Activity Report 2019

# Project-Team TRIBE

inTeRnet BEyond the usual

RESEARCH CENTER
**Saclay - Île-de-France**

THEME
**Networks and Telecommunications**

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## Project-Team TRIBE

*Creation of the Project-Team: 2019 June 01*

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# 1. Team, Visitors, External Collaborators

**Research Scientists**

Aline Carneiro Viana [Team leader, Inria, Researcher, from Jun 2019, HDR]
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Emmanuel Baccelli [Inria, Researcher, from Jun 2019, HDR]
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Oumaima Attia [Inria, Engineer, from Mar 2019]
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Felipe Fonseca [Inria, from Nov 2019]
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**Administrative Assistant**

Laurence Fontana [Inria, Administrative Assistant, from Jun 2019]

# 2. Overall Objectives

## 2.1. Vision and approach

TRiBE stands for "Internet Beyond the Usual" and belongs to the Inria theme "Networks and Telecommunications" as well as contributes to the "Challenge no 11: Toward a trustworthy Internet of Everything" of the strategic plan of Inria. *Building on an approach combining protocol design, data analytics, and experimental research, the research contributions of TRiBE aims at contributing to the design of smart, unified, and tactful Internet edge networks, skilled for answering application, services, or end-users' purposes.*

All the emerging IoT specificities and requirements (i.e., heterogeneity of devices and services, densification, traffic growth, ubiquitous cyber-physical context, etc) bring new demands and consequently, new scientific and technological challenges to the edge of the Internet. In this context, our conviction is that the success of the Internet of Things is rooted in the **network designing choices** involving its devices and related protocols/services as well as the edge-core network communication loop.

Toward this belief, the research of the team will be organized around three research directions: *(1) technologies for accomodating low-end IoT devices; (2) technologies for leveraging high-end IoT devices' advents; and (3) technologies for edge-core network interaction.* With those three research directions, the team place its efforts in the three main elements composing the ecosystem of IoT devices: (1) the device itself, (2) their usability, and (3) their network context.

More specifically, the first element tackles the optimization, simplicity, and unification requirements imposed by the heterogeneity and low capabilities of low-end IoT devices. This brings the necessity to deal with hardware and software specificity of devices, while adapting designing choices and simplifying deployment. The second element focus on issues related to "how" and "for what" IoT devices are used. This also brings the human element into play, which dynamics are shaping the way their mobile devices are interacting with the edge of the Internet and consequently, are requesting and consuming network resources and services. Finally, the third element closes the *network→usability→device→network* loop by bringing solutions supporting functions and communication between IoT devices and the core of the Internet.

## 2.2. New challenges

The Internet has steadily evolved over the past decades from a small homogeneous to a gigantic Internet of Things (IoT) interconnecting an extremely wide variety of machines (e.g., PCs, smart-phones, sensors/actuators, smart appliances, smart vehicles), and providing an extremely wide variety of services. Globally, devices and connections are growing faster than both the population and Internet users, as foreseen by Cisco. Forecasts mention an IoT market that will attain a compound annual growth rate of 28.5% from 2016 to 2020 as well as an installed base of IoT devices over 75.4B devices by 2025. Added to these statistics is the fact that global mobile data traffic will grow nearly twice as fast as fixed IP traffic from 2017 to 2022: Smartphones account for most of this growth.

Hence, the edge of this network now consists in a dense deployment of machines ranging from PCs to smartphones, from sensors/actuators to smart appliances, and from smart vehicles to diverse kinds of robots. As a consequence, humans are immersed in a highly connected and ubiquitous cyber-physical context, and as end-users of the network and its numerous services, their satisfaction has become the main focus.

In this context, the IoT is simultaneously used as a tool to gather more data, and as a mean to automate more advanced control. Some businesses and institutions aim to gather more data to better understand their customers, so as to improve services. Others efforts aim to further immerse their customers into a flourishing, integrated cyber-physical environment, which can automatically and optimally adapts to their needs. All these emerging IoT-related opportunities bring new requirements and consequently, new scientific and technological challenges to the edge of the Internet.

First, the densified deployment of heterogeneous **low-end IoT devices** (e.g. sensors, actuators, etc.) at the edge of the Internet requires to deal with (1) the accommodation of machines with extremely limited capabilities, with a primary focus on low power requirements while (2) allowing their seamless integration in interoperable systems (often using IP as a common factor).

Second, today's pervasiveness of **high-end IoT devices** (e.g. smart handheld devices) distribute increasing capabilities (i.e., processing, storage, connectivity) at the edge of the network, and make our real life and virtual activities seamlessly merged together. In this domain, we need a better understanding of: (1) when, where, and for what the high-end IoT devices are used, (2) how the uses vary among individuals, and (3) how social norms and structure dictating individuals' behavior influence the way they interact with network services and demand resources.

The research contributions of the team aims thus, at dealing with such requirements and challenges brought to the edge of the Intenet. One should design adequate algorithms and communication mechanisms for addressing such challenges as well as for leveraging the new technological opportunities brought by the Internet of Things.

# 3. Research Program

## 3.1. Research program

Following up on the effort initiated by the team members during the last few years and building on an approach combining protocol design, data analytics, and experimental research, we propose a research program organized around three closely related objectives that are briefly described in the following.

- **Technologies for accommodating low-end IoT devices:** The IoT is expected to gradually connect billions of low-end devices to the Internet, and thereby drastically increase communication without human source or destination. Low-end IoT devices differ starkly from high-end IoT devices in terms of resources such as energy, memory, and computational power. Projections show this divide will not fundamentally change in the future and that IoT should ultimately interconnect a dense population of devices as tiny as dust particles, feeding off ambient power sources (energy harvesting). These characteristics constrain the software and communication protocols running on low-end IoT devices: they are neither able to run a common software platform such as Linux (or its derivatives), nor

the standard protocol stack based on TCP/IP. Solutions for low-end IoT devices require thus: **(i) optimized communication protocols** taking into account radio technology evolution and devices constrained requirements; **(ii) tailored software platforms** providing high level programming, modular software updates as well as advanced support for new security and energy concentration features; **(iii) unification of technologies** for low-end IoT, which is too fragmented at the moment, guaranteeing integration with core or other edge networks.

- **Technologies for leveraging high-end IoT devices' advents:** High-end IoT devices are one of the most important instances of the connected devices supporting a noteworthy shift towards mobile Internet access. As our lives become more dependent on pervasive connectivity, our social patterns (as human being in the Internet era) are nowadays being reflected from our real life onto the virtual binary world. This gives birth to two tendencies. From one side, edge networks can now be utilized as mirrors to reflect the inherent human dynamics, their context, and interests thanks to their well organized recording and almost ubiquitous coverage. From the other side, social norms and structure dictating human behavior (e.g., interactions, mobility, interest, cultural patterns) are now directly influencing the way individuals interact with the network services and demand resources or content. In particular, we observe the particularities present in human dynamics *shape the way (i.e., where, when, how, or what) resources, services, and infrastructures are used at the edge of the Internet*. Hence, we claim a need to digitally study high-end IoT devices' end-users behaviors and to leverage this understanding in networking solutions' design, so as to optimize network exploitation. This suggests the **integration of the heterogeneity and uncertainty of behaviors in designed networking solutions**. For this, *useful knowledge* allowing the understanding of behaviors and context of users has to be *extracted and delivered out* of large masses of data. Such knowledge has to be then *integrated in current design practices*. This brings the idea of a more *tactful networking design practice* where the network is assigned with the human like capability of observation, interpretation, and reaction to daily life features and entities involving high-end IoT devices. Research activities here include: **(i) the quest for meaningful data**, which includes the integration of data from different sources, the need for scaling up data analysis, the usage and analysis of fine-grained datasets, or still, the completion of sparse and coarse grained datasets; **(ii) expanding edge networks' usage understanding**, which concerns analysis on how and when contextual information impact network usage, fine-grained analysis of short-term mobility of individuals, or the identification of patterns of behavior and novelty-seeking of individuals; **(iii) human-driven prediction models**, extensible to context awareness and adapted to individuals preferences in terms of novelty, difersity, or routines.
- **Articulating the IoT edge with the core of the network:** The edge is the interface between the IoT devices and the core network: some of the challenges encountered by IoT devices have their continuity at the edge of the network inside the gateway (i.e., interoperability, heterogeneity and mobility support). Besides, the edge should be able to support intermediary functions between devices and the rest of the core (e.g., the cloud). This includes: **(i) proxying functionality**, facilitating connections between devices and the Internet; **(ii) machine learning enhanced IoT solutions**, designed to improve performance of advanced IoT networked systems (e.g., through methods such as supervised, unsupervised or reinforcement learning) at adapted levels of the protocol stack (e.g., for multiple access, coding, choices); **(iii) IoT data contextualization**, so collection of meaningful IoT data (i.e., right data collected at the right time) can be earlier determined closer to the data source; **(iv) intermediary computation** through fog or Mobile Edge Computing (MEC) models, where IoT devices can obtain computing, data storage, and communication means with lower latency in a decentralized way; or **(v) security of end-to-end IoT software supply-chain**, including remote management and over-the-air updates.

