Non-asymptotic fundamental limits of dense wireless networks

Laboratory:
IETR: Institut d'électronique et des technologies du numérique (https://www.ietr.fr)
Start date : November 1st, 2020 **–** ***duration :*** 36 months

Topic

This PhD position will be supervised by researchers from INSA Rennes, INSA Lyon and INRIA and be part of a project with Orange Labs.

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 sporadic 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 goal of the PhD is to characterize the Pareto front that gives a tradeoff between the reliability, the access density and the latency of IoT/M2M networks using the non-asymptotic information theory framework [1,2] and the large-scale deployment, i.e. use of stochastic geometry tool [3].

The existing non-asymptotic achievability and converse bounds of the multiple access channel (MAC) and broadcast channel (BC) do not converge and are based on the evaluation of the system error probability, i.e. the system is in error if at least one user is not correctly decoded. In the context of IoT where hundreds or thousands of nodes can communicate, this definition is not relevant anymore and the individual error has to be considered. A first attempt has been provided in a previous thesis but the complete satisfying solution is still not reached due to the small tractability of expressions. The error probability mainly relies on the evaluation of the tail distribution of a sum of random variables. We developed a method that allows to estimate these probabilities far more accurately than the classical method based on the Berry-Esseen theorem [4]. However, the extension to the individual error probability needs to be done.

Moreover, the high number of communicating nodes advocates for the use of the continuum spatial model for defining and characterizing the fundamental performance achievable in a cell. The capacity of a cell in a spatial continuum should be understood as the set of the user rate request densities, defined on the vectorial space of measurable functions, that are achievable. The works in [5,6] have investigated this problem in the asymptotic coding regime, i.e. when the number of channel uses (c.u.) n→inf, but these results need to be extended when the number of c.u. remains bounded. This is challenging because one would need to i) define and derive the equivalent of a dispersion of the continuous Gaussian MAC/BC and ii) characterize the distribution of the remaining interference when decoding the signal of a particular user in a MAC or BC in order to be able to derive converse bounds in particular. Indeed, the meta-converse bound [1] relies on the maximization of the input distributions which is challenging because the marginal distributions of each user minimizing the error probability (system or individual) are unknown. It is well known that a power-shell distribution is second-order rate optimal in a point-to-point. A promising way would be to search if there exists some marginals such that the joint distribution would be on the power-shell.

The work proposed in this PhD could be of a great importance for industrial actors and researchers in the deployment of the future IoT/M2M networks. The bounds 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

[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] P. Mary, J.-M. Gorce, A. Unsal, H. V. Poor, "Finite Blocklength Information Theory: What is the Practical Impact on Wireless Communications?", *Globecom'16 Workshops, IOTLINK*, Washington D. C., 2016.
[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.
[4] Dadja Anade, Jean-Marie Gorce, Philippe Mary, Samir Perlaza. "An Upper Bound on the Error Induced by Saddlepoint Approximations - Applications to Information Theory". *Entropy, MDPI,* 2020, Wireless Networks: Information Theoretic Perspectives, 22 (6), pp.690
[5] JM Gorce, D Tsilimantos, P Ferrand, HV Poor, "Energy-Capacity Trade-off Bounds in a downlink typical cell", *in IEEE 25th International Symposium on Personal, Indoor and Mobile Radio Communications*, Sep 2014, Washington, United States.
[6] Gorce, J. M., Poor, H. V., Kelif, J. M. "Spatial continuum model: Toward the fundamental limits of dense wireless networks". *In 2016 IEEE Global Communications Conference (GLOBECOM).*

Key skills

The candidate should have earned an MSc degree, or equivalent, in one of the following field: information theory, signal processing, 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++ language or Python.

Key words:

Asymptotic and non-asymptotic information theory, second-order rate, probabilities, mutual information, measure theory, Poisson point process, spatial continuum.

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**

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