Activity Report 2016

Project-Team INFINE

INFormation NEtworks

RESEARCH CENTER
Saclay - Île-de-France

THEME
Networks and Telecommunications

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Project-Team INFINE

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1.2.3. - Routing
1.2.5. - Internet of things
1.2.6. - Sensor networks
1.2.9. - Social Networks
1.3. - Distributed Systems
2.6.1. - Operating systems
3.3.2. - Data mining
3.4.2. - Unsupervised learning
3.5. - Social networks
3.5.1. - Analysis of large graphs
3.5.2. - Recommendation systems
4.8. - Privacy-enhancing technologies
5.9.2. - Estimation, modeling

Other Research Topics and Application Domains:

4.4. - Energy delivery
4.4.1. - Smart grids
6.4. - Internet of things
8.1.2. - Sensor networks for smart buildings
8.2. - Connected city

1. Members

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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.

2.1.1. 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.

2.1.2. 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 Spontaneous Wireless Networks/Internet of Things, 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...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. Spontaneous Wireless Networks (SWN) and Internet of Things (IoT)

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. Highlights of the Year

4.1.1. Conferences and Presentations

We organized a high-profile conference in May 2016 at the Institut Henri Poincaré on "Networks: learning, information and complexity" (see: http://www.msr-inria.fr/conferences-workshops/workshop-on-networks-learning-information-and-complexity/) which gathered leading scientists in computer science, maths and statistical physics.

We organized in January 2016 a workshop at the Turing building involving top executives of LVMH and Inria researchers to exchange on innovation opportunities for LVMH notably around advertising with online social networks, data visualization, and computer vision.

We gave several invited talks at: Stochastic Networks Conference, UCSD; CIRM workshop on random matrices; Institut Henri Poincaré's "Nexus" of Information and Computation Theories; EPFL workshop for birthdays of Shannon, Urbanke and Telatar (see: http://www.etru50.com/invited-speakers/) ; LINCS scientific advisory board.

4.1.2. RIOT Summit

We successfully organized in July 2016 the first RIOT Summit in Berlin. The RIOT Summit 2016 gathered 100+ enthusiastic industrial participants, makers and academics involved in RIOT. Relevant partners such as Cisco, Samsung, Siemens, Nordic Semiconductors, 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.

4.1.3. Opening of the IoT-LAB experimental platform at the site Saclay

The project Equipex FIT deploys experimental facilities on several sites. In 2016, at the site of Saclay, the opening of the FIT IoT-LAB site followed the move from its previous location at Rocquencourt.

The platform of Saclay is an Internet-of-Things testbed and includes more than 300 nodes (175 A8-M3, 12 M3 and 120 WSN430), deployed in large experimentation rooms and space. All A8 nodes are equipped with GPS.

More information about the topology and the resources of this new site is available here: https://www.iot-lab.info/deployment/saclay/.

4.1.4. Awards

The team members have received a number of awards:

M1 intern Davi Castro de Silva received best internship prize of LIX for his work on modifying spectral methods for community detection to increase their robustness.

Best Poster Award [26] O. Hahm, C. Adjih, E. Baccelli, T. C. Schmidt, M. Waehlisch. ICN over TSCH: Potentials for Link-Layer Adaptation in the IoT, September 2016, pp. 195-196, ACM-ICN '16 Proceedings of the 3rd ACM Conference on Information-Centric Networking , Poster. [DOI:10.1145/2984356.2985226] https://hal.inria.fr/hal-01369704

Best Demo Award [18] H. Petersen, C. Adjih, O. Hahm, E. Baccelli.

Demo: IoT Meets Robotics - First Steps, RIOT Car, and Perspectives, in: ACM International Conference on Embedded Wireless Systems and Networks (EWSN), Graz, Austria, February 2016. https://hal.inria.fr/hal-01262638

BEST PAPER AWARD:

[15]
F. SOMAA, C. ADJIH, I. E. KORBI, L. A. SAIDANE. *A Bayesian Model for Mobility Prediction in Wireless Sensor Networks*, in "5th IFIP International Conference on Performance Evaluation and Modeling in Wired and Wireless Networks (PEMWN 2016)", Paris, France, November 2016, https://hal.inria.fr/hal-01405277

5. New Software and Platforms

5.1. RIOT

KEYWORDS: Internet of things - Operating system - Sensors - Iot - Wireless Sensor Networks - 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 powerful API (partially POSIX compliant) that is consistent across heterogeneous low-end IoT hardware (8-bit, 16-bit and 32-bit architectures). This API is developer-friendly in that it enables multi-threading, standard C and C++ application programming (as well as scripting) and the use of standard debugging tools – all of which was not possible so far for such embedded programming. On top of this, RIOT supports a large number of software libraries (e.g. crypto, maths, drivers...) and aggregates in a simple manner a wide variety of third-party open source software packages. In particular, various network stacks are available with RIOT, 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. Other use-cases include also IoT-enabled low-cost robots.

