RESEARCH CENTRE

Sophia Antipolis - Méditerranée

2021 ACTIVITY REPORT

Project-Team NEO

Network Engineering and Operations

DOMAIN

Networks, Systems and Services, Distributed Computing

THEME

Networks and Telecommunications

Contents

Project-Team NEO

Creation of the Project-Team: 2017 December 01

Keywords

Computer sciences and digital sciences

A1.1.11. – Quantum architectures
A1.2.4. – QoS, performance evaluation
A1.2.5. – Internet of things
A1.2.6. – Sensor networks
A1.5. – Complex systems
A1.5.1. – Systems of systems
A1.5.2. – Communicating systems
A3.3.3. – Big data analysis
A3.4. – Machine learning and statistics
A3.5. – Social networks
A3.5.2. – Recommendation systems
A4.1. – Threat analysis
A5.9. – Signal processing
A6.1.1. – Continuous Modeling (PDE, ODE)
A6.1.2. – Stochastic Modeling
A6.2.2. – Numerical probability
A6.2.3. – Probabilistic methods
A6.2.6. – Optimization
A6.4.1. – Deterministic control
A6.4.2. – Stochastic control
A6.4.6. – Optimal control
A7.1. – Algorithms
A7.1.1. – Distributed algorithms
A7.1.2. – Parallel algorithms
A7.1.4. – Quantum algorithms
A8.1. – Discrete mathematics, combinatorics
A8.2.1. – Operations research
A8.6. – Information theory
A8.8. – Network science
A8.9. – Performance evaluation
A8.11. – Game Theory
A9.2. – Machine learning

A9.6. – Decision support

A9.9. – Distributed AI, Multi-agent

Other research topics and application domains

B2.3. – Epidemiology

B2.5.1. – Sensorimotor disabilities

B3.1. – Sustainable development

B3.1.1. – Resource management

B4.3.4. – Solar Energy

B4.4. – Energy delivery

B4.4.1. – Smart grids

B4.5.1. – Green computing

B6. – IT and telecom

B6.2. – Network technologies

B6.2.1. – Wired technologies

B6.2.2. – Radio technology

B6.3.3. – Network Management

B6.3.4. – Social Networks

B6.4. – Internet of things

B6.6. – Embedded systems

B8.1. – Smart building/home

B9.2.1. – Music, sound

B9.5.1. – Computer science

B9.5.2. – Mathematics

B9.6.3. – Economy, Finance

B9.6.4. – Management science

B9.6.5. – Sociology

1 Team members, visitors, external collaborators

Research Scientists

- Alain Jean-Marie [Team leader, Inria, Senior Researcher]
- Sara Alouf [Inria, Researcher, HDR]
- Eitan Altman [Inria, Senior Researcher, HDR]
- Konstantin Avrachenkov [Inria, Senior Researcher, HDR]
- Samir Medina Perlaza [Inria, Researcher, on leave to the University of French Polynesia from May 1 to October 30, HDR]
- Philippe Nain [Inria, Emeritus, from Aug 2021, HDR]
- Giovanni Neglia [Inria, Researcher, HDR]

Post-Doctoral Fellows

- Gabriele Castellano [Inria]
- Jake Clarkson [Inria, from Oct 2021]
- Kishor Yashavant Patil [Inria, until Jun 2021]
- Ramakrishnan Sambamoorthy [Inria, until Aug 2021]
- Sadaf Ul Zuhra [Inria]

PhD Students

- Younes Ben Mazziane [Univ Côte d'Azur]
- Olha Chuchuk [Organisation européenne pour la recherche nucléaire]
- Mandar Datar [Inria]
- Maximilien Dreveton [Inria]
- Guilherme Iecker Ricardo [Institut Telecom ex GET Groupe des Écoles des Télécommunications , until Sep 2021]
- Mikhail Kamalov [Inria]
- Caelin Kaplan [SAP Labs, from Jul 2021]
- Othmane Marfoq [Inria]
- Angelo Rodio [Inria, from Apr 2021]
- Tareq Si Salem [Univ Côte d'Azur]

Technical Staff

- Chuan Xu [Inria, Engineer, until Aug 2021]

Interns and Apprentices

- Yuzhou Chen [Inria, from Feb 2021 until Jul 2021]
- Ibtihal El Mimouni [Inria, from Mar 2021 until Aug 2021]
- Kausthub Keshava [Inria, until Apr 2021]
- Nandan Malhotra [Inria, until Apr 2021]
- Oualid Zari [Univ Côte d'Azur, from Mar 2021 until Aug 2021]

Administrative Assistant

- Jane Desplanques [Inria]

Visiting Scientists

- Yury Demidovich [Moscow Institute of Physics and Technology - Russia, from Jul 2021 until Sep 2021]
- Maksim Mironov [Moscow Institute of Physics and Technology - Russia, from Mar 2021 until Jun 2021]

External Collaborator

- Patrick Brown [Orange, from Mar 2021 until Aug 2021]

2 Overall objectives

NEO is an Inria project-team whose members are located in Sophia Antipolis (S. Alouf, K. Avrachenkov, G. Neglia, S. M. Perlaza), in Avignon (E. Altman) at LIA (Lab. of Informatics of Avignon) and in Montpellier (A. Jean-Marie). E. Altman is also with the LINCS (Lab. for Information, Networking and Communication Sciences). S. M. Perlaza is also with the ECE department at Princeton Univ., N.J. USA; and the Mathematics Department of the Univ. de la Polynésie française (Laboratoire GAATI), Faaa, Tahiti.

The team is positioned at the intersection of Operations Research and Network Science. By using the tools of Stochastic Operations Research, we model situations arising in several application domains, involving networking in one way or the other. The aim is to understand the rules and the effects in order to influence and control them so as to engineer the creation and the evolution of complex networks.

3 Research program

The problems studied in NEO involve generally optimization, dynamic systems or randomness, and often all at the same time. The techniques we use to tackle these problems are those of Stochastic Operations Research, Applied Probabilities and Information Theory.

Stochastic Operations Research is a collection of modeling, optimization and numerical computation techniques, aimed at assessing the behavior of man-made systems driven by random phenomena, and at helping to make decisions in such a context.

The discipline is based on applied probability and focuses on effective computations and algorithms. Its core theory is that of Markov chains over discrete state spaces. This family of stochastic processes has, at the same time, a very large modeling capability and the potential of efficient solutions. By "solution" is meant the calculation of some *performance metric*, usually the distribution of some random variable of interest, or its average, variance, etc. This solution is obtained either through exact "analytic" formulas, or numerically through linear algebra methods. Even when not analytically or numerically tractable, Markovian models are always amenable to "Monte-Carlo" simulations with which the metrics can be statistically measured.

An example of this is the success of classical Queueing Theory, with its numerous analytical formulas. Another important derived theory is that of the Markov Decision Processes, which allows to formalize *optimal* decision problems in a random environment. This theory allows to characterize the optimal decisions, and provides algorithms for calculating them.

Strong trends of Operations Research are: a) an increasing importance of multi-criteria multi-agent optimization, and the correlated introduction of Game Theory in the standard methodology; b) an increasing concern of (deterministic) Operations Research with randomness and risk, and the consequent introduction of topics like Chance Constrained Programming and Stochastic Optimization. Data analysis is also more and more present in Operations Research: techniques from statistics, like filtering and estimation, or Artificial Intelligence like clustering, are coupled with modeling in Machine Learning techniques like Q-Learning.

4 Application domains

4.1 Network Science

Network Science is a multidisciplinary body of knowledge, principally concerned with the emergence of global properties in a network of individual agents. These global properties emerge from "local" properties of the network, namely, the way agents interact with each other. The central model of "networks" is the graph (of Graph Theory/Operations Research). Nodes represent the different entities managing information and taking decisions, whereas, links represent the fact that entities interact, or not. Links are usually equipped with a "weight" that measures the intensity of such interaction. Adding evolution rules to this quite elementary representation leads to dynamic network models, the properties of which Network Science tries to analyze.

A classical example of properties sought in networks is the famous "six degrees of separation" (or "small world") property: how and why does it happen so frequently? Another ubiquitous property of real-life networks is the Zipf or "scale-free" distribution for degrees. Some of these properties, when properly exploited, lead to successful business opportunities: just consider the PageRank algorithm of Google, which miraculously connects the relevance of some Web information with the relevance of the other information that points to it.

4.2 Network Engineering

In its primary acceptation, Network Science involves little or no engineering: phenomena are assumed to be "natural" and emerge without external interventions. However, the idea comes fast to intervene in order to modify the outcome of the phenomena. This is where NEO is positioned. Beyond the mostly descriptive approach of Network Science, we aim at using the techniques of Operations Research so as to engineer complex networks.

To quote two examples: controlling the spread of diseases through a "network" of people is of primarily interest for mankind. Similarly, controlling the spread of information or reputation through a social network is of great interest in the Internet. Precisely, given the impact of web visibility on business income, it is tempting (and quite common) to manipulate the graph of the web by adding links so as to drive the PageRank algorithm to a desired outcome.

Another interesting example is the engineering of community structures. Recently, thousands of papers have been written on the topic of community *detection* problem. In most of the works, the researchers propose methods, most of the time, heuristics, for detecting communities or dense subgraphs inside a large network. Much less effort has been put in the understanding of community formation process and even much less effort has been dedicated to the question of how one can influence the process of community formation, e.g. in order to increase overlap among communities and reverse the fragmentation of the society.

Our ambition for the medium term is to reach an understanding of the behavior of complex networks that will make us capable of influencing or producing a certain property in a given network. For this purpose, we will develop families of models to capture the essential structure, dynamics, and uncertainty of complex networks. The "solution" of these models will provide the correspondence between metrics of interest and model parameters, thus opening the way to the synthesis of effective control techniques.

In the process of tackling real, very large size networks, we increasingly deal with large graph data analysis and the development of decision techniques with low algorithmic complexity, apt at providing answers from large datasets in reasonable time.

5 Highlights of the year

5.1 Awards

- Best paper award at ITC-33 for AÇAI: Ascent Similarity Caching with Approximate Indexes [45], co-authored by T. Si Salem, G. Neglia, and D. Carra (Univ. of Verona).
- M. Dreveton has received the best presentation award at French Regional Conference on Complex Systems (FRCCS 2021) for presenting the work "Higher-Order Spectral Clustering for Geometric Graphs" [13], co-authored by K. Avrachenkov and A. Bobu.
- Best paper runner-up award at the 10th International Conference on Computational Data and Social Networks (CSoNet 2021) for the work "Recovering Communities in Temporal Networks Using Persistent Edges" [32], co-authored by K. Avrachenkov and L. Leskelä.

5.2 Acknowldegments

- E. Altman was elected vice chairman of the IFIP TC6 working group 6.3.
- S. M. Perlaza defended the HDR "Contributions aux Systèmes d'Information et d'Énergie" [53] at the Université Claude Bernard Lyon I, Lyon, France, June 29, 2021.
- S. M. Perlaza was appointed as a Visiting Research Collaborator (VRC) at the Electrical and Computer Engineering Department at Princeton University, Princeton, N.J. USA.
- S. M. Perlaza was appointed as Associate Member of the Laboratoire GAATI (Algebraic Geometry and Applications to Information Theory) at the Univ. de la Polynésie Française, Faaa, Tahiti.

6 New software and platforms

Let us describe new/updated software.

6.1 New software

6.1.1 marmoteCore

Name: Markov Modeling Tools and Environments - the Core

Keywords: Modeling, Stochastic models, Markov model

Functional Description: marmoteCore is a C++ environment for modeling with Markov chains. It consists in a reduced set of high-level abstractions for constructing state spaces, transition structures and Markov chains (discrete-time and continuous-time). It provides the ability of constructing hierarchies of Markov models, from the most general to the particular, and equip each level with specifically optimized solution methods.

This software was started within the ANR MARMOTE project: ANR-12-MONU-00019.

News of the Year: No active development. Current development lies now in the MARTO project (next generations of PSI and marmoteCore) and in the forthcoming Marmote project.