# 4. Highlights of the Year

## 4.1. Highlights of the Year

### *4.1.1. Awards*

Together with his co-authors, Aline Carneiro Viana was awarded: (1) the **best poster award** at the main conference on the scientific analysis of mobile phone datasets (NetMob) in Oxford, UK, Jul. 2019, for the poster on **Complete Trajectory Reconstruction from Sparse Mobile Phone Data** (collaboration with G. Chen, M. Fiore, and C. Sarraute); (2) the **top-six best paper award** at the 27th International Conference on Advances in Geographic Information Systems 2019 (ACM SIGSPATIAL), in Chicago, USA, Nov. 2019, for the paper on **Deciphering Predictability Limits in Human Mobility**.

### *4.1.2. RIOT Summit 2019*

We successfully organized in September 2019 the fourth RIOT Summit, in Helsinki. The RIOT Summit 2019 gathered ∼100 enthusiastic industrial participants, makers and academics involved in RIOT. Highlights included a keynote from IoT expert and former IETF general chair Jari Arkko (Ericsson Research), and a new car-sharing product using RIOT announced by Continental (and now deployed on thousands of vehicles). Aside of big companies and academics, 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.

### *4.1.3. Associated team - EMBRACE*

2019 was the third and last year of the EMBRACE Associated team. The EMBRACE (lEveraging huMan Behavior for Resource AlloCation and services orchestration modEls) team was composed by members of the INFINE and by three Brazilian teams from three different Brazilian Universities. The EMBRACE project addressed the topic of designing efficient solutions for 5G networks taking into account human behavior, uncertainty, and heterogeneity of networking resources. A proposal requesting the extension of the project was submitted in Nov. 2019.

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

### *4.1.4. IETF Hackathons*

Concerning Internet Standardization, we contributed to all three IETF Hackathons in 2019. In particular, Oumaima Attia and Cedric Adjih were some major contributors (with many others including Vincent Roca, EPI Privatics) in the NWCRG Hackathon which allowed to release in first prototype of SWIF-codec, a sliding-window forward-error correction codec, see: **https://github.com/irtf-nwcrg/swif-codec**. Cedric Adjih is also a major contributor to the LPWAN Hackathon on the SCHC protocol (IPv6 compression for IoT networks), which resulted this year in code at **https://github.com/openschc/openschc**, a working prototype of the protocol.

# 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 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
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- URL: http://www.riot-os.org

## 5.2. openschc

KEYWORDS: Internet of things - Internet protocols - Low-Power WIreless

FUNCTIONAL DESCRIPTION: OpenSCHC is a OpenSource Implementation of SCHC (Static Context Header Compression) currently being standardized by the LPWAN Working Group at the IETF. Oversimplifying, this is essentially IPv6 compression and fragmentation intended for low datarate, long range IoT networks.

The short/medium term goal is to organize SCHC Hackathons that occur at the IETF meetings.

The long term wish is to have a stable, open-source, reference codebase for the SCHC protocol (in Python).

The authors of OpenSCHC are listed here: https://github.com/openschc/openschc/blob/master/AUTHORS.txt

- Partner: OpenSCHC Authors
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- URL: https://github.com/openschc/openschc

## 5.3. 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
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# 6. New Results

## 6.1. Human Mobility completion of Sparse Call Detail Records

**Participants:** Guangshuo Chen [Inria], Aline Carneiro Viana, Marco Fiore [CNR], Carlos Sarraute [GranData].

Mobile phone data are a popular source of positioning information in many recent studies that have largely improved our understanding of human mobility. These data consist of time-stamped and geo-referenced communication events recorded by network operators, on a per-subscriber basis. They allow for unprecedented tracking of populations of millions of individuals over long time periods that span months. Nevertheless, due to the uneven processes that govern mobile communications, the sampling of user locations provided by mobile phone data tends to be sparse and irregular in time, leading to substantial gaps in the resulting trajectory information. In this work, we illustrate the severity of the problem through an empirical study of a large-scale Call Detail Records (CDR) dataset. We then propose two novel and effective techniques to reduce temporal sparsity in CDR that outperform existing ones. the fist technique performs completion (1) at nightime by identifying temporal home boundary and (2) at daytime by inferring temporal boundaries of users, i.e., the time span of the cell position associated with each communication activity. The second technique, named Context-enhanced Trajectory Reconstruction, complete individual CDR-based trajectories that hinges on tensor factorization as a core method by leveraging regularity in human movement patterns.

Our approach lets us revisit seminal works in the light of complete mobility data, unveiling potential biases that incomplete trajectories obtained from legacy CDR induce on key results about human mobility laws, trajectory uniqueness, and movement predictability. In addition, the CTR solution infers missing locations with a median displacement within two network cells from the actual position of the user, on a hourly basis and even when as little as $1\%$ of her original mobility is known.

These works have been published at two journals: EPJ Data Science in 2019 and at Computer Communication Elsevier in 2018.

## 6.2. Adaptive sampling frequency of human mobility

**Participants:** Panagiota Katsikouli [AGORA], Aline Carneiro Viana, Marco Fiore [CNR], Diego Madariaga.

In recent years, mobile device tracking technologies based on various positioning systems have made location data collection a ubiquitous practice. Applications running on smartphones record location samples at different frequencies for varied purposes.The frequency at which location samples are recorded is usually pre-defined and fixed but can differ across applications; this naturally results in big location datasets of various resolutions. What is more, continuous recording of locations results usually in redundant information, as humans tend to spend significant amount of their time either static or in routine trips, and drains the battery of the recording device.

In this work, 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 first analyses on fine-grained GPS trajectories from users around the world unveil *(i)* seemingly universal spectral properties of human mobility, and *(ii)* a linear scaling law of the localization error with respect to the sampling interval. Such results were published at a paper at IEEE Globecom 2017.

Building on these results, we challenge the idea of a fixed sampling frequency and present a lightweight mobility aware adaptive location sampling mechanism. This is an on-going work with Panagiota Katsikouli, who spent 5 months in our team working as an internship in 2017, and Diego Madariaga who spent 3 months in 2018 in our team working as an internship and has started a PhD in co-tutelle with Aline C. Viana and Javier Bustos (NIC/Univ. of Chile).

Our mechanism can serve as a standalone application for *adaptive location sampling*, or as complimentary tool alongside auxiliary sensors (such as accelerometer and gyroscope). In this work, we implemented our mechanism as an application for mobile devices and tested it on mobile users worldwide. Our experiments show that our method adjusts the sampling frequency to the mobility habits of the tracked users, it reliably tracks a mobile user incurring acceptable approximation errors and significantly reduces the energy consumption of the mobile device.

