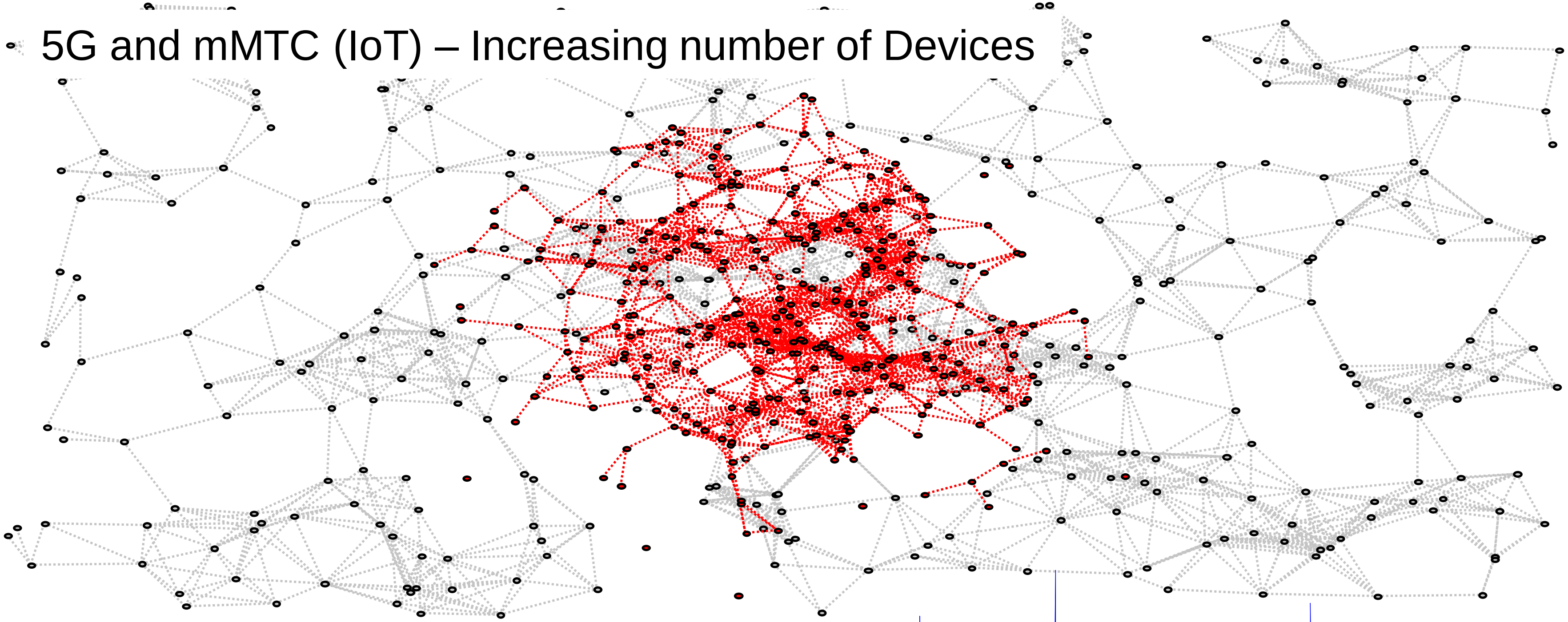
IOT INTERFERENCE MODELLING AND EXPERIMENTAL VALIDATION