URL: http://marmotecore.gforge.inria.fr/

Publications: hal-01651940, hal-01276456

Contact: Alain Jean-Marie

Participants: Alain Jean-Marie, Hlib Mykhailenko, Benjamin Briot, Franck Quessette, Issam Rabhi, Jean-Marc Vincent, Jean-Michel Fourneau

Partners: Université de Versailles St-Quentin-en-Yvelines, Université Paris Nanterre

7 New results

7.1 Stochastic Modeling

Participants: Sara Alouf, Eitan Altman, Konstantin Avrachenkov, Younes Ben Mazziane, Alain Jean-Marie, Kausthub Keshava, Giovanni Neglia, Kishor Yashavant Patil, Samir Medina Perlaza.

7.1.1 Calculation of Cumulative Distribution Functions of Sums of Random Vectors

The calculation of cumulative distribution functions (CDFs) of sums of random vectors is omnipresent in the realm of engineering. Approximations to these CDFs, e.g., Gaussian approximations and saddlepoint approximations have gained remarkable popularity. In the case of Gaussian approximations, multi-dimensional Berry-Esseen-type theorems provide upper bounds on the approximation errors. These bounds are particularly precise around the mean. Alternatively, saddlepoint approximations are known to be more precise than Gaussian approximations far apart from the mean. Unfortunately, this claim is often justified by numerical analysis as formal upper bounds on the error induced by saddlepoint approximations are rather inexistent.

In [29] and [54], S. M. Perlaza, together with J.-M. Gorce and D. Anade (both from Inria, MARACAS) and P. Mary (INSA de Rennes), proposed a real-valued function that approximates the CDF of a finite sum of real-valued independent and identically distributed random vectors. The approximation error is upper bounded by an expression that is easy to calculate. As a byproduct, an upper bound and a lower bound on the CDF are obtained. Finally, in the case of lattice and absolutely continuous random variables, the proposed approximation is shown to be identical to the saddlepoint approximation of the CDF.

7.1.2 Controlled Markov Chains and Freshness of Information

Many systems require frequent and regular updates of certain information. These updates have to be transferred regularly from the 5G(s) to a common destination. In [39], K. Veeraruna (IIT Bombay) and E. Altman consider scenarios in which an old packet (entire information unit) becomes completely obsolete, in the presence of a new packet. We consider transmission channels with unit storage capacity; upon arrival of a new packet, if another packet is being transmitted then one of the packets is lost. We consider the control problem that consists of deciding which packet to discard so as to maximise the average age of information (AAoI). We derive drop policies that optimize the AAoI. We show that the state independent (static) policies like dropping always the old packets or dropping always the new packets are optimal in many scenarios, among an appropriate set of stationary Markov policies.

7.1.3 Random Surfers and Prefetching

Prefetching is a basic technique used to reduce the latency of diverse computer services. In [19], K. Keshava, A. Jean-Marie and S. Alouf propose and analyze a model for optimizing the prefetching of documents, in the situation where the connection between documents is discovered progressively. A random surfer moves along the edges of a random tree representing possible sequences of documents, which is known to a controller only up to depth d. A quantity k of documents can be prefetched between two movements. The question is to determine which nodes of the known tree should be prefetched so as to minimize the probability of the surfer moving to a node not prefetched. The model is analyzed with the tools of Markov decision process theory. The optimal policy is identified formally in several situations, and only numerically in others.

7.1.4 Count-Min Sketch with Conservative Updates

Count-Min Sketch with Conservative Updates (CMS-CU) is a popular algorithm to approximately count items'appearances in a data stream. Despite CMS-CU's widespread adoption, the theoretical analysis of its performance is still wanting because of its inherent difficulty. Y. Ben Mazziane, under the supervision of S. Alouf and G. Neglia, has proposed a novel approach to study CMS-CU and derive new upper bounds on the expected value and the CCDF of the count estimation error under an i.i.d. request process. The formulas obtained can be successfully employed to derive improved estimates for the precision of heavy-hitter detection methods and improved configuration rules for CMS-CU. The bounds have been evaluated both on synthetic and real traces.

7.1.5 Infinite Dimensional Linear Programming Approach to Optimal Stochastic Control

In [33], K. Avrachenkov together with V. Gaitsgory and L. Gamertsfelder (both from Macquarie Univ., Australia) study asymptotic properties of problems of control of stochastic discrete time systems with time averaging and time discounting optimality criteria and with general compact state and action spaces (equivalently Markov Decision Processes, MDPs), and they establish that the Cesàro and Abel limits of the optimal values in such problems can be estimated with the help of a certain infinite-dimensional (ID) linear programming (LP) problem and its dual.

7.1.6 Online Algorithms for Estimating Change Rates of Web Pages

A search engine maintains local copies of different web pages to provide quick search results. This local cache is kept up-to-date by a web crawler that frequently visits these different pages to track changes in them. Ideally, the local copy should be updated as soon as a page changes on the web. However, finite bandwidth availability and server restrictions limit how frequently different pages can be crawled. This brings forth the following optimization problem: maximize the freshness of the local cache subject to the crawling frequencies being within prescribed bounds. While tractable algorithms do exist to solve this problem, these either assume the knowledge of exact page change rates or use inefficient methods such as MLE for estimating the same. We address this issue here. In [15] K. Avrachenkov and K. Patil together with G. Thoppe (Indian Institute of Science) provide three novel schemes for online estimation of page change rates, all of which have extremely low running times per iteration. The first is based on the law of large numbers and the second on stochastic approximation. The third is an extension of the second and includes a heavy-ball momentum term. Our main theoretical results concern asymptotic convergence and convergence rates of these three schemes. In fact, our work is the first to show convergence of the original stochastic heavy-ball method when neither the gradient nor the noise variance is uniformly bounded. We also provide some numerical experiments (based on real and synthetic data) to demonstrate the superiority of our proposed estimators over existing ones such as MLE.

7.1.7 Data Injection Attacks in Power Systems

Monitoring and control processes in power systems are supported by supervisory control and data acquisition (SCADA) systems, and more recently, by advanced communication systems that acquire and transmit observations to a state estimator. This new sensing and communication infrastructure, which possesses security vulnerabilities, exposes the power system to malicious attacks. In this context, one of the main threats faced by modern power systems are data injection attacks (DIAs). A DIA can alter the state estimate obtained by the power-system operator by tampering with the observations (measurements) without triggering the attack detection system. In [61], S. M. Perlaza together with X. Ye, I. Esnaola, and R. F. Harrison (all from Univ. of Sheffield, UK) presented sparse attacks that minimize simultaneously the information obtained by the operator and the probability of detection. When the assumption on the sparsity is dropped, S. M. Perlaza together with S. Ke and I. Esnaola (both from Univ. of Sheffield) have studied these attacks in [51].

7.2 Random Graph and Random Matrix Models

Participants: Konstantin Avrachenkov, Maximilien Dreveton, Alain Jean-Marie.

7.2.1 Clustering Random Geometric Graphs

In [13], K. Avrachenkov, A. Bobu (former postdoctoral fellow in NEO) and M. Dreveton study clustering random geometric graphs. While the standard spectral clustering is often not effective for geometric graphs, they present an effective generalization, which they call higher-order spectral clustering (HOSC). It resembles in concept the classical spectral clustering method but uses for partitioning the eigenvector associated with a higher-order eigenvalue. They establish the weak consistency of this algorithm for a wide class of random geometric graphs which is called Soft Geometric Block Model. A small adjustment of the algorithm provides strong consistency. They also show that the HOSC method is effective in numerical experiments even for graphs of modest size.

7.2.2 Community Recovery in Temporal Networks

In [32], K. Avrachenkov and M. Dreveton together with L. Leskelä (Aalto Univ., Finland) study the recovery of static communities in a temporal network. They introduce a temporal stochastic block model where dynamic interaction patterns between node pairs follow a Markov chain. They render this model versatile by adding degree correction parameters, describing the tendency of each node to start new interactions. It is shown that in some cases the likelihood of this model is approximated by the regularized modularity of a time-aggregated graph. This time aggregated graph involves a trade-off between new edges and persistent edges. A continuous relaxation reduces the regularized modularity maximization to a normalized spectral clustering. The authors illustrate by numerical experiments the importance of edge persistence, both on simulated and real data sets.

7.2.3 Social Networking and Population Dynamics

In [63], A. Hodgkinson (Univ. Exter, UK) and A. Jean-Marie explore the hypothesis that the growth of a population may be limited by the social constraints on pair-bonding (necessary for reproduction in some societies) rather than by ecological constraints. They propose a novel nonlinear Markovian mechanism and embed it within a dynamic graph model, called the Dynamic Markovian Ecological Network (DyME-Net). They study in particular how subdivision in the population may overcome these nonlinearities.

7.3 Data Analysis and Learning

Participants: Konstantin Avrachenkov, Gabriele Castellano, Alain Jean-Marie, Mikhail Kamalov, Othmane Marfoq, Giovanni Neglia, Kishor Yashavant Patil, Samir Medina Perlaza, Tareq Si Salem, Chuan Xu, Oualid Zari.

7.3.1 Reinforcement Learning

In [50] K. Avrachenkov and K. Patil together with V.S. Borkar and H. Dolhare (both from Indian Institute of Technology Bombay) analyze the DQN reinforcement learning algorithm, reinforcement learning algorithm with a neural network, as a stochastic approximation scheme using the o.d.e. (for 'ordinary differential equation') approach and point out certain theoretical issues. They then propose a modified scheme called Full Gradient DQN (FG-DQN, for short) that has a sound theoretical basis and compare it with the original scheme on sample problems. They establish a rigorous convergence proof and observe a better performance for FG-DQN on the sample problems.

In [31] K. Avrachenkov and K. Patil together with V.S. Borkar from (Indian Institute of Technology Bombay) apply FG-DQN reinforcement learning algorithm to web crawling. Specifically, a search engine

uses a web crawler to crawl the pages from the world wide web (WWW) and aims to maintain its local cache as fresh as possible. Unfortunately, the rates at which different pages change in WWW are highly nonuniform and also, unknown in many real-life scenarios. In addition, the finite available bandwidth and possible server restrictions on crawling frequency make it very difficult for the crawler to find the optimal scheduling policy that maximizes the freshness of the local cache. We model this problem in a multi-armed restless bandits framework, where each arm represents a web page or an aggregate of statistically identical web pages. The objective is to find the scheduling policy that gives the exact indices of the pages to be crawled at a particular instance. We provide an online learning scheme using FG-DQN algorithm which learns the unknown page change dynamics on the fly along with the optimal crawling policy. Finally, we run numerical simulations to compare our approach with state-of-the-art algorithms such as static optimisation and Thompson sampling. We observe better performance for our approach.

7.3.2 Semi-supervised Learning

In [30], K. Avrachenkov and M. Kamalov together with A. Boisbunon (MyDataModels) propose a novel framework called Graph Diffusion & PCA (GDPCA) in the context of semi-supervised learning on graph structured data. It combines a modified Principal Component Analysis with the classical supervised loss and Laplacian regularization, thus handling the case where the adjacency matrix is sparse and avoiding the curse of dimensionality. Our framework can be applied to non-graph datasets as well, such as images by constructing similarity graph. GDPCA improves node classification by enriching the local graph structure by node covariance. We demonstrate the performance of GDPCA in experiments on citation networks and images, and we show that GDPCA compares favourably with the best state-of-the-art algorithms and has significantly lower computational complexity.

7.3.3 Personalized Federated Learning

The increasing size of data generated by smartphones and IoT devices motivated the development of *Federated Learning* (FL), a framework for on-device collaborative training of machine learning models. First efforts in FL focused on learning a single global model with good average performance across clients, but the global model may be arbitrarily bad for a given client, due to the inherent heterogeneity of local data distributions. Federated *multi-task learning* (MTL) approaches can learn *personalized models* by formulating an opportune penalized optimization problem. The penalization term can capture complex relations among personalized models, but eschews clear statistical assumptions about local data distributions.

In [40], O. Marfoq together with G. Neglia, A. Bellet (Inria team MAGNET), R. Vidal (Accenture Labs) and L. Kameni (Accenture Labs) propose to study federated MTL under the flexible assumption that each local data distribution is a *mixture of unknown underlying distributions*. This assumption encompasses most of the existing personalized FL approaches and leads to federated EM-like algorithms for both client-server and fully decentralized settings. Moreover, it provides a principled way to serve personalized models to clients not seen at training time. The algorithms' convergence is analyzed through a novel federated surrogate optimization framework, which can be of general interest. Experimental results on FL benchmarks show that this approach provides models with higher accuracy and fairness than state-of-the-art methods.