A journal paper is being prepared for submission.

## 6.3. Inference of human personality from mobile phones datasets

**Participants:** Adriano Di Luzio [Sapienza U. di Rome], Aline Carneiro Viana, Julinda Stefa [Sapienza U. di Rome], Katia Jaffres-Runser [U. of Toulouse], Alessandro Mei [Sapienza U. di Rome].

Related to human behavioral studies, personality prediction research has enjoyed a strong resurgence over the past decade. Due to the recognition that personality is predictive of a wide range of behavioral and social outcomes, the human migration to the digital environment renders also possible to base prediction of individual personality traits on digital records (i.e., datasets) mirroring human behaviors. In psychology, one of the most commonly used personality model is the Big5, based on five crucial traits and commonly abbreviated as OCEAN: Openness (O), Conscientiousness (C), Extroversion (E), Agreeableness (A), and Neuroticism (N). They are relatively stable over time, differ across individuals, and, most importantly, guide our emotions and our reactions to life circumstances. It is so for social and work situations, and even for things as simple as the way we use our smartphone. For instance, a person that is curious and open to new experiences will tend to look continuously for new places to visit and thrills to experience.

This work brings the deepest investigation in the literature on the prediction of human personality (*i.e.,* captured by the Big5 traits) from smartphone data describing daily routines and habits of individuals. This work shows that human personality can be accurately predicted by looking at the data generated by our smartphones. GPS location, calls, battery usage and charging, networking context like bluetooth devices and WiFi access points in proximity, and more give enough information about individual habits, reactions, and idiosyncrasies to make it possible to infer the psychological traits of the user. We demonstrate this by using machine learning techniques on a dataset of 55 volunteers who took a psychological test and allowed continuous collection of data from their smartphones for a time span of up to three years. Openness, Conscientiousness, Extroversion, Agreeableness, and Neuroticism (the so called Big5 personality traits) can be predicted with good accuracy even by using just a handful of features. The possible applications of our findings go from network optimization, to personal advertising, and to the detection of mental instability and social hardship in cities and neighborhoods. We also discuss the ethical concerns of our work, its privacy implications, and ways to tradeoff privacy and benefits.

A paper describing this work is under submission at ACM Transactions on Data Science (TDS) , but a technical report is also registered under the name hal-01954733.

## 6.4. Data offloading decision via mobile crowdsensing

**Participants:** Emanuel Lima [U. of Porto], Aline Carneiro Viana, Ana Aguiar [U. of Porto], Paulo Carvalho [Univ. Do Minho].

According to Cisco forecasts, mobile data traffic will grow at a compound annual growth rate of 47 % from 2016 to 2021 with smartphones surpassing four-fifths of mobile data traffic. It is known that mobile network operators are struggling to keep up with such traffic demand, and part of the solution is to offload communications to WiFi networks. Mobile data offloading systems can assist mobile devices in the decision making of when and what to offload to WiFi networks. However, due to the limited coverage of a WiFi AP, the expected offloading performance of such a system is linked with the users mobility. Unveiling and understanding human mobility patterns is a crucial issue in supporting decisions and prediction activities for mobile data offloading.

Several studies on the analysis of human mobility patterns have been carried out focusing on the identification and characterization of important locations in users' life in general. We extended these works by studying human mobility from the perspective of mobile data offloading. In our study, offloading zones are identified and characterized from individual GPS trajectories when small offloading time windows are considered. The characterization is performed in terms availability, sojourn, transition time; type and spatial characteristics. We then evaluate the offloading opportunities provided to users while they are travelling in terms of availability, time window to offload and offloading delay. We also study the mobility predictability in an offloading scenario through the theoretical and practical evaluation of several mobility predictors. The results show that (i) attending to users mobility, ten seconds is the minimum offloading time window that can be considered; (ii) offloading predictive methods can have variable performance according to the period of the day; and (iii) per-user opportunistic decision models can determine offloading system design and performance.

This work was published at ACM CHANTS 2018 and its extension will be submitted to WoWMON 2020. This is an on-going work with the the PhD Emanuel Lima (one of my co-supervision), who spent 4 months as an intern in our team in 2018, and his advisors.

## 6.5. Identifying how places impact each other by means of user mobility

**Participants:** Lucas Santos de Oliveira [EMBRACE], Pedro Olmo Stancioli [Federal U. of Minas Gerais], Aline Carneiro Viana.

The way in which city neighborhoods become popular and how people trajectory impacts the number of visitation is a fundamental area of study in traditional urban studies literature. Many works address this problem by means of user mobility prediction and POI recommendation. In a different approach, other works address the human mobility in terms of social influence which refers to the case when individuals change their behaviors persuaded by others. Nevertheless, fewer works measure influence of POI based on human mobility data.

Different from previous literature, in this work, we are interested in understanding how the neighborhood POI affect each other by means of human mobility using location-based social networks (LBSNs) data source. Key location identification in cities is a central in human mobility investigation as well as for societal problem comprehension. In this context, we propose a methodology to quantify the power of point-of-interests (POIs) in their vicinity, in terms of impact and independence – the first work in the literature (to the best of our knowledge). Different from literature, we consider the flow of people in our analysis, instead of the number of neighbor POIs or their structural locations in the city. Thus, we first modeled POI's visits using the multiflow graph model where each POI is a node and the transitions of users among POIs are a weighted direct edge. Using this multiflow graph model, we compute the attract, support and independence powers. The attract power and support power measure how many visits a POI gather from and disseminate over its neighborhood, respectively. Moreover, the independence power captures the capacity of POI to receive visitors independently from other POIs. Using a dataset describing the mobility of individuals in the Dartmouth College campus, we identify a slight dependence among buildings as well as the tendency of people to be mostly stationary in few buildings with short transit periods among them.

This work was published in ACM MobiWac 2019 [14] and an extended version is being prepared. Lucas is doing an internship in our team from Nov. 2019 to Jan. 2020.

## 6.6. Infering friends in the crowd in Device-to-Device communication

**Participants:** Rafael Lima Da Costa [CAPES], Aline Carneiro Viana, Leobino Sampaio [Federal U. of Bahia], Artur Ziviani [LNCC].

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 first introduce the Tactful Networking paradigm, whose goal is to add perceptive senses to the network, by assigning it with human-like capabilities of observation, interpretation, and reaction to daily-life features and involved entities. To achieve this, knowledge extracted from human inherent behavior (routines, personality, interactions, preferences, among others) is leveraged, empowering user-needs learning and prediction to improve QoE while respecting privacy. We survey the area, propose a framework for enhancing human raw data to assist networking solutions and discuss the tactful networking impact through representative examples. Finally, we outline challenges and opportunities for future research. This tutorial paper is under submittion to ACM Computing and Surveys and a technical report is registered as hal-01675445.

Besides, we investigate how human-aspects and behavior can be useful to leverage future device-to-device communication. We have designed a strategy to select next-hops in a D2D communication that will be human-aware: i.e., that will consider not only available physical resources 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. Such forwarders nodes will be then used at the offloading of content data through Device-to-Device (D2D) communication, from devices to the closest Mobile Edge Computing infrastructure, transforming mobile phone neighbors in service providers. The selection of next hops based on mobility behavior, resource capability as well as collaboration constitute the novelty we plan to exploit. A conference paper is under preparation and a Brazilian paper under submission to SBRC 2020.

## 6.7. Deciphering Predictability Limits in Human Mobility

**Participants:** Douglas Do Couto Teixiera, Aline Carneiro Viana, Jussara Almeida [Federal U. of Minas Gerais], Mario S. Alvim [Federal U. of Minas Gerais].