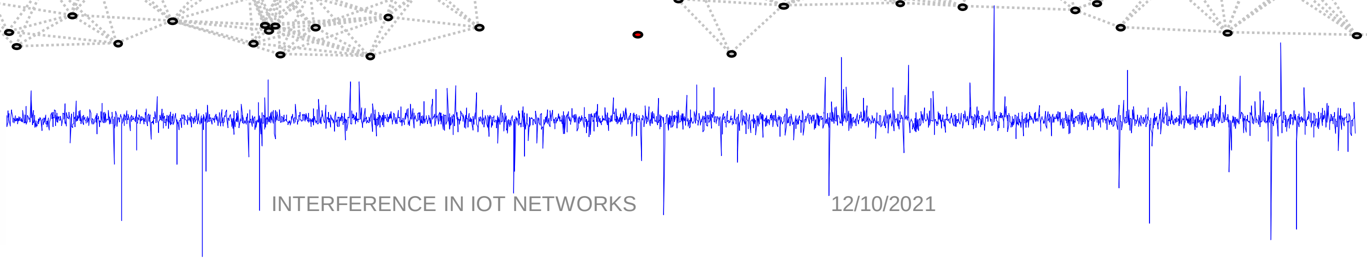
Laurent Clavier

IOT INTERFERENCE MODELLING AND EXPERIMENTAL VALIDATION

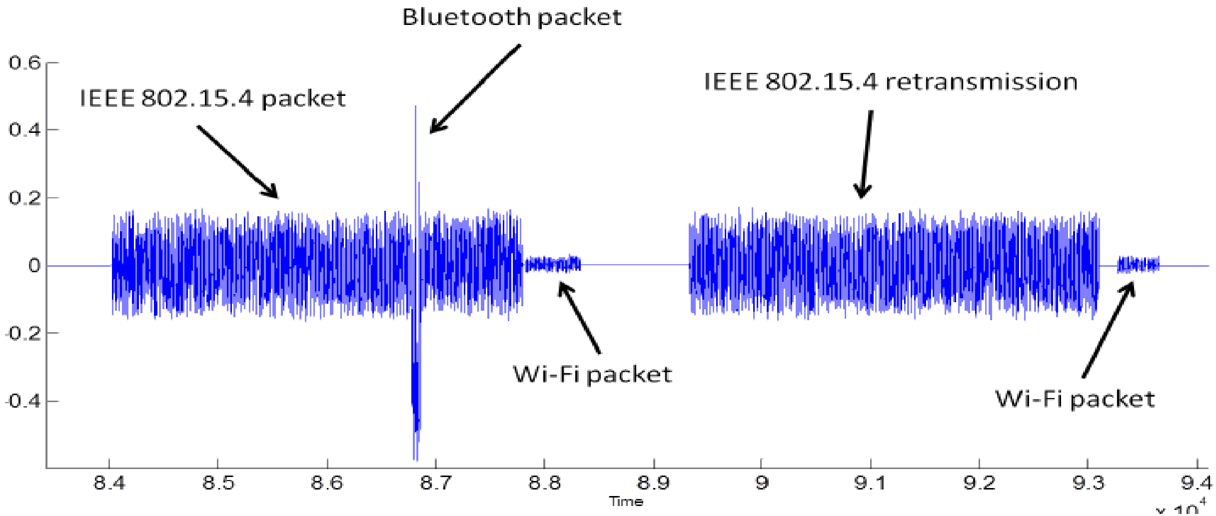
Laurent Clavier

- 5G and mMTC (IoT) – Increasing number of Devices





Coexistence is a major concern as more devices begin to operate on unlicensed bands. Many networks share the same bandwidth but PHY/MAC layer characteristics or application requirements may differ;



Different networks will be **uncoordinated**, it is difficult to assess for a given network in real time its impact on another (i.e., interference).

SOMMAIRE

1. MODELING INTERFERENCE

2. MEASURING INTERFERENCE

3. HANDLING INTERFERENCE

Institut Mines-Télécom

SOMMAIRE

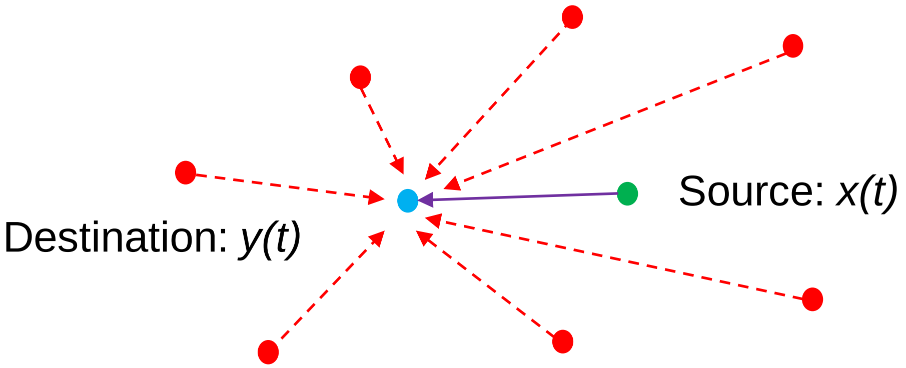
1. MODELING INTERFERENCE

2. MEASURING INTERFERENCE

3. HANDLING INTERFERENCE

Institut Mines-Télécom

What is interference?
Collection of other transmitters using the same frequency band at the same time (from the same networks but not necessarily).



All the contributions add at the destination.

$$I = \sum_{k \in \Phi_t} r_{k,t}^{-\frac{\eta}{2}} \underbrace{h_{k,t}}_{\text{Channel}} \underbrace{x_{k,t}}_{\text{PHY layer}}$$

Channel   PHY layer

Brief state of the art

Common approach: interference is modelled by a Gaussian random process.

Problem:

→ when the number of interferers is large but there are dominant interferers

In many cases, the interference pdf exhibits a heavier tail than what is predicted by the Gaussian model.

→ impulsive interference: Middleton Class A, Gaussian-mixture, generalized Gaussian, Laplace, α-stable...

$$I = \sum_{k=1}^{\infty} r_k^{-\frac{\eta}{2}} h_k x_k = \sum_{k=1}^{\infty} r_k^{-\frac{\eta}{2}} (z_{k,r} + i z_{k,i})$$