7.3.4 Privacy Leakage in Federated Learning

Federated learning offers naturally a certain level of privacy, as clients' data is not collected at a third party. However, maintaining the data locally does not provide itself formal privacy guarantees. An (honest-but-curious) adversary can still infer some sensitive client information just by eavesdropping the exchanged messages (e.g., gradients).

In [48], C. Xu, and G. Neglia, initiate the study of local model reconstruction attacks for FL, where a honest-but-curious adversary eavesdrops the messages exchanged between the client and the server and reconstructs the local model of the client. The success of this attack enables better performance of other known attacks, such as the membership attack, attribute inference attacks, etc. They provide analytical guarantees for the success of this attack when training a linear least squares problem with full batch size and arbitrary number of local steps. One heuristic is proposed to generalize the attack to other machine

learning problems. Experiments are conducted on logistic regression tasks, showing high reconstruction quality, especially when clients' datasets are highly heterogeneous (as it is common in FL).

In [49], O. Zari, C. Xu and G. Neglia, study the membership inference attack, where the adversary can infer whether the client owns a specific data instance. They propose a new passive inference attack that requires much less computation power and memory than existing methods. Empirical results show that this attack achieves a higher accuracy on CIFAR100 dataset (more than 4 percentage points) with three orders of magnitude less memory space and five orders of magnitude less calculations.

7.3.5 Dynamic Backup Workers for Parallel Machine Learning

In [26], C. Xu, G. Neglia, in collaboration with N. Sebastianelli (previous intern in NEO), study how to speed up the distributed training of machine learning models in the framework of synchronous parameters server. This paradigm consists of n workers, which iteratively compute updates of the model parameters, and a stateful PS, which waits and aggregates all updates to generate a new estimate of model parameters and sends it back to the workers for a new iteration. Transient computation slowdowns or transmission delays can intolerably lengthen the time of each iteration. An efficient way to mitigate this problem is to let the PS wait only for the fastest $n-b$ updates, before generating the new parameters. The slowest b workers are called backup workers. The correct choice of the number b of backup workers depends on the cluster configuration and workload, but also (as they show in this paper) on the hyper-parameters of the learning algorithm and the current stage of the training. They propose DBW, an algorithm that dynamically decides the number of backup workers during the training process to maximize the convergence speed at each iteration. The experiments show that DBW 1) removes the necessity to tune b by preliminary time-consuming experiments, and 2) makes the training up to a factor 3 faster than the optimal static configuration.

7.3.6 Distributed Inference

An increasing number of applications rely on complex inference tasks that are based on machine learning (ML). Currently, there are two options to run such tasks: either they are served directly by the end device (e.g., smartphones, IoT equipment, smart vehicles), or offloaded to a remote cloud. Both options may be unsatisfactory for many applications: local models may have inadequate accuracy, while the cloud may fail to meet delay constraints. In [44], T. Si Salem, G. Castellano, and G. Neglia, in collaboration with F. Pianese (Nokia Bell Labs), and A. Araldo (Télécom SudParis) present the novel idea of Inference Delivery Networks (IDNs), networks of computing nodes that coordinate to satisfy ML inference requests achieving the best trade-off between latency and accuracy. IDNs bridge the dichotomy between device and cloud execution by integrating inference delivery at the various tiers of the infrastructure continuum (access, edge, regional data center, cloud). Authors propose a distributed dynamic policy for ML model allocation in an IDN by which each node dynamically updates its local set of inference models based on requests observed during the recent past plus limited information exchange with its neighboring nodes. Their policy offers strong performance guarantees in an adversarial setting and shows improvements over greedy heuristics with similar complexity in realistic scenarios.

7.3.7 Empirical Risk Minimization with Relative Entropy Regularization

In the context of the exploratory action IDEM (Information and Decision Making), S. M. Perlaza and A. Jean-Marie, together with G. Bisson (Univ. de la Polynésie française), I. Esnaola (Univ. of Sheffield), and S. Rini (National Chiao Tung Univ.), studied the problem of empirical risk minimization (ERM) with relative entropy regularization (ERM-RER) in the context of supervised learning from the perspective of measure theory. In particular, the relative entropy is assumed to be with respect to a given measure, the reference measure, and not necessarily a probability mesure. This provides a unified treatment of two relevant problems in supervised learning. First, when the reference measure is a probability measure, the ERM-RER problem is shown to be a risk-information minimization problem. Alternatively, when the reference measure is the Lebesgue measure or a counting measure, the solution of the ERM-RER problem is shown to be identical to the solution to an entropy minimization problem with linear constraints, as the one typically induced by Jayne's maximum entropy principle. The main result consists in a number of

properties for the solution to the ERM-RER in terms of the reference measure, the regularization factor, and the training data. Some of the most important properties are described hereunder:
(i) The optimal solution to the ERM-RER is a probability measure that is unique and concentrates into a set arbitrarily small containing the minimizers of the empirical risk with arbitrarily high probability. The tradeoff between the cardinality of such set and the probability is governed by the regularization factor.
(ii) The expected value of the empirical risk, with respect to the ERM-RER optimal measure, is decreasing with the regularization factor. Nonetheless, via simple examples, monotonicity of the variance and higher cumulants is shown to be subject to conditions.
(iii) The transport of the ERM-RER optimal measure through the loss function is a sub-Gaussian probability measure. This property is central to study the sensitivity of the empirical risk for a particular data set with respect to changes around the optimal ERM-RER optimal measure.

7.3.8 Advanced Methods for Data Analytics in Power Systems

A broad view at some advanced topics in data analytics for power systems is presented in the book [52], edited by S. M. Perlaza together with Ali Tajer (Rensselaer Polytechnic Institute, NY, USA) and H. Vincent Poor (Princeton Univ., USA). Therein, experts in data analytics and power engineering present techniques addressing the needs of modern power systems, covering theory and applications related to power system reliability, efficiency, and security. The book explores topics spanning large-scale and distributed optimization, statistical learning, big data analytics, graph theory, and game theory.

7.3.9 Data Analytics for Health Assesments

In [22], S. M. Perlaza and collaborators at Edhec Business School (Nice, France), HEC Montreal (Montreal, QC, Canada), Cimiez Hospital (Nice, France), Univ. Hospital of Nice (Nice, France), Paul Brousse Hospital (Paris, France), and Centre Hospitalier Le Vinatier (Lyon, France), assessed the impact of the COVID-19 pandemic on hospital workers' psychological parameters and attitudes toward substance use, before and during the French COVID-19 lockdown. An online survey was proposed to the staff of the University Hospital of Nice and Sainte-Marie psychiatric hospital in France assessing changes in daily habits, psychological distress and changes in substance use, including smoking. During the first lockdown, significant psychological changes (sadness, distress, irritability) associated with changes in tobacco use and physical activity were reported. Such results should encourage hospital leaders to implement dedicated policies to better accompany hospital workers' psychological distress. Data analysis suggests that negative changes in health behaviors are associated with increased psychological distress in hospital workers during the COVID-19 lockdown. Tobacco consumers are having increased psychological distress than their non-consuming counterparts. Health promotion strategies aimed at embracing or preserving positive health behaviors should go toward reducing critical and chronic increases in psychological distress during these unparalleled times. Ongoing assessment of the impact of lockdown and social distancing on health behaviors is needed to shape targeted health promotion strategies.

7.4 Game Theory and Applications

Participants: Eitan Altman, Konstantin Avrachenkov, Mandar Datar, Alain Jean-Marie, Samir Medina Perlaza.

7.4.1 Dynamic Social Learning under Graph Constraints

In [14], K. Avrachenkov together with V.S. Borkar, S. Moharir and S. M. Shah (all from Indian Institute of Technology Bombay) introduce a model of graph-constrained dynamic social choice with reinforcement modeled by positively α-homogeneous rewards. They show that its empirical process, which can be written as a stochastic approximation recursion with Markov noise, has the same probability law as a certain vertex reinforced random walk. Furthermore, its fluid limit has a relation to the replicator dynamics. They use these equivalences to show that for $\alpha > 0$, the asymptotic outcome concentrates around the optimum in a certain limiting sense when 'annealed' by letting $\alpha \to \infty$ slowly.

7.4.2 Routing games on loss networks

The work [36] is the fourth in a series of papers that appeared in international conferences that came out of homework by students in a course by E. Altman on initiation to research on routing games. The students, S. Dalalli and C. Fontaine were in their 3rd year in Central-Supelec. They consider a splittable atomic game with lossy links on a ring in which the cost that each player i minimizes is their own loss rate of packets. The costs are therefore non-additive (unlike costs based on delays or tolls) and moreover, there is no flow conservation (total flow entering a link is greater than the flow leaving it). We derive a closed-form for the equilibrium, which allows us to obtain insight on the structure of the equilibrium. We also derive the globally optimal solution and obtain conditions for the equilibrium to coincide with the globally optimal solution.

7.4.3 Epidemic Games

Epidemiology relies on models for propagation in populations through various types of propagation mechanisms. The control of such propagation may be useful in different contexts: in broadcasting information, in epidemic advertisement, in fighting against intrusion and denial of service and more generally in protection in context of cyberwar. On the other hand game theory is a powerful tool for protection against epidemics, and in particular pandemics such as the one due to SARS-CoV-2 (coronavirus). We have been studying during 2021 two game theoretic epidemic models for the study of cooperation versus free riding within various population types. This includes the mask game and the vaccination game.

The Mask Game. Wearing a mask provides partial protection against epidemics but at some cost of discomfort. The players can be differentiated according to both their risk-state as well as their health-state (susceptible, infected and recovered). E. Altman, M. Datar, and S. M. Perlaza in cooperation with F. de Pellegrini (Univ. of Avignon) and D. Sadoc Menasche (Federal Univ. of Rio de Janeiro, Brazil) formulate the problem as a Bayesian game [11]. A player takes decisions based on their own risk-state. Yet they have no information on the health and risk-state of the interacting players. They may not know their own health-state. Using ideas inspired from evolutionary games, we reduce the problem into a one shot equivalent game and derive the equilibrium.

The Vaccination Game. In the second game, E. Altman studied [27] the case in which each player decides whether to purchase a vaccine or not, and if so, then they further decide which vaccine to purchase among a finite number of vaccine producers. The players need not be indistinguishable. A potential consumer belongs to a risk type that characterizes how important it is for them to be vaccinated. The cost of a vaccine may depend on the demand, on the cost of the production, and on the consumer's class. We prove the existence of an equilibrium within pure policies in the general multipopulation case. We further derive some properties of the equilibria in the case of a single risk-class.

7.4.4 Games of Water Extraction

In [18], A. Jean-Marie together with M. Tidball (INRAe, France) and V. Bucarey (Univ. O'Higgins, Chile), consider a discrete time, infinite horizon dynamic game of groundwater extraction. A Water Agency charges an extraction cost to water users, and controls the marginal extraction cost so that it depends, not only on the level of groundwater, but also on total water extraction (through a parameter n that represents the degree of strategic interactions between water users) and on rainfall (through parameter m). The water users are selfish and myopic, and the goal of the agency is to give them incentives so as to improve their total discounted welfare. The authors look at this problem in several situations. In the first situation, the parameters n and m are considered to be fixed over time. A first result shows that when the Water Agency is patient (the discount factor tends to 1) the optimal marginal extraction cost asks for strategic interactions between agents. The contrary holds for a discount factor near 0. In a second situation, the authors look at the dynamic Stackelberg game where the Agency decides at each time what cost parameter they must announce. they study theoretically and numerically the solution of this problem. Simulations illustrate the possibility that threshold policies are good candidates for optimal policies.

In [57], A. Jean-Marie, T. Jimenez (Univ. Avignon) and M. Tidball (INRAe, France), consider the application of conjectural learning to a water management model. They introduce the family of Conjectural Learning procedures, in which agents form conjectures about what the opponent will play, as a function of their action or some state variable. They prove general properties of these procedures, comparing them to two dynamic systems generated by nearsighted agents solving repeatedly a static game, either cooperatively, or noncooperatively. They then specify three simple functional forms of conjectures and analyze the five resulting dynamic systems, in terms of steady states and convergence conditions. They next further specify these procedures to the case of a game of groundwater management, using a quadratic functional form for the profit function of agents. They obtain then explicit expressions for steady states and convergence conditions for the dynamic systems. Finally, they conduct numerical experiments in order to assess the "performance" of pairs of agents adopting each of the five behaviors.

