Activity Report 2017

Project-Team INFINE

INFormation NEtworks

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Project-Team INFINE

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2. Overall Objectives

2.1. Overall Objectives

The INFINE proposal aims to design and analyse novel communication paradigms, protocols and architectures based on concepts of ultra distributed, information- and user-centric networking. The project is motivated by the recent and forthcoming evolution of Internet uses. Based on an information- and user-centric perspective, not only does it address issues pertaining to physical communication networks such as traffic routing, regulation and caching, but also issues about online social networks such as content recommendation and privacy protection.

INFINE team is engaged in research along three main themes: *Online social networking*, *Traffic and Resource Management*, and *Spontaneous Wireless Networks*. All these research activities encompass both theoretical research (on elaboration of models, algorithms, protocols and formal characterization of their performance), and applied research (to validate and/or experiment the proposed concepts against real networking scenarios). INFINE fits in the theme "Networks and Telecommunications" of the research field "Networks, Systems and Services, Distributed Computing" at Inria.

2.2. New challenging demands

Nowadays, we use networks not only to transport information from where it resides to ourselves but also, with online social networks, to determine what information might be of interest to us. Such a social recommendation functionality holds the promise of allowing us to access more relevant information. At the same time there is ample scope for improving its efficiency. Moreover it creates threats to user privacy.

At the same time, the physical context in which we access communication networks has drastically changed. While in the past, Internet was mostly accessed through fixed desktop computers, users are now mobile about 50% of their time online. In addition, while communicating machines used to be sparse and wired, with the advent of the Internet of Things we now evolve in a dense, interconnected environment of heterogeneous devices communicating via wireless and/or via wires.

This new context of Internet uses challenges several aspects of currently deployed networks. Some aspects pertain to the physical architecture of the Internet. In particular, at the core of the Internet, a drastic increase in volume of data traffic is anticipated due to the emergence of new applications, generalization of cloud services, or the advent of the Internet of Things (IoT) and Machine-to-Machine (M2M) communications. On the other hand, at the edge of the Internet, user mobility and today's pervasiveness of computing devices with increasingly higher capabilities (i.e., processing, storage, sensing) have a fundamental impact on the adequacy of algorithms and communication mechanisms.

Other aspects concern the logical architecture of the network. For instance, currently deployed protocols at layers above IP must now carry massive publish-subscribe traffic, preserve user privacy, be social-aware, and support delay tolerant communications and paradigms for which they were not initially designed. Concerning actual content distribution, the avalanche of data and privacy concerns puts more and more pressure on filter/push mechanisms to provide users with relevant information.

While considering physical and logical aspects of networks, the INFINE team will pursue research activities combining theoretical and experimental approaches.

2.3. Research agenda

Our general goal is to develop distributed mechanisms for optimizing the operation of networks both at the mentioned logical and physical levels of the architecture. Taking an information- and user-centric perspective, we envision networks as means to convey relevant information to users, while adapting to customary practices (in terms of context, interests, or content demands) of such users. At the logical level, online social networks (OSNs) allow users to choose what information to access. At the physical level, communication, computation, and memory resources allow users to retrieve some content eventually selected on the basis of the online social network.

The two setups feature scarce resources: for instance, in OSNs, these are the users' budget of attention, which must be used sparingly by recommending only relatively few potential content items. At the physical level this is typically the channels' capacity or networking resources, which cannot be oversubscribed.

Beyond a formal resemblance between the optimizations that one must carry at these two levels, there is a strong commonality in the methods adequate for conducting optimizations in the two setups. To illustrate this point, consider *contact recommendation*, that is a key objective in our agenda on online social networks. This entails automatically proposing to users potential contacts for optimizing the subsequent efficiency of social content filtering. We envision addressing contact recommendation by first performing some community detection, i.e. identification of similarly behaving users. Similarly, at the physical level, user-centric approaches, sometimes also related to community detection, have guided routing decisions in challenged network environments, where delay-tolerant networking is used. Still, associated with dynamic centrality metrics, community detection can guide the replication of a specific content in well-selected users, while exploiting the advantages of distributed decentralized storage and opportunistic communications.

As an additional example at the logical level, we consider *content recommendation*, whereby a list of potential contents is filtered before being presented to a user, with the aim of maximizing the chance this user finds an item of interest therein. This has an exact analogue at the physical level, where by taking an information- and user-centric approach, we intend to off-load communication resources via pre-loaded content replicas at various storage points in the network. The problem of determining which content to cache so as to maximize the chance of it being accessed in the vicinity of the corresponding cache memory corresponds precisely to the aforementioned content recommendation problem.

We now detail further our agenda along three main specific axes, namely Online Social Networks, Traffic and Resource Management, and Internet of Things/Spontaneous Wireless Networks, bearing in mind that we will develop generic solutions relevant to several of these axes wherever possible.

3. Research Program

3.1. Online Social Networks (OSN)

Large-scale online social networks such as Twitter or FaceBook provide a powerful means of selecting information. They rely on "social filtering", whereby pieces of information are collectively evaluated and sorted by users. This gives rise to information cascades when one item reaches a large population after spreading much like an epidemics from user to user in a viral manner. Nevertheless, such OSNs expose their users to a large amount of content of no interest to them, a sign of poor "precision" according to the terminology of information retrieval. At the same time, many more relevant content items never reach those users most interested in them. In other words, OSNs also suffer from poor "recall" performance.

This leads to a first challenge: *what determines the optimal trade-off between precision and recall in OSNs? And what mechanisms should be deployed in order to approach such an optimal trade-off?* We intend to study this question at a theoretical level, by elaborating models and analyses of social filtering, and to validate the resulting hypotheses and designs through experimentation and processing of data traces. More specifically, we envision to reach this general objective by solving the following problems.

3.1.1. Community Detection

Identification of implicit communities of like-minded users and contact recommendation for helping users "rewire" the information network for better performance. Potential schemes may include variants of spectral clustering and belief propagation-style message passing. Limitations / relative merits of candidate schemes, their robustness to noise in the input data, will be investigated.

3.1.2. Incentivization

Design of incentive mechanisms to limit the impact of users' selfishness on system behavior: efficiency should be maintained even when users are gaming the system to try and increase their estimated expertise. By offering rewards to users on the basis of their involvement in filtering and propagation of content, one might encourage them to adjust their action and contribute to increase the overall efficiency of the OSN as a content access platform.

One promising direction will be to leverage the general class of Vickrey-Clarke-Groves incentive-compatible mechanisms of economic theory to design so-called marginal utility reward mechanisms for OSN users.

3.1.3. Social Recommendation and Privacy

So far we have only alluded to the potential benefits of OSNs in terms of better information access. We now turn to the risks they create. Privacy breaches constitute the greatest of these risks: OSN users disclose a wealth of personal information and thereby expose themselves to discrimination by potential employers, insurers, lenders, government agencies etc. Such privacy concerns are not specific to OSNs: internauts' online activity is discretely tracked by companies such as Bluekai, and subsequently monetized to advertisers seeking better ad targeting. While disclosure of personal data creates a privacy risk, on the other hand it fuels personalized services and thereby potentially benefits everyone.

One line of research will be to focus on the specific application scenario of content categorization, and to characterize analytically the trade-off between user privacy protection (captured by differential privacy), accuracy of content categorization, and sample complexity (measured in number of probed users).

3.2. Traffic and Resource Management

Despite the massive increases in transmission capacity of the last few years, one has every reason to believe that networks will remain durably congested, driven among other factors by the steadily increasing demand for video content, the proliferation of smart devices (i.e., smartphones or laptops with mobile data cards), and the forecasted additional traffic due to machine-to-machine (M2M) communications. Despite this rapid traffic growth, there is still a rather limited understanding of the features protocols have to support, the characteristics of the traffic being carried and the context where it is generated. There is thus a strong need for smart protocols that transport requested information at the cheapest possible cost on the network as well as provide good

quality of service to network subscribers. One particularly new aspect of up-and-coming networks is that networks are now used to not only (i) access information, but also (ii) distributively process information, en-route.

We intend to study these issues at the theoretical and protocol design levels, by elaborating models and analysis of content demands and/or mobility of network subscribers. The resulting hypothesis and designs will be validated through experimentation, simulation, or data trace processing. It is also worth mentioning the provided solutions may bring benefits to different entities in the network: to content owners (if applied at the core of Internet) or to subscribers or network operators (if applied at the edge of the Internet).

