Activity Report 2018

Team MYRIADS

Design and Implementation of Autonomous Distributed Systems

Joint team with Inria Rennes – Bretagne Atlantique

D1 – Large Scale Systems

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Project-Team MYRIADS

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Keywords:

Computer Science and Digital Science:

A1.1.9. - Fault tolerant systems
A1.1.13. - Virtualization
A1.2. - Networks
A1.2.4. - QoS, performance evaluation
A1.2.5. - Internet of things
A1.3. - Distributed Systems
A1.3.2. - Mobile distributed systems
A1.3.4. - Peer to peer
A1.3.5. - Cloud
A1.3.6. - Fog, Edge
A1.6. - Green Computing
A2.1.7. - Distributed programming
A2.2.5. - Run-time systems
A2.3.2. - Cyber-physical systems
A2.4.2. - Model-checking
A2.6. - Infrastructure software
A2.6.1. - Operating systems
A2.6.2. - Middleware
A2.6.3. - Virtual machines
A2.6.4. - Ressource management
A3.1.2. - Data management, quering and storage
A3.1.3. - Distributed data
A4.9. - Security supervision
A4.9.1. - Intrusion detection
A4.9.3. - Reaction to attacks
A5.6. - Virtual reality, augmented reality
A6.1.3. - Discrete Modeling (multi-agent, people centered)
A7.1. - Algorithms
A8.2. - Optimization

Other Research Topics and Application Domains:

B2.3. - Epidemiology
B3.1. - Sustainable development
B3.2. - Climate and meteorology
B4.3. - Renewable energy production
B4.4. - Energy delivery
B4.4.1. - Smart grids
B4.5. - Energy consumption

B4.5.1. - Green computing
B5.1. - Factory of the future
B5.8. - Learning and training
B6.1. - Software industry
B6.1.1. - Software engineering
B6.3. - Network functions
B6.3.3. - Network Management
B6.4. - Internet of things
B6.5. - Information systems
B6.6. - Embedded systems
B8.1. - Smart building/home
B8.2. - Connected city
B8.3. - Urbanism and urban planning
B8.5. - Smart society
B9.1. - Education
B9.1.1. - E-learning, MOOC
B9.1.2. - Serious games
B9.5.1. - Computer science
B9.7. - Knowledge dissemination
B9.7.1. - Open access
B9.7.2. - Open data
B9.8. - Reproducibility
B9.9. - Ethics
B9.10. - Privacy

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2. Overall Objectives

2.1. General Objectives

MYRIADS is a joint team with INRIA, CNRS, UNIVERSITY RENNES 1, INSA RENNES and ENS RENNES. It is part of IRISA (D1 department on large scale systems) and INRIA RENNES – BRETAGNE ATLANTIQUE.

The objective of MYRIADS is to design and implement systems for autonomous service and resource management in interconnected and distributed clouds. The team tackles the challenges of dependable application execution and efficient resource management in highly distributed clouds.

2.2. Context

The MYRIADS team research activities are conducted in the context of the future of Internet.

Internet of Services. Myriads of applications are provided to more than one billion users [1] all over the world. Over time, these applications are becoming more and more sophisticated, a given application being a composition of services likely to be executed on various sites located in different geographical locations. The Internet of Services is spreading all domains: home, administration, business, industry and science. Everyone is involved in the Internet of Services: citizens, enterprises, scientists are application, service and resource consumers and/or providers over the Internet.