7.5 Applications in Telecommunications

7.5.1 Caching

Participants: Olga Chuchuk, Guilherme Iecker Ricardo, Giovanni Neglia, Tareq Si Salem.

Online Learning Algorithms for Caching. In [46], T. Si Salem and G. Neglia in collaboration with S. Ioannidis (Northeastern Univ., USA) study an online caching problem in which requests can be served by a local cache to avoid retrieval costs from a remote server. The cache can update its state after a batch of requests and store an arbitrarily small fraction of each content. They study no-regret algorithms based on Online Mirror Descent (OMD) strategies and show that the choice of OMD strategy depends on the request diversity present in a batch and that OMD caching policies may outperform traditional eviction based policies. In [20], T. Si Salem and G. Neglia in collaboration with Y. Li, and S. Ioannidis (Northeastern Univ., USA) study a cache network under arbitrary adversarial request arrivals. They propose a distributed online policy based on the online tabular greedy algorithm. Their distributed policy achieves sublinear $(1-1/e)$-regret, also in the case when update costs cannot be neglected. Numerical evaluation over several topologies supports their theoretical results and demonstrates that their algorithm outperforms state-of-art online cache algorithms.

Caching in dense cellular networks. In 5G and beyond network architectures, operators and content providers base their content distribution strategies on Heterogeneous Networks, where macro and small(er) cells are combined to offer better Quality of Service (QoS) to wireless users. On top of such networks, edge caching and Coordinated Multi-Point (CoMP) transmissions are used to further improve performance. The problem of optimally utilizing the cache space in dense and heterogeneous cell networks has been extensively studied under the name of "FemtoCaching." However, the literature usually assumes relatively simple physical layer (PHY) setups and known or stationary content popularity.

In [24], G. Neglia and G. Iecker Ricardo, together with E. Leonardi (Politechnic Univ. of Turin, Italy) and T. Spyropoulos (EURECOM) present qLRU-Δ, a general-purpose online caching policy that can be tailored to optimize different performance metrics also in presence of coordinated multipoint transmission techniques. The policy requires neither direct communication among BSs, nor a priori knowledge of content popularity and, under stationary request processes, has provable performance guarantees.

In [25], G. Iecker Ricardo and G. Neglia, together with T. Spyropoulos (EURECOM), address the average delay minimization problem by first formulating it as a static optimization problem. Even though the problem is NP-hard they are able to solve it via an efficient algorithm that guarantees a 1/2-approximation ratio. They then proceed to propose two fully distributed and dynamic caching policies for the same problem. The first one asymptotically converges to the static optimal solution under the Independent Reference Model (these results rely on the general framework proposed in [24]. The second one provides better results in practice under real (nonstationary) request processes. These online policies outperform existing dynamic solutions that are PHY-unaware. In [38], G. Iecker Ricardo and G. Neglia, together with T. Spyropoulos (EURECOM), extend these results to the case when files have heterogeneous sizes.

Caching for CERN Experimental Data. In [16], O. Chuchuk, together with A. Di Girolamo, M. Lassnig, M. Schulz, A. Sciaba (all four from CERN, Geneva, Switzerland), T. Beermann (Bergische Univ. Wuppertal, Germany), M. Grigorieva (Lomonosov Moscow State Univ., Russian Federation), A.Klimentov (Brookhaven National Laboratory, USA), and E.Tretyakov (National Research Nuclear Univ. MEPhI, Russian Federation) have performed a multilateral evaluation of the complete data life cycle of the ATLAS Experiment at the Large Hadron Collider. This experiment generates petabytes of data that is distributed among 160 computing sites all over the world and is processed continuously by various central production and user analysis tasks. The popularity of data, which is typically measured as the number of accesses, plays an important role in resolving data management issues: deleting, replicating, moving between tapes, disks and caches. Previously, these data management procedures were carried out in a semi-manual mode and in this study the efforts have been focused on automating it, making use of the historical knowledge about existing data management strategies. The authors described the sources of information about data popularity and demonstrated their consistency. Based on the calculated popularity measurements, various distributions were obtained. Auxiliary information about replication and task processing allowed them to evaluate the correspondence between the number of tasks with popular data executed per site and the number of replicas per site. They also examine the popularity of user analysis data that is much less predictable than in the central production and requires more indicators than just the number of accesses.

Similarity Caching. In similarity caching systems, a user request for an object o that is not in the cache can be (partially) satisfied by a similar stored object o', at the cost of a loss of user utility. Similarity caching systems can be effectively employed in several application areas, like multimedia retrieval, recommender systems, genome study, and machine learning training/serving. However, despite their relevance, the behavior of such systems is far from being well understood.

In [23], G. Neglia, in collaboration with M. Garetto (Univ. of Turin, Italy), and E. Leonardi (Politechnic Univ. of Turin, Italy), provides a first comprehensive analysis of similarity caching in the offline, adversarial, and stochastic settings. The authors show that similarity caching raises significant new challenges, for which we propose the first dynamic policies with some optimality guarantees. They evaluate the performance of the proposed schemes under both synthetic and real request traces.

In [42], T. Si Salem and G. Neglia in collaboration with A. Sabnis, R. K. Sitaraman (Univ. of Massachusetts Amherst, USA), M. Garetto (Univ. of Turin, Italy), and E. Leonardi (Politechnic Univ. of Turin, Italy) propose a policy that uses gradient descent to navigate the continuous embedding space of objects and find the optimal objects to store in the cache.

In [45], T. Si Salem and G. Neglia in collaboration with D. Carra (Univ. of Verona, Italy) present AÇAI, a new similarity caching policy which improves on the state of the art by using (i) an (approximate) index for the whole catalog to decide which objects to serve locally and which to retrieve from the remote server, and (ii) a mirror ascent algorithm to update the set of local objects with strong guarantees even when the request process does not exhibit any statistical regularity. This paper received the best paper award at ITC 2021.

The k-Nearest Neighbors method aims at efficiently finding items close to a query in a large collection of objects, and it is used in different applications, from image retrieval to recommendation. These applications achieve high throughput combining two different elements: 1) approximate nearest neighbours searches that reduce the complexity at the cost of providing inexact answers and 2) caches that store the most popular items. In [35], G. Neglia, in collaboration with D. Carra (Univ. of Verona, Italy), proposes to combine the approximate index for the whole catalog with a more precise index for the items stored in the cache. Experiments on realistic traces show that this approach is doubly advantageous as it 1) improves the quality of the final answer provided to a query, 2) additionally reduces the service latency.

In [17], G. Neglia, in collaboration with M. Garetto (Univ. of Turin, Italy), and E. Leonardi (Politechnic Univ. of Turin, Italy), makes a first step into the novel area of similarity caching networks, where requests can be forwarded along a path of caches to get the best efficiency–accuracy tradeoff. The offline problem of content placement can be easily shown to be NP-hard, while different polynomial algorithms can be devised to approach the optimal solution in discrete cases. As the content space grows large, the authors propose a continuous problem formulation whose solution exhibits a simple structure in a class of tree topologies. They verify their findings using synthetic and realistic request traces.

7.5.2 5G Cellular Networks

Participants: Eitan Altman, Mandar Datar, Marie Masson, Samir Medina Perlaza, Sadaf Ul Zuhra.

Several networking applications studied in NEO are specifically on 5G or 6G networks.

Scheduling and Coordination in 5G access. In [41], M. Masson, Z. Altman from Orange Labs and E. Altman consider a network with Massive Multiple Input Multiple Output (M-MIMO) base stations using a Grid of Beams (GoB) for data and control channels. 5G allows to establish interference relations between beams of neighboring cells. Such relations can be used to automatically generate a beam relation matrix, denoted as Automatic Neighbor Beam Relation (ANBR) matrix that can be very useful for optimizing different resource allocation processes. This paper shows how the ANBR matrix can be used to coordinate scheduling of neighboring cells with a small amount of information exchange. The coordination is performed by judicially muting or reducing the bandwidth of certain beams in the process of MultiUser (MU) Proportional Fair (PF) scheduling. Numerical results show how the coordination approach can bring about significant performance gain.

Slicing and Resource Allocation. Network Slicing is one of the essential concepts that has been introduced in 5G networks design to support demand expressed by next generation services. Network slicing will also bring new business opportunities for service providers (SPs) and virtual network operators, allowing them to run their virtual, independent business operations on shared physical infrastructure. In [37], M. Datar and E. Altman consider a marketplace where service providers (SPs) i.e., slice tenants lease the resources from an infrastructure provider (InP) through a network slicing mechanism. They compete to offer a certain communication service to end-users. We show that the competition between SPs can be model using the multiresource Tullock contest (TC) framework, where SPs exert effort by expending costly resource to attract users. We study the competition between the SPs under a static and dynamic resource sharing scheme. In a dynamic resource sharing scheme, SPs are pre-assigned with fixed shares (budgets) of infrastructure, and they are allowed to redistribute their shares and customise their allocation to maximise their profit. The decision problem of SPs is analysed using non-cooperative game theory, and it is shown that the resultant game admits a unique Nash Equilibrium (NE). Furthermore, a distributed reinforcement algorithm is proposed that allows each SP to reach the game's unique Nash equilibrium. Finally, simulations results are conducted to analyse the interaction between market players and the economic efficacy of the network sharing mechanism.

Fundamental Bounds on the Amount of Transmitted Information. Mobile phones rely on batteries to provide the power needed for transmission and for reception (up and downlink communications). Considering uplink, E. Altman, M. Datar and G. Ferrat (former intern in NEO) analyse in [28] how the characteristics of the battery affect the amount of information that one can draw out from the terminal. They focus in particular on the impact of the charge in the battery on the internal resistance which grows as the battery depletes.

Simultaneous Information and Energy Transmission. Battery dependency is a critical issue when communications systems are deployed in hard-to-reach locations, e.g., remote geographical areas, concrete structures, human bodies, or disaster/war zones. In this case, the lifetime of the electronic devices or even the whole communications system is determined by the battery life. An effective remedy is using energy harvesting technologies. Specifically, energy can be harvested from different ambient sources such as light, vibrations, heat, chemical reactions, physiological processes, or the radio frequency (RF) signals produced by other communications systems. This observation rises the idea of simultaneous information and energy transmission (SIET) via RF. In [47] and [62], S. U. Zuhra, S. M. Perlaza, and E. Altman have studied the fundamental limits on the rates at which information and energy can be simultaneously transmitted over an additive white Gaussian noise channel. The underlying assumption is that the number of channel input symbols (constellation size) is finite. The main results are mathematical expressions of

the achievable and converse information-energy rates as a function of the constellation size, number of channel uses, decoding error probability, and energy-outage probability. As a by product, guidelines for optimal constellation design for SIET are obtained in terms of all real-system implementation parameters.

7.5.3 Graph Neural Networks based Scheduling

Participants: Eitan Altman, Ramakrishnan Sambamoorthy.

In [43], R. Sambamoorthy and E. Altman in cooperation with J. Mandalapu, S. Peruru, B. Jain (IIT Madras and Kanpur) propose a Graph Convolutional Neural Networks (GCN) based scheduling algorithm for ad-hoc networks. In particular, we consider a generalized interference model called the k-tolerant conflict graph model and design an efficient approximation for the well-known Max-Weight scheduling algorithm. A notable feature of this work is that the proposed method do not require labeled data set (NP-hard to compute) for training the neural network. Instead, we design a loss function that utilises the existing greedy approaches and trains a GCN that improves the performance of greedy approaches. Our extensive numerical experiments illustrate that using our GCN approach, we can significantly (4-20 percent) improve the performance of the conventional greedy approach.

7.5.4 Distributed Denial of Service Attacks

Participant: Philippe Nain.

Botnets such as Mirai use insecure home devices to conduct Distributed Denial of Service (DDoS) attacks on the Internet infrastructure. Although some of those attacks involve large amounts of traffic, they are generated from a large number of homes, which hampers their early detection. In [12], P. Nain in collaboration with A. Ramtin and D. Towsley (both from Univ. Massachusetts), D. Sadoc Menasche and E. de Souza e Silva (both from Federal Univ. of Rio Janeiro), addresses the following question: what is the maximum amount of damage that a DDoS attacker can produce at the network edge without being detected? To that aim, the authors consider a statistical hypothesis testing approach for attack detection at the network edge. The proposed system assesses the goodness of fit of traffic models based on the ratio of their likelihoods. Under such a model, it is shown that the amount of traffic that can be generated by a covert attacker scales according to the square root of the number of compromised homes. Theoretical results are evaluated and validated using real data collected from thousands of home-routers connected to a mid-sized Internet service provider.