3.2.1. At the Internet Core

One important optimization variable consists in content replication: users can access the closest replica of the content they are interested in. Thus the memory resource can be used to create more replicas and reduce the usage of the bandwidth resource. Another interesting arbitrage between resources arises because content is no longer static but rather dynamic. Here are two simple examples: i) a video could be encoded at several resolutions. There is then a choice between pre-recording all possible resolutions, or alternatively synthesizing a lower-resolution version on the fly from a higher resolution version when a request arises. ii) A user requests the result of a calculation, say the average temperature in a building; this can either be kept in memory, or recomputed each time such a query arises. Optimizing the joint use of all three resources, namely bandwidth, memory, computation, is a complex task. Content Delivery Network companies such as Akamai or Limelight have worked on the memory/bandwidth trade-off for some years, but as we will explain more can be done on this. On the other hand optimizing the memory/computation trade-off has received far less attention. We aim to characterize the best possible content replication strategies by leveraging fine-grained prediction of i) users' future requests, and ii) wireless channels' future bandwidth fluctuations. In the past these two determining inputs have only been considered at a coarse-grained, aggregate level. It is important to assess how much bandwidth saving can be had by conducting finer-grained prediction. We are developing light-weight protocols for conducting these predictions and automatically instantiating the corresponding optimal replication policies. We are also investigating generic protocols for automatically trading replication for computation, focusing initially on the above video transcoding scenario.

3.2.2. At the Internet Edge

Cellular and wireless data networks are increasingly relied upon to provide users with Internet access on devices such as smartphones, laptops or tablets. In particular, the proliferation of handheld devices equipped with multiple advanced capabilities (e.g., significant CPU and memory capacities, cameras, voice to text, text to voice, GPS, sensors, wireless communication) has catalyzed a fundamental change in the way people are connected, communicate, generate and exchange data. In this evolving network environment, users' social relations, opportunistic resource availability, and proximity between users' devices are significantly shaping the use and design of future networking protocols.

One consequence of these changes is that mobile data traffic has recently experienced a staggering growth in volume: Cisco has recently foreseen that the mobile data traffic will increase 18-fold within 2016, in front of a mere 9-fold increase in connection speeds. Hence, one can observe today that the inherently centralized and terminal-centric communication paradigm of currently deployed cellular networks cannot cope with the increased traffic demand generated by smartphone users. This mismatch is likely to last because (1) forecasted mobile data traffic demand outgrows the capabilities of planned cellular technological advances such as 4G or LTE, and (2) there is strong skepticism about possible further improvements brought by 5G technology.

Congestion at the Internet's edge is thus here to stay. Solutions to this problem relates to: densify the infrastructure, opportunistically forward data among neighbors wireless devices, to offload data to alternate networks, or to bring content from the Internet closer to the subscribers. Our recent work on leveraging user mobility patterns, contact and inter-contact patterns, or content demand patterns constitute a starting point to these challenges. The projected increase of mobile data traffic demand pushes towards additional complementary offloading methods. Novel mechanisms are thus needed, which must fit both the new context

that Internet users experience now, and their forecasted demands. In this realm, we will focus on new approaches leveraging ultra-distributed, user-centric approaches over IP.

3.3. Internet of Things (IoT) and Spontaneous Wireless Networks (SWN)

The unavailability of end-to-end connectivity in emergent wireless mobile networks is extremely disruptive for IP protocols. In fact, even in simpler cases of spontaneous wireless networks where end-to-end connectivity exists, such networks are still disruptive for the standard IP protocol stack, as many protocols rely on atomic link-local services (such as link-local multicast/broadcast), while these services are inherently unavailable in such networks due to their opportunistic, wireless multi hop nature. In this domain, we will aim to characterize the achievable performance in such IP-disruptive networks and to actively contribute to the design of new, deployable IP protocols that can tolerate these disruptions, while performing well enough compared to what is achievable and remaining interoperable with the rest of the Internet.

Spontaneous wireless networking is also a key aspect of the Internet of Things (IoT). The IoT is indeed expected to massively use this networking paradigm to gradually connect billions of new devices to the Internet, and drastically increase communication without human source or destination – to the point where the amount of such communications will dwarf communications involving humans. Large scale user environment automation require communication protocols optimized to efficiently leverage the heterogeneous and unreliable wireless vicinity (the scope of which may vary according to the application). In fact, extreme constraints in terms of cost, CPU, battery and memory capacities are typically experienced on a substantial fraction of IoT devices. We expect that such constraints will not vanish any time soon for two reasons. On one hand the progress made over the last decade concerning the cost/performance ratio for such small devices is quite disappointing. On the other hand, the ultimate goal of the IoT is ubiquitous Internet connectivity between devices as tiny as dust particles. These constraints actually require to redesign not only the network protocol stack running on these devices, but also the software platform powering these machines. In this context, we will aim at contributing to the design of novel network protocols and software platforms optimized to fit these constraints while remaining compatible with legacy Internet.

3.3.1. Design & Development of Open Experimental IoT Platforms

Manufacturers announce on a regular basis the availability of novel tiny devices, most of them featuring network interfaces: the Internet of Things (IoT) is already here, from the hardware perspective, and it is expected in the near future that we will see a massive increase of the number of muti-purpose smart objects (from tiny sensors in industrial automation to devices like smart watches and tablets). Thus, one of the challenges is to be able to test architectures, protocols and applications, in realistic conditions and at large scale.

One necessity for research in this domain is to establish and improve IoT hardware platforms and testbeds, that integrate representative scenarios (such as Smart Energy, Home Automation etc.) and follow the evolution of technology, including radio technologies, and associated experimentation tools. For that, we plan to build upon the IoT-LAB federated testbeds, that we have participated in designing and deploying recently. We plan to further develop IoT-LAB with more heterogeneous, up-to-date IoT hardware and radios that will provide a usable and realistic experimentation environment. The goal is to provide a tool that enables testing a validation of upcoming software platforms and network stacks targeting concrete IoT deployments.

In parallel, on the software side, IoT hardware available so far made it uneasy for developers to build apps that run across heterogeneous hardware platforms. For instance Linux does not scale down to small, energy-constrained devices, while microcontroller-based OS alternatives were so far rudimentary and yield a steep learning curve and lengthy development life-cycles because they do not support standard programming and debugging tools. As a result, another necessity for research in this domain is to allow the emergence of it more powerful, unifying IOT software platforms, to bridge this gap. For that, we plan to build upon RIOT, a new open source software platform which provides a portable, Linux-like API for heterogeneous IoT hardware. We plan to continue to develop the systems and network stacks aspects of RIOT, within the open source developer community currently emerging around RIOT, which we co-founded together with Freie Universitaet Berlin.

The key challenge is to improve usability and add functionalities, while maintaining architectural consistency and a small enough memory footprint. The goal is to provide an IoT software platform that can be used like Linux is used for less constrained machines, both (i) in the context of research and/or teaching, as well as (ii) in industrial contexts. Of course, we plan to use it ourselves for our own experimental research activities in the domain of IoT e.g., as an API to implement novel network protocols running on IoT hardware, to be tested and validated on IoT-LAB testbeds.

3.3.2. *Design & Standardization of Architectures and Efficient Protocols for Internet of Things*

As described before, and by definition, the Internet of Things will integrate not only a massive number of homogeneous devices (e.g., networks of wireless sensors), but also heterogeneous devices using various communication technologies. Most devices will be very constrained resources (memory resources, computational resources, energy). Communicating with (and amongst) such devices is a key challenge that we will focus on. The ability to communicate efficiently, to communicate reliably, or even just to be able to communicate at all, is non-trivial in many IoT scenarios: in this respect, we intend to develop innovative protocols, while following and contributing to standardization in this area. We will focus and base most of our work on standards developed in the context of the IETF, in working groups such as 6lo, CORE, LWIG etc., as well as IRTF research groups such as NWCRG on network coding and ICNRG on Information Centric Networking. We note however that this task goes far beyond protocol design: recently, radical rearchitecturing of the networks with new paradigms such as Information Centric Networking, ICN, (or even in wired networks, software-defined networks), have opened exciting new avenues. One of our direction of research will be to explore these content-centric approaches, and other novel architectures, in the context of IoT.

4. Highlights of the Year

4.1. Awards

Laurent Massoulié received the Grand Prix Scientifique Cino Del Duca 2017, awarded by the French Academy of Sciences for his project on *S*ocial Information Networks. More details about the price here: http://www.academie-sciences.fr/fr/Prix-en-chimie-et-sciences-du-vivant/grand-prix-scientifique-fondation-simone-et-cino-del-duca.html. More details about his project here: https://www.inria.fr/en/centre/saclay/news/laurent-massoulie-grand-prix-cino-del-duca.

Oliver Hahm received the 1st prize of Université Paris Saclay (Prix Doctorant ED STIC 2017) for his PhD work on RIOT, supervised by Emmanuel Baccelli.

4.2. Associated team - EMBRACE

2017 was the first year of the EMBRACE Associated team. The EMBRACE (lEveraging huMan Behavior for Resource AlloCation and services orchestration modEls) team is composed by members of the INFINE and by three Brazilian teams from three different Brazilian Universities. The EMBRACE project addresses the topic of designing efficient solutions for 5G networks taking into account human behavior, uncertainty, and heterogeneity of networking resources.