Human mobility has been studied from different perspectives. One approach addresses predictability, deriving theoretical limits on the accuracy that any prediction model can achieve in a given dataset. Measuring the predictability of any phenomenon is a very useful, but hard task, and especially so in the case of human behavior. Such complexity is due to the uncertain and heterogeneous behavior of humans, as well as to the variability of parameters influencing such behavior. Predictability is concerned with the maximum theoretical accuracy that an ideal prediction model could achieve in a scenario expressed by a given dataset. As such, unlike particular comparisons of alternative prediction models on different datasets, it does not depend on a specific prediction strategy but rather on human behavior, as captured by the available data. Besides, it does not rely on the tuning of a multitude of sensible parameters, providing instead a parameter-free view of how predictable human mobility can be (as expressed in the data).

This approach focuses on the inherent nature and fundamental patterns of human behavior captured in the dataset, filtering out factors that depend on the specificities of the prediction method adopted. In this work, we revisit the state-of-the-art method for estimating the predictability of a person's mobility, which, despite being widely adopted, suffers from low interpretability and disregards external factors that have been suggested to improve predictability estimation, notably the use of contextual information (e.g., weather, day of the week, and time of the day). We propose a new measure, *regularity*, which together with *stationarity*, helps us understand what makes a person's mobility trajectory more or less predictable, as captured by Song et al.'s technique. We show that these two simple measures are complementary and jointly are able to explain most of the variation in Song et al.'s predictability. As such, we here use them as proxies of that technique to analyze how one's mobility predictability varies.

Additionally, we investigate strategies to incorporate different types of contextual information into predictability estimates. In particular, we were the first to quantify the impact of different types of contextual information on predictability in human mobility, for different prediction tasks and datasets. Our results show that, for the next place prediction problem, the use of contextual information plays a larger role than one's history of visited locations in estimating their predictability. Finally, we propose and evaluate alternative estimates of predictability which, while being much easier to interpret, provide comparable results to the state-of-the-art. We show that these estimators, while being more interpretable, provide comparable results in terms of predictability.

This paper was published at ACM SIGSPATIAL 2019, a A+-ranked conference in our domain, and was indicated as a top-six best paper candidate. An extended version is being prepared for submission to a journal.

## 6.8. Identifying and profiling novelty-seeking behavior in human mobility

**Participants:** Licia Amichi, Aline Carneiro Viana, Mark Corvella [Boston Univ.], Antonio F. Loureiro [Federal U. of Minas Gerais].

The prediction of individuals' dynamics has attracted significant community attention and has implication for many fields: e.g. epidemic spreading, urban planning, recommendation systems. Current prediction models, however, are unable to capture uncertainties in the mobility behavior of individuals, and consequently, suffer from *the inability to predict visits to new places*. This is due to the fact that current models are oblivious to the exploration aspect of human behavior.

Many prediction models have been proposed to forecast individuals trajectories. However, they all show limited bounded predictive performance. Regardless of the applied methods (e.g., Markov chains, Naive Bayes, neural networks), the type of prediction (i.e., next-cell or next place) or the used data sets (e.g., GPS, CDR, surveys), accuracy of prediction never reaches the coveted 100%. The reasons for such limitations in the accuracy are manyfold: the lack of ground truth data, human beings' complex nature and behavior, as well the exploration phenomenon (i.e., visits to never seen before places). In this work, we focus on the exploration problem, which has rarely been tackled in the literature but indeed, represents a real issue. By construction, most prediction models attempt to forecast future locations from the set of known places, which hinders predicting new unseen places and by consequence, reduces the predictive performance.

Thus, when considering the exploration problem, previous studies either did not provide any consideration of the exploration factors of individuals, or divided the population based on properties that are not always consistent, or assumed that all individuals have the same propensity to explore. Our main goal in this work is to understand the exploration phenomenon and answer the following question: *What type of visits characterize the mobility of individuals?* Using newly designed metrics capturing spatiotemporal properties of human mobility – i.e., known/new and recurrent/intermittent visits – our strategy identifies three groups of individuals according to their degree of exploration: scouters, routineers, and regulars. In the future, we plan to deeply investigate the mobility behavior of individuals in each profile and to assign to each individual an *exploration factor* describing her susceptibility to explore.

This work was published at the Student workshop of ACM CONEXT 2019 [9]. An extended version is being prepared for submission to an int. conference.

## 6.9. How Geo-indistinguishability Affects Utility in Mobility-based Geographic Datasets

**Participants:** Adriano Di Luzio [Inria], Aline Carneiro Viana, Catuscia Palamidessi [Comete – Inria], Konstantinos Chatzikokolakis [Comete – Inria], Georgi Dikov [Comete – Inria], Julinda Stefa [Sapienza University].

Many of the scientific challenges that we face today deal with improving the quality of our everyday lives. They aim at making the cities around us smarter, more efficient, and more sustainable (e.g., how to schedule public transport during peak hours or what is the most efficient path for waste disposal). All these challenges share a common ground. They rely on datasets gathered from the real world that depict the mobility of hundreds of thousands individuals and picture, with great detail, the whereabouts of their lives—where they live, work, shop for groceries, and hangout with friends. At the same time, however, the collection of personal data also endangers the privacy of the users that to whom these data belong. To protect the privacy of the users, it is necessary to sanitize these datasets before releasing them to the public.

When we sanitize the datasets we trade the accuracy of the information they contain to protect the privacy of their users. The task of this work is to shed light on the effects of the trade-off between privacy and utility in mobility-based geographic datasets. We aim at finding out whether it is possible to protect the privacy of the users in a dataset while, at the same time, maintaining intact the utility of the information that it contains. In particular, we focus on geo-indistinguishability as a privacy-preserving sanitization methodology, and we evaluate its effects on the utility of the Geolife dataset. We test the sanitized dataset in two real world scenarios: (1) Deploying an infrastructure of WiFi hotspots to offload the mobile traffic of users living, working, or commuting in a wide geographic area; (2) Simulating the spreading of a gossip-based epidemic as the outcome of a device-to-device communication protocol. We show the extent to which the current geo-indistinguishability techniques trade privacy for utility in real world applications and we focus on their effects at the levels of the population as a whole and of single individuals.

This paper was published at the LocalRec 2019 workshop, jointly with ACM SIGSPATIAL [12].

## 6.10. General-purpose Low-power Secure Firmware Updates for Constrained IoT Devices

**Participants:** Koen Zandberg [Inria / Freie Universität Berlin], Kaspar Schleiser [Inria / Freie Universität Berlin], Francisco Acosta [Inria], Hannes Tschofenig [Arm Ltd., Cambridge, U.K], Emmanuel Baccelli.

While the IoT deployments multiply in a wide variety of verticals, the most IoT devices lack a built-in secure firmware update mechanism. Without such a mechanism, however, critical security vulnerabilities cannot be fixed, and the IoT devices can become a permanent liability, as demonstrated by recent large-scale attacks. In this paper, we survey open standards and open source libraries that provide useful building blocks for secure firmware updates for the constrained IoT devices–by which we mean low-power, microcontroller-based devices such as networked sensors/actuators with a small amount of memory,among other constraints. We design and implement a prototype that leverages these building blocks and assess the security properties of this prototype. We present experimental results including first experiments with SUIT, a new IETF standard for secure IoT firmware updates. We evaluate the performance of our implementation on a variety of commercial off-the-shelf constrained IoT devices. We conclude that it is possible to create a secure, standards-compliant firmware update solution that uses the state-of-the-art security for the IoT devices with less than 32 kB of RAM and 128 kB of flash memory. Moreover, our prototype is general-purpose, in that it works out-of-the-box or with minimal adaptation on 80% of the hardware supported by RIOT (i.e. approximately 100 different types of IoT devices). As such, this work paves the way towards generic and secure low-power IoT firmware updates.

This paper was published in the IEEE journal IEEE Access [8].