8 Bilateral contracts and grants with industry

8.1 Bilateral contracts with industry

NEO members are involved in the

- Inria-Nokia Bell Labs joint laboratory: the joint laboratory consists of five ADRs (Action de Recherche/ Research Action) in its third phase (starting October 2017). NEO members participate in two ADRs: “Distributed Learning and Control for Network Analysis” (see §8.1.1) and “Rethinking the network: virtualizing network functions, from middleboxes to application” (see §8.1.2);

- Inria-Orange Labs joint laboratory (see §8.1.3).

NEO has contracts with Accenture (see §8.1.4), MyDataModels (see §8.1.5), Qu’Est-Ce Qui Tourne (see §8.1.6), and NSP (see §8.1.7).

8.1.1 ADR Nokia on the topic "Distributed Learning and Control for Network Analysis" (October 2017 – September 2021)

Participants: Eitan Altman, Konstantin Avrachenkov, Jake Clarkson, Mandar Datar, Maximilien Dreveton.

- Contractor: Nokia Bell Labs
- Collaborator: Gérard Burnside

Over the last few years, research in computer science has shifted focus to machine learning methods for the analysis of increasingly large amounts of user data. As the research community has sought to optimize the methods for sparse data and high-dimensional data, more recently new problems have emerged, particularly from a networking perspective that had remained in the periphery.

The technical program of this ADR consists of three parts: Distributed machine learning, Multiobjective optimisation as a lexicographic problem, and Use cases / Applications. We address the challenges related to the first part by developing distributed optimization tools that reduce communication overhead, improve the rate of convergence and are scalable. Graph-theoretic tools including spectral analysis, graph partitioning and clustering will be developed. Further, stochastic approximation methods and D-iterations or their combinations will be applied in designing fast online unsupervised, supervised and semi-supervised learning methods.

8.1.2 ADR Nokia on the topic "Rethinking the network: virtualizing network functions, from middleboxes to application" (October 2017 – February 2022)

Participants: Sara Alouf, Gabriele Castellano, Giovanni Neglia.

- Contractor: Nokia Bell Labs
- Collaborators: Fabio Pianese, Massimo Gallo

A growing number of network infrastructures are being presently considered for a software-based replacement: these range from fixed and wireless access functions to carrier-grade middle boxes and server functionalities. On the one hand, performance requirements of such applications call for an increased level of software optimization and hardware acceleration. On the other hand, customization and modularity at all layers of the protocol stack are required to support such a wide range of functions. In this scope the ADR focuses on two specific research axes: (1) the design, implementation and evaluation of a modular NFV architecture, and (2) the modelling and management of applications as virtualized network functions. Our interest is in low-latency machine learning prediction services and in particular how the quality of the predictions can be traded off with latency.

8.1.3 Orange CIFRE on the topic "Self-organizing features in the virtual 5G radio access network" (November 2017 – October 2020)

Participants: Eitan Altman, Marie Masson.

- Contractor: Orange Labs
- Collaborator: Zwi Altman

The considerable extent of the complexity of 5G networks and their operation is in contrast with the increasing demands in terms of simplicity and efficiency. This antagonism highlights the critical importance of network management. Self-Organizing Networks (SON), which cover self-configuration, self-optimization and self-repair, play a central role for 5G Radio Access Network (RAN).

This CIFRE thesis aims at innovating in the field of managing 5G RAN, with a special focus on the features of the SON-5G. Three objectives are identified: a) develop self-organizing features (SON in 5G-RAN), b) develop cognitive managing mechanisms for the SON-5G features developed, and c) demonstrate how do the self-organizing mechanisms fit in the virtual RAN.

8.1.4 Accenture contract on the topic "Distributed Machine Learning for IoT applications" (Dec 2019 – November 2023)

Participants: Othmane Marfoq, Giovanni Neglia.

- Contractor: Accenture Labs
- Collaborators: Laetitia Kameni, Richard Vidal

IoT applications will become one of the main sources to train data-greedy machine learning models. Until now, IoT applications were mostly about collecting data from the physical world and sending them to the Cloud. Google's federated learning already enables mobile phones, or other devices with limited computing capabilities, to collaboratively learn a machine learning model while keeping all training data locally, decoupling the ability to do machine learning from the need to store the data in the cloud. While Google envisions only users' devices, it is possible that part of the computation is executed at other intermediate elements in the network. This new paradigm is sometimes referred to as Edge Computing or Fog Computing. Model training as well as serving (provide machine learning predictions) are going to be distributed between IoT devices, cloud services, and other intermediate computing elements like servers close to base stations as envisaged by the Multi-Access Edge Computing framework. The goal of this project is to propose distributed learning schemes for the IoT scenario, taking into account in particular its communication constraints. A first 12-month pre-PhD contract has been followed by a PhD grant.

8.1.5 MyDataModels contract on the topic "Semi-supervised variational autoencoders for versatile data" (June 2019 – May 2022)

Participants: Konstantin Avrachenkov, Mikhail Kamalov.

- Contractor: MyDataModels
- Collaborators: Denis Bastiment, Aurélie Boisbunon

Variational autoencoders are highly flexible machine learning techniques for learning latent dimension representation. This model is applicable for denoising data as well as for classification purposes. In this thesis we plan to add semi-supervision component to the variational autoencoder techniques. We plan to develop methods which are universally applicable to versatile data such as categorical data, images, texts, etc. Initially starting from static data we aim to extend the methods to time-varying data such as audio, video, time-series, etc. The proposed algorithms can be integrated into the internal engine of MyDataModels company and tested on use cases of MyDataModels.

8.1.6 Qu'est-ce qui tourne contract on "Recommendation system for automatic suggestion of theatres to show producers" (1 January 2021 – 31 July 2021)

Participants: Konstantin Avrachenkov, Alain Jean-Marie.

- Contractor: Qu'est-ce qui tourne (QQT)
- Collaborators: Pierre Beffeyte, Benoit Justeau

In this project, together with InriaTech (Jean-Luc Szpyrka, Riham Nehmeh), we have designed, prototyped and tested a recommendation system for automatic suggestion of theatres to show producers. In particular, it was very interesting to observe that our Personalized PageRank, graph-based recommendation system performs much better than a more standard text-based recommendation system.

8.1.7 NSP-SmartProfile contract on the topic "Recommendation systems with heterogeneous data" (1 March 2021 – 31 August 2021)

Participants: Konstantin Avrachenkov, Ibtihal El Mimouni.

- Contractor: NSP-SmartProfile
- Collaborators: Julien Musso, Hervé Baile

SmartProfile is a marketing platform that allows to collect, to enhance and to analyse marketing data. Typically the data is very heterogeneous (binary data, integer numbers, real numbers, functional data, images, etc) This contract was funding the internship of Ibtihal El Mimouni on the exploratory investigation of recommendation systems with heterogeneous data. Currently, we are following up with Cifre application.

9 Partnerships and cooperations

9.1 International initiatives

9.1.1 Participation in other International Programs

The Embassy of France in the United States, via the progamme "make our planet great again", has funded an initiative led by S. M. Perlaza and A. Tajer (RPI, USA) for addressing foundational questions pertinent to two emerging wireless communication technologies: (i) energy harvesting (EH) systems, and (ii) ultra low-latency systems for critical missions. This project explores two strongly symbiotic research directions for establishing the fundamental limits of (i) data transmission and, (ii) simultaneous energy and data transmission, in mission critical systems empowered by EH. The expected results have applications in, e.g., disaster relief, medical instruments, cyber-physical systems, and the Internet of things. This program was launched by the President of France Emmanuel Macron in June 2017 and handled by the Embassy of France in the United States of America. The aim of such fellowships is to reinforce the international engagements of the 2015 Paris Agreement on Climate Change by fostering collaborations between scholars in both US and France.

9.2 International research visitors

9.2.1 Visits of international scientists

Other international visits to the team

Francescomaria Faticanti

Status (researcher, PhD, post-Doc, intern (master/eng)) Researcher

Institution of origin: Fondazione Bruno Kessler

Country: Italy

Dates: 13–16 December 2021

Context of the visit: Research in the framework of Inria Exploratory Action MAMMALS

Mobility program/type of mobility: Research stay

9.2.2 Visits to international teams

Research stays abroad

Samir Medina Perlaza

Visited institution: Laboratory of Algebraic Geometry and Applications to Information Theory (French acronym: GAATI)

Country: French Polynesia

Dates: May 1 - October 30. 2021 (Six Months)

Context of the visit: This research stay was dedicated to work on theoretical machine learning. In particular, together with G. Bisson (GAATI), the problem of empirical risk minimization with relative entropy regularization was studied from the perspective of measure and information theory.

Mobility program/type of mobility: Research Stay and Keynote at the Conference GTA-2021

9.3 European initiatives

9.3.1 FP7 & H2020 projects

TESTBED2

Participants: Samir Medina Perlaza, Sadaf Ul Zuhra.

Project Acronym: TESTBED2

Project Title: Testing and Evaluating Sophisticated information and communication Technologies for enaBling scalablE smart griD Deployment

Coordinator: University of Durham, UK.

Duration: February 2020 – January 2024

Others Partners: The University of Durham (UDUR); University of Tuebingen (EKUT); Heriot-Watt University (HWU); University of Klagenfurt (AAU); University of Northumbria at Newcastle (UNN); DotX Control Solutions (DotX); BEIA Consult International (BEIA); DEPSys (DEPS); Hellenic Telecommunications Organization S.A (OTE); Princeton University (PU); University of California, Santa Barbara (UC); University of Nebraska–Lincoln (UNL); Institute of Electrical Engineering of the Chinese Academy of Sciences (CAS); China Electric Power Research Institute (EPRI); Southeast University (SEU); and Jinan University (JNU)

Abstract: TESTBED2 is a major interdisciplinary project that combines wisdoms in three academic disciplines - Electronic & Electrical Engineering, Computing Sciences and Macroeconomics, for developing new techniques to improve the scalability of smart grid services, particularly considering the joint evolution of decarbonised power, heat and transport systems. Moreover, new experimental testbeds will be created to evaluate scalable smart grid solutions. Overall, the main objective of this project is to coordinate the action of 12 Universities and 5 companies (3 SMEs and 2 large companies) with complementary expertise to develop and test various promising strategies for ensuring the scalability of smart grid services, thereby facilitating successful deployment and full roll-out of smart grid technologies.

9.4 National initiatives

PIA ANSWER

Participants: Konstantin Avrachenkov, Kishor Yashavant Patil.

Project Acronym: ANSWER

Project Title: Advanced aNd Secured Web Experience and seaRch

Coordinator: QWANT

Duration: 15 November 2017 – 31 July 2021

Others Partners: Inria Project-Teams WIMMICS, INDES, COFFEE

Abstract: ANSWER is a joint project between QWANT and Inria, funded by the French Government's initiative PIA "Programme d'Investissement d'Avenir".

The aim of the ANSWER project is to develop the new version of the search engine of Qwant by introducing radical innovations in terms of search criteria as well as indexed content and security. This initiative is a part of the Big Data Big Digital Challenges field, since a Web search engine deals with large volumes of heterogeneous and dynamic data.

Of the five characteristics of big data, the ANSWER project will focus more particularly on the aspects of Velocity in terms of near real-time processing of results, and Variety for the integration of new indicators (emotions, sociality, etc.) and meta-data. The Volume, Value and Veracity aspects will necessarily be addressed jointly with these first ones and will also be the subject of locks, especially on the topics of crawling and indexing.

This registration of the search engine in the Big Data domain will only be reinforced by developments in the Web such as the Web of data, and generally by the current trend to integrate the Web of increasingly diverse, rich and complex resources.

ANR MAESTRO5G

Participant: Eitan Altman.

Project Acronym: MAESTRO5G

Project Title: MAnagEment of Slices in The Radio access Of 5G networks

Coordinator: Orange Labs

Duration: February 2019 – January 2022

Others Partners: Nokia Bell Labs, U. Avignon, Inria Project-Team AGORA, Sorbonne U., Telecom SudParis, CentraleSupélec.