More information is available here: https://team.inria.fr/infine/embrace/

4.3. RIOT Summit 2017

We successfully organized in September 2017 the second RIOT Summit in Berlin. The RIOT Summit 2017 gathered 100+ enthusiastic industrial participants, makers and academics involved in RIOT. Relevant partners such as Cisco, Fujitsu, OTA Keys, Wolf SSL, as well as a number of SMEs and startups from various places in Europe gave talks on aspects of IoT communication, use cases IoT hardware, IoT open source community aspects and concepts for future IoT software and networks, as well as hands-on sessions and tutorials. See: http://summit.riot-os.org/#speakers.

5. New Software and Platforms

5.1. Gardinet

KEYWORD: Distributed networks

FUNCTIONAL DESCRIPTION: Gardinet (previously DragonNet) is a generic framework for network coding in wireless networks. It is a initially result of the GETRF project of the Hipercom2 team.

It is based on intra-flow coding where the source divides the flow in a sequence of payloads of equal size (padding may be used). The design keys of DragonNet are simplicity and universality, DragonNet does not use explicit or implicit knowledge about the topology (such as the direction or distance to the source, the loss rate of the links, ...). Hence, it is perfectly suited to the most dynamic wireless networks. The protocol is distributed and requires minimal coordination. DragonNet architecture is modular, it is based on 5 building blocks (LIB, SIG, Protocol, SEW and DRAGON). Each block is almost independent. This makes DragonNet generic and hence adaptable to many application scenarios. DragonNet derives from a prior protocol called DRAGONCAST. Indeed, DragonNet shares the same principles and theoretical overview of DRAGONCAST. It enriches DRAGONCAST by the information base and signaling required to perform broadcast in wireless networks and in wireless sensor networks in particular.

- Participants: Antonia Masucci, Cédric Adjih, Hana Baccouch and Ichrak Amdouni
- Contact: Cédric Adjih
- URL: http://gitlab.inria.fr/gardinet

5.2. MACACO

Mobile context-Adaptive CAching for COntent-centric networking

FUNCTIONAL DESCRIPTION: MACACOapp is developed in the context of the EU CHIST-ERA MACACO project. It consists in a mobile phone application that periodically samples phone's information on the mobility (through, e.g., GPS sensor, accelerometer and WiFi/Bluetooth/Cellular environment, connectivity type) and on the data traffic it generates (through, e.g., Internet browser history and applications data consumption). The information collected will be time-stamped and will be periodically sent to the central servers for analysis and visualization. We expect that (1) the collected information will allow us studying the correlation between mobility and content demand patterns and that (2) the results of this analysis will allow us inferring the best times and places to transfer content from/to users' phones location and/or from/to the wireless infrastructure closest to the users' phones location. Users will be also invited to fill a non-mandatory questionnaire relevant to this study. Our questionnaire collects information about the personality traits and application preferences of people. We expect that the information collected from questionnaire will allow us to analyse the correlation between users personality traits and their application preferences and interests. User's application preferences and interests will be inferred from the Internet browsing history and running app information obtained from the MACACO App.

- Participants: Aline Carneiro Viana, Katia Jaffres and Marco Fiore
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5.3. RIOT

KEYWORDS: Internet of things - Wireless Sensor Networks - Iot - Sensors - Operating system - Internet protocols

SCIENTIFIC DESCRIPTION: While requiring as low as 1,5kB of RAM and 5kB or ROM, RIOT offers real time and energy efficiency capabilities, as well as a single API (partially POSIX compliant) across heterogeneous 8-bit, 16-bit and 32-bit low-hardware. This API is developer-friendly in that it enables multi-threading, standard C and C++ application programming and the use of standard debugging tools (which was not possible so far for embedded programming). On top of this, RIOT includes several network stacks, such as a standard IPv6/6LoWPAN stack and a information-centric network stack (based on CCN).

FUNCTIONAL DESCRIPTION: RIOT is an Open Source operating system that provides standard protocols for embedded systems. RIOT allows, for example, the development of applications that collect sensor data and transmit it to a central node (e.g. a server). This data can then be used for smart energy management for instance.

RIOT is specially designed for embedded systems, which are strongly constrained in memory and energy. Further, RIOT can easily be ported to different hardware devices and follows the latest evolution of IP standards.

RIOT applications can readily be tested in the FIT IoT-Lab, which provides a large-scale infrastructure facility with 3000 nodes for testing remotely small wireless devices.
- Participants: Emmanuel Baccelli and Oliver Hahm
- Partner: Freie Universität Berlin
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- URL: http://www.riot-os.org

6. New Results

6.1. Online Social Networks (OSN)

6.1.1. *Capacity of Information Processing Systems*
- Participants: Laurent Massoulié and Kuang Xu

We propose and analyze a family of information processing systems, where a finite set of experts or servers are employed to extract information about a stream of incoming jobs. Each job is associated with a hidden label drawn from some prior distribution. An inspection by an expert produces a noisy outcome that depends both on the job's hidden label and the type of the expert, and occupies the expert for a finite time duration. A decision maker's task is to dynamically assign inspections so that the resulting outcomes can be used to accurately recover the labels of all jobs, while keeping the system stable. Among our chief motivations are applications in crowd-sourcing, diagnostics, and experiment designs, where one wishes to efficiently learn the nature of a large number of items, using a finite pool of computational resources or human agents. We focus on the capacity of such an information processing system. Given a level of accuracy guarantee, we ask how many experts are needed in order to stabilize the system, and through what inspection architecture. Our main result provides an adaptive inspection policy that is asymptotically optimal in the following sense: the ratio between the required number of experts under our policy and the theoretical optimal converges to one, as the probability of error in label recovery tends to zero. This work was firstly accepted and presented at the COLT conference.

6.2. Spontaneous Wireless Networks (SWN)

6.2.1. *Spatio-Temporal Prediction of Cellular Data Traffic*
- Participants: Guangshuo Chen, Aline Carneiro Viana, Marco Fiore, Carlos Sarraute

The understanding of human behaviors is a central question in multi-disciplinary research and has contributed to a wide range of applications. The ability to foresee human activities has essential implications in many aspects of cellular networks. In particular, the high availability of mobility prediction can enable various application scenarios such as location-based recommendation, home automation, and location-related data dissemination; the better understanding of future mobile data traffic demand can help to improve the design of solutions for network load balancing, aiming at improving the quality of Internet-based mobile services. Although a large and growing body of literature has investigated the topic of predicting human mobility, there has been little discussion in anticipating mobile data traffic in cellular networks, especially in spatiotemporal view of individuals. We address the problem of understanding spatiotemporal mobile data traffic demand for individuals and perform an theoretical and empirical analysis of jointly predicting human whereabouts and mobile data traffic, by collaboratively mining human mobility dataset and mobile data traffic dataset. Our contributions are summarized as follows:

- We investigate the limits of predictability by measuring the maximum predictability that any algorithm has potential to achieve based on tools of information theory. Our theoretical analysis shows that it is theoretically possible to anticipate the individual demand with a typical accuracy of 75% despite the heterogeneity of users and with an improved accuracy of 80% using joint prediction with mobility information. This work was published at the IEEE LCN 2017 international conference and the Technical report RT-0483 brings a full description of the work, which is being prepared for a journal submission.

- We evaluate the state-of-the-art predictors and propose novel solutions for predicting mobile data traffic via machine learning algorithms. Our data-driven test on the performance of these predictors show that the 2nd order Markov predictor outperforms all the legacy time series predictors. It can achieve a mean accuracy of 62% but can hardly have an enhancement from knowing human mobility information. Besides, based on machine learning techniques, our proposed solutions can achieve a typical accuracy of 70% and have a 1% 5% degree of improvement by learning individual whereabouts (what confirms the predictability theoretical results). Finally, our analysis show that knowing mobile data traffic of a user can significantly help the prediction of his whereabouts for 50% of the users, leading to an improvement up to 10% regarding accuracy. The Technical Report hal-01675573 brings more details on this work. A conference paper is also in preparation.

All those works were performed in the context of the Guangshuo Chen's PhD thesis, who will defend in March 2018.

6.2.2. *Human Mobility completion of Sparse Call Detail Records for Mobility Analysis*

- Participants: Guangshuo Chen, Aline Carneiro Viana, Marco Fiore, Sahar Hoteit

Call Detail Records (CDR) are an important source of information in the study of diverse aspects of human mobility. The accuracy of mobility information granted by CDR strongly depends on the radio access infrastructure deployment and the frequency of interactions between mobile users and the network. As cellular network deployment is highly irregular and interaction frequencies are typically low, CDR are often characterized by spatial and temporal sparsity, which, in turn, can bias mobility analyses based on such data. In this paper, we precisely address this subject. First, we evaluate the spatial error in CDR, caused by approximating user positions with cell tower locations. Second, we assess the impact of the limited spatial and temporal granularity of CDR on the estimation of standard mobility metrics. Third, we propose novel and effective techniques to reduce temporal sparsity in CDR, by leveraging regularity in human movement patterns.