## 6.11. LoRa-MAB: A Flexible Simulator for Decentralized Learning Resource Allocation in IoT Networks

**Participants:** Duc-Tuyen Ta [LRI and Inria], Kinda Khawam [UVSQ], Samer Lahoud [ESIB], Cédric Adjih, Steven Martin [LRI, Université Paris-Saclay].

LoRaWAN is a media access control (MAC) protocol for wide area networks. It is designed to allow low-powered devices to communicate with Internet-connected applications over long-range wireless connections. The targeted dense deployment will inevitably cause a shortage of radio resources. Hence, autonomous and lightweight radio resource management is crucial to offer ultra-long battery lifetime for LoRa devices. One of the most promising solutions to such a challenge is the use of artificial intelligence. This will enable LoRa devices to use innovative and inherently distributed learning techniques, thus freeing them from draining their limited energy by constantly communicating with a centralized controller.Before proceeding with the deployment of self-managing solutions on top of a LoRaWAN application, it is sensible to conduct simulation-based studies to optimize the design of learning-based algorithms as well as the application under consideration. Unfortunately, a network simulator for such a context is not fully considered or lacks real deployment parameters. In order to address this shortcoming, we have developed an event-based simulator for resource allocation in LoRaWAN. To demonstrate the usefulness of our simulator, extensive simulations were run in a realistic environment taking into account physical phenomenon in LoRaWAN such as the capture effect and inter-spreading factor interference. The simulation results show that the proposed simulator provides a flexible and efficient environment to evaluate various network design parameters and self-management solutions as well as verify the effectiveness of distributed reinforcement-based learning algorithms for resource allocation problems in LoRaWAN.

This paper was published at the conference WCNC 2019 [15].

## 6.12. A Survey of Recent Extended Variants of the Traveling Salesman and Vehicle Routing Problems for Unmanned Aerial Vehicles

**Participants:** Ines Khoufi [Telecom SudParis], Anis Laouiti [Telecom SudParis], Cédric Adjih.

The use of Unmanned Aerial Vehicles (UAVs) is rapidly growing in popularity. Initially introduced for military purposes, over the past few years, UAVs and related technologies have successfully transitioned to a whole new range of civilian applications such as delivery, logistics, surveillance, entertainment, and so forth. They have opened new possibilities such as allowing operation in otherwise difficult or hazardous areas, for instance. For all applications, one foremost concern is the selection of the paths and trajectories of UAVs, and at the same time, UAVs control comes with many challenges, as they have limited energy, limited load capacity and are vulnerable to difficult weather conditions. Generally, efficiently operating a drone can be mathematically formalized as a path optimization problem under some constraints. This shares some commonalities with similar problems that have been extensively studied in the context of urban vehicles and it is only natural that the recent literature has extended the latter to fit aerial vehicle constraints. The knowledge of such problems, their formulation, the resolution methods proposed—through the variants induced specifically by UAVs features—are of interest for practitioners for any UAV application. Hence, in this study, we propose a review of existing literature devoted to such UAV path optimization problems, focusing specifically on the sub-class of problems that consider the mobility on a macroscopic scale. These are related to the two existing general classic ones—the Traveling Salesman Problem and the Vehicle Routing Problem. We analyze the recent literature that adapted the problems to the UAV context, provide an extensive classification and taxonomy of their problems and their formulation and also give a synthetic overview of the resolution techniques, performance metrics and obtained numerical results.

This paper was published in the journal "Drones" 2019, 3(3), 66 [5].

## 6.13. LoRa-MAB: Toward an Intelligent Resources Allocation Approach for LoRaWAN Networks

**Participants:** Duc-Tuyen Ta [LRI and Inria], Kinda Khawam [UVSQ], Samer Lahoud [ESIB], Cédric Adjih, Steven Martin [LRI, Université Paris-Saclay].

For a seamless deployment of the Internet of Things (IoT), self-managing solutions are needed to overcome the challenges of IoT, including massively dense networks and careful management of constrained resources in terms of calculation, memory, and battery. Leveraging on artificial intelligence will enable IoT devices to operate autonomously by using inherently distributed learning techniques. Fully distributed resource management will free devices from draining their limited energy by constantly communicating with a centralized controller. The present work is devoted to a specific IoT context, that of LoRaWAN, where devices communicate with the access network via ALOHA-type access and spread spectrum technology. Concurrent transmissions on different spreading factors increase the network capacity. However, the bottleneck is inevitable with the expected massive deployment of LoRa devices. To address this issue, we resort to the popular EXP3 (Exponential Weights for Exploration and Exploitation) algorithm to steer autonomously the decision of LoRa devices towards the least solicited spreading factors. Furthermore, the spreading factor selection is cast as a proportional fair optimization problem used as a benchmark for the learning-based algorithm. Extensive simulations were run in a realistic environment taking into account physical phenomena in LoRaWAN such as the capture effect and inter-spreading factor collision, as well as non-uniform device distribution. In such a realistic setting, we evaluate the performances of the EXP3.S algorithm, an efficient variant of the EXP3 algorithm, and show its relevance against the fair centralized solution and basic heuristics.

This paper was published at the conference GLOBECOM 2019 [16].

## 6.14. An IoT-Blockchain Architecture Based on Hyperledger Framework for Healthcare Monitoring Application

**Participants:** Oumaima Attia, Ines Khoufi [Telecom SudParis], Anis Laouiti [Telecom SudParis], Cédric Adjih.

Blockchains are one of the most promising technologies in the domain of the Internet of Things (IoT). At the same time, healthcare monitoring is one of IoT applications where many devices are connected, and collect data that need to be stored in a highly secure way. In this context, we focus on IoT Blockchain architectures for healthcare monitoring applications. We start our study by exploring both IoT and blockchain technologies and identify how Fabric Hyperledger is a blockchain framework that fits our application needs. In this paper, we propose a security architecture based on this framework. We validate our approach first at a design level through concrete examples, then by showing some implemented functionalities.

This paper was published at the conference NTMS 2019 [10].

# 7. Bilateral Contracts and Grants with Industry

## 7.1. Bilateral Contracts with Industry

### *7.1.1. GranData:*

**Participants:** Douglas Do Couto Teixiera, Licia Amichi, Lucas Santos de Oliveira [EMBRACE], Aline Carneiro Viana.

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. For the time being, the collaboration with Grandata has generated knowledge transfer. From both directions, (1) from myself to GranData, I have being transferring my knowledge in modeling and analysing human behavior in terms of mobility, encounters, and content demand, (2) from them to myself, they have advising me on issues related to machine learning and statistical methods to be used. It describes **an industrial partner's collaboration having the outcomes of our works impacting their products** (e.g., GranData data mining algorithms can be improved based on the better understanding on mobility and content consumption of mobile users) **or research/business decisions** (e.g., proved strong correlations between mobility and data traffic consumption can open new perspectives of services to telecom operators, i.e., clients of GranData).

Part of the thesis of Guangshuo Chen (endend April 2018) and of Eduardo Mucelli (ended in 2015) on data traffic analysis used telco traces provided by GranData.

## 7.2. Bilateral Grants with Industry

### *7.2.1. Nokia (ADR):*

**Participants:** Cedric Adjih, Iman Hmedoush.

Through the common Inria-Nokia laboratory, the team is involved in the action "Network Information Theory" (ADR, "Action De Recherche"). In collaboration with Nokia, and Inria EPI MARACAS, and EPI EVA, we are working on the subject of optimization and evaluating communications for IoT networks. This includes 5G and beyond, medium-access level/random access techniques protocols and applying machine learning techniques to wireless communications.

# 8. Partnerships and Cooperations

## 8.1. Regional Initiatives

### *8.1.1. Digicosme - Thesis - ECOMICENE*

**Participants:** Cedric Adjih, Hirah Malik, Michel Kieffer [L2S, CNRS–CentraleSupelec–Univ Paris-Sud, Univ Paris-Saclay], Claudio Weidmann [ETIS / ENSEA - Université de Cergy-Pontoise, CNRS (UMR 8051)].