Outsourcing. Software is provided as a service over the Internet. Myriads of applications are available on-line to billions of users as, for instance, *GoogleApps* (Gmail). After decades in which companies used to host their entire IT infrastructures in-house, a major shift is occurring where these infrastructures are outsourced to external operators such as Data Centers and Computing Clouds. In the Internet of Services, not only software but also infrastructure are delivered as a service. Clouds turned computing and storage into a utility. Just like water or electricity, they are available in virtually infinite amounts and their consumption can be adapted within seconds like opening or closing a water tap. The main transition, however, is the change in business models. Companies or scientists do not need to buy and operate their own data centers anymore. Instead, the compute and storage resources are offered by companies on a "pay-as-you-go" basis. There is no more need for large hardware investments before starting a business. Even more, the new model allows users to adapt their resources within minutes, e.g., scale up to handle peak loads or rent large numbers of computers for a short experiment. The risk of wasting money by either under-utilization or undersized data centers is shifted from the user to the provider.

Sharing and Cooperation. Sharing information and cooperating over the Internet are also important user needs both in the private and the professional spheres. This is exemplified by various services that have been developed in the last decade. Peer-to-peer networks are extensively used by citizens in order to share musics and movies. A service like *Flickr* allowing individuals to share pictures is also very popular. Social networks such as *FaceBook* or *Linkedln* link millions of users who share various kinds of information within communities. Virtual organizations tightly connected to Grids allow scientists to share computing resources aggregated from different institutions (universities, computing centers...). The EGEE European Grid is an example of production Grid shared by thousands of scientists all over Europe.

2.3. Challenges

The term cloud was coined 12 years ago. Today cloud computing is widely adopted for a wide range of usage: information systems outsourcing, web service hosting, scientific computing, data analytics, back-end of mobile and IoT applications. There is a wide variety of cloud service providers (IaaS, PaaS, SaaS) resulting in difficulties for customers to select the services fitting their needs. Production clouds are powered by huge data centers that customers reach through the Internet. This current model raises a number of issues. Cloud computing generates a lot of traffic resulting in ISP providers needing to increase the network capacity. An increasing amount of always larger data centers consumes a lot of energy. Cloud customers experience poor quality of experience for highly interactive mobile applications as their requests are dealt with in data centers that are several hops away. The centralization of data in clouds also raises (i) security issues as clouds are a target of choice for attackers and (ii) privacy issues with data aggregation.

Recently new cloud architectures have been proposed to overcome the scalability, latency, and energy issues of traditional centralized data centers. Various flavors of distributed cloud computing are emerging depending on the resources exploited: resources in the core network (distributed cloud), resources at the edge of the network (edge clouds) and even resources in the people swarms of devices (fog computing) enabling scalable cloud computing. These distributed clouds raise new challenges for resource and application management.

[1] According to World Stats, there are 3.67 billion Internet users i.e. more than half of the total world population in June 2016 http://www.internetworldstats.com/stats.htm.

The ultimate goal of Myriads team is making highly distributed clouds sustainable. By sustainability we mean green, efficient and secure clouds. We plan to study highly distributed clouds including edge clouds and fog computing. In this context, we will investigate novel techniques for greening clouds including the optimization of energy consumption in distributed clouds in the context of smart grids. As more and more critical information system are outsourced in the cloud and personal data captured by sensors embedded in smart objects and smartphones are stored in the cloud, we will investigate security and privacy issues in two directions: cloud security monitoring and personal data protection in cloud-based IoT applications.

System research requires experimental validation based on simulation and/or prototyping. Reproducible experimentation is essential. We will contribute to the design and implementation of simulators well suited to the study of distributed clouds (architecture, energy consumption) and of large scale experimentation platforms for distributed systems enabling reproducible experiments.

3. Research Program

3.1. Introduction

In this section, we present our research challenges along four work directions: resource and application management in distributed cloud and fog computing architectures for scaling clouds in Section 3.2, energy management strategies for greening clouds in Section 3.3, security and data protection aspects for securing cloud-based information systems and applications in Section 3.4, and methods for experimenting with clouds in Section 3.5.