These works have been published as invited papers at the ACM CHANTS 2016 workshop (in conjunction with ACM MobiCom 2016) and at the IEEE DAWM workshop (in conjunction with IEEE Percom 2017). A journal version (also registered as TR: hal-01646608) is in revision at the Computer Communication Elsevier Journal, and got the first notification asking for minor revisions. Finally, a new completion methodology improving the previously described that leverages tensor factorization was designed and will be submitted to a journal: the technical report hal-01675570 describes this work.

6.2.3. *Sampling frequency of human mobility*

- Participants: Panagiota Katsikouli, Aline Carneiro Viana, Marco Fiore, Alberto Tarable

Recent studies have leveraged tracking techniques based on positioning technologies to discover new knowledge about human mobility. These investigations have revealed, among others, a high spatiotemporal regularity of individual movement patterns. Building on these findings, we aim at answering the question *"at what frequency should one sample individual human movements so that they can be reconstructed from the collected samples with minimum loss of information?"*. Our quest for a response leads to the discovery of *(i)* seemingly universal spectral properties of human mobility, and *(ii)* a linear scaling law of the localization error with respect to the sampling interval. Our findings are based on the analysis of fine-grained GPS trajectories of 119 users worldwide. The applications of our findings are related to a number of fields relevant to ubiquitous computing, such as energy-efficient mobile computing, location-based service operations, active probing of

subscribers' positions in mobile networks and trajectory data compression. to an international conference in the next months. This work was published at the IEEE Globecom 2017 international conference.

We are improving the currently published sampling approache by incorporating human behavioral features at the sampling decisions to make it more adaptive. This is an on-going work with Panagiota Katsikouli, who spent 5 months in our team working as an internship and is currently doing a Post-Doc at the AGORA Inria team.

6.2.4. Inference of human personality from mobile phones datasets

- Participants: Adriano di Luzio, Aline Carneiro Viana, Julinda Stefa, Katia Jaffres

Personality research has enjoyed a strong resurgence over the past decade. Trait-based personality theories define personality as the traits that predict a person's behavior through learning and habits. Personality traits are relatively stable over time, differ across individuals, and most importantly, influence behavior. In psychology, the human personality has been modeled into a set of independent factors that, together, accurately describe any individual: The Five Factors Personality Model. This personality model presents the Big Five personality traits, often represented by the OCEAN acronym: Openness: appreciation for a variety of experiences; Conscientiousness: planning ahead rather than being spontaneous; Extraversion: being sociable, energetic and talkative; Agreeableness: being kind, sympathetic and happy to help; Neuroticism: inclined to worry or be vulnerable or temperamental.

This is a very recently started work, where we are firstly analysing the relationship between smartphone usages (i.e., social interactions, content interest, mobility, and communication) and personality traits in the Big Five Model. Most of the studies on personality traits were performed by social scientists and in particular, by psychologists. Studies reveal that one of the most distal influences shaping personality lie in the environment where development occurs. Nevertheless, the identification of precise environmental sources impacting personality is still an open research. More recently, computer science researchers have tried to extract personality from datasets collected through smartphones. Although laying the ground work to understand human personality from smartphones usage, much still remain to be investigated. Thus, we are performing analysis to study the correlation between traits and technological features. We plan then to establish a methodology to infer traints from features and consequently, to investigate how different traits influence different features.

This is an on-going work with Adriano di Luzio, who spent 4 months in our team working as an internship, and Julinda Stefa, an invited research visitor at Infine.

6.2.5. Predicting new places to visit in human mobility decision

- Participants: Maria Astefanoaei, Aline Carneiro Viana, Rik Sarkar

Most location prediction methods need a large user mobility history to accurately predict the next location of a user (markov chains, rnn). These methods are particularly good for predicting locations that are frequently visited by users, but not as good for predicting new places or how a user?s trajectories change in case of random events. We amend this by using contextual information to manage new places and random events and the movement patterns of users who exhibit similar behaviours. In this context, we plan to use the user?s profile and social ties to identify the most probable next category of locations (type of actions: entertainment, social, food etc.). Then, use subtrajectory similarity to predict the route taken to the identified area. This is an on-going work with the intern Maria Astefanoaei and her advisor, who spent 5 months in our team.

6.2.6. Data offloading decision via mobile crowdsensing

- Participants: Emanuel Lima, Aline Carneiro Viana, Ana Aguiar

With the steady growth of smart-phones sales [1], the demand for services that generate mobile data traffic has grown tremendously. WiFi offloading has been considered as a promising solution to the recent boost up of mobile data consumption that is making excessive demands on cellular networks in metropolitan areas. The idea consists in shifting the traffic off of cellular networks to WiFi networks. Characterizing the capacity and availability of a chaotic deployed dense WiFi network is crucial to understand and decide where and when to o

oad data. This is the first goal of this work, where the MACACO dataset was considered in the characterization. Our final goal is the design of a decision strategy allowing a mobile phone of a user to decide if offload or not her traffic, i.e., when, where (using what Access Point in her usual mobility) and how (if the traffic will be offloadied to one or more Access Points). This is an on-going work with the intern emanuel Lima and his advisor, who spent 4 months in our team.

6.2.7. *Infering friends in the crowd in Device-to-Device communication*

- Participants: Rafael Costa, Aline Carneiro Viana, Leobino Sampaio, Artur Ziviani

The next generation of mobile phone networks (5G) will have to deal with spectrum bottleneck and other major challenges to serve more users with high-demanding requirements. Among those are higher scalability and data rates, lower latencies and energy consumption plus reliable ubiquitous connectivity. Thus, there is a need for a better spectrum reuse and data offloading in cellular networks while meeting user expectations. According to literature, one of the 10 key enabling technologies for 5G is device-to-device (D2D) communications, an approach based on direct user involvement. Nowadays, mobile devices are attached to human daily life activities, and therefore communication architectures using context and human behavior information are promising for the future. User-centric communication arose as an alternative to increase capillarity and to offload data traffic in cellular networks through opportunistic connections among users. Although having the user as main concern, solutions in the user-centric communication/networking area still do not see the user as an individual, but as a network active element. Hence, these solutions tend to only consider user features that can be measured from the network point of view, ignoring the ones that are intrinsic from human activity (e.g., daily routines, personality traits, etc). In this work, we plan to investigate how human-aspects and behavior can be useful to leverage future device-to-device communication. This is a recently started PhD thesis subject, aiming the design of a methodology to select next-hops in a D2D communication that will be human-aware: i.e., that will consider not only available physical resoures at the mobile device of a wireless neighbor, her mobility features and restrictions but also any information allowing to infer how much sharing willing she is.

6.3. Internet of Things (IoT) and Information Centric Networking (ICN)

6.3.1. *Low-power Internet of Things with NDN and Cooperative Caching*

- Participants: Oliver Hahm, Emmanuel Baccelli, Thomas C. Schmidt, Matthias Wählisch, Cédric Adjih, and Laurent Massoulié

Energy efficiency is a major driving factor in the Internet of Things (IoT). In this context, an IoT approach based on Information-Centric Networking (ICN) offers prospects for low energy consumption. Indeed, ICN can provide local in-network content caching so that relevant IoT content remains available at any time while devices are in deep-sleep mode most of the time. In our paper on the subject, we evaluated NDN enhanced with CoCa, a simple side protocol we designed to exploit content names together with smart interplay between cooperative caching and power-save sleep capabilities on IoT devices. We performed extensive, large scale experiments on real hardware with IoT networks comprising of up to 240 nodes, and on an emulator with up to 1000 nodes. We have shown in practice that, with NDN+CoCa, devices can reduce energy consumption by an order of magnitude while maintaining recent IoT content availability above 90 %. We furthermore provided auto-configuration mechanisms enabling practical ICN deployments on IoT networks of arbitrary size with NDN+CoCa. With such mechanisms, each device could autonomously configure names and auto-tune parameters to reduce energy consumption as demonstrated in our paper.

6.3.2. *Information Centric Networking for the IoT Robotics*

- Participants: Loic Dauphin, Emmanuel Baccelli, Cédric Adjih

In the near-future, humans will interact with swarms of low-cost, interconnected robots. Such robots will hence integrate the Internet of Things, and coin the term IoT robotics. Using ROS (Robot Operating System) is currently the dominant approach to implement distributed robotic software modules communicating with one another. ROS nodes can publish or subscribe to topics, which are named and typed data streams sent over the network. In our work on the subject, we presented preliminary work exploring the potential of using NDN as network primitive for ROS2 nodes (the newest version of ROS).
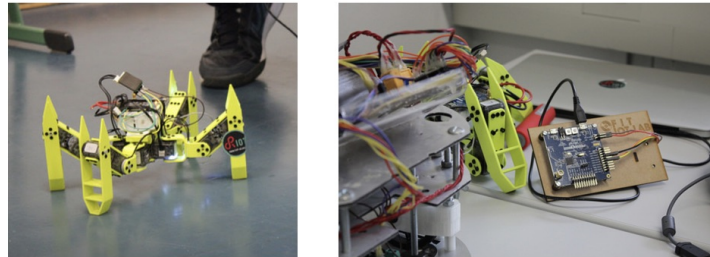
Figure 1. Demonstration of the use of NDN in IoT Robotics

6.3.3. *Data Synchronization through Information Centric Networking*

- Participants: Ayat Zaki Hindi, Cédric Adjih, Michel Kieffer, Claudio Weidmann

The use of Named Data Networking (NDN) for distributed multiuser applications, e.g. group messaging and file sharing, requires NDN synchronization protocols to maintain the same shared dataset (and its updates) among all nodes. ChronoSync, RoundSync, and PartialSync are some proposals to address this issue.