From a Poisson Point Process

Mapping theorem: r_k^2 is a 1D-PPP with intensity $\lambda\pi$

Lepage Series representation of SαS random variables

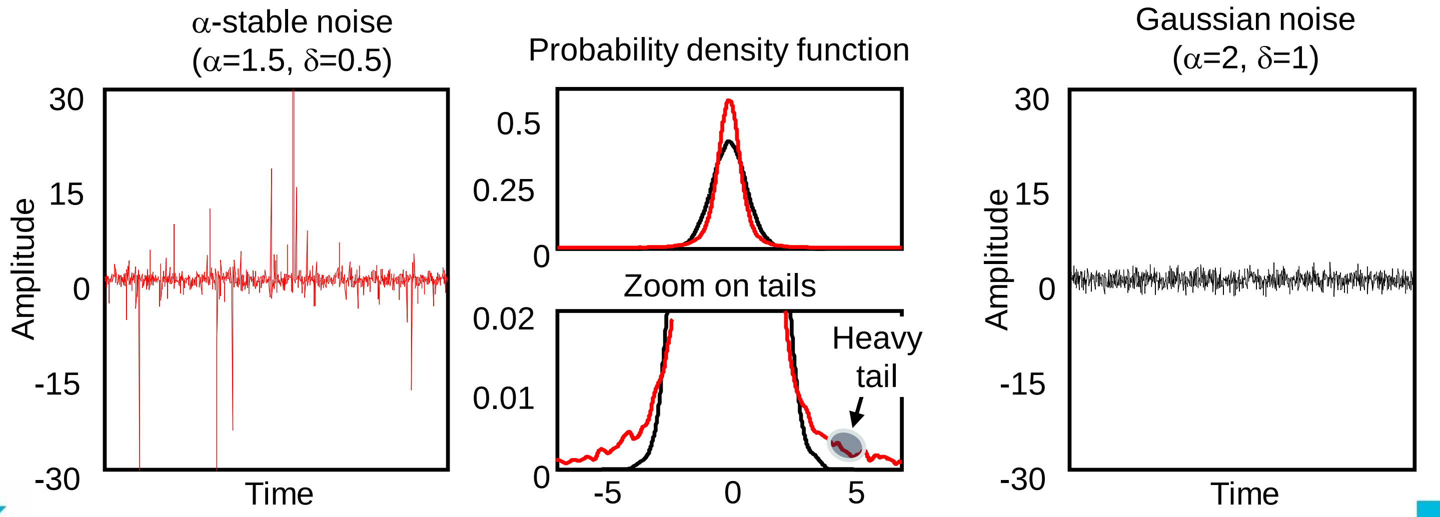
$\mathbf{I} = Z_r + iZ_i$ is an isotropic 4/η-stable and

$$\sigma_N = \left(\pi\lambda C_{\frac{4}{\eta}}^{-1} \mathbb{E}\left[|\mathcal{R}(h_k x_k)|^{\frac{4}{\eta}}\right]\right)^{\frac{\eta}{4}}$$

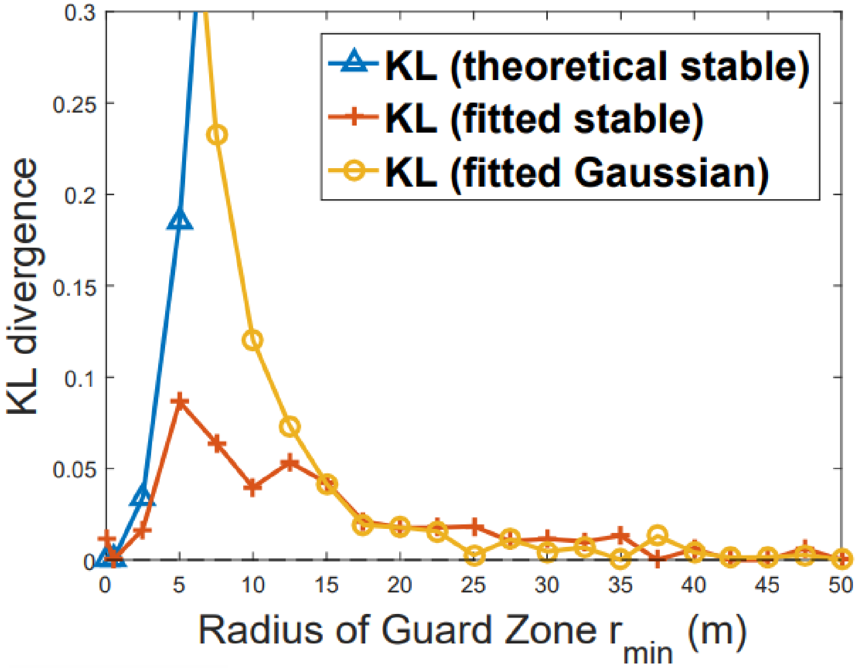
INT M. Egan et al., “Wireless communication in dynamic interference,” GLOBECOM 2017.