3.2. Scaling fogs and clouds

3.2.1. Resource management in hierarchical clouds

The next generation of utility computing appears to be an evolution from highly centralized clouds towards more decentralized platforms. Today, cloud computing platforms mostly rely on large data centers servicing a multitude of clients from the edge of the Internet. Servicing cloud clients in this manner suggests that locality patterns are ignored: wherever the client issues his/her request from, the request will have to go through the backbone of the Internet provider to the other side of the network where the data center relies. Besides this extra network traffic and this latency overhead that could be avoided, other common centralization drawbacks in this context stand in limitations in terms of security/legal issues and resilience.

At the same time, it appears that network backbones are over-provisioned for most of their usage. This advocates for placing computing resources directly within the backbone network. The general challenge of resource management for such clouds stands in trying to be locality-aware: for the needs of an application, several virtual machines may exchange data. Placing them *close* to each others can significantly improve the performance of the application they compose. More generally, building an overlay network which takes the hierarchical aspects of the platform without being a hierarchical overlay – which comes with load balancing and resilience issues is a challenge by itself.

We expect to integrate the results of these works in the Discovery initiative [41] which aims at revisiting OpenStack to offer a cloud stack able to manage utility computing platforms where computing resources are located in small computing centers in the backbone's PoPs (Point of Presence) and interconnected through the backbone's internal links.

3.2.2. Resource management in fog computing architectures

Fog computing infrastructures are composed of compute, storage and networking resources located at the edge of wide-area networks, in immediate proximity to the end users. Instead of treating the mobile operator's network as a high-latency dumb pipe between the end users and the external service providers, fog platforms aim at deploying cloud functionalities *within* the mobile phone network, inside or close to the mobile access points. Doing so is expected to deliver added value to the content providers and the end users by enabling new types of applications ranging from Internet-of-Things applications to extremely interactive systems (e.g., augmented reality). Simultaneously, it will generate extra revenue streams for the mobile network operators, by allowing them to position themselves as cloud computing operators and to rent their already-deployed infrastructure to content and application providers.

Fog computing platforms have very different geographical distribution compared to traditional clouds. While traditional clouds are composed of many reliable and powerful machines located in a very small number of data centers and interconnected by very high-speed networks, mobile edge cloud are composed of a very large number of points-of-presence with a couple of weak and potentially unreliable servers, interconnected with each other by commodity long-distance networks. This creates new demands for the organization of a scalable mobile edge computing infrastructure, and opens new directions for research.

The main challenges that we plan to address are:

- How should an edge cloud infrastructure be designed such that it remains scalable, fault-tolerant, controllable, energy-efficient, etc.?
- How should applications making use of edge clouds be organized? One promising direction is to explore the extent to which stream-data processing platforms such as Apache Spark and Apache Flink can be adapted to become one of the main application programming paradigms in such environments.

3.2.3. Self-optimizing applications in multi-cloud environments

As the use of cloud computing becomes pervasive, the ability to deploy an application on a multi-cloud infrastructure becomes increasingly important. Potential benefits include avoiding dependence on a single vendor, taking advantage of lower resource prices or resource proximity, and enhancing application availability. Supporting multi-cloud application management involves two tasks. First, it involves selecting an initial multi-cloud application deployment that best satisfies application objectives and optimizes performance and cost. Second, it involves dynamically adapting the application deployment in order to react to changes in execution conditions, application objectives, cloud provider offerings, or resource prices. Handling price changes in particular is becoming increasingly complex. The reason is the growing trend of providers offering sophisticated, dynamic pricing models that allow buying and selling resources of finer granularities for shorter time durations with varying prices.

Although multi-cloud platforms are starting to emerge, these platforms impose a considerable amount of effort on developers and operations engineers, provide no support for dynamic pricing, and lack the responsiveness and scalability necessary for handling highly-distributed, dynamic applications with strict quality requirements. The goal of this work is to develop techniques and mechanisms for automating application management, enabling applications to cope with and take advantage of the dynamic, diverse, multi-cloud environment in which they operate.

The main challenges arising in this context are:

- selecting effective decision-making approaches for application adaptation,
- supporting scalable monitoring and adaptation across multiple clouds,
- performing adaptation actions in a cost-efficient and safe manner.