In our work on the subject, we focused on the state-of-the-art protocol RoundSync: we study its core features, that permit participating nodes to detect, propagate, and reconcile all changes. Particular attention is given to the case of multiple changes per round. We then proposed an improved variant, iRoundSync, that exchanges fewer messages in the multiple-change case and is more resilient to packet losses. We have quantified the performance gain of iRoundSync on a simple topology.

6.4. Internet of Things (IoT) and 5G

6.4.1. *Efficient Random Access for 5G Systems: Coded Slotted Aloha*

- Participants: Ehsan Ebrahimi Khaleghi, Cédric Adjih, Amira Alloum, Paul Mï¿œhlethaler, Vinod Kumar

Motivated by scenario requirements for 5G cellular networks, we have studied one of the candidate protocols for massive random access: the family of random access methods known asCoded Slotted ALOHA (CSA). A recent trend in research hasexplored aspects of such methods in various contexts, but oneaspect has not been fully taken into account: the impact of pathloss, which is a major design constraint in long-range wireless networks. In one article, we explored the behavior of CSA, by focusing on the path loss component correlated to the distanceto the base station. Path loss provides opportunities for capture,improving the performance of CSA. We revised methods for estimating CSA behavior, provide bounds of performance, and then,focusing on the achievable throughput, we extensively explored the key parameters, and their associated gain (experimentally). Our results shed light on the behavior of the optimal distribution of repetitions in actual wireless networks.

6.4.2. *Real Implementation of Coded Slotted Aloha*

- Participants: Cédric Adjih, Vinod Kumar

In 2017, we implemented Coded Slotted Aloha (CSA) as a proof of concept on our FIT IoT-LAB testbed (with 20+ nodes), with 802.15.4 transmissions and using a real SDR software.

This was presented in the seminar of the GT task 2 Future Access Networks of Digicosme. It was also presented as part of the tutorial "IoT in practice" in the ANTS 2017 conference.
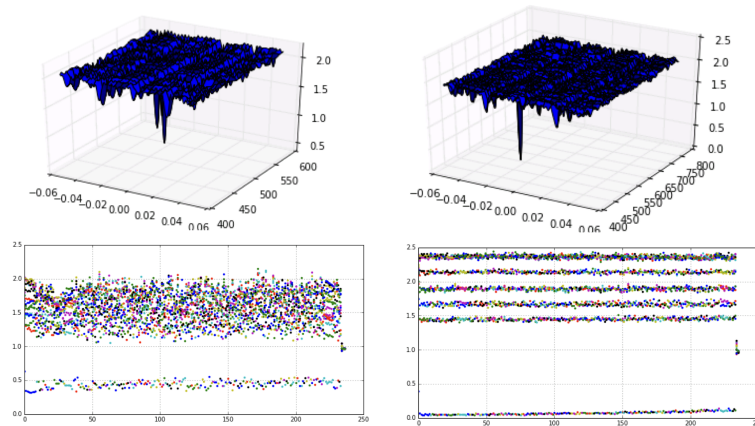
Figure 2. Example of demodulation steps in Coded Slotted Aloha

6.5. Resource and Traffic Management

6.5.1. *Utility Optimization Approach to Network Cache Design*

Participants: Mostafa Dehghan, Laurent Massoulié, Don Towsley, Daniel Menasche, Y.c. Tay.

In any caching system, the admission and eviction policies determine which contents are added and removed from a cache when a miss occurs. Usually, these policies are devised so as to mitigate staleness and increase the hit probability. Nonetheless, the utility of having a high hit probability can vary across contents. This occurs, for instance, when service level agreements must be met, or if certain contents are more difficult to obtain than others. In this paper, we propose utility-driven caching, where we associate with each content a utility, which is a function of the corresponding content hit probability. We formulate optimization problems where the objectives are to maximize the sum of utilities over all contents. These problems differ according to the stringency of the cache capacity constraint. Our framework enables us to reverse engineer classical replacement policies such as LRU and FIFO, by computing the utility functions that they maximize. We also develop online algorithms that can be used by service providers to implement various caching policies based on arbitrary utility functions.

This work was published and presented at the IEEE Infocom 2016 conference as "A Utility Optimization Approach to Network Cache Design".

7. Bilateral Contracts and Grants with Industry

7.1. Bilateral Contracts with Industry

1. Participation to Microsoft Research & Inria Joint Centre, which funds two PhD students (Lennart Gulikers and Remi Varloot).
2. Fujitsu has funded further development of RIOT and sponsored the RIOT Summit 2017.
3. Cisco Systems Silicon Valley has sponsored the RIOT Summit 2017.
4. In the framework of the joint research lab between Nokia Bell Labs and Inria, we participate in the ADR (action de recherche) Network Information Theory.

7.2. GranData

- Participants: Aline Carneiro Viana, Guangshuo Chen, Adriano Di Luzio

Since June 2014, we have a collaboration with GranData (http://grandata.com/), Buenos Aires, Argentina on traffic vs mobility modeling of smartphone users. GranData is a small company that integrates first-party and telco partner data to understand key market trends, to predict customer behavior, and to deliver business results. Its products integrates and analyzes diverse data traces (e.g., telco, social media, or mobile data) to generate behavioral insights and deliver targeted mobile marketing. Part of the thesis of Eduardo Mucelli analysis data traffic using telco traces provided by GranDatas. While this collaboration allow us collaborating with machine learning experts, GranData has the opportunity to get our expertise in mobility analysis.

8. Partnerships and Cooperations

8.1. National Initiatives

8.1.1. *Equipex FIT*

Participants: Cedric Adjih, Emmanuel Baccelli, Alexandre Abadie, Philippe Lubrano, Ichrak Amdouni, Alaeddine Weslati, Vincent Ladeveze.

Partners: Inria (Lille, Sophia-Antipolis, Grenoble), INSA, UPMC, Institut Telecom Paris, Institut Télécom Evry, LSIIT Strasbourg.

Figure 3. FIT IoT-LAB site in Saclay

FIT (Future Internet of Things) aims to develop an experimental facility, a federated and competitive infrastructure with international visibility and a broad panel of customers. It provides this facility with a set of complementary components that enable experimentation on innovative services for academic and industrial users. The project gives french internet stakeholders a means to experiment on mobile wireless communications at the network and application layers thereby accelerating the design of advanced networking technologies for the future internet. FIT was one of 52 winning projects from the first wave of the French Ministry of Higher Education and Research's "Équipements d'Excellence" (Equipex) research grant program, in 2011.

One component of the FIT platform is the sets of IoT-LAB testbeds (see the IoT-LAB web site). These were motivated by the observation that the world is moving towards an "Internet of Things", in which most communication over networks will be between objects rather than people.

The Infine team is more specifically managing the FIT IoT-LAB site formerly at Rocquencourt, which recently moved to Saclay (on-going re-deployment), and is participating in the deployment of an additional IoT-lab testbed in Berlin (at Freie Universitaet Berlin).

8.2. European Initiatives

8.2.1. FP7 & H2020 Projects

8.2.1.1. AGILE (H2020 project)
Participants: Emmanuel Baccelli, Cedric Adjih.

Program: H2020 ICT-30-2015 Topic: Internet of Things and Platforms for Connected Smart Objects

Project acronym: AGILE

Project title: Adoptive Gateways for dIverse muLtiple Environments

Duration: 2015-2017

Coordinator: Emmanuel Baccelli

Other partners: Canonical (UK), Eclipse IoT Foundation (IE), Mobistar (BE), Libelium (ES), Startupbootcamp IoT (SP), CREATE-NET (IT), iMinds (BE), Atos (SP), Rulemotion (UK), Jolocom (DE), Passau University (DE), Sky-Watch (DN), BioAssist (GR), Graz Technical University (AT), Eurotech (IT), IoTango (US).

Abstract:

The AGILE project is a 3-year H2020 project started in January 2016, which will deliver an integrated framework of open source tools and platforms that interoperate for enabling the delivery of adaptive, self-configurable and secure IoT elements (both software and hardware) that can be utilized in a variety of scenarios. Such tools target actors with heterogeneous skills, including entrepreneurs, researchers, and individuals, aiming to enable the realization of IoT applications respecting user privacy and data ownership.