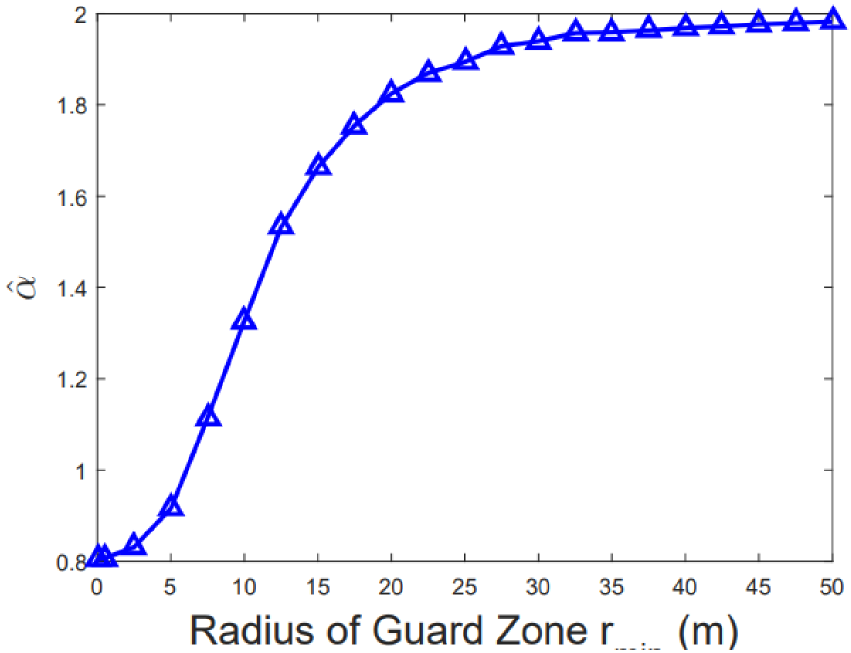
α-stable

- Parametric : 4 parameters: α, in]0,2], is the characteristic exponent (how impulsive), β the skewness, dispersion, location.
- Gaussian is a special case



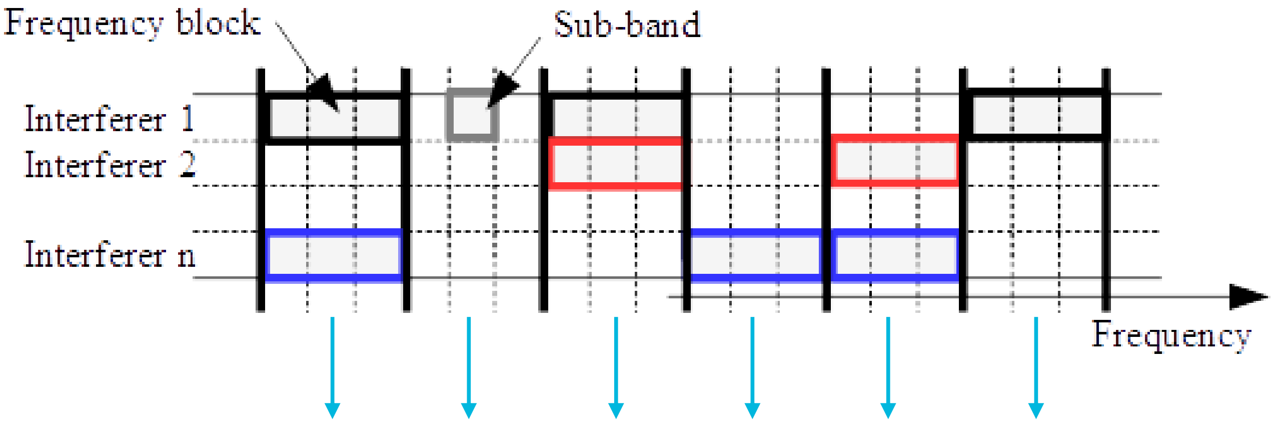
Model validity





Introducing access policy.

To make it “simple”: One user access a Frequency block with probability *p*.



The access policy can introduce dependence between different blocks. How can we model it?

How to introduce dependence?

Traditionally

- Finite second order moments
- Correlation coefficient is an adapted concordance measure

$$\rho_{X,Y} = \frac{E[X - \mu_X]E[Y - \mu_y]}{\sigma_X \sigma_Y}$$

But:

- Not adapted to impulsive interference (and especially α-stable distributions)
- Do not allow to model tail dependence (simultaneous strong samples in the same vector)

As a consequence we are interested in other dependence models allowing more flexible concordance measures.

Multivariate α-stable models exist… but are difficult to handle (intractable distribution function).

As an alternative, we keep the marginal behavior of the stable random variables and propose a copula to model the dependence structure