3.3. Greening clouds

The ICT (Information and Communications Technologies) ecosystem now approaches 5% of world electricity consumption and this ICT energy use will continue grow fast because of the information appetite of Big Data, big networks and big infrastructures as Clouds that unavoidably leads to big power.

3.3.1. Smart grids and clouds

We propose exploiting Smart Grid technologies to come to the rescue of energy-hungry Clouds. Unlike in traditional electrical distribution networks, where power can only be moved and scheduled in very limited ways, Smart Grids dynamically and effectively adapt supply to demand and limit electricity losses (currently 10% of produced energy is lost during transmission and distribution).

For instance, when a user submits a Cloud request (such as a Google search for instance), it is routed to a data center that processes it, computes the answer and sends it back to the user. Google owns several data centers spread across the world and for performance reasons, the center answering the user's request is more likely to be the one closest to the user. However, this data center may be less energy efficient. This request may have consumed less energy, or a different kind of energy (renewable or not), if it had been sent to this further data center. In this case, the response time would have been increased but maybe not noticeably: a different trade-off between quality of service (QoS) and energy-efficiency could have been adopted.

While Clouds come naturally to the rescue of Smart Grids for dealing with this big data issue, little attention has been paid to the benefits that Smart Grids could bring to distributed Clouds. To our knowledge, no previous work has exploited the Smart Grids potential to obtain and control the energy consumption of entire Cloud infrastructures from underlying facilities such as air conditioning equipment (which accounts for 30% to 50% of a data center's electricity bill) to network resources (which are often operated by several actors) and to computing resources (with their heterogeneity and distribution across multiple data centers). We aim at taking advantage of the opportunity brought by the Smart Grids to exploit renewable energy availability and to optimize energy management in distributed Clouds.

3.3.2. Energy cost models

Cloud computing allows users to outsource the computer resources required for their applications instead of using a local installation. It offers on-demand access to the resources through the Internet with a pay-as-you-go pricing model.However, this model hides the electricity cost of running these infrastructures.

The costs of current data centers are mostly driven by their energy consumption (specifically by the air conditioning, computing and networking infrastructure). Yet, current pricing models are usually static and rarely consider the facilities' energy consumption per user. The challenge is to provide a fair and predictable model to attribute the overall energy costs per virtual machine and to increase energy-awareness of users.

Another goal consists in better understanding the energy consumption of computing and networking resources of Clouds in order to provide energy cost models for the entire infrastructure including incentivizing cost models for both Cloud providers and energy suppliers. These models will be based on experimental measurement campaigns on heterogeneous devices. Inferring a cost model from energy measurements is an arduous task since simple models are not convincing, as shown in our previous work. We aim at proposing and validating energy cost models for the heterogeneous Cloud infrastructures in one hand, and the energy distribution grid on the other hand. These models will be integrated into simulation frameworks in order to validate our energy-efficient algorithms at larger scale.

3.3.3. Energy-aware users

In a Cloud moderately loaded, some servers may be turned off when not used for energy saving purpose. Cloud providers can apply resource management strategies to favor idle servers. Some of the existing solutions propose mechanisms to optimize VM scheduling in the Cloud. A common solution is to consolidate the mapping of the VMs in the Cloud by grouping them in a fewer number of servers. The unused servers can then be turned off in order to lower the global electricity consumption.

Indeed, current work focuses on possible levers at the virtual machine suppliers and/or services. However, users are not involved in the choice of using these levers while significant energy savings could be achieved with their help. For example, they might agree to delay slightly the calculation of the response to their applications on the Cloud or accept that it is supported by a remote data center, to save energy or wait for the availability of renewable energy. The VMs are black boxes from the Cloud provider point of view. So, the user is the only one to know the applications running on her VMs.