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, Oliver Hahm, Cedric Adjih, Francisco Acosta
- Partner: Freie Universität Berlin
- Contact: Emmanuel Baccelli
- URL: https://github.com/RIOT-OS/RIOT

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
- Contact: Aline Carneiro Viana
- URL: https://macaco.inria.fr/macacoapp/

5.3. GardiNet (previously DragonNet)

FUNCTIONAL DESCRIPTION

GardiNet (previously known as DragonNet) is a generic framework for network coding in wireless networks. It is initially a 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, GardiNet 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: Cedric Adjih, Ichrak Amdouni, Hana Baccouch and Antonia Masucci
- Contact: Cedric Adjih
- URL: http://getrf.gforge.inria.fr/ https://github.com/GardiNet/gardinet

6. New Results

6.1. Online Social Networks (OSN)

Community detection; bandit algorithms; privacy preservation; reward mechanisms

6.1.1. Capacity of Information Processing Systems

Participants: Laurent Massoulié, 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 accepted and presented under the title "On the capacity of information processing systems" at the COLT 2016 conference.

6.2. Spontaneous Wireless Networks and Internet of Things

internet of things; wireless sensor networks; dissemination; resource management

6.2.1. Platform Design for the Internet of Things

Participants: Emmanuel Baccelli, Cedric Adjih, Oliver Hahm, Francisco Acosta, Hauke Petersen.

Within this activity, we have further developed the platforms we champion for the Internet of Things: the open source operating system RIOT on one hand, and open-access IoT-lab testbeds on the other hand. RIOT now aggregates open source contributions from 130+ people (and counting) from all over the world, coming both from academia and from industry, and received financial backing from top companies including Cisco and Google. We further developed RIOT for low-cost mobile robots and received the Best Demo Award at the ACM EWSN'16 conference for our work on this topic. As steering RIOT community members, we also participated in the prestigious Internet Architecture Board (IAB) workshop on IoT Software Updates, a hot and essential topic for the future of Internet of Things. The year culminated in this domain with the successful organization of the first RIOT Summit in Berlin, where 100+ participants from all over the world, from industry, academia as well as hackers/makers involved in RIOT gathered to discuss various aspects of the future of RIOT and open source IoT software. In addition, 2016, at the site of Saclay, one of the testbeds from FIT IoT-LAB was opened: the platform of Saclay includes more than 300 IoT nodes (175 A8-M3, 12 M3, 120 WSN430, some Arduinos and some SAMR21-xpro). In parallel, the platform from Freie Universitat Berlin also joined the OneLab/FIT IoT-LAB testbed federation.

6.2.2. Energy-Efficient Communication Protocols for the Internet of Things

Participants: Oliver Hahm, Emmanuel Baccelli, Cedric Adjih, Matthias Waehlisch, Thomas Schmidt.

Within this activity, we have designed distributed algorithms providing improved trade-off between content availability and energy efficiency (which plays a crucial role). The approach we developed leverages distributed caching for IoT content, based on an information-centric networking paradigm. We extended the NDN protocol with a variety of caching and replacement strategies, and we analyzed alternative approaches for extending NDN to accommodate such IoT use cases. Based on extensive experiments on real IoT hardware in a network gathering hundreds of nodes, we demonstrate these caching strategies can bring 90% reduction in energy consumption while maintaining IoT content availability above 90%. This work was published in IEEE Globecom'16 workshop on Named Data Networks for Challenged Communication Environments.

We also have designed new mechanisms to jointly exploit ICN communication patterns and dynamically optimize the use of TSCH (Time Slotted Channel Hopping), a wireless link layer technology increasingly popular in the IoT. Through a series of experiments on FIT IoT-LAB interconnecting typical IoT hardware, we find that our proposal is fully robust against wireless interference, and almost halves the energy consumed for transmission when compared to CSMA. Most importantly, our adaptive scheduling prevents the time-slotted MAC layer from sacrificing throughput and delay. Our work on ICN and on TSCH was published at NTMS'16, at ACM ICN'16, and in Proceedings of the IEEE.

6.2.3. Standards for Spontaneous Wireless Networks

Participant: Emmanuel Baccelli.