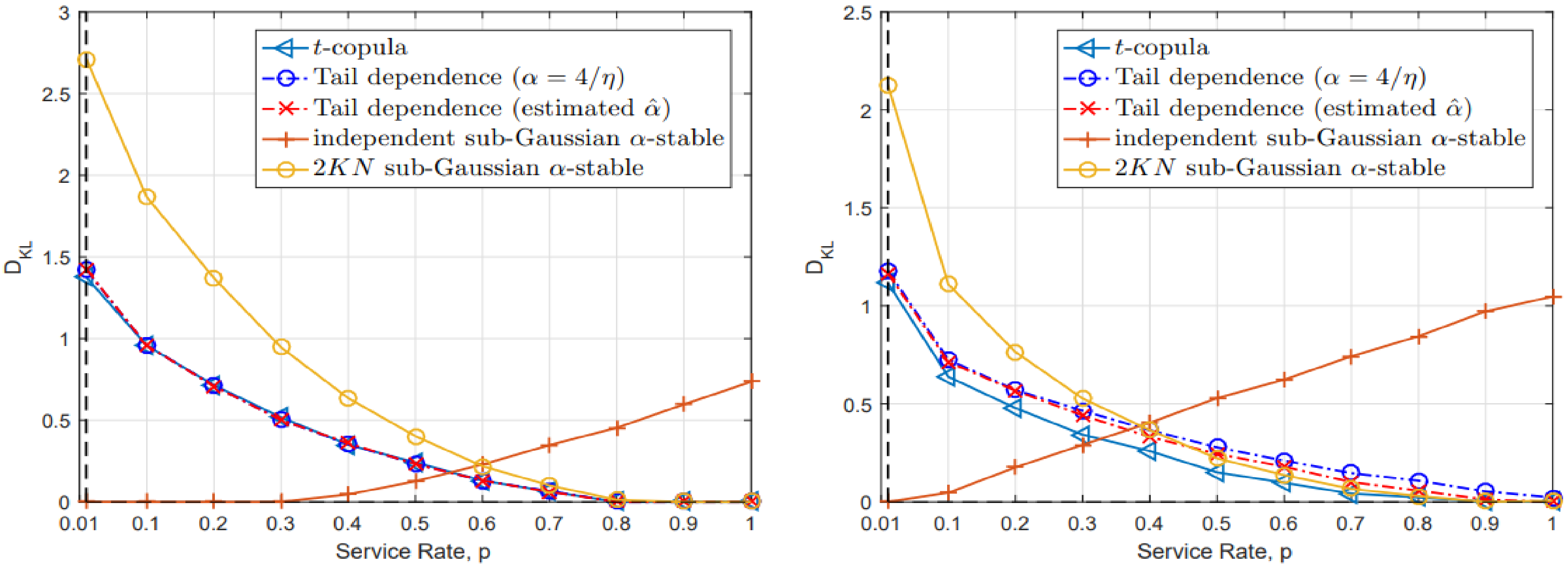
Copulas

We can define a copula as follows. Consider a random vector $X \in R^d$ with a continuous distribution *F*. Then to *X* one can associate a *d*-copula $C: [0,1]^d \rightarrow [0,1]$ defined by:

$$F(x_1, x_2, \ldots, x_d) = C\big(F_1(x_1), \ldots, F_d(x_d)\big)$$

Marginals (1D) distributions of X_i

Model validity - K = 4 blocks and N = 2 subcarriers in each block



(a) HPPP (b) Doubly Poisson cluster process

SOMMAIRE

1. MODELING INTERFERENCE

2. MEASURING INTERFERENCE

3. HANDLING INTERFERENCE

Institut Mines-Télécom

Five distinct locations at street level within Aalborg

- shopping area,
- business park,
- hospital complex,
- industrial area,
- residential area.

Measured power measurements on

- a frequency grid from **863 to 870 Mhz**,
- with **7kHz bins**,
- sampling time was **200 ms**,
- measurements were conducted during **two hours**.

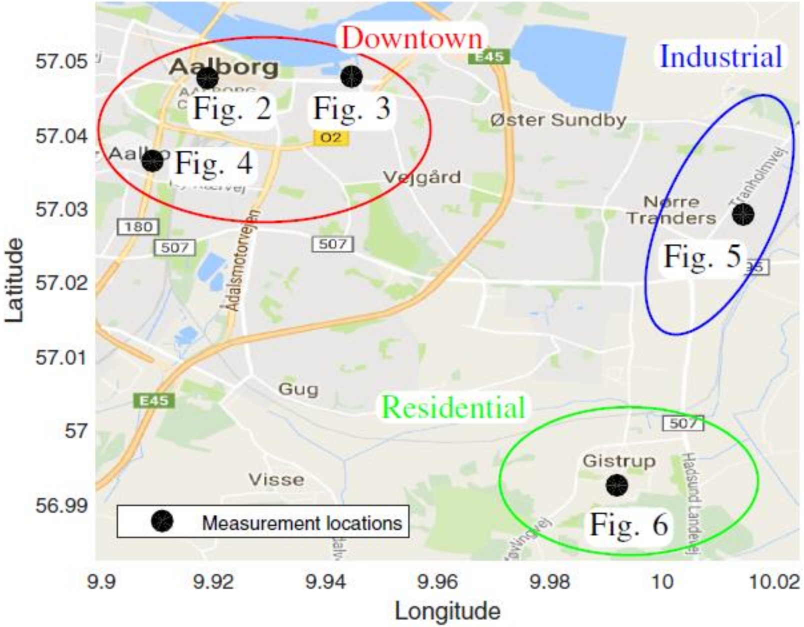
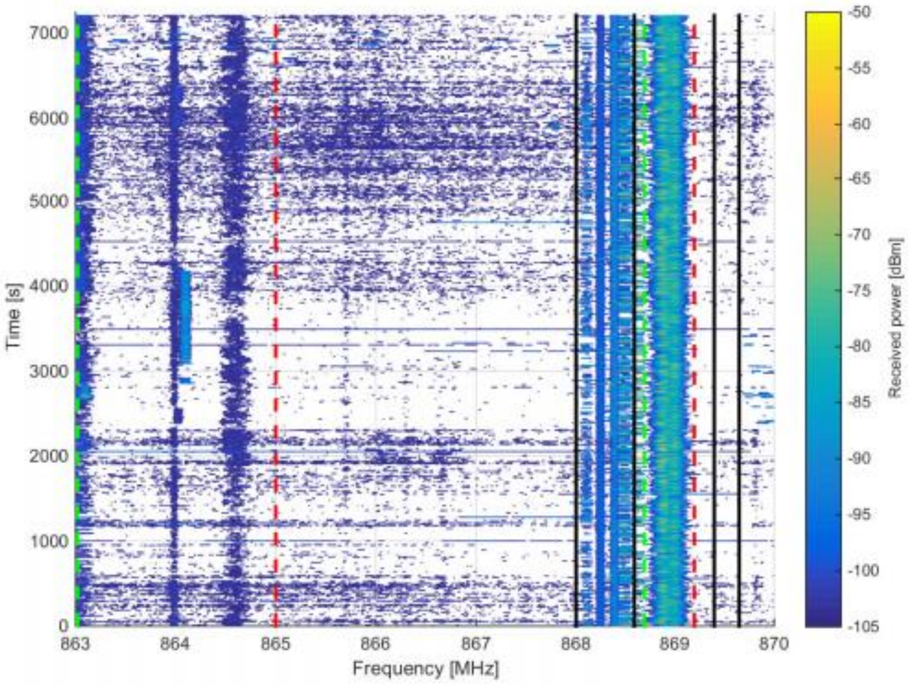