We plan to explore possible collaborations between virtual machine suppliers, service providers and users of Clouds in order to provide users with ways of participating in the reduction of the Clouds energy consumption. This work will follow two directions: 1) to investigate compromises between power and performance/service quality that cloud providers can offer to their users and to propose them a variety of options adapted to their workload; and 2) to develop mechanisms for each layer of the Cloud software stack to provide users with a quantification of the energy consumed by each of their options as an incentive to become greener.

3.4. Securing clouds

3.4.1. Security monitoring SLO

While the trend for companies to outsource their information system in clouds is confirmed, the problem of securing an information system becomes more difficult. Indeed, in the case of infrastructure clouds, physical resources are shared between companies (also called tenants) but each tenant controls only parts of the shared resources, and, thanks to virtualization, the information system can be dynamically and automatically reconfigured with added or removed resources (for example starting or stopping virtual machines), or even moved between physical resources (for example using virtual machine migration). Partial control of shared resources brings new classes of attacks between tenants, and security monitoring mechanisms to detect such attacks are better placed out of the tenant-controlled virtual information systems, that is under control of the cloud provider. Dynamic and automatic reconfigurations of the information system make it unfeasible for a tenant's security administrator to setup the security monitoring components to detect attacks, and thus an automated self-adaptable security monitoring service is required.

Combining the two previous statements, there is a need for a dependable, automatic security monitoring service provided to tenants by the cloud provider. Our goal is to address the following challenges to design such a security monitoring service:

1. to define relevant Service-Level Objectives (SLOs) of a security monitoring service, that can figure in the Service-Level Agreement (SLA) signed between a cloud provider and a tenant;
2. to design heuristics to automatically configure provider-controlled security monitoring software components and devices so that SLOs are reached, even during automatic reconfigurations of tenants' information systems;
3. to design evaluation methods for tenants to check that SLOs are reached.

Moreover in challenges 2 and 3 the following sub-challenges must be addressed:

- although SLAs are bi-lateral contracts between the provider and each tenant, the implementation of the contracts is based on shared resources, and thus we must study methods to combine the SLOs;
- the designed methods should have a minimal impact on performance.

3.4.2. Data Protection in Cloud-based IoT Services

The Internet of Things is becoming a reality. Individuals have their own swarm of connected devices (e.g. smartphone, wearables, and home connected objects) continually collecting personal data. A novel generation of services is emerging exploiting data streams produced by the devices' sensors. People are deprived of control of their personal data as they don't know precisely what data are collected by service providers operating on Internet (oISP), for which purpose they could be used, for how long they are stored, and to whom they are disclosed. In response to privacy concerns the European Union has introduced, with the Global Data Protection Regulation (GDPR), new rules aimed at enforcing the people's rights to personal data protection. The GDPR also gives strong incentives to oISPs to comply. However, today, oISPs can't make their systems GDPR-compliant since they don't have the required technologies. We argue that a new generation of system is mandatory for enabling oISPs to conform to the GDPR. We plan to to design an open source distributed operating system for native implementation of new GDPR rules and ease the programming of compliant cloud-based IoT services. Among the new rules, transparency, right of erasure, and accountability are the most challenging ones to be implemented in IoT environments but could fundamentally increase people's confidence in oISPs. Deployed on individuals' swarms of devices and oISPs' cloud-hosted servers, it will enforce detailed data protection agreements and accountability of oISPs' data processing activities. Ultimately we will show to what extend the new GDPR rules can be implemented for cloud-based IoT services.

3.5. Experimenting with Clouds

Cloud platforms are challenging to evaluate and study with a sound scientific methodology. As with any distributed platform, it is very difficult to gather a global and precise view of the system state. Experiments are not reproducible by default since these systems are shared between several stakeholder. This is even worsen by the fact that microscopic differences in the experimental conditions can lead to drastic changes since typical Cloud applications continuously adapt their behavior to the system conditions.