**Partners:** Centrale-Supelec L2S, ETIS-ENSEA

Subject : Efficient COding of Meta-information in Information-CEntric NEtworks.

### *8.1.2. Digicosme - Post doc - ICN-based-Vehicles*

**Participants:** Cedric Adjih, Ines Khoufi [Telecom SudParis], Anis Laouiti [Telecom SudParis].

**Partners:** SAMOVAR, Telecom Sud-Paris (IPP)

Subject: In this work, the project is to design and propose a new architecture model that combines several new emerging research fields which are FANETs (Flying Ad-hoc NETworks). We will modelled a FANET problem of information gathering and distribution, reviewed related literature in [5]. We are now focusing on some mobility patterns for the FANETs in order to optimize the movement of the flying vehicles while they are enhancing the radio coverage for the VANETs and trying to improve data exchange experience between different damaged locations, using genetic algorithms. (link)

### *8.1.3. Digicosme - Engineer - LoRaWAN simulator*

**Participants:** Cedric Adjih, Kinda Khawam [UVSQ], Samer Lahoud [ESIB], Steven Martin [LRI, Université Paris-Saclay].

Subject: LoRa-MAB: A Flexible Simulator for Decentralized Learning Resource Allocation in IoT Networks

The simulator is available at https://github.com/tuyenta/IoT-MAB

## 8.2. National Initiatives

### *8.2.1. Equipex FIT:*

**Participants:** Cedric Adjih, Alexandre Abadie [Inria, SED], Emmanuel Baccelli.

**Partners:** Sorbonne Université, Inria (Lille, Sophia-Antipolis, Grenoble), INSA, 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.

### *8.2.2. ANR*

#### *8.2.2.1. MITIK*

**Participants:** Aline Carneiro Viana, Catuscia Palamidessi.

Funding instrument/scientific committee: PRC/CE25

Project acronym: MITIK

Project title: Mobility and contact traces from non-intrusive passive measurements

Duration: 2020–2023

Coordinator: Aline Carneiro Viana

Other partners: COMETE/Inria, Universite de la Rochelle, Sorbonne Universite.

Abstract: The MITIK project is a 42-month ANR project that will start in February 2020. Mitik's primary objective is the design of an entirely new methodology to help the community obtain real wireless contact traces that are non-intrusive, representative, and independent of third parties. The secondary outcome of the project is be the public release of (1) the measurement tool designed for the easy contact gathering task; (2) contact traces which are clean, processed, and privacy-preserving, i.e., protecting both the anonymity and the location privacy of the users; and (3) their spatiotemporal statistical analysis. We expect that Miti's outcomes will support non-biased research on the modeling as well as on the leveraging of wireless contact patterns.

#### *8.2.2.2. GORILLA*

**Participants:** Cedric Adjih, Aline Carneiro Viana, Nadjib Achir.

Funding instrument/scientific committee: Under submission to the PRC/CE25 (Phase I)

Project acronym: GORILLA

Project title: GeO-distributed pRivacy-preserving InteLLigent orchestrAtion of data-hungry Services

Duration: 2021–2024

Coordinator: Cedric Adjih

Other partners: IRIT – Toulouse INP, LS2N – IMT Atlantiquen L2TI – University Paris 13.

Abstract: The GORILLA project has been submitted to the ANR - PCR program (PHASE I). Users of mobile applications keep calling for better user privacy while getting better user experience, and this fact has become a competitive challenge for application developers. As of today, privacy is often promoted through personal storage and is sometimes opposed to cloud solutions which are nevertheless well-established. GORILLAS proposes to revisit this dilemma with the recent emergence of edge computing. The idea is to leverage edge computing as a middle ground that will act as a trusted third party that ensures privacy and confidentiality requirements. GORILLAS will design a framework that captures the user's privacy requirements, the services requirements as well as current and future users, networks, edge, and cloud operational contexts to perform privacy-persistent and QoE-aware data placement in addition to a tailored QoE-aware service computing orchestration over edge and cloud resources

## 8.3. European Initiatives

### *8.3.1. H2020 SPARTA project*

**Participants:** Emmanuel Baccelli, Francois-Xavier Molina.

Program: H2020 SU-ICT-03-2018: Establishing and operating a pilot for a Cybersecurity Competence Network to develop and implement a common Cybersecurity Research & Innovation Roadmap

Project acronym: SPARTA

Project title: Strategic Programs for Advanced Research and Technology in Europe

Duration: 2019-2022

Participant from TRiBE: Emmanuel Baccelli, Francois-Xavier Molina

Other partners include CEA, TU Muenchen, IMT among many others

Abstract: The Sparta project is a 3-year H2020 project started in February 2019, which will put in motion a competence network on cybersecurity, with a view to shape a future EU-wide cybersecurity agency. In more details: TRiBE participates on topics around low-power IoT security, whereby RIOT is used as the base platform on top of which advances will be experimented with and made available in practice.

## 8.4. International Initiatives

### *8.4.1. Inria Project Lab RIOT-fp*

Project lead: Emmanuel Baccelli

Full name: Reconcile IoT & Future-Proof Security

Partners: teams EVA, PROSECCO (Inria Paris), teams GRACE, TRiBE (Inria Saclay), team TEA, CELTIQUE (Inria Rennes), Freie Universitaet Berlin

Project Start: April 2019

Project Length: 4 years

Website: https://future-proof-iot.github.io/

Summary:

Today's Internet of Things (IoT) does not provide an acceptable tradeoff of functionality vs. risk for end-users. To improve this tradeoff, we must simultaneously

(i) enrich IoT functionality and (ii) improve IoT cyber-security with respect to diverse attack vectors. Concerning the former, RIOT is emerging as one of the major open-source software platforms for low-end IoT devices. Concerning the latter, research challenges must be addressed in various domains including secure network protocol stacks, cryptography, software execution guarantees, embedded system design. RIOT-fp is a research project on IoT cyber-security. Taking a global and

practical approach, RIOT-fp gathers partners planning a scientific agenda aiming to enhance RIOT with an array of security mechanisms. The main scientific challenges tackled by RIOT-fp are: (1) developing high-speed, high-security, low-memory IoT crypto primitives, (2) providing guarantees for software execution on low-end IoT devices, and (3) enabling secure IoT software updates and supply-chain, over the network.

### *8.4.2. Inria Associate Teams Not Involved in an Inria International Labs*

#### *8.4.2.1. 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 Acadêmico de Informática (DAINF) Curso de Pós-Graduação em Engenharia Elétrica e Informática 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 – Ending year: 2019

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

Abstract: EMBRACE propose une architecture novatrice pour gérer des ressources et des services opérationnels hétérogènes. 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 réseaux 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 coûts. La nouveauté de l'architecture réside dans les algorithmes conçus 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.

Nest steps: A new proposal extending the EMBRACE project was submitted in Nov. 2019. Besides, partners keep going their collaborations with two students currently visiting the team (Lucas Santos from UFMG and Felipe Fonseca from UFG) and with two researchers from UFG starting their sabbatical year from February 2020.

### *8.4.3. Inria International Partners*

*8.4.3.1. 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.

*8.4.3.2. Informal International Partners*

1. Although the project has finished, the team keep going their collaboration with UFMG and UFG institutions, previous partners of EMBRACE project, on human behavior leveraging in 5G networks.
2. Collaboration with Mark Crovella from Boston University, where Licia Amichi will spend 5 months in an internship from March 2020. She will work on our current collaboration on the modelling and analysis of novelty-seeking preferences in human mobility.
3. Collaboration with Javier Bustos from NIC Lab/University of Chile, involving the PhD co-advising of Diego Madriaga, who is doing a joint PhD between Univ. of Chile and IPP and is working on short-term time series analysis and prediction for anticipatory Nnetworking.
4. Collaboration with Ana Aguiar from University of Porto, involving the PhD co-advising of Emanuel Lima, who is working on data offloading via mobile crowdsensing.
5. Collaboaration with Marco Fiore from IMDEA on adaptive sampling of human mobility. This collaboration involves the participation of Diego Madriaga.
6. Informal collaborations with ENSI Tunis and ENIso.