Within this activity, we have contributed to new network protocol standards for spontaneous wireless networking, applied to ad hoc networks and the Internet of Things. In particular, collaborating with Fraunhofer, we have published RFC 7779, standardizing Directional Airtime Metric (DAT), a new wireless metric standard targeting wireless mesh networks. Furthermore, collaborating with ARM and Sigma Designs, we published RFC 7733, which provides guidance in the configuration and use of protocols from the RPL protocol suite to implement the features required for control in building and home environments. In collaboration with various industrial partners, with have also published a number of other Internet drafts, including an analysis of the characteristics of multi-hop ad hoc wireless communication between interfaces in the context of IP networks, and an analysis of the challenges of information-centric networking in the Internet of Things.

6.2.4. Spatio-Temporal Predictability of Cellular Data Traffic

Participants: Guangshuo Chen, Aline Carneiro Viana, Marco Fiore, Sahar Hoteit, Carlos Sarraute.

The ability to foresee the data traffic activity of subscribers opens new opportunities to reshape mobile network management and services. In this work, we leverage two large-scale real-world datasets collected by a major mobile carrier in Mexico to study how predictable are the cellular data traffic demands generated by individual users. We focus on the predictability of mobile traffic consumption patterns in isolation. Our results show that it is possible to anticipate the individual demand with a typical accuracy of 85%, and reveal that this percentage is consistent across all user types. Despite the heterogeneity in usage patterns of users, we also find a lack of significant variability in predictability when considering demographic factors or different mobility or mobile service usage. We also analyze the joint predictability of the traffic demands and mobility patterns. We find that the two dimensions are correlated, which improves the predictability upper bound to 90%on average. This first work is in submission in an international conference.

6.2.5. Completion of Sparse Call Detail Records for Mobility Analysis

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

Call Detail Records (CDRs) have been widely used in the last decades for studying different aspects of human mobility. The accuracy of CDRs strongly depends on the user-network interaction frequency: hence, the temporal and spatial sparsity that typically characterize CDR can introduce a bias in the mobility analysis. In this work, we evaluate the bias induced by the use of CDRs for inferring important locations of mobile subscribers, as well as their complete trajectories. Besides, we propose a novel technique for estimating real human trajectories from sparse CDRs. Compared to previous solutions in the literature, our proposed technique reduces the error between real and estimated human trajectories and at the same time shortens the temporal period where users' locations remain undefined. This work has been published as an invited paper at the ACM CHANTS 2016 workshop in conjunction with ACM MobiCom 2016. Related to CDRs, we have also investigated whether the information of user's instantaneous whereabouts provided by CDRs enables us to estimate positions over longer time spans. Our results confirm that CDRs ensure a good estimation of radii of gyration and important locations, yet they lose some location information. Most importantly, we show that temporal completion of CDRs is straightforward and efficient: thanks to the fact that they remain fairly static before and after mobile communication activities, the majority of users' locations over time can be accurately inferred from CDRs. Finally, we observe the importance of user's context, i.e.,of the size of the current network cell, on the quality of the CDR temporal completion. This work is in submission in an international conference.

Finally, driven by real-world data across a large population, we propose two approaches as the refinement of the legacy solution, which complete CDR data adaptively according to the information of users and activities. Our proposed methods outperform the legacy solution in terms of the combination of accuracy and temporal coverage. Besides, our work reveals the important factors to the data completion. This paper has been accepted for publication at the IEEE DAWM workshop in conjunction with IEEE Percom 2017.

6.2.6. Completion of Sparse Call Detail Records for Mobility Analysis

Participants: Panagiota Katsikouli, Aline Carneiro Viana, Marco Fiore, Alessandro Nordio, Alberto Tarable.

The increasing usage of smart devices and location-tracking systems has made it possible to study and understand the behaviour of users as well as human mobility at an unprecedented scale. The insights of such studies can help improve many aspects of our everyday lives, from road network infrastructure to mobile network quality of service. Human mobility is repetitive and regular.In addition to our tendency to revisit the same locations, those visits happen with relevant temporal regularity, where each visited location has been assigned with an ID. The daily interaction with our smart devices, such as smartphones, results in collecting fine grained information on our activities and whereabouts. This information can be used to detect and analyze the routinary behaviour of humans but also to discover interests, preferences and hidden patterns of mobility. However, frequent recording of data tends to quickly drain the battery of the smartphone. A natural alternative is to sample the collected data. Maintaining a summary or sample as close to the original collected data as possible is the key challenge. Deciding what constitutes a representative sample depends on the type of information we wish to maintain from the data collected. In this work, we wish to sparsely sample mobility traces of GPS data with the goal to reconstruct the movement of the users both in space and time at the desired granularity. An ideal sample would allow us to reconstruct the traces in such a way that we preserve the frequency of visits and the time spent to the various locations. Therefore, the problem we tackle here is to *sparsely sample the mobility trace of a user with the goal to reconstruct her complete trace in space and time*. This is an on-going work and will be submitted to an international conference in the next months.

