Two PhD position
Information theory and wireless communication for M2M and IoT Communications.

We propose two PhD positions (if possible preceded with a master's level internship) in France: one in **Lyon**, one in **Lille**. *They will start when possible, as soon as the candidates are found.*

Context:

With the recent development of machine-to-machine (M2M) communications and internet-of-things (IoT) networks, the infrastructures have to support more users (or nodes) but each of them requesting a very small quantity of information. This project aims at defining a more appropriate formalism allowing to estimate the theoretical limits of M2M communications. The performance of large scale networks has been widely studied during the past 10 years with usual theoretical tools such as Shannon theory or stochastic geometry. These tools provided interesting insights about scaling laws and theoretical limits but with a limited applicability in the context of M2M, IoT and future 5G services due to the inherent spurious and bursty nature of the associated information flows. While the small packet size invalidates the use of the asymptotic Shannon capacity as a performance indicator, the consequent bursty nature also invalidates the Gaussian assumption usually used to model the interference distribution. As a consequence fundamental limits are neither well known nor even well formulated. The goals of these PhDs are to propose new design criteria for IoT/M2M networks based on the non-asymptotic information theory framework [1] but taking into account bursty communications, i.e. use of non-Gaussian interference distribution [2], and large-scale deployment, i.e. use of stochastic geometry tool [3].

[1] Y. Polyanskiy, H. V. Poor and S. Verdu, "Channel coding rate in the finite blocklength regime", *IEEE Transactions on Information Theory*, vol. 56, no. 5, pp. 2307-2359, May 2010.
[2] G. Samorodnitsky and M. S. Taqqu, *Stable Non-Gaussian Random Processes: Stochastic Models with Infinite Variance*, Chapmann and Hall, 1994.
[3] F. Baccelli and B. Blaszczyszyn, "Stochastic geometry and wireless networks: volume 1 theory", *Foundations and Trends in Networking*, Vol. 3, No. 3-4, pp. 249-449, 2010.

Key skills

The candidate should have earned an MSc degree, or equivalent, in one of the following field: information theory, signal processing, electrical engineering, applied mathematics. He should have a strong background in probabilities and information theory as well as in signal processing for wireless communications. The candidate should be familiar with Matlab and C/C++ languages.

How to apply:

- Email a motivation letter
- Full CV with project and courses that could be related to the subject
- Complete academic records (from Bachelor to MSc)
- 2 or 3 references
- **Applications will be reviewed when they arrive until one candidate is select**

Contacts:	**e-mails**:
Prof. Jean-Marie Gorce Laboratoire CITI / INSA Lyon 6 avenue des Arts, 69621 Villeurbanne, France	jean-marie.gorce@insa-lyon.fr laurent.clavier@telecom-lille.fr philippe.mary@insa-rennes.fr
Prof. Laurent Clavier IRCICA / USR CNRS 3380 Avenue Hallez, 59650, Villeneuve d'Ascq, France	**Web sites:** http://perso.citi.insa-lyon.fr/jmgorce/ http://pmary.perso.insa-rennes.fr
Dr. Philippe Mary INSA de Rennes / IETR UMR CNRS - 6164 Avenue des buttes de Cöesmes, 35708 Rennes, France	

PhD1: Non-asymptotic fundamental limits of impulsive radio communications

***Laboratory*:**
CITI Lab. Centre of Innovation in Telecommunications and Integration of Service, Lyon, France
(http://www.citi-lab.fr)

Start date : As soon as possible ***– duration :*** 36 months

Key words:
Asymptotic and non-asymptotic information theory, second-order rate, probabilities, mutual information, measure theory, Poisson point process, alpha-stable.

The candidate will first address the problem of the non-asymptotic bounds (achievability and converse) in *network asymptotic regime,* i.e. with a spatial continuum of nodes. The main challenge here is to derive the channel dispersion when an infinite number of nodes is considered in multiple access channel (MAC) and broadcast channel (BC) scenarios [1,5]. The inherent dependence between the rate and the error-probability in finite blocklength regime will help us to define a multi-objective framework for the evaluation of IoT/M2M network performances.

Then, the candidate will concentrate on the problem of the non-asymptotic bounds in a non-Gaussian peer-to-peer (P2P) link. The impulsive noise could be represented by an alpha-stable distribution or other distribution able to capture the impulsiveness of the noise. The Polyanskiy's approach will be investigated trough the kbbound method for the achievability part. One the challenge would be to derive an expression (or compute) the dispersion of the impulsive channel [1]. The MolavianJazi's method [4], based on the central limit theorem (CLT) for functions, could also be investigated in order to approach the mutual information density for stable noise.