3.5.1. Experimentation methodologies for clouds

We propose to combine two complementary experimental approaches: direct execution on testbeds such as Grid'5000, that are eminently believable but rather labor intensive, and simulations (using *e.g.* SimGrid) that are much more light-weighted, but requires are careful assessment. One specificity of the Myriads team is that we are working on these experimental methodologies *per se*, raising the standards of *good experiments* in our community.

We plan to make SimGrid widely usable beyond research laboratories, in order to evaluate industrial systems and to teach the future generations of cloud practitioners. This requires to frame the specific concepts of Cloud systems and platforms in actionable interfaces. The challenge is to make the framework both easy to use for simple studies in educational settings while modular and extensible to suit the specific needs of every advanced industrial-class users.

We aim at leveraging the convergence opportunities between methodologies by further bridging simulation and real testbeds. The predictions obtained from the simulator should be validated against some real-world experiments obtained on the target production platform, or on a similar platform. This (in)validation of the predicted results often improves the understanding of the modeled system. On the other side, it may even happen that the measured discrepancies are due to some mis-configuration of the real platform that would have been undetected without this (in)validation study. In that sense, the simulator constitutes a precious tool for the quality assurance of real testbeds such as Grid'5000.

Scientists need more help to make there Cloud experiments fully reproducible, in the sprit of Open Science exemplified by the HAL Open Archive, actively backed by Inria. Users still need practical solutions to archive, share and compare the whole experimental settings, including the raw data production (particularly in the case of real testbeds) and their statistical analysis. This is a long lasting task to which we plan to collaborate through the research communities gathered around the Grid'5000 and SimGrid scientific instruments.

Finally, since correction and performance can constitute contradictory goals, it is particularly important to study them jointly. To that extend, we want to bridge the performance studies, that constitute our main scientific heritage, to correction studies leveraging formal techniques. SimGrid already includes to exhaustively explore the possible executions. We plan to continue this work to ease the use of the relevant formal methods to the experimenter studying Cloud systems.

3.5.2. Use cases

In system research it is important to work on real-world use cases from which we extract requirements inspiring new research directions and with which we can validate the system services and mechanisms we propose. In the framework of our close collaboration with the Data Science Technology department of the LBNL, we will investigate cloud usage for scientific data management. Next-generation scientific discoveries are at the boundaries of datasets, e.g., across multiple science disciplines, institutions and spatial and temporal scales. Today, data integration processes and methods are largely adhoc or manual. A generalized resource infrastructure that integrates knowledge of the data and the processing tasks being performed by the user in the context of the data and resource lifecycle is needed. Clouds provide an important infrastructure platform that can be leveraged by including knowledge for distributed data integration.

4. Application Domains

4.1. Main Application Domains

The Myriads team investigates the design and implementation of system services. Thus its research activities address a broad range of application domains. We validate our research results with selected use cases in the following application domains:

- Smart city services,
- Smart grids,
- Energy and sustainable development,
- Home IoT applications,
- Bio-informatics applications,
- Data science applications,
- Computational science applications,
- Numerical simulations.

5. Highlights of the Year

5.1. Highlights of the Year

5.1.1. Awards

- Best Doctoral Symposium paper award for Clément Elbaz at Foundations and Applications of Self* Systems (FAS* 2018, the event colocating SASO 2018 and ICAC 2018) for the paper entitled "Reactive and Adaptive Security Monitoring in Cloud Computing"

BEST PAPER AWARD:

[20]
C. ELBAZ, L. RILLING, C. MORIN. *Reactive and Adaptive Security Monitoring in Cloud Computing*, in "FAS* Doctoral Symposium 2018", Trento, Italy, September 2018, pp. 1-3, https://hal.inria.fr/hal-01884739

6. New Software and Platforms

6.1. GinFlow

KEYWORDS: Workflow - Distributed computing - Distributed - Distributed Applications - Dynamic adaptation - Framework

FUNCTIONAL DESCRIPTION: GinFlow decentralizes the coordination of the execution of workflow-based applications