6.3. Resource and Traffic Management

Traffic offloading; infrastructure deployment; opportunistic routing; traffic modeling; intermittently connected networks.

6.3.1. 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

- Participation to Microsoft Research – Inria Joint Centre, which funds two PhD students (Lennart Gulikers and Remi Varloot).
- During 2016, Cisco and Nordic Semiconductors have funded further development of RIOT and sponsored the RIOT Summit.

7.2. GranData

Participants: Aline Carneiro Viana, Eduardo Mucelli.

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. Regional Initiatives

8.1.1. LiveGrid

Participants: Cedric Adjih, Emmanuel Baccelli.

Infine is one of the teams from Inria participating to LiveGrid: LiveGrid is a consortium of the main actors of industry, research organisations, local authorities and competitive cluster from the Paris-Saclay campus. The goal of LiveGrid is make the Paris-Saclay campus one of the leader regions of smart grids. Infine expertise is in infrastructure: testbeds, communication protocols, embedded open source OS.

8.2. National Initiatives

8.2.1. 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.

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).

The Infine team is actively collaborating with UPEC on wireless sensor network testbeds (and protocols): in 2015 and 2016, the testbed from UPEC with 45 Arduino nodes has been integrated with the FIT IoT-LAB testbed.

8.3. European Initiatives

8.3.1. FP7 & H2020 Projects

8.3.1.1. 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.

8.3.1.2. ARMOUR (H2020 project)

Participants: Cedric Adjih, Emmanuel Baccelli, Oliver Hahm.

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.

8.3.2. Collaborations in European Programs, Except FP7 & H2020

8.3.2.1. 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: 2013-2016

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. 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 prefetch 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.

8.4. International Initiatives

8.4.1. Inria International Partners

8.4.1.1. Declared Inria International Partners

- 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.
- 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, ...

8.4.1.2. Informal International Partners

- On-going collaboration with Hamburg University of Applied Science around RIOT.
- Informal collaborations with UIUC and UMass.
- Informal collaborations with ENSI Tunis and Sesame Tunis.

8.4.2. Participation in Other International Programs

8.4.2.1. PHC PESSOA 2015

Participant: Aline Carneiro Viana.

PHC PESSOA 2015 with University of Coimbra (2015-2016).

Program: -FCT - Programa PESSOA

Project title: Routine-based Enhanced Connectivity under User Mobility

Duration: 2015-2016

Coordinator: Aline Carneiro Viana and João Paulo da Silva Machado Garcia Vilela (University of Coimbra)

Abstract: The main goal of this project is to improve WiFi connectivity of users under mobility. The steady growth of smart-phones usage has put cellular networks under great strain, justifying the need for WiFi offloading as a solution that transfers part of the demand on cellular networks to WiFi hotspots that are in many cases already available. However, this must be performed in a way that provides benefits to the cellular operator while ensuring users a similar level of connectivity that they would achieve with cellular networks, even under user mobility (e.g. walking, taking a bus/train, etc). In this work we aim at (1) developing prediction mechanisms for selection of best hotspots by users under mobility, and (2) develop lightweight security schemes to reduce the burden of the association/authentication process of WiFi networks, therefore making WiFi offloading an effective and secure alternative to the growing demand on cellular networks.

8.5. International Research Visitors

8.5.1. Visits to International Teams

8.5.1.1. Research Stays Abroad

Emmanuel Baccelli was Visiting Professor at Freie Universitaet (FU) Berlin in 2016, 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

- In 2016, Emmanuel Baccelli was general chair of the RIOT Summit.

9.1.1.2. Member of the Organizing Committees

- In 2016, Aline Viana was on the conference program committee for IEEE International Conference on Advanced Information Networking and Applications (IEEE AINA-2017).
- In 2016, Emmanuel Baccelli was in the conference programm committee of the ACM Mobile-Health'16.

9.1.2. Scientific Events Selection

9.1.2.1. Reviewer

- In 2016, Cédric Adjih was reviewer for WINCOM'16, and Globecom 2016.

9.1.3. Journal

9.1.3.1. Member of the Editorial Boards

- In 2016, Aline Viana was Associate Editor of ACM Computer Communication Review (ACM CCR) and Editorial Board member of "Wireless Communications and Mobile Computing Open Access Journal" of John Wiley&Sons and Hindawi.