Fig. 1. The five measurement locations within Aalborg municipality.

M. Lauridsen et al., “Interference measurements in the European 868 MHZ ISM band with focus on LoRa and Sigfox,” WCNC 2017.

We focus on a LoRa-like receiver.

- Frequency band of 125 MHz (we aggregate 18 bands of 7 MHz, which makes 126 MHz bands)
- We select a time-frequency window where *interference is stationary*.
- Resource block: time-frequency area of 200ms and 126 MHz



How to define impulsiveness? "*Rare*" events with "*large*" values
Can be related to "*a larger probability of getting very large values*"
https://reference.wolfram.com/language/guide/HeavyTailDistributions.html

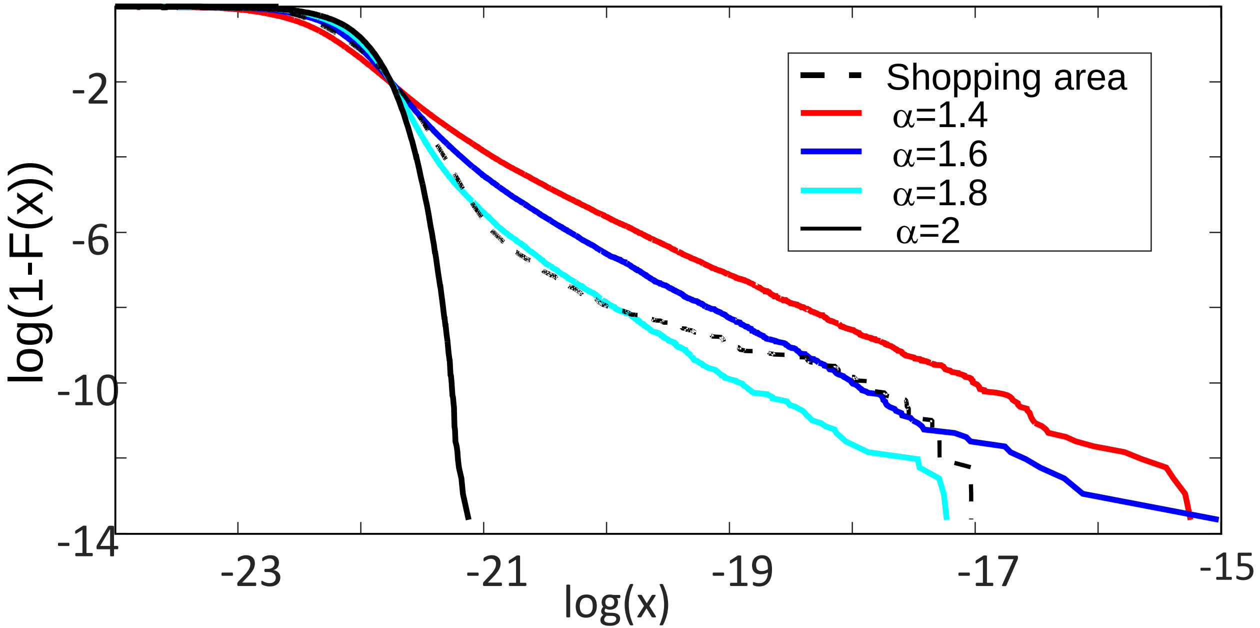
We can find several ways to define it, one interesting is:

✓ **Heavy Tail** (A distribution with a "tail" that is "heavier" than an Exponential)

have tails which fail to satisfy the following bound on the complementary cumulative distribution function $\bar{F}(x) = \mathbb{P}(X > x)$ for any positive real numbers *M* and *t*, $\boldsymbol{\bar{F}(x) \leq Me^{-tx}, \forall x > 0}$. (log-normal, Weibull, Pareto, α-Stable…)

Log-tail test

The idea is to represent the log of the survival function $\log(\bar{F}(x))$ as a function of $\log(x)$. For heavy-tailed distribution we will obtain a straight line while for exponential distributions γ will be 0 leading to a very abrupt fall.