Based on these results, the PhD candidate will extend the previous approaches to the multi-user case, by merging the results obtained with spatial continuum of users for MAC/BC scenarios and the channel dispersion for impulsive noise. Based on the *outage-splitting theorem* for Gaussian MAC [4], the candidate will address the problem of the achievable region of MAC/BC in impulsive noise. In Gaussian framework, the achievable region of multi-user communications is derived under finite second-order moment. This assumption does not hold in impulsive noise, overall if alpha-stable distributions are considered, alternative constraint-cost functions need to be considered. A part of the research will consist to clearly define on which assumptions the achievability can be studied in bursty context.

The work proposed in this PhD could be of a great importance for industrial actors and researchers in the deployment of the future IoT networks. The limits derived in the thesis could provide guidelines to sustain the dramatic increase of the number of connected devices by giving a set of design criteria for these networks.

References

[4] E. MolavianJazi and J. N. Laneman. "A finite blocklength perspective on Gaussian multi-access channels", *CoRR, abs/1309.2343*, 2013.
[5] J.-M. Gorce, H. Vincent Poor, J.-M. Kelif, "Spatial Continuum Extensions of Asymmetric Gaussian Channels (Multiple Access and Broadcast)", https://hal.inria.fr/hal-01265184

PhD2: Impact of impulsive – dependent interference on radio communications

***Laboratory*:**
IRCICA - Institut de Recherche sur les Composants logiciels et matériels pour l'Information et la Communication Avancée - USR 3380 du CNRS, Lille, France
Start date : As soon as possible ***– duration :*** 36 months

Topic

This PhD position takes part of the fully funded ANR project ARBurst in collaboration with INSA/IETR Rennes and IRCICA Lille.

Interference will not exhibit the traditional Gaussian behavior that is usually assumed in IoT/M2M heterogeneous networks but could rather be impulsive [6]. This impulsiveness will have a major impact on future networks [7] and it is important to understand its real impact on the expected performance of the system, and especially on short packets for which a single, or a couple, of strong pulses can drastically degrade the performance. Based on the clear separation of short-term and long-term effects, we can establish the short term statistics of the interference. The α-stable distributions offer a very attractive framework for studying the interference variations related to these short term variations: they have a theoretical justification; they are the only stable distributions (generalized central limit theorem); they are parametric; their heavy tails allow an accurate representation of impulsive (rare and large) events. But they do not have a closed form expression and have infinite moments for orders such as $p \geq \alpha$. Consequently the theoretical limits under additive α-stable noise is not known [8,9] and the analysis cannot rely on second order statistics, so that, for instance, new solutions for dependence modeling are required [10]. Most of the classical digital communication tools have to be adapted, or completely revised, at physical layer as well as at MAC layer.

The PhD objectives will be to contribute on three aspects:

- Modelling interference and essentially the dependent case. Many works have dealt with independent interference samples but this can critically reduce the validity of the model. The general framework of copulas offer a nice tool for modeling the dependence structure.
- Capacity has then to be revisited – some recent approaches started to address the i.i.d case but further investigation is needed to incorporate the impact of dependence.
- Other metrics will also be necessary because capacity is not necessarily the good one for bursty communications. Besides spectral efficiency, energy and latency can also be critical. This will lead to multi-objective optimization to find the best adapted solutions.

References

[6] S.Weber and J.G. Andrews. "Transmission capacity of wireless networks." *Foundations and Trends in Networking, volume 5. NOW Publishers*, 2012.

[7] M.Z. Win, P.C. Pinto, and L.A. Shepp. "A mathematical theory of network interference and its applications." *Proceedings of the IEEE*, 97(2):205–230, February 2009.

[8] Yan Xin, L. Clavier, G.W. Peters, N. Azzaoui, F. Septier, and I. Nevat. "Skew-t copula for dependence modelling of impulsive (α-stable) interference." *Int. Conference on Communications (ICC)*, 2015.

[9] M. Egan, M. de Freitas, L Clavier, A Goupil, G. Peters, and N. Azzaoui. "Achievable rates for additive isotropic a-stable noise channels." *IEEE Int. Symposium on Information Theory (ISIT)*, July 2016.

[10] J. Fahs and I. Abou-Faycal. "A cauchy input achieves the capacity of a cauchy channel under a logarithmic constraint." In *IEEE Int. Symposium on Information Theory (ISIT)*, pp. 3077–3081, June 2014.