Abstract: The project develops enablers for implementing and managing slices in the 5G radio access network, not only for the purpose of serving heterogeneous services, but also for dynamic sharing of infrastructure between operators. MAESTRO-5G develops a framework for resource allocation between slices and a business layer for multi-tenant slicing. It provides an orchestration framework based on Software Define Networking that manages resources and virtual functions for slices. A hardware demonstrator brings the slicing concept to reality and showcases the project's innovations.

Exploratory action Inria MAMMALS

Project Acronym: MAMMALS

Project Title: Memory-augmented Models for low-latency Machine-learning Serving

Coordinator: Giovanni Neglia

Duration: November 2020 - November 2022

Others Partners: Univ. Turin, Polytechnic Turin, Univ. Verona, Univ. of Massachusetts, Northeastern Univ.

Abstract: A machine learning model is often trained for inference's purposes. Inference does not involve complex iterative algorithms and is therefore generally presumed to be easy. Nevertheless, it presents fundamental challenges that are likely to become dominant as machine learning adoption increases and machine learning systems are ubiquitously deployed and need to make timely and safe decisions in unpredictable environments. MAMMALS aims to provide low-latency inferences by running—close to the end user—simple machine learning models that can also take advantage of a (small) local data store of examples. The focus is on algorithms to learn online what to store locally to improve inference quality and achieve domain adaptation.

Exploratory action Inria IDEM

Project Acronym: IDEM

Project Title: Information and Decision Making

Coordinators: Samir Medina Perlaza, Alain Jean-Marie

Duration: November 2021 - November 2023

Others Partners: Univ. of Sheffield, the National Chiao Tung Univ. in Taiwan, Princeton Univ.

Abstract: IDEM aims to characterize the interplay between data acquisition and information processing in decentralized decision making by bringing together tools from information theory and game theory. This characterization is central in the comprehension of problems including decentralized optimization and Machine Learning subject to local information constraints.

10 Dissemination

Participants: Sara Alouf, Eitan Altman, Konstantin Avrachenkov, Othmane Marfoq, Alain Jean-Marie, Philippe Nain, Giovanni Neglia, Samir Medina Perlaza, Tareq Si Salem, Chuan Xu.

10.1 Promoting scientific activities

10.1.1 Scientific events: organisation

Conference steering committee member

- NetGCoop: Workshop on Networking Games Control and Optimization (E. Altman, chairman)
- WiOpt: Workshop on Modeling and Optimization in Mobile, Ad Hoc and Wireless Networks (E. Altman)
- Valuetools: Conference on Performance Evaluation Methodologies and Tools (E. Altman)
- InThingS: Workshop on Intelligent Things and Services (G. Neglia).
- WSA 2021: The 25th International Workshop on Smart Antennas, Special Session on Security and Privacy for Future Wireless Communication Systems. November 10-12, 2021, Sophia Antipolis, France. (S. M. Perlaza)

Member of the organizing committees

- IEEE MedComNet: 19th Mediterranean Communication and Computer Networking Conference, 15-17 June 2021, Online (C. Xu).

10.1.2 Scientific events: selection

Member of the conference program committees

- ACM Sigmetrics/IFIP Performance 2022 (Mumbai, India) (S. Alouf, K. Avrachenkov);
- ACM Sigmetrics 2021 (Beijing, China) (S. Alouf);
- Complex Networks 2021 (K. Avrachenkov);
- Conference on Decision and Game Theory for Security, GameSec 2021 (K. Avrachenkov);
- 14th EAI International Conference on Performance Evaluation Methodologies and Tools, Valuetools 2021 (online) (K. Avrachenkov, A. Jean-Marie);
- 17th European Performance Evaluation Workshop, EPEW 2021 (online) (A. Jean-Marie);
- European Wireless 2021 (S. M. Perlaza);
- IEEE INFOCOM 2022 (online) (G. Neglia);
- IEEE 29th International Symposium on the Modeling, Analysis and Simulation of Computer and Telecommunication Systems, MASCOTS 2021 (Houston, USA) (A. Jean-Marie);
- IEEE International Workshop on Pervasive and Resource-constrained Artificial Intelligence, PeR-ConAI 2022 (G. Neglia);
- IEEE International Conference on Communications (ICC) (S. M. Perlaza);
- IEEE International Symposium on Personal, Indoor and Mobile Radio Communications, PIMRC (S. M. Perlaza);
- 33nd International Teletraffic Congress, ITC 33 (Avignon, France) (K. Avrachenkov, A. Jean-Marie);
- IEEE Wireless Communications and Networking Conference, WCNC (S. M. Perlaza);
- 26th International Conference on Analytical & Stochastic Modelling Techniques & Applications, ASMTA 2021 (K. Avrachenkov);

- International Conference on Computer Communications and Networks, ICCCN 2021, Social Networks and Computing Track (K. Avrachenkov);
- International Symposium on Modeling and Optimization in Mobile, Ad hoc, and Wireless Networks, WiOpt 2021 (K. Avrachenkov);
- 2nd International Workshop on Energy-Efficient Learning at the Edge, WEEE 2021 (online) (G. Neglia);
- 19th Mediterranean Communication and Computer Networking Conference, MedComNet 2021 (online) (G. Neglia);
- Reinforcement Learning in Networks and Queues, RLNQ 2021, Sigmetrics workshop (K. Avrachenkov);
- SIAM International Conference on Data Mining, SDM 2021 (K. Avrachenkov);
- 23nd Workshop on MAthematical performance Modeling and Analysis, MAMA 2021 (online) (A. Jean-Marie).

Reviewer

- 25th International Conference on Artificial Intelligence and Statistics, AISTATS 2022 (O. Marfoq and G. Neglia);
- IEEE International Symposium on Information Theory - ISIT (S. M. Perlaza, since 2012)
- IEEE Information Theory Workshop - ITW (since 2012)

10.1.3 Journal

Members of the editorial boards

- ACM Transactions on Modeling and Performance Evaluation of Computing Systems (ACM ToMPECS) (K. Avrachenkov, since 2016);
- AIMS (American Institute of Mathematical Sciences) Journal of Dynamics and Games (JDG) (E. Altman, since 2015);
- Elsevier Computer Communications journal (S. Alouf since May 2021, G. Neglia since 2014);
- Elsevier International Journal of Performance Evaluation (K. Avrachenkov, since 2009);
- Frontiers in Communications and Networks (S. M. Perlaza, since 2020);
- IEEE Transactions on Communications (S. M. Perlaza, since 2017);
- IEEE Transactions on Mobile Computing (G. Neglia since 2019);
- IEEE Transactions on Network Science and Engineering special issue on Communication-Efficient Distributed Machine Learning (G. Neglia);
- IEEE/ACM Transactions on Networking (E. Altman, since 2013);
- IEEE Network Magazine (K. Avrachenkov, since 2020);
- IET Smart Grid (S. M. Perlaza, since 2018);
- International journal “IRAN Journal of Computer Science” (published by Springer) (E. Altman, advisory board);
- Journal on Dynamic Games and Applications (Birkhauser) (E. Altman, since 2012). Also co-editor of Special Issue on Dynamic Games for Modeling and Control of Epidemics;

- Probability in the Engineering and Informational Sciences (K. Avrachenkov, since 2018);
- Springer Dynamic Games and Applications, Special Issue “Multi-agent Dynamic Decision Making and Learning” (K. Avrachenkov, 2021);
- Stochastic Models (K. Avrachenkov, since 2019).

Reviewer - reviewing activities NEO members regularly perform reviews for journals such as *Discrete Applied Maths, European Journal of Operations Research, IEEE Trans. on Communications, on Parallel and Distributed Systems, on Information Theory, on Communications, on Signal Processing, IEEE Communication Letters* and many others.

10.1.4 Invited talks

E. Altman was Keynote in Valuetools 2021.

G. Neglia

- gave a talk on “Personalized Federated Learning” at Nokia Bell Labs’ “Big Thought Time Talk” seminars on 9/12/2021.
- gave a talk on “Personalized Federated Learning” at SophIA Summit on 19/11/2021.

S. M. Perlaza

- presented the keynote: **“Shannon’s Mathematical Theory of Data Transmission**”, at the conference Géométrie algébrique, Théorie des nombres et Applications, University of French Polynesia, Tahiti, French Polynesia, August 2021.
- was invited to deliver the talk **“An upper bound on the error induced by saddlepoint approximations: Applications to information theory”** in the School of Electrical, Computer, and Systems Engineering at Rensselear Polytechnic Institute (RPI), NY, USA. (postponed until further notice)

10.1.5 Leadership within the scientific community

S. Alouf

- is an elected member at the Board of Directors of ACM SIGMETRICS (July 2019 - June 2023);
- is a member of the Equality and Diversity committee of ACM SIGMETRICS;
- is a member of the Conference Advisory committee of ACM SIGMETRICS.

K. Avrachenkov

- is a member of the scientific committee for Labex UCN@Sophia;
- is a member of Conseil Scientifique & Pédagogique EUR DS4H Univ. Côte d’Azur.

S. M. Perlaza

- is a member of the **Digital Presence Committee** of the IEEE Information Theory Society. Dec. 2019 - Dec. 2024.
- is a Senior Member of the IEEE (class of 2015);
- is a Marie Sklodowska-Curie Action (MSCA) Fellow. Individual Fellowship, (Class of 2015);

10.1.6 Research administration

S. Alouf

- is a member of NICE, the Invited Researchers Committee of Inria Sophia Antipolis Méditerranée, since June 2020;
- is member of CLF, the training committee of Inria Sophia Antipolis Méditerranée, since November 2014;
- is vice-head of project-team Neo since January 2017.

K. Avrachenkov

- is in charge of RAWeb process for Inria SAM;

A. Jean-Marie

- is the scientific coordinator of Inria activities in Montpellier (since 2008); as part of this duty, he represents Inria at: the Scientific Council of the Doctoral School “Sciences and Agrosciences” of the Univ. of Avignon; at the Regional Conference of Research Organisms (CODOR); at the board of the Labex NUMEV.
- is Head of project-team NEO since January 2017.

G. Neglia

- is a committee member for UCA Academy of Excellence “Networks, Information, and Digital Society” since 2021;
- is member of Inria COST GTRI (groupe de travail des relations internationales du comité d’orientation scientifique et technique) since 2016

10.2 Teaching - Supervision - Juries

10.2.1 Teaching

Note: UCA is the Univ Côte d’Azur.

PhD

- G. Neglia, “Online Learning with applications to Caching”, 3.5H, PhD school “E2E validation of 5G networks” organized by the H2020 Innovative Training Network SEMANTIC, 18/2/2021;
- G. Neglia, “Distributed Machine Learning Training”, 1.5H, PhD school “Complex Networks and Telecommunications, Towards 6G”, Lake Como School of Advanced Studies, Italy;
- G. Neglia, “Distributed Machine Learning”, 2H, IEEE/DEI PhD school of Information Engineering “Silvano Pupolin”, Bressanone, Italy.

Master

- S. Alouf, "Performance Evaluation of Networks", 21H, M2 Ubinet, UCA, France;
- K. Avrachenkov, G. Neglia, and P. Nain, “Quantum Computing and Networking,” 21H out of 24H, a minor for the Research Graduate School DS4H (Digital Systems for Humans) UCA;
- O. Marfoq, G. Neglia, “Machine Learning: Theory and Algorithms", 24H, M2 Ubinet, UCA, France;
- O. Marfoq, G. Neglia, T. Si Salem, C. Xu, “Optimization for Data Science”, 30H, M1 Data Science and Artificial Intelligence.

10.2.2 Supervision

PhD

- Guilherme Iecker Ricardo, "Design and Optimization of Cache Systems for Small Cell Networks", UCA, defense date 9 Sep. 2021, advisors: Giovanni Neglia and Pietro Elia (EURECOM).

- Marie Masson, " Fonctionnalités auto-organisantes dans le réseau d'accès radio 5G virtuel", Univ Avignon, defense date 15 Dec. 2021, advisors: Eitan Altman and Zwi Altman (Orange).

PhD in progress

- Younes Ben Mazziane, "Online learning for Caching at the Edge", UCA, 1 Oct. 2020, advisors: Sara Alouf and Giovanni Neglia.