Definitely Heavy Tail behavior

SOMMAIRE

1. MODELING INTERFERENCE

2. MEASURING INTERFERENCE

3. HANDLING INTERFERENCE

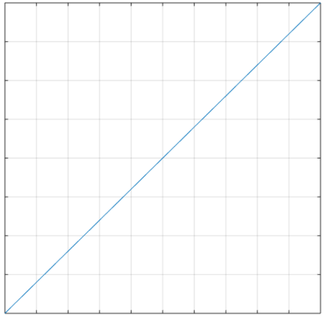
Institut Mines-Télécom

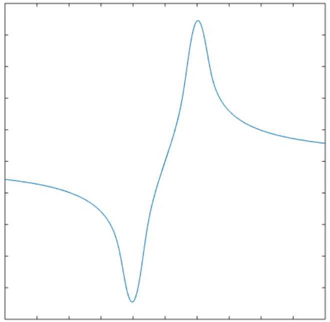
Receiver design

We use a LDPC code.
The input of the decorder (Belief Propagation) is based on the log-likelihood ratio.

In the Gaussian case it is a straight line. In an impusive case it is not !

Gaussian case



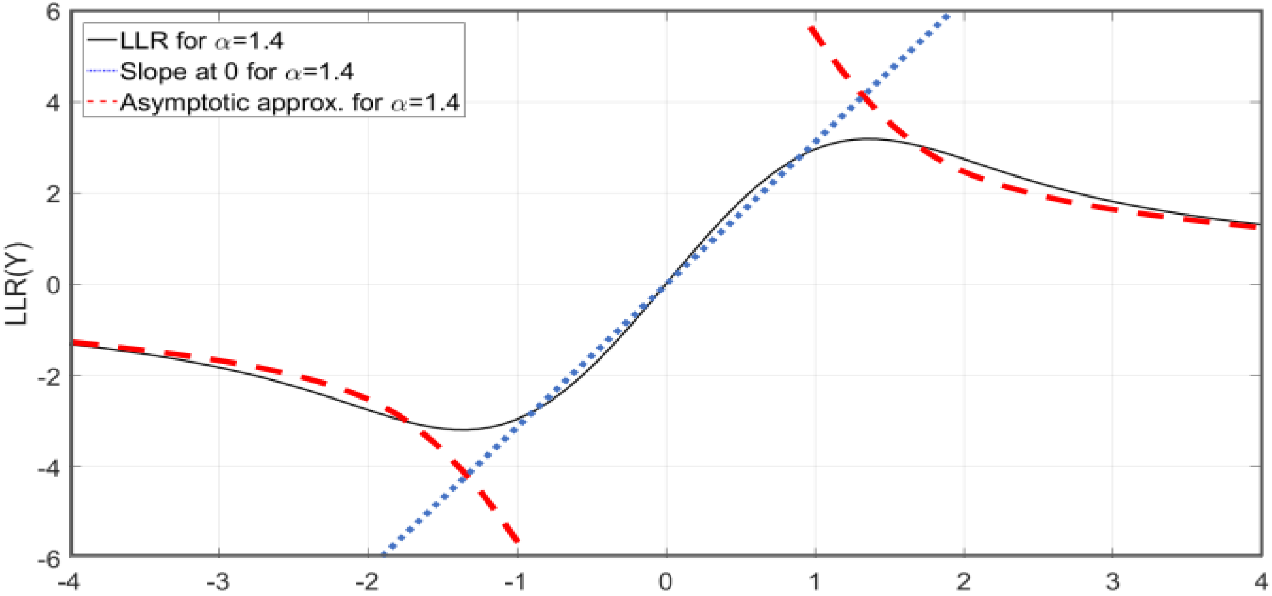


Stable case

We approximate the LLR with a simple function

$$L_{a,b}(x) = \min\left(ax, \frac{b}{x}\right)$$

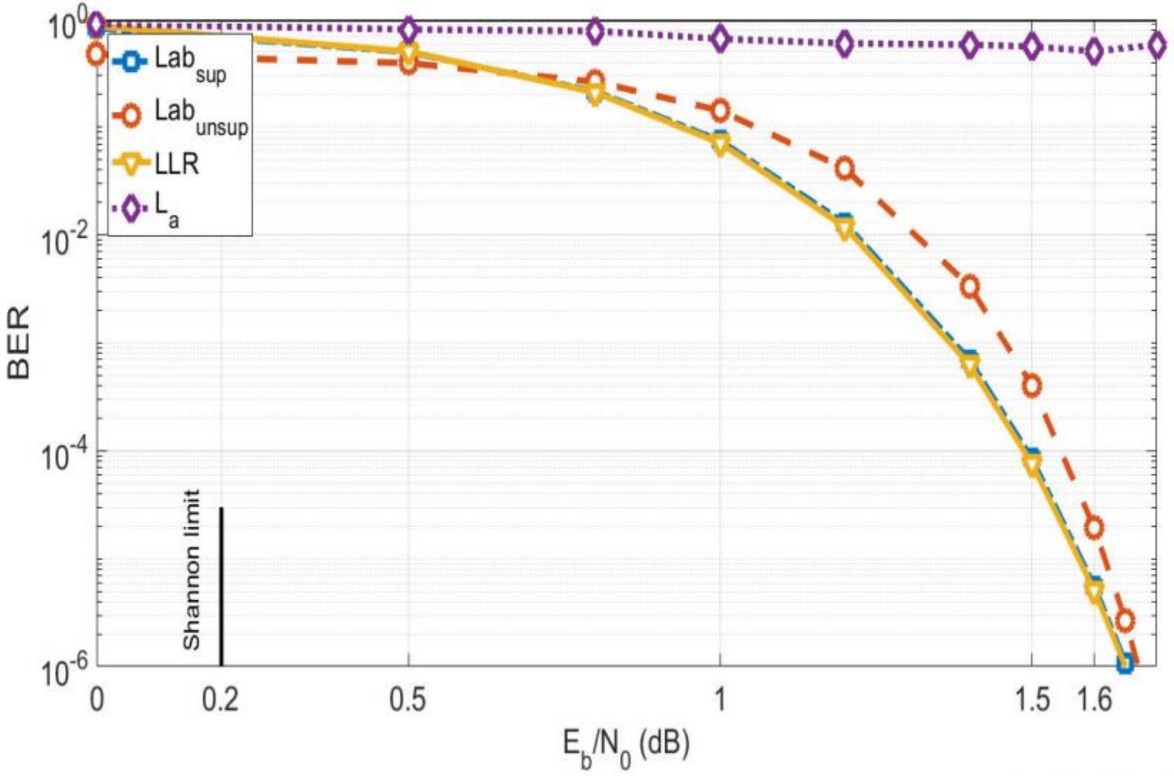
This, in fact, does not depend on the noise/interference distribution



$$\theta^* = \arg\min_{\theta} \widehat{H}(X|Y) = \arg\min_{\theta} \mathbb{E}\left[\log_2\left(1 + e^{-XL_\theta(Y)}\right)\right]$$

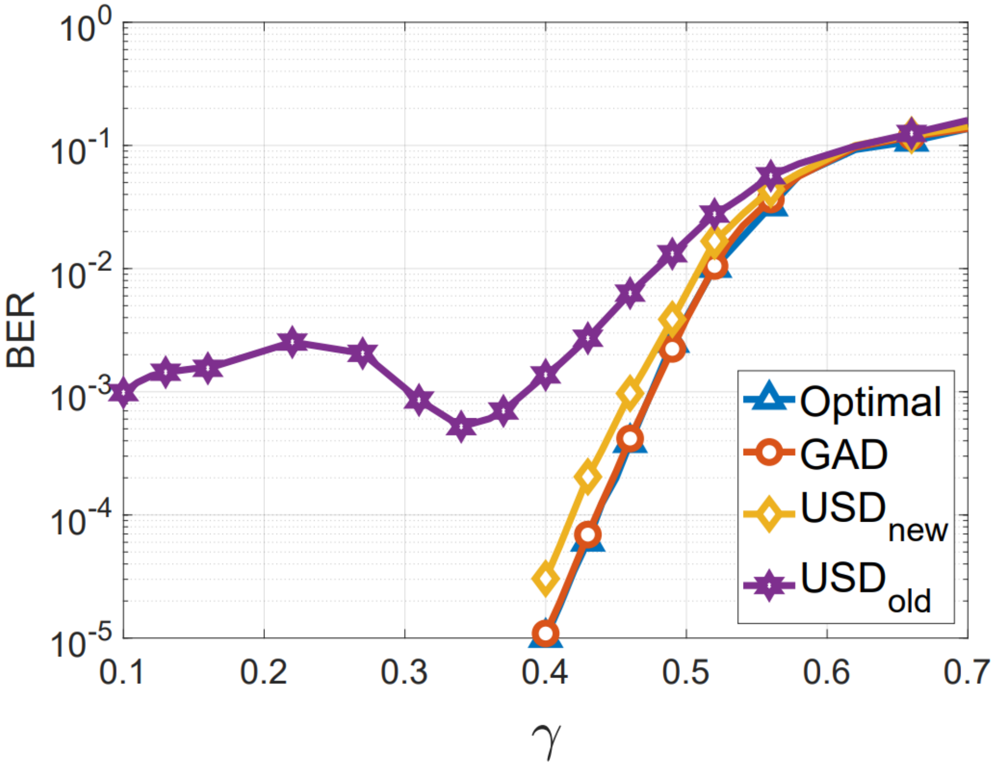
Example with a Middleton class A noise.

- Very poor performance of the linear receiver
- Significant improvement with the non linear approach
- The approximation works well



But it fails with short codewords

- Estimation problems due to the impulsive noise
- We need to improve the optimisation case



SOMMAIRE

1. MODELING INTERFERENCE

2. MEASURING INTERFERENCE

3. HANDLING INTERFERENCE

Institut Mines-Télécom

Main conclusions

Gaussian interference is not always adapted (it depends on the variation of the interferer set)

Impulsive interference is more complex to model but we can use an α-stable distribution.

- The characteristic exponent (a) is linked to the channel attenuation
- The dispersion is linked to the density of users, the PHY layer and the fading

Dependence can in that case be modeled with a t-copula

- The degrees of freedom is linked to the probability of access to a resource block