9.1.3.2. Reviewer - Reviewing Activities

- In 2016, Aline Viana was reviewer for IEEE Transaction on Mobile Computing (TMC), Elsevier Pervasive and Mobile Computing, Elsevier AdHoc Networks, Elsevier Computer Networks.
- In 2016, Emmanuel Baccelli was member of the IETF Routing Directorate, and as such was reviewing RFCs in the making.

9.1.4. Invited Talks

- In 2016, Emmanuel Baccelli gave a number of invited talks on the topic of RIOT, including at the IoT Meetup (April 2016 in Athens, Greece), at the RIOT Summit (July 2016 in Berlin, Germany), at TelecomParisTech for ICSSEA'16 (June 2016, Paris, France), at EclipseCon'16 (October 2016 in Ludwigsburg, Germany), at Fraunhofer FOKUS for ASQF Day (December 2016 in Berlin, Germany)
- In 2016, Cédric Adjih gave a talk on RIOT at IFSSTAR (November 2016 in paris, France).
- In 2016, we also gave several invited talks at: Stochastic Networks Conference, UCSD; CIRM workshop on random matrices; Institut Henri Poincaré's "Nexus" of Information and Computation Theories; EPFL workshop for birthdays of Shannon, Urbanke and Telatar (see: http://www.etru50.com/invited-speakers/) ; LINCS scientific advisory board.

9.1.5. Scientific Expertise

- In 2016, Cédric Adjih served as a expert reviewer for one ANR call for proposals.

9.2. Teaching - Supervision - Juries

9.2.1. Teaching

- **Masters**
- Engineering school, third year students at Ecole Polytechnique: Laurent Massoulié taught a course on "Networks: distributed control and emerging phenomena".
- Course for Corps des Mines: Emmanuel Baccelli gave a half day course on "Communication Protocols and Operating Systems for the Internet of Things" in the context of the formation PESTO.
- Engineering school, third year students at Telecom ParisTech: Aline Carneiro Viana taught an 1 hour lesson on "Wireless Network" course.
- Engineering school, third year students at Telecom SudParis: Aline Carneiro Viana taught an 6 hour lessons on "Wireless Network" course.

9.2.2. Supervision

- Laurent Massoulie currently advises 2 PhD students: Lennart Gulikers and Remi Varloot.
- Cedric Adjih currently advises Fatma Somaa, on "handling mobility in routing in wireless sensor networks", thesis started in 2013 and co-advised with Inès El Korbi (Institut Supérieur d'Informatique et de Gestion de Kairouan, Tunisie).
- Emmanuel Baccelli and Cédric Adjih are advising: Loïc Dauphin on "Robotics meets the Internet of Things", (June 2016-).
- Aline Viana currently advises 2 PhD students: Roni Shigueta, on "Resource allocation in highly mobile wireless networks" (January 2012-2017). Guangshuo Chen, on "Understanding and predicting human demanded content and mobility" (September 2014-).
- PhD completed: Felipe Domingos on "identifying social attributes in VANETs" (January 2013-June 2016). Advisor: Aline Carneiro Viana.
- PhD completed: Oliver Hahm, "Enabling Energy Efficient Smart Object Networking at Internet-Scale", 2012-2016. Advisor: Emmanuel Baccelli.

9.2.3. Juries

- 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.
- Aline Viana was on the PhD jury as reviewer of Wenjing Shuai, ”Management of electric vehicle systems with self-interested actors” Telecom Bretagne, September 2016.
- Aline Viana was on the PhD jury as examiner of Mouna Rekik, ”Protocols for Smart Girds”, Universite de Lille, France July 2016.
- Aline Viana was on the Master jury of Fausto Silva Moraes ”Explorando Interações em Redes Sociais Online, Comunicação D2D e Estratégias de Cache para Uso Eficiente de Recursos em Redes Celulares”, Brazil November 2016.
- Emmanuel Baccelli was on the PhD jury of Francisco Acosta, “Self-adaptation for Internet of Things applications”, Universite de Rennes 1, Dec. 2016.
- Emmanuel Baccelli was on the PhD jury of Kevin Roussel, “Évaluation et amélioration des plates-formes logicielles pour réseaux de capteurs sans-fil, pour optimiser la qualite de service et l’énergie,” Université de Lorraine, June 2016.

9.3. Popularization

- Publication of “RIOT, le Systeme d’Exploitation pour l’Internet des Objets” in the magazine Open Silicium, Mars 2016. Co-authors: Alexandre Abadie, Cedric Adjih, Emmanuel Baccelli, Francisco Acosta, Hauke Petersen.
- Francisco Padilla and Loïc Dauphin participated to the "Fête de la Science 2016".

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