8.2.1.2. ARMOUR (H2020 project)
Participants: Emmanuel Baccelli, Cedric Adjih.

Program: H2020 ICT-12-2015 Topic: Integrating experiments and facilities in FIRE+

Project acronym: ARMOUR

Project title: Large-Scale Experiments of IoT Security Trust

Duration: 2016-2018

Coordinator: Serge Fdida (UPMC)

Other partners: UPMC (France), Synelixis (Greece), SMA (France), UI (Portugal), JRC (Belgium), EGM (France), OdinS (Spain).

Abstract: The ARMOUR project is a 2-year H2020 project started in February 2016. The ARMOUR project is aimed at providing duly tested, benchmarked and certified Security & Trust technological solutions for large-scale IoT using upgraded FIRE large scale IoT/Cloud testbeds properly-equipped for Security & Trust experimentations. To this, ARMOUR will: (1) Enhance two outstanding FIRE testbeds (> 2700 nodes; 500 users) with the ARMOUR experimentation toolbox for enabling large-scale IoT Security & Trust experiments; (2) Deliver six properly experimented, suitably validated and duly benchmarked methods and technologies for enabling Security & Trust in the large-scale IoT; and (3) Define a framework to support the design of Secure & Trusted IoT applications as well as establishing a certification scheme for setting confidence on Security & Trust IoT solutions.

8.2.2. Collaborations with Major European Organizations

8.2.2.1. EU CHIST-ERA MACACO

Participants: Aline Carneiro Viana, Emmanuel Baccelli, Eduardo Mucelli.

Program: EU CHIST-ERA, topic Context- and Content-Adaptive Communication Networks

Project acronym: MACACO

Project title: Mobile context-Adaptive CAching for COntent-centric networking

Duration: 2013-2017 (extended until December 2017)

Coordinator: Aline Carneiro Viana

Other partners: INPT-ENSEEIHT at University of Toulouse, University of Birmingham (UK), SUPSI (Switzerland), CNR (Italy) and Federal University of Minas Gerais (Brazil)

Abstract:

MACACO (Mobile context-Adaptive CAching for COntent-centric networking) is a 3-year CHIST-ERA European Project addressing the topic Context- and Content-Adaptive Communication Networks. Due to delay in funding access and data collection campaign we got an extension until December 2017. It is funded by ANR in France, SNSF in Switzerland, and ESPRC in UK. It focus on data offloading mechanisms that take advantage of context and content information. Our intuition is that if it is possible to extract and forecast the behaviour of mobile network users in the three dimensional space of time, location and interest (i.e. what, when and where users are pulling data from the network), it is possible to derive efficient data offloading protocols. Such protocols would pre-fetch the identified data and cache it at the network edge at an earlier time, preferably when the mobile network is less charged, or offers better quality of service. This project has officially started in November 2013.

8.3. International Initiatives

8.3.1. Inria Associate Teams Not Involved in an Inria International Labs

8.3.1.1. EMBRACE

Title: Leveraging Human Behavior and Uncertainty in 5G Networks to Build Robust Resource Allocation and Services Orchestration Models

International Partners (Institution - Laboratory - Researcher):

UTFPR (Brazil) - Departamento Academico de Informitica (DAINF) Curso de Pos-Graduacao em Engenharia Eletrica e Informatica Industrial (CPGEI) - Anelise Munaretto

UFG (Brazil) - Institute of Computational Mathematics and Scientific / Engineering Computing - Kleber Vieira Cardoso

UFMG (Brazil) - Dpt of Statistics - Antonio A. F. Loureiro

Start year: 2017

See also: https://team.inria.fr/infine/embrace/

EMBRACE propose une architecture novatrice pour gérer des ressources et des services opérationnels hétérogénes. EMBRACE se concentre sur les défis scientifiques liés des ensembles de données collectées dans le monde réel et décrivant le comportement du réseau des utilisateurs. En particulier, EMBRACE exploite la modélisation du comportement humain en termes de mobilité, de demande de contenu, d'intérêts communs et des interactions entre-utisateurs. En construisant des modèles d'allocation les ressources tenant compte de l'utilisateur, EMBRACE a pour objectif de diminuer l'incertitude et mieux cerner les profils humains dans les rï¿œseaux 5G. La communication D2D sera également utilisée comme service opérationnel pour gérer la croissance du trafic mobile en libérant des ressources des réseaux cellulaires, sans augmenter les couts. La nouveauté de l'architecture réside dans les algorithmes concus qui exploiteront les caractérisations tirés de l'analyse du comportement des utilisateurs, l'hétérogénéité du réseau, et de l'incertitude. L'évaluation par simulation et l'émulation sera également l'un des thèmes clés. Enfin, les équipes concernées (Inria Infine, UFMG, UFG, UTFPR) ont un long historique de coopération sur ces thèmes.

8.3.2. Inria International Partners

8.3.2.1. Declared Inria International Partners

1. Renewed IOTPUSH collaboration with Freie Universitaet Berlin around the long-term stay of Emmanuel Baccelli in Berlin, on research topics about the Internet of Things, RIOT and Information-Centric Networking.

8.3.2.2. Informal International Partners

1. On-going collaboration with Freie Universitaet Berlin and Hamburg University of Applied Science around RIOT.
2. Informal collaborations with UIUC and UMass.
3. Informal collaborations with ENSI Tunis and Sesame Tunis.
4. On-going strong collaboration with Sapienza University of Rome, Italy.
5. On-going strong collaboration with CNR Torino, Italy.
6. On-going collaboration with University of Porto, Portugal.
7. On-going collaboration with ENSAE/CNRS, France.
8. On-going collaboration with University of Edinburgh, UK.

8.3.3. Participation in Other International Programs

8.3.3.1. Indo-French project

The Inria teams Infine and Eva are part of the "D2D Communication for LTE Advanced Cellular Network" , a project funded by the Indo-French Centre for the Promotion of Advanced Research (CEFIPRA). With industrial partners, and also with Indian partners, this project is focusing on the evolution of cellular networks towards 5G: this includes exploration of device-to-device (D2D) communication, and more generally IoT communication in a cellular context. Research directions include efficient access for IoT devices (massive numbers of devices with low volume communication); combination of random access protocols/error coding/physical layer ; efficient neighbor discovery, ...

8.3.3.2. STIC AmSud MOTIf 2017
Participant: Aline Carneiro Viana.

Program: STIC AmSud

Project title: Mobile phone sensing of human dynamics in techno-social environment

Duration: 2017-2019

Coordinators: Marton Karsai (ENS/Inria) and Jussara M. Almeida (UFMG) and Alejo Salles (Univ. of Buenos Aires)

Abstract: Information and Communication Technology (ICT) is becoming increasingly social, as demonstrated by the multitude of emerging technologies and technology platforms that facilitate social interactions, taking place as communication via telephone, text message, email, online social networks etc. At the same time, our social activities are increasingly embedded in the ICT environments that enable and enhance our ability to transact, share experiences, and maintain social relationships. One of the best ways to explore these developments is through the mining and analysis of data, which are collected through mobile phones and allow us to investigate how individuals act when embedded in a technology-enabled environment. The MOTIf project builds on the analysis and modeling of geo-localized temporally detailed but fully anonymised mobile phone call networks. These datasets allow us to address the two scientific objectives about spatiotemporal patterns of service usage of anonymised individuals to learn when, where, and what people are doing; and about the fine-grained sociodemographic structure of society and its effect on the the individual social behaviour. In other words our goal in general is to understand how individuals behave in a dynamic techno-social environment.

8.4. International Research Visitors

8.4.1. Visits of International Scientists

Rik Sarkar was Visiting Researcher at Infine for 3 days. He worked with Aline C. Viana and the internship Maria Astefanoaei on predicting new places to visit in human mobility decision.

Julinda Stefa was Visiting Researcher at Infine for 3 months. She worked with Aline C. Viana and the internship Adriano Di Luzio on the inference of human personality from mobile phones datasets.

Ana Aguiar was Visiting Researcher at Infine for 3 days. She worked with Aline C. Viana and the internship Emanuel Lima on data offloading decision via mobile crowdsensing.

8.4.1.1. Internships

Panagiota Katsikouli did an internship of 5 months at Infine working with Aline C. Viana and Marco Fiore on sampling frequency of human mobility.

Maria Astefanoaei did an internship of 5 months at Infine working with Aline C. Viana and Rik Sarkar on predicting new places to visit in human mobility decision.

Adriano Di Luzio did an internship of 4 months at Infine working with Aline C. Viana and Julinda Stefa on the inference of human personality from mobile phones datasets.

Emanuel Lima did an internship of 3 months at Infine working with Aline C. Viana and Ana Aguiar on on data offloading decision via mobile crowdsensing.

Ayat Zaki Hindi did an internship of 6 months at Infine working with Cedric Adjih, Michel Kieffer and C. Weidmann on synchronization strategy in Information-Centric Networks.

8.4.2. Visits to International Teams

8.4.2.1. Research Stays Abroad

Emmanuel Baccelli is Visiting Professor at Freie Universitaet (FU) Berlin, within the context of the formal collaboration IOTPUSH with this university on research topics about the Internet of Things, RIOT and Information-Centric Networking.