### *8.4.4. Participation in Other International Programs*

*8.4.4.1. 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.

## 8.5. International Research Visitors

### *8.5.1. Visits of International Scientists*

**Prof. Kleber Vieira Cardoso and Sand Luz Correa** forom UFG, Brazil, will do their sabbatical year at the TRiBE team, under Brazilian funding and in the context of the EMBRACe project. They will work with Aline C. Viana and Felipe Fonseca on trajectory reconstruction of tourists and their 5G resource optimization.

### *8.5.2. Internships*

**Felipe Fonseca** is doing an internship of 3 months in our team (Nov 201-Jan 2020). He work with Aline C. Viana, Kleber V. Cardoso and Sand L. Correa on trajectory reconstruction of tourists.
**Lucas Santos** is doing an internship of 3 months in our team (Nov 201-Jan 2020) in the context of EMBRACE associated team. He work with Aline C. Viana and Pedro Olmo on the investigation of causalities in habits of human visits.
**Douglas Teixira** did an internship of 10 months our team (May 2019-Jan 2020) in the context of EMBRACE associated team. He is in cotutelle between IPP and UFMG and is co-advised by Aline C. Viana and Jussara Almeida on the limits of a context-aware predictability of human mobility.
**Amina Ben Hassine** did an intership of 6 months (2019) in collaboration with Ichrak Amdouni (ENSISo) and Anis Laouiti (Telecom SudParis) on the subject of "Unmanned Aerial Vehicles Path Planning Using Machine Learning" using reinforcement learning.

### *8.5.3. Visits to International Teams*

#### *8.5.3.1. Research Stays Abroad*

Aside of working for Inria, **Emmanuel Baccelli** is also Professor at Freie Universitaet (FU) Berlin, within the context of a chair resulting of a partnership between Inria, FU Berlin and Einstein Center for Digital Future (ECDF: umbrella organization for Berlin's technical universities). The topic of this chair is *Open and Secure IoT Ecosystem*. In this context, Emmanuel Baccelli stays at FU Berlin. See online: https://www.digital-future.berlin/en/about-us/professors/prof-dr-emmanuel-baccelli/

# 9. Dissemination

## 9.1. Promoting Scientific Activities

### *9.1.1. Scientific Events: Organisation*

*9.1.1.1. Member of the Organizing Committees*

- Aline C. Viana is **Publicity co-chair** of ESWN 2020; was **Student Travel Grant co-chair** of IEEE Infocom 2019;
- **Emmanuel Baccelli** was co-chair of the RIOT Summit'19.

### *9.1.2. Scientific Events: Selection*

*9.1.2.1. Chair of Conference Program Committees*

- Aline C. Viana is **TPC co-chair** of Shadow Algotel/Cores 2020; This will be the first time a shadow TPC will be organized for these two French conferences. A shadow TPC aims at providing an educational experience for young PhD graduates, post docs, and junior researchers by simulating a TPC meeting entitled to discuss some papers submitted to Algotel and Cores 2020.

*9.1.2.2. Member of the Conference Program Committees*

- Aline C. Viana is TPC member of Algotal 2020;

### *9.1.3. Journal*

*9.1.3.1. Member of the Editorial Boards*

- Aline C. Viana is an Editorial Board member of Ad Hoc Networks, Elsevier journal since Nov 2029; Urban Computing Spring book series (http://www.springer.com/series/15552), since Feb. 2018; an Associate Editor of ACM SIGCOMM Computer Communication Review (ACM CCR), since May 2014; an 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*

- **Aline C. Viana** reviewed papers for ACM SIGCOMM CCR Journal, IEEE Transaction on Mobile Computing journal, Elsevier Pervasive and Mobile Computing Journal, and Computer Communication Elsevier Journal.
- **Emmanuel Baccelli** reviewed papers for IEEE IoT Journal, IETF Routing Directory, IFIP/IEEE PEMWN.
- **Cedric Adjih** was a reviewer for ACM SIGCOMM CCR Journal.

### *9.1.4. Invited Talks*

- **Aline C. Viana** was invited to give a seminar at (1) the GDR RSD and ASF Winter School, Pleynet, France, in Feb. 2019; (2) the AGRANDA symposium in Salta, Argentina in Sep. 2019; (3) at IFIP TMA 2019 Expert Summit, https://tma.ifip.org/2019/tma-experts/.
- **Emmanuel Baccelli** was invited to give talks at the French Ministry of Defence (Innovation Defence Lab), at the Berlin Innovation Agency Smart Cities Meetup, and at Eclipse IoT Day.

### *9.1.5. Standardization*

1. **Emmanuel Baccelli and Cedric Adjih** have participated at several working groups at IETF during 2019.
2. **Cedric Adjih** has participated at all IETF Hackathons in 2019 (IETF 104, IETF 105, IETF 106), along with **Oumaima Attia**; they were major contributors to
   - LPWAN Hackathon on the SCHC protocol (IPv6 compression for IoT networks), see: https://github.com/openschc/openschc

   - NWCRG Hackathon on the SWIF-codec, a sliding-window forward-error correction codec, see: https://github.com/irtf-nwcrg/swif-codec

3. **Emmanuel Baccelli** has participated at several IETF hackathons during 2019.

### *9.1.6. Scientific Expertise*

- **Aline C. Viana** served as (1) Remote evaluator of the *ERC's Starting Grant 2019*; (2) as member of *4 PhD defense committees* (2 as reviewer and 2 as examiner); (3) as examiner in *4 PhD mid-term committees* in 2019.
- **Emmanuel Baccelli** served as reviewer for 1 PhD defense committee in 2019.

## 9.2. Teaching - Supervision - Juries

### *9.2.1. Teaching*

- **Aline C. Viana** gave talks/seminars at conferences and workshops, on subjects related to human behavior analysis: (1) the GDR RSD and ASF Winter School, Pleynet, France, in Feb. 2019 (https://sites.google.com/site/rsdwinterschool/last-editions/asf-winter-school-2019); (2) the AGRANDA symposium in Salta, Argentina in Sep. 2019 (http://48jaiio.sadio.org.ar/simposios/AGRANDA); (3) at IFIP TMA 2019 Expert Summit, in Jun 2019 (https://tma.ifip.org/2019/tma-experts/).
- Master : **Emmanuel Baccelli**, "IoT & Security", summer semester seminar, Freie Universitaet Berlin.
- Master : **Emmanuel Baccelli**, "IoT & Security", winter semester seminar, Freie Universitaet Berlin.
- Master : **Emmanuel Baccelli**, "Operating Systems for Small Connected Devices in the Internet of Things", cours magistral, Formation PESTO Corps des Mines, Telecom ParisTech, Paris France
- Engineering School: Cédric Adjih, "Internet of Thing", 3h practical courses, Telecom SudParis
- Engineering School: Cédric Adjih, "Internet of Thing", 9h practical courses, ENSEA

### *9.2.2. Supervision*

- PhD in progress: Licia Amichi, "Identifying and profiling novelty-seeking behavior in human mobilityModelling exploration factor of human beings", since Oct. 2018. Advisor: Aline C. Viana
- PhD in progress: Lucas Santos, "Investigating causalities in habits of human visits", since May 2018. Advisor: Aline C. Viana and Pedro Olmo
- PhD in progress: Douglas Teixeira, "Deciphering Predictability Limits in Human Mobility", since April 2018. Advisor: Aline C. Viana and Jussara Almeida.
- PhD in progress: Rafael Costa, "Human-enhanced forwarding strategies for Device-to-Device (D2D) communication", since May 2017. Advisor: Aline C. Viana and Leobino Sampaio.
- PhD in progress: Diego Madriaga, "Short-term Time Series Analysis and Prediction for Anticipatory Networking", since Jan 2019. Advisor: Aline C. Viana and Javier Bustos.
- PhD in progress: Anne Josiane Kouam Djuigne, "Detection of bypass frauds in cellular network datasets", since Nov 2019. Advisor: Aline C. Viana and Alain Tchana.
- PhD in progress: Hirah Malik, "Efficient COding of Meta-information in Information-CEntric NEtworks", since Oct. 2017. Advisors: C. Adjih, Michel Kieffer, and Claudio Weidmann
- PhD in progress: Iman Hmedoush, "Connection protocols for the 5G IoT", since Oct. 2018. Advisors: C. Adjih and Paul Mühlethaler.