- Olha Chuchuk, "Optimization of data access at CERN and in the World Large Hadron Collider Computing Grid (WLCG)", UCA, 1 Sept. 2020, advisor: Giovanni Neglia.

- Mandar Datar, "Singular perturbation approach for machine learning in multiobjective optimisation", Univ Avignon, 1 May 2018, advisor: Eitan Altman.

- Francisco Daunas, "Data Injection Attacks in Machine Learning Systems", 1 Oct. 2020, U. of Sheffield, co-advisor: S. M. Perlaza.

- Maximilien Dreveton, "Statistical Physics Methods for Distributed Machine Learning", UCA, 1 Oct. 2018, advisor: Konstantin Avrachenkov.

- Mikhail Kamalov, "Semi-supervised variational autoencoders versatile data", UCA, 1 June 2019, advisor: Konstantin Avrachenkov.

- Caelin Kaplan, "Privacy and fairness for machine learning", UCA, 1 July 2021, advisor: Giovanni Neglia.

- Othmane Marfoq, "Distributed machine learning for IoT applications", UCA, 1 December 2020, advisor: Giovanni Neglia.

- Angelo Rodio, "Sustainable distributed machine learning", UCA, 1 April 2021, advisor: Giovanni Neglia and Alain Jean-Marie.

- Tareq Si Salem, "Federated Learning", UCA, 1 October 2019, advisor: Giovanni Neglia.

- Xiuzhen Ye, "Data Injection Attacks in Smart Grids", 1 Oct. 2019, U. of Sheffield, co-advisor: S. M. Perlaza.

10.2.3 Juries

HDR

- Majed Haddad, "Resource optimization and mobility management in wireless networks", Univ. Avignon, 16 December 2021 (E. Altman, jury president);

- Samir M. Perlaza, "Contributions aux Systèmes d'Information et d'Énergie", INSA Lyon and Univ. Claude Bernard, Lyon, 29 June 2021 (A. Jean-Marie, jury member).

PhD

- Dadja Anade, "Communications in the non-asymptotic block-length regime", INSA de Lyon, 7 October 2021, (S. M. Perlaza, Reviewer);
- Amaury Bouchra Pilet, "Contributions to distributed multi-task machine learning", Univ. Rennes, 10 November 2021 (G. Neglia, reviewer);
- Arnaud Cadas, "Stochastic matching models and their applications to demand-supply balancing", Univ. PSL, 4 October 2021 (A. Jean-Marie, jury president);
- Loic Guégan, "Resource allocation with observable and unobservable environments", École Normale Supérieure de Rennes, 29 January 2021 (S. Alouf, reviewer);
- P.N. Karthik, "Sequential controlled sensing to detect an anomalous process", IISc Bangalore, India, 8 November 2021, (K. Avrachenkov, Reviewer);
- Graziano Mita, "Toward Interpretable Machine Learning, with Applications to Large-scale", Sorbonne Univ., 27 April 2021 (G. Neglia, reviewer);
- Elie Robert-Nicoud, "The Book and the Screen: The Relationship between Fiction and Information Technology", Univ. of Avignon, 10 December 2021 (E. Altman, jury member);
- Benoit Sohet, "Optimisation Couplée des Stratégies Roulage/Recharge pour Véhicules Électriques en Environnement Urbain", Univ. of Avignon, October 11 2021 (S. M. Perlaza, reviewer);
- Thibaud Troillet, "Study of the properties and modeling of complex social networks", UCA, 25 June 2021 (G. Neglia, jury member).

11 Scientific production

11.1 Major publications

[1] D. Anade, J.-M. Gorce, P. Mary and S. M. Perlaza. 'Saddlepoint Approximations of Cumulative Distribution Functions of Sums of Random Vectors'. In: ISIT 2021 - IEEE International Symposium on Information Theory. Melbourne / Virtual, Australia: IEEE, 12th July 2021, pp. 1–6. URL: https://hal.inria.fr/hal-03226009.

[2] K. Avrachenkov and V. S. Borkar. 'Whittle Index Policy for Crawling Ephemeral Content'. In: *IEEE Transactions on Control of Network Systems* 5.1 (Mar. 2018), pp. 446–455. DOI: 10.1109/TCNS.2016.2619066. URL: https://hal.inria.fr/hal-01937994.

[3] K. Avrachenkov, P. Chebotarev and A. Mishenin. 'Semi-supervised learning with regularized Laplacian'. In: *Optimization Methods and Software* 32.2 (Jan. 2017), pp. 222–236. DOI: 10.1080/10556788.2016.1193176. URL: https://hal.inria.fr/hal-01671800.

[4] K. Avrachenkov, A. Y. Kondratev, V. V. Mazalov and D. Rubanov. 'Network partitioning algorithms as cooperative games'. In: *Computational Social Networks* 5.11 (Oct. 2018). DOI: 10.1186/s40649-018-0059-5. URL: https://hal.inria.fr/hal-01935419.

[5] E. Leonardi and G. Neglia. 'Implicit Coordination of Caches in Small Cell Networks under Unknown Popularity Profiles'. In: *IEEE Journal on Selected Areas in Communications* 36.6 (June 2018), pp. 1276–1285. DOI: 10.1109/JSAC.2018.2844982. URL: https://hal.inria.fr/hal-01956307.

[6] A. R. Masson, Y. Hayel and E. Altman. 'Posting behaviour Dynamics and Active Filtering for Content Diversity in Social Networks'. In: *IEEE transactions on Signal and Information Processing over Networks* 3.2 (2017), pp. 376–387. DOI: 10.1109/TSIPN.2017.2696738. URL: https://hal.inria.fr/hal-01536172.

[7] K. P. Naveen, E. Altman and A. Kumar. 'Competitive Selection of Ephemeral Relays in Wireless Networks'. In: *IEEE Journal on Selected Areas in Communications* 35 (2017), pp. 586–600. DOI: 10.1109/JSAC.2017.2659579. URL: https://hal.inria.fr/hal-01536123.

[8] G. Neglia, D. Carra, M. Feng, V. Janardhan, P. Michiardi and D. Tsigkari. 'Access-Time-Aware Cache Algorithms'. In: *ACM Transactions on Modeling and Performance Evaluation of Computing Systems* 2.4 (Dec. 2017), pp. 1–29. DOI: 10.1145/3149001. URL: https://hal.inria.fr/hal-01956285.

[9] G. Neglia, D. Carra and P. Michiardi. 'Cache Policies for Linear Utility Maximization'. In: *IEEE/ACM Transactions on Networking* 26.1 (Feb. 2018), pp. 302–313. DOI: 10.1109/TNET.2017.2783623. URL: https://hal.inria.fr/hal-01956319.

[10] A. Tajer, S. M. Perlaza and H. V. Poor. *Advanced Data Analytics for Power Systems*. Cambridge University Press, 1st Jan. 2021. URL: https://hal.archives-ouvertes.fr/hal-03128425.

11.2 Publications of the year

International journals

[11] E. Altman, M. Datar, F. De Pellegrini, S. Perlaza and D. S. Menasché. 'The Mask Game with Multiple Populations'. In: *Dynamic Games and Applications* (2022). URL: https://hal.inria.fr/hal-03527522.

[12] R. Amir, P. Nain, D. Sadoc Menasche, D. Towsley and E. De Souza. 'Fundamental Scaling Laws of Covert DDoS Attacks'. In: *Performance Evaluation* 151 (Nov. 2021). URL: https://hal.inria.fr/hal-03372124.

[13] K. Avrachenkov, A. Bobu and M. Dreveton. 'Higher-Order Spectral Clustering for Geometric Graphs'. In: *Journal of Fourier Analysis and Applications* 27 (15th Mar. 2021). DOI: 10.1007/s00041-021-09825-2. URL: https://hal.inria.fr/hal-03169834.

[14] K. Avrachenkov, V. S. Borkar, S. Moharir and S. M. Shah. 'Dynamic social learning under graph constraints'. In: *IEEE Transactions on Control of Network Systems* (21st Sept. 2021). DOI: 10.1109/TCNS.2021.3114377. URL: https://hal.archives-ouvertes.fr/hal-03462479.

[15] K. Avrachenkov, K. Patil and G. Thoppe. 'Online algorithms for estimating change rates of web pages'. In: *Performance Evaluation*. SI: ValueTools 2020 153 (11th Nov. 2021). DOI: 10.1016/j.peva.2021.102261. URL: https://hal.inria.fr/hal-03461575.

[16] O. Chuchuk, T. Beermann, A. Di Girolamo, M. Grigorieva, A. Klimentov, M. Lassnig, M. Schulz, A. Sciaba and E. Tretyakov. 'Methods of Data Popularity Evaluation in the ATLAS Experiment at the LHC'. In: *EPJ Web of Conferences* 251 (2021). DOI: 10.1051/epjconf/202125102013. URL: https://hal.inria.fr/hal-03378922.

[17] M. Garetto, E. Leonardi and G. Neglia. 'Content placement in networks of similarity caches'. In: *Computer Networks* 201 (Dec. 2021), p. 108570. DOI: 10.1016/j.comnet.2021.108570. URL: https://hal.inria.fr/hal-03499870.

[18] A. Jean-Marie, M. Tidball and V. Bucarey. 'The Stackelberg games of water extraction with myopic agents'. In: *International Game Theory Review* (2022). URL: https://hal.inrae.fr/hal-03429257.

[19] K. Keshava, A. Jean-Marie and S. Alouf. 'Optimal Prefetching in Random Trees'. In: *Mathematics* 9.19 (1st Oct. 2021), p. 2437. DOI: 10.3390/math9192437. URL: https://hal.inria.fr/hal-03361953.

[20] Y. Li, T. Si Salem, G. Neglia and S. Ioannidis. 'Online Caching Networks with Adversarial Guarantees'. In: *Proceedings of the ACM on Measurement and Analysis of Computing Systems* 5 (14th Dec. 2021), pp. 1–39. DOI: 10.1145/3491047. URL: https://hal-ineris.archives-ouvertes.fr/ineris-03484121.

[21] X. Liu, Y.-Z. J. Chen, J. C. S. Lui and K. Avrachenkov. 'Learning to count: A deep learning framework for graphlet count estimation'. In: *Network Science* 9 (Oct. 2021), S23–S60. DOI: 10.1017/nws.2020.35. URL: https://hal.inria.fr/hal-02942321.

[22] I. Mounir, L. MENVIELLE, S. Perlaza, D. Chênevert, J.-H. Planchard, R. Fabre, M. Benoit, A. Benyamina, B. Rolland, F. Cherikh and R. David. 'Psychological Distress and Tobacco Use Among Hospital Workers During COVID-19'. In: *Frontiers in Psychiatry* 12 (28th July 2021). DOI: 10.3389/fpsyt.2021.701810. URL: https://hal.archives-ouvertes.fr/hal-03429343.

[23] G. Neglia, M. Garetto and E. Leonardi. 'Similarity Caching: Theory and Algorithms'. In: *IEEE/ACM Transactions on Networking* (Dec. 2021), pp. 1–12. DOI: 10.1109/TNET.2021.3126368. URL: https://hal.inria.fr/hal-03498773.

[24] G. Neglia, E. Leonardi, G. I. Ricardo and T. Spyropoulos. 'A Swiss Army Knife for Online Caching in Small Cell Networks'. In: *IEEE/ACM Transactions on Networking* (9th Aug. 2021), pp. 1–12. DOI: 10.1109/TNET.2021.3100757. URL: https://hal.archives-ouvertes.fr/hal-03346268.

[25] G. I. Ricardo, A. Tuholukova, G. Neglia and T. Spyropoulos. 'Caching Policies for Delay Minimization in Small Cell Networks with Coordinated Multi-Point Joint Transmissions'. In: *IEEE/ACM Transactions on Networking* 29.3 (June 2021), pp. 1105–1115. DOI: 10.1109/TNET.2021.3062269. URL: https://hal.archives-ouvertes.fr/hal-03346292.

[26] C. Xu, G. Neglia and N. Sebastianelli. 'Dynamic Backup Workers for Parallel Machine Learning'. In: *Computer Networks* (7th Apr. 2021). URL: https://hal.archives-ouvertes.fr/hal-03364773.