9. Dissemination

9.1. Promoting Scientific Activities

9.1.1. Scientific Events Organisation

9.1.1.1. General Chair, Scientific Chair

1. **Aline C. Viana** was scientific chair of Algotel 2017.
2. **Emmanuel Baccelli** was chair of the RIOT Summit 2017.

9.1.1.2. Member of the Organizing Committees

1. **Aline C. Viana** is Publicity Chair of: IEEE PICom 2018; IEEE MiSeNet 2018 jointly with IEEE Infocom 2018; DCOSS 2018.

9.1.2. Scientific Events Selection

9.1.2.1. Chair of Conference Program Committees

1. **Aline C. Viana** was scientific chair of Algotel 2017.

9.1.2.2. Member of the Conference Program Committees

1. **Aline C. Viana** is/was TPC member of: Altogel 2018; IFIP NTMS 2018 New Technolog; WCU 2017 jointly with SBRC 2017; IEEE AINA-2017.

9.1.2.3. Reviewer

1. **Cedric Adjih** was reviewer for PEMWN 2017, IEEE PIMRC 2017 Workshop WS-07, WINCOM 2017, WCNC 2018.

2. **Emmanuel Baccelli** was reviewer for ACM ICN 2017 (Poster/Demo), PEMWN 2017.

9.1.3. Journal

9.1.3.1. Member of the Editorial Boards

1. **Aline C. Viana** is Associate Editor of ACM SIGCOMM Computer Communication Review (ACM CCR), since May 2014; Editorial Board member of Wireless Communications and Mobile Computing Open Access Journal of John Wiley&Sons and Hindawi since 2016.

9.1.3.2. Reviewer - Reviewing Activities

1. **Aline C. Viana** reviewed papers for ACM SIGCOMM CCR Journal, elsevier Pervasive and Mobile Computing Journal and Computer Communication Elsevier Journal.

9.1.3.3. Reviewer

1. **Cedric Adjih** was reviewer for Future Generation Computer Systems, and IEEE Transactions on Communications.

2. **Emmanuel Baccelli** was reviewer for ACM Transactions on Networking (TON), Elsevier Future Generation Computer Systems.

9.1.4. Standardization

1. **Emmanuel Baccelli and Cedric Adjih** have participated at several working groups at IETF (March, July and November 2017)

2. **Emmanuel Baccelli and Cedric Adjih** have participated at the IETF hackathons (July and November 2017)

9.1.5. Invited Talks

1. **Aline C. Viana** was invited to give a talk at (1) University of Coimbra, Portugal in December 2016; (2) University of Porto, Portugal in December 2016; (3) EBSIS Summer School in Timmendorfer Strand, Germany in July 2017; (4) University of Edinburgh, UK in February 2017, (5) Spring School on Networks (SSN) 2017 at ChileCON Conference, Pucon, Chile in October 2017, all on "Toward a more Tactful Networking".

2. **Aline C. Viana** will be the keynote speaker of the CoUrb 2018 Workshop jointly organized with SBRC 2018, Brazil in May 2018.

3. **Laurent Massoulie** gave several invited talks at: Stochastic Networks Conference, UCSD; CIRM workshop on random matrices; Institut Henri Poincariï¿œes Nexus of Information and Computation Theories; LINCS scientific advisory board.

4. **Cedric Adjih** has presented in the June seminar of Digicosme GT task 2 Future Access Networks : "On Doing 5G with Old Low Cost Wireless Sensor Nodes (with RIOT, FIT IoT-LAB and one SDR device)". This presented work-in-progress experimenting of some 5G-related method(s) on low cost wireless sensor nodes, focusing on massive access (for machine-type communication), and describing one of the most readily experimental family of methods for random access known as "Coded Slotted Aloha", along with its already known features and performance evaluation aspects. Proof-of-concept experimentation was also described starting from the underlying hardware platform, FIT IoT-LAB (a large scale open testbed IoT Lab), and the underlying software platform, RIOT (an Operating System from the Internet of Things). Using additionally a software-defined receiver, it was shown how such 5G-like random access can be experimented on such typical 802.15.4-based devices. An analysis of preliminary results was provided, along with some lessons learned and some consequences on the design space of such methods.

5. **Cedric Adjih** has presented a tutorial at ANTS 2017 in Bhubaneswar, Odisha, India, on the subject of "IoT in Practice": it presented a comparative study of embedded OS?s such as RIOT, Contiki, ARM Mbed, Zephyr as well as implementation specificities of IoT protocol stacks e.g. RPL/6LoWPAN. Insight on how do hardware and software building blocks and transport level and application level protocols fit together was be provided. Addressed practical issues include the analysis of actual protocol performance (e.g. 802.15.4 or LoRa stacks) in experimental settings, and topics such as reasons for adopting open source approaches for IoT solutions. Presentation of experimental proof of concepts concluded the tutorial.

6. **Emmanuel Baccelli** gave an invited talk at CiscoX Symposium 2017, on the topic of "ICN for IoT: Energy Efficiency, Opportunities & Challenges"

7. **Emmanuel Baccelli** gave an invited talk at Bremen University in February, on the topic of "End-to-End Open Source IoT with RIOT".

9.1.6. Research Administration

1. **Aline C. Viana** is the President of the Scientific Commission at Inria Saclay, responsible for the selection of candidates for the CORDI-S, Post-Doc and Delegation campaigns.

2. **Aline C. Viana** will be the new leader of Infine team due to the fact that Laurent Massoulie had to leave Inria Saclay to join the Inria & Microsoft Lab at Inria Paris.

9.2. Teaching - Supervision - Juries

9.2.1. Teaching

Master : Emmanuel Baccelli, "Operating Systems for Small Connected Devices in the Internet of Things", 3h cours magistral, Formation PESTO Corps des Mines, Telecom ParisTech, Paris France

Licence: Aline C. Viana, "Toward a more Tactful Networking", 2h TD, niveau L3, Federal University of Goias (UFG) and Federal University of Minas Gerais, Brazil

Licence: Aline C. Viana, "Opportunistic communication in disconnected mobile Ad Hoc networks", 6h TD, niveau L3, Telecom SudParis, France

Licence: Cédric Adjih, "Microcontrollers: from embedded systems to the Internet of Things", 3h TD, Niveau L3, Telecom SudParis, France

Licence: Laurent Massoulie, "Networks: distributed control and emerging phenomena", 18h TD, Niveau L3, Ecole Polytechnique, France

Master : Aline C. Viana, "Toward a more Tactful Networking", 2h TD, niveau M2, Federal University of Goias (UFG), Federal University of Minas Gerais, Brazil

Master : Aline C. Viana, "Toward a more Tactful Networking", 3h TD, niveau M2, Telecom SudParis, France

Master : Aline C. Viana, Master Project evaluation, 4h TD, niveau M2, Telecom SudParis, France

Doctorat : Aline C. Viana, "Toward a more Tactful Networking", 2h TD, Federal University of Goias (UFG) and Federal University of Minas Gerais, Brazil

9.2.2. Supervision

PhD: Guangshuo Chen, "Human habits investigation: From mobility reconstruction to mobile traffic prediction", Ecole Polytechnique, March 2018, Aline C. Viana.

PhD in progress: (1) Rafael Costa, "Infering friends in the crowd in Device-to-Device communication", June 2016, Aline C. Viana and Leobino Sampaio (co-tutele); (2) Roni Shigetta, "Distributed channel allocation strategy based on human behavior", January 2014, Aline C. Viana and Mauro Fonseca (co-tutele).

PhD in progress: Loic Dauphin, "IoT Robotics", June 2016, Emmanuel Baccelli and Cédric Adjih co-supervision.

9.2.3. *Juries*

1. Aline Viana will be on the PhD jury as reviewer of: Florent Coriat, "Geolocalisation en situation de crise", UPMC ? Sorbonne Universitï¿œs, France, may 2018.

2. Aline Viana was on the PhD jury as examiner of: (1) S. Eddine Belouanas, "Dessemination de contenus populaires et tolerants au delai dans les reseaux cellulaires", UPMC ? Sorbonne Universitï¿œs, France, September 2017; (2) P. Salgueiro Santos, "Wireless Protocols and Channel Estimation for Data Gathering with Mobile Nodes", Univ. of Porto, Portugal, May 2017; (3) Amal Ellouzem, "Mobile Applications Offloading in Mobile Cloud Environment", Telecom ParisTech, France, March 2017.

3. Aline C. Viana was on the PhD jury as invited member of Tanel Razafimandimby "Toward Internet of Heterogeneous Things: Wireless communication maintenance and efficient data sharing among devices", University Lille 1, Inria Lille, France, October 2017.

4. Aline C. Viana was on the PhD Qualification jury as examiner of T. Duc Ha, "Allocation de ressources et association utilisateur/cellule optimisees pour les reseaux C-RAN" (Univ. Paris Sud, 2017);

5. Aline C. Viana was on the Master jury of Bruno Farias Fausto "Um mecanismo de deteccao e controle de congestionamento usando redes ad hoc veiculares sem infraestrutura", Federal Univ. of Rio de Janeiro State, Brazil, October 2017.