### *9.2.3. Juries*

- **Reviewer for PhD thesis committee:** Aline C. Viana was reviewer for the following PhDs: R. Teles, Industrial IoT (Univ. de Strasbourg, fin 2019). Nadjib Achir was was reviewer for the following PhDs: M. Rautu, Déploiement temporaire d'une infrastructure de communication à base de drones (Univ. de Toulouse, octobre 2019).

- **Examiner for PhD thesis committee:**C. Adjih was examiner for the committees of the following PhDs: Safan ALWAN (UPEC, LSSI, Dev. 2019); Aline C. Viana was examiner for the committees of the following PhDs: H. Mazouzi, Algorithms for Tasks Offloading on Multiple Mobile Edge Servers (Univ. Paris 13, Nov 2019); J. Loudet, Distributed and Privacy-Preserving Personal Queries on Personal Clouds (Univ. de Versailles/PETRUS Inria, Oct 2019); J. Munoz, km-scale Industrial Networking (UPMC/EVA Inria, Mar. 2019); A. Boubrima, Deployment and Scheduling of Wireless Sensor Networks for Air Pollution Monitoring (INSA-Lyon/AGORA Inria, Mar. 2019).
- **Examiner for PhD mid-term committee:**Aline C. Viana was examiner for the committees in the following mid-term juries: J. Kamal, Détection d'anomalies comportementales pour les systèmes de transport intelligents et coopératifs, (TPT, Apr. 2019); Y. Du, In-Network Collaborative Mobile Crowd Sensing: a Context-Aware Sensing Group Framework, (UPMC/MIMOVE Inria, Mar. 2019).
- **Examiner for M.Sc. thesis committee:**Aline C. Viana was examiner for the committees in the following M.Sc. jury: W. Z. Xavier, (PUC-MG, Minas Gerais, March 2019).

## 9.3. Popularization

### *9.3.1. Internal or external Inria responsibilities*

1. **Aline C. Viana** was 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** is the coordinator of the ANR MITIK project to start Feb 2020 and was the international coordinator of the EMBRACE associated team of Inria.
3. Together with the members of the team, **Aline C. Viana** has submitted the short proposal of the new team as well as has presented it at the BCEP and CEP, for validation. TRiBE was officially created in Jun 2019.
4. **Aline C. Viana** is a member of BCEP, evaluating Inria teams in process of creation, discussing main issues related to different scientific commissions, discussing changes in the institution.
5. **Aline C. Viana** is co-Coordinator of the mentoring program for researchers at Inria Saclay (https://project.inria.fr/mentoratscl/). The program goal is the coach of junior researchers by more experienced ones in order to provide them with a complementary perspective for their career, independently of any hierarchical link.

# 10. Bibliography

## Major publications by the team in recent years

[1] CISCO. *Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2016-2021 White Paper*, 2018

[2] FORBES. *2017 Roundup Of Internet Of Things Forecasts*, 2017

[3] GARTNER. *Gartner Says 8.4 Billion Connected "Things" Will Be in Use in 2017, Up 31 Percent From 2016*, 2017

## Publications of the year

### Articles in International Peer-Reviewed Journals

[4] G. CHEN, A. CARNEIRO VIANA, M. FIORE, C. SARRAUTE. *Complete Trajectory Reconstruction from Sparse Mobile Phone Data*, in "EPJ Data Science", October 2019 [*DOI :* 10.1140/EPJDS/S13688-019-0206-8], https://hal.inria.fr/hal-02286080

[5] I. KHOUFI, A. LAOUITI, C. ADJIH. *A survey of recent extended variants of the traveling salesman and vehicle routing problems for Unmanned Aerial Vehicles*, in "Drones", September 2019, vol. 3, n$^{o}$ 3, pp. 66:1-30 [*DOI :* 10.3390/DRONES3030066], https://hal.inria.fr/hal-02431644

[6] T. H. SILVA, A. CARNEIRO VIANA, F. BENEVENUTO, L. VILLAS, J. SALLES, A. A. F. LOUREIRO, D. QUERCIA. *Urban Computing Leveraging Location-Based Social Network Data: a Survey*, in "ACM Computing Surveys", March 2019 [*DOI :* 10.1145/3301284], https://hal.inria.fr/hal-01972129

[7] H. TSCHOFENIG, E. BACCELLI. *Cyberphysical Security for the Masses: A Survey of the Internet Protocol Suite for Internet of Things Security*, in "IEEE Security and Privacy Magazine", September 2019, vol. 17, n$^{o}$ 5, pp. 47-57 [*DOI :* 10.1109/MSEC.2019.2923973], https://hal.inria.fr/hal-02351892

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### International Conferences with Proceedings

[9] L. AMICHI, A. CARNEIRO VIANA, M. CROVELLA, A. A. F. LOUREIRO. *Mobility profiling: Identifying scouters in the crowd*, in "CoNEXT '19: Proceedings of the 15th International Conference on emerging Networking EXperiments and Technologies", Orlando, United States, December 2019, pp. 9-11 [*DOI :* 10.1145/3360468.3366771], https://hal.inria.fr/hal-02433795

[10] O. ATTIA, I. KHOUFI, A. LAOUITI, C. ADJIH. *An IoT-blockchain architecture based on hyperledger framework for health care monitoring application*, in "NTMS 2019: 10th IFIP International Conference on New Technologies, Mobility and Security", Canary islands, Spain, 2019 10th IFIP International Conference on New Technologies, Mobility and Security (NTMS), IEEE Computer Society, 2019, pp. 1-5 [*DOI :* 10.1109/NTMS.2019.8763849], https://hal.inria.fr/hal-02434834

[11] J. B. BORGES, H. S. RAMOS, R. A. F. MINI, A. CARNEIRO VIANA, A. A. F. LOUREIRO. *The quest for sense: Physical phenomena classification in the Internet of Things*, in "ISIoT 2019 - 1st International Workshop on Intelligent Systems for IoT", Santorini, Greece, May 2019, https://hal.inria.fr/hal-02165145

[12] A. DI LUZIO, A. C. VIANA, K. CHATZIKOKOLAKIS, G. DIKOV, C. PALAMIDESSI, J. STEFA. *Catch Me If You Can: How Geo-indistinguishability Affects Utility in Mobility-based Geographic Datasets*, in "Proceedings of the 3rd ACM SIGSPATIAL International Workshop", Chicago, United States, ACM Press, 2019, pp. 1-10 [*DOI :* 10.1145/3356994.3365498], https://hal.archives-ouvertes.fr/hal-02423337

[13] F. FONSECA, L. MAMATAS, A. CARNEIRO VIANA, S. L. CORREA, K. V. CARDOSO. *Personalized Travel Itineraries with Multi-access Edge Computing Touristic Services*, in "IEEE Globecom 2019 - IEEE Global Communications Conference", Big Island, Hawaii, United States, December 2019, https://hal.inria.fr/hal-02285929

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Wireless and Mobile Networking Conference", Paris, France, IEEE, September 2019, pp. 55-62 [*DOI :* 10.23919/WMNC.2019.8881393], https://hal.inria.fr/hal-02431653

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