International peer-reviewed conferences

[27] E. Altman. 'The vaccination Game in Susceptible-Infected-Susceptible (SIS) networks with multi-populations'. In: Game Theory for Networks (Gamenets) 2021. Virtual, France, 16th Dec. 2021. URL: https://hal.inria.fr/hal-03484177.

[28] E. Altman, M. Datar and G. Ferrat. 'Maximizing amount of transferred traffic for battery powered mobiles'. In: Netgcoop 2020 - International Conference on NETwork Games, Control and Optimisation. Cargese, France, 22nd Sept. 2021. URL: https://hal.inria.fr/hal-02931313.

[29] D. Anade, J.-M. Gorce, P. Mary and S. M. Perlaza. 'Saddlepoint Approximations of Cumulative Distribution Functions of Sums of Random Vectors'. In: ISIT 2021 - IEEE International Symposium on Information Theory. Melbourne / Virtual, Australia: IEEE, 12th July 2021, pp. 1–6. URL: https://hal.inria.fr/hal-03226009.

[30] K. Avrachenkov, A. Boisbunon and M. Kamalov. 'Graph Diffusion & PCA Framework for Semi-supervised Learning'. In: Learning and Intelligent Optimization (LION 2021). Vol. 12931. Lecture Notes in Computer Science. Athens, Greece: Springer International Publishing, 9th Dec. 2021, pp. 25–39. DOI: 10.1007/978-3-030-92121-7_3. URL: https://hal.inria.fr/hal-03477308.

[31] K. Avrachenkov, V. Borkar and K. Patil. 'Deep Reinforcement Learning for Web Crawling'. In: The Seventh Indian Control Conference 2021. Mumbai, India, 20th Dec. 2021. URL: https://hal.inria.fr/hal-03461189.

[32] K. Avrachenkov, M. Dreveton and L. Leskelä. 'Recovering Communities in Temporal Networks Using Persistent Edges'. In: CSoNet 2021 - International Conference on Computational Data and Social Networks. Vol. 13116. Lecture Notes in Computer Science. Montreal, Canada: Springer International Publishing, 4th Dec. 2021, pp. 243–254. DOI: 10.1007/978-3-030-91434-9_22. URL: https://hal.inria.fr/hal-03472963.

[33] K. Avrachenkov, V. Gaitsgory and L. Gamertsfelder. 'LP Based Bounds for Cesàro and Abel Limits of the Optimal Values in Non-ergodic Stochastic Systems'. In: 2021 European Control Conference (ECC). Delft, Netherlands: IEEE, July 2021, pp. 2444–2449. DOI: 10.23919/ECC54610.2021.9655136. URL: https://hal.inria.fr/hal-03517927.

[34] K. Avrachenkov and M. Mironov. 'Cluster-size constrained network partitioning'. In: ICPR 2020 - 25th International Conference on Pattern Recognition. Milano, Italy, 10th Jan. 2021. URL: https://hal.inria.fr/hal-02972577.

[35] D. Carra and G. Neglia. 'Taking two Birds with one k-NN Cache'. In: Proceedings of IEEE Global Communications Conference. Madrid, Spain, 7th Dec. 2021. URL: https://hal.inria.fr/hal-03498796.

[36] S. Dallali, C. Fontaine and E. Altman. 'Splittable Routing Games in Ring Topology with Losses'. In: ASMTA 2021 - 26th International Conference on Analytical & Stochastic Modelling Techniques & Applications. Virtual, Japan, 13th Dec. 2021. URL: https://hal.archives-ouvertes.fr/hal-03340020.

[37] M. Datar and E. Altman. 'Strategic Resource Management in 5G Network Slicing. (Invited paper)'. In: ITC 33 - Networked Systems and Services. Avignon, France, 31st Aug. 2021. URL: https://hal.inria.fr/hal-03333659.

[38] G. IECKER RICARDO, G. Neglia and T. Spyropoulos. 'Caching Heterogeneous Size Content in Small Cell Networks with CoMP Joint Transmissions'. In: *GLOBECOM 2021, IEEE Global Communications Conference*. GLOBECOM 2021, IEEE Global Communications Conference, 7-11 December 2021, Madrid, Spain. GLOBECOM 2021, IEEE Global Communications Conference. Madrid, Spain, 7th Dec. 2021. URL: https://hal.archives-ouvertes.fr/hal-03411870.

[39] V. Kavitha and E. Altman. 'Controlling Packet Drops to Improve Freshness of information'. In: Netgcoop 2020 - International Conference on NETwork Games, Control and Optimisation. Cargese, France, 22nd Sept. 2021. URL: https://hal.inria.fr/hal-02931314.

[40] O. Marfoq, G. Neglia, A. Bellet, L. Kameni and R. Vidal. 'Federated Multi-Task Learning under a Mixture of Distributions'. In: NeurIPS 2021 - 35th Conference on Neural Information Processing Systems. Sydney, Australia, 6th Dec. 2021. URL: https://hal.archives-ouvertes.fr/hal-03406994.

[41] M. Masson, Z. Altman and E. Altman. 'Coordinated scheduling based on automatic neighbor beam relation'. In: NETGCOOP 2020 - International Conference on NETwork Games, Control and Optimisation. Cargèse, France, 18th Mar. 2021. URL: https://hal.inria.fr/hal-02566350.

[42] A. Sabnis, T. Si Salem, G. Neglia, M. Garetto, E. Leonardi and R. K. Sitaraman. 'GRADES: Gradient Descent for Similarity Caching'. In: *IEEE INFOCOM 2021 - IEEE Conference on Computer Communication*. IEEE International Conference on Computer Communications (INFOCOM 2021). Virtual Conference, United States, 10th May 2021. URL: https://hal.archives-ouvertes.fr/hal-03484133.

[43] R. Sambamoorthy, J. Mandalapu, S. S. Peruru, B. Jain and E. Altman. 'Graph Neural Network based scheduling : Improved throughput under a generalized interference model'. In: EAI - Valuetools. Guangzhou, China, 30th Oct. 2021. URL: https://hal.archives-ouvertes.fr/hal-03410462.

[44] T. Si Salem, G. Castellano, G. Neglia, F. Pianese and A. Araldo. 'Towards inference delivery networks: distributing machine learning with optimality guarantees'. In: *19th Mediterranean Communication and Computer Networking Conference (MEDCOMNET 2021)*. 19th Mediterranean Communication and Computer Networking Conference (MEDCOMNET 2021). Ibiza (virtual), Spain: IEEE, 2021, pp. 1–8. DOI: 10.1109/MedComNet52149.2021.9501272. URL: https://hal.archives-ouvertes.fr/hal-03376168.

[45] T. Si Salem, G. Neglia and D. Carra. 'AÇAI: Ascent Similarity Caching with Approximate Indexes'. In: *The 33rd International Teletraffic Congress (ITC 33)*. The 33rd International Teletraffic Congress (ITC 33). Avignon (virtual), France, 31st Aug. 2021. URL: https://hal.archives-ouvertes.fr/hal-03376175.

[46] T. Si Salem, G. Neglia and S. Ioannidis. 'No-Regret Caching via Online Mirror Descent'. In: *IEEE International Conference on Communications (ICC 2021)*. IEEE International Conference on Communications (ICC 2021). Montreal (virtual), Canada, 14th July 2021. URL: https://hal.archives-ouvertes.fr/hal-03376156.

[47] S. u. Zuhra, S. M. Perlaza and E. Altman. 'Simultaneous Information and Energy Transmission with Finite Constellations'. In: ITW 2021 - IEEE Information Theory Workshop. Kanazawa, Japan: IEEE, 17th Oct. 2021, pp. 1–6. URL: https://hal.inria.fr/hal-03339165.

Conferences without proceedings

[48] C. Xu and G. Neglia. 'What else is leaked when eavesdropping Federated Learning?' In: CCS workshop Privacy Preserving Machine Learning (PPML). Soeul, South Korea, 19th Nov. 2021. DOI: 10.1145/1122445.1122456. URL: https://hal.archives-ouvertes.fr/hal-03364766.

[49] O. Zari, C. Xu and G. Neglia. 'Efficient passive membership inference attack in federated learning'. In: Privacy in Machine Learning - NeurIPS PriML workshop. Virtual, France, 14th Dec. 2021. URL: https://hal.archives-ouvertes.fr/hal-03410152.

Scientific book chapters

[50] K. Avrachenkov, V. S. Borkar, H. P. Dolhare and K. Patil. 'Full Gradient DQN Reinforcement Learning: A Provably Convergent Scheme'. In: *Modern Trends in Controlled Stochastic Processes: Theory and Applications, V.III*. Vol. 41. Emergence, Complexity and Computation. Springer International Publishing, 5th June 2021, pp. 192–220. DOI: 10.1007/978-3-030-76928-4_10. URL: https://hal.inria.fr/hal-03462350.

[51] I. Esnaola, S. M. Perlaza and K. Sun. 'Data-Injection Attacks'. In: *Advanced Data Analytics for Power Systems*. 28th Jan. 2021. URL: https://hal.archives-ouvertes.fr/hal-03129791.

Edition (books, proceedings, special issue of a journal)

[52] A. Tajer, S. M. Perlaza and H. V. Poor. *Advanced Data Analytics for Power Systems*. Cambridge University Press, 1st Jan. 2021. URL: https://hal.archives-ouvertes.fr/hal-03128425.

Doctoral dissertations and habilitation theses

[53] S. M. Perlaza. 'Contributions to Information and Energy Systems'. INSA de Lyon; Université Claude Bernard Lyon I, 29th June 2021. URL: https://hal.archives-ouvertes.fr/tel-03429274.

Reports & preprints

[54] D. Anade, J.-M. Gorce, P. Mary and S. M. Perlaza. *Saddlepoint Approximations of Cumulative Distribution Functions of Sums of Random Vectors*. RR-9388. Inria Grenoble - Rhône-Alpes, May 2021, p. 32. URL: https://hal.inria.fr/hal-03143508.

[55] V. Bucarey, E. Della Vecchia, A. Jean-Marie and F. Ordóñez. *Stationary Strong Stackelberg Equilibrium in Discounted Stochastic Games*. RR-9271. Inria, Mar. 2021, p. 62. URL: https://hal.inria.fr/hal-02144095.

[56] M. Datar, E. Altman and H. Le Cadre. *Strategic Resource Pricing and Allocation in a 5G Network Slicing Stackelberg Game*. 10th Jan. 2022. URL: https://hal.inria.fr/hal-03519362.

[57] A. Jean-Marie, T. Jimenez and M. Tidball. *Nearsighted, farsighted behaviors and learning. Application to a groundwater management problem*. RR-9406. Inria, 30th Apr. 2021, p. 46. URL: https://hal.inria.fr/hal-03213518.

[58] A. Reiffers-Masson, N. Shimkin, D. Sadoc Menasche and E. Altman. *A Backpropagation Approach for Distributed Resource Allocation*. 22nd July 2021. URL: https://hal-imt-atlantique.archives-ouvertes.fr/hal-03295994.

[59] A. Sales-De-Queiroz, G. G. Sales Santa Cruz, A. Jean-Marie, D. Mazauric, J. Roux and F. Cazals. *Gene prioritization based on random walks with restarts and absorbing states, to define gene sets regulating drug pharmacodynamics from single-cell analyses*. 21st Nov. 2021. URL: https://hal.inria.fr/hal-03438430.

[60] R. Sambamoorthy, M. Datar and E. Altman. *A Bidding Mechanism for Resource Allocation in Network Slicing*. 1st Sept. 2021. URL: https://hal.archives-ouvertes.fr/hal-03330535.

[61] X. Ye, I. Esnaola, S. M. Perlaza and R. F. Harrison. *Stealth Data Injection Attacks with Sparsity Constraints*. 7th Jan. 2022. URL: https://hal.archives-ouvertes.fr/hal-03516567.

[62] S. u. Zuhra, S. M. Perlaza and E. Altman. *Simultaneous Information and Energy Transmission with Finite Constellations*. RR-9409. Inria Sophia Antipolis - Méditerranée, 19th May 2021, p. 17. URL: https://hal.inria.fr/hal-03230482.

Other scientific publications

[63] A. Hodgkinson and A. Jean-Marie. 'Social Networking and Population Growth - A complex mathematical relationship'. In: FRCCS 2021 - French Regional Conference on Complex Systems. Dijon, France, 26th May 2021. URL: https://hal.inria.fr/hal-03516417.