6. Laurent Massoulié was on the PhD jury as reviewer for the PhD theses of Anna Benhamou and Alaa Saade, and he presided the PhD thesis committee of Kevin Scaman.

9.3. Popularization

1. Aline C. Viana gave a scientific talk on "Le smartphone, votre 6e sens ?" and "The research career", December 2017, for college students visiting Inria Saclay

2. Cédric Adjih, Emmanuel Baccelli, Alexandre Abadie, Raul Fuentes participated to the "Inria-Industry Meetings" on 17 and 18 October 2017, with two demonstrations:

   – RIOT, the friendly OS for the Internet of Things - it has shown the various functionalities from RIOT on hardware of the type sensor/actuator to demo a control loop via the cloud. RIOT was used to generate IoT data locally (via sensors), sending them to the cloud where this data is analyzed. This analysis will result in a physical action (via actuators). We highlighted two use-cases: building automation, and low-cost robotics

   – End-to-end IoT with FIT IoT-LAB - this presented the use of FIT IoT-LAB for experimenting with IoT; in particular the end-to-end Over-the-air updates of RIOT.

10. Bibliography

Publications of the year

Articles in International Peer-Reviewed Journals

[1] L. GULIKERS, M. LELARGE, L. MASSOULIÉ. *A spectral method for community detection in moderately sparse degree-corrected stochastic block models*, in "Advances in Applied Probability", June 2017, vol. 49, nᵒ 03, pp. 686 - 721 [*DOI :* 10.1017/APR.2017.18], https://hal.archives-ouvertes.fr/hal-01622731

[2] E. MUCELLI REZENDE OLIVEIRA, A. CARNEIRO VIANA, K. P. NAVEEN, C. SARRAUTE. *Mobile Data Traffic Modeling: Revealing Temporal Facets*, in "Computer Networks", January 2017, vol. 112, pp. 176-193, https://hal.inria.fr/hal-01453379

Invited Conferences

[3] G. CHEN, A. CARNEIRO VIANA, C. SARRAUTE. *Towards an Adaptive Completion of Sparse Call Detail Records for Mobility Analysis*, in "Workshop on Data Analytics for Mobile Networking", Kona, United States, March 2017, https://hal.inria.fr/hal-01448822

International Conferences with Proceedings

[4] G. CHEN, S. HOTEIT, A. CARNEIRO VIANA, M. FIORE, C. SARRAUTE. *The Spatiotemporal Interplay of Regularity and Randomness in Cellular Data Traffic*, in "LCN 2017 - The 42nd IEEE Conference on Local Computer Networks", Singapore, Singapore, October 2017, https://hal.inria.fr/hal-01646359

[5] L. DAUPHIN, H. PETERSEN, C. ADJIH, E. BACCELLI. *Low-Cost Robots in the Internet of Things: Hardware, Software & Communication Aspects*, in "NextMote Workshop - Next Generation Platforms for the Cyber-Physical Internet", Uppsala, Sweden, February 2017, The workshop is hosted by the International Conference on Embedded Wireless Systems and Networks (EWSN), https://hal.inria.fr/hal-01666441

[6] O. HAHM, E. BACCELLI, T. C. SCHMIDT, M. WÄHLISCH, C. ADJIH, L. MASSOULIÉ. *Low-power Internet of Things with NDN & Cooperative Caching*, in "ACM ICN 2017 - 4th ACM Conference on Information-Centric Networking", Berlin, Germany, September 2017, https://hal.inria.fr/hal-01666434

[7] P. KATSIKOULI, A. CARNEIRO, M. FIORE, A. TARABLE. *On the Sampling Frequency of Human Mobility*, in "IEEE GLOBECOM 2017", Singapore, Singapore, December 2017, pp. 1-6, https://hal.inria.fr/hal-01651856

[8] E. E. KHALEGHI, C. ADJIH, A. ALLOUM, P. MUHLETHALER. *Near-Far Effect on Coded Slotted ALOHA*, in "PIMRC 2017 - IEEE 28th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications - Workshop WS-07 on "The Internet of Things (IoT), the Road Ahead: Applications, Challenges, and Solutions"", Montreal, Canada, October 2017, https://hal.inria.fr/hal-01675805

[9] P. KIETZMANN, C. GÜNDOGAN, T. C. SCHMIDT, O. HAHM, M. WÄHLISCH. *The Need for a Name to MAC Address Mapping in NDN: Towards Quantifying the Resource Gain*, in "ACM ICN 2017 - 4th ACM Conference on Information-Centric Networking", Berlin, Germany, September 2017, https://hal.inria.fr/hal-01666601

[10] R. F. SHIGUETA, M. FONSECA, A. CARNEIRO VIANA. *A Mobility-Aware Channel Allocation Strategy for Clustered Ad hoc Network*, in "VTC2017-Spring - 2017 IEEE 85th Vehicular Technology Conference", Sydney, Australia, June 2017, https://hal.inria.fr/hal-01676499

Conferences without Proceedings

[11] L. GULIKERS, M. LELARGE, L. MASSOULIÉ. *Non-Backtracking Spectrum of Degree-Corrected Stochastic Block Models*, in "ITCS 2017 - 8th Innovations in Theoretical Computer Science", Berkeley, United States, January 2017, https://arxiv.org/abs/1609.02487 , https://hal.archives-ouvertes.fr/hal-01622719

[12] V. SHAH, L. GULIKERS, L. MASSOULIÉ, M. VOJNOVIC. *Adaptive Matching for Expert Systems with Uncertain Task Types*, in "Allerton 2017 - 55th Annual Allerton Conference on Communication, Control, and Computing", Monticello, IL, United States, October 2017, https://arxiv.org/abs/1703.00674 , https://hal.archives-ouvertes.fr/hal-01622739

Research Reports

[13] G. CHEN. *Spatiotemporal Individual Mobile Data Traffic Prediction*, Inria Saclay - Ile-de-France, January 2018, n⁰ RT-0497, https://hal.inria.fr/hal-01675573

[14] G. CHEN, S. HOTEIT, A. CARNEIRO VIANA, M. FIORE, C. SARRAUTE. *Enriching Sparse Mobility Information in Call Detail Records*, Inria Saclay - Ile-de-France, November 2017, n⁰ RT-0496, https://hal.inria.fr/hal-01646608

[15] G. CHEN, S. HOTEIT, A. CARNEIRO VIANA, M. FIORE, C. SARRAUTE. *Spatio-Temporal Predictability of Cellular Data Traffic*, Inria Saclay - Ile-de-France, January 2017, n⁰ RT-0483, 17 p. , https://hal.inria.fr/hal-01393361

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[17] P. KATSIKOULI, A. C. CARNEIRO VIANA, M. FIORE, A. TARABLE. *On The Sampling Frequency of Human Mobility*, Inria, February 2017, n⁰ RT-0487, 19 p. , https://hal.inria.fr/hal-01470393

[18] R. LIMA COSTA, A. CARNEIRO VIANA, A. ZIVIANI, L. NASCIMENTO SAMPAIO. *Tactful Networking: Humans in the communication loop* , Inria Saclay - Ile-de-France, January 2018, https://hal.inria.fr/hal-01675445

Other Publications

[19] B. ADAMSON, C. ADJIH, J. BILBAO, V. FIROIU, F. FITZEK, G. A. M. SAMAH, E. LOCHIN, A. MASUCCI, M.-J. MONTPETIT, M. V. PEDERSEN, G. PERALTA, V. ROCA, S. PARESH, S. SIVAKUMAR. *Network Coding Taxonomy*, July 2017, Internet Research Task Force - Working document of the Network Coding Research Group (NWCRG), draft-irtf-nwcrg-network-coding-taxonomy-05 (work in progress), https://datatracker.ietf.org/doc/draft-irtf-nwcrg-network-coding-taxonomy/, https://hal.inria.fr/hal-00998506

[20] C. ADJIH, M. KIEFFER, C. GRECO. *Network Coding with Random Packet-Index Assignment for Mobile Crowdsensing*, June 2017, working paper or preprint, https://hal-centralesupelec.archives-ouvertes.fr/hal-01538115

[21] L. DAUPHIN, E. BACCELLI, C. ADJIH, H. PETERSEN. *NDN-based IoT Robotics*, September 2017, ACM ICN'17 - 4th ACM Conference on Information-Centric Networking, Poster, https://hal.inria.fr/hal-01666539

[22] V. ROCA, J. DETCHART, C. ADJIH, M. V. PEDERSEN, I. SWETT. *Generic Application Programming Interface (API) for Window-Based Codes*, October 2017, Internet Research Task Force - Working document of the Network Coding Research Group (NWCRG), draft-roca-nwcrg-generic-fec-api-00 (work in progress), https://datatracker.ietf.org/doc/draft-roca-nwcrg-generic-fec-api/, https://hal.inria.fr/hal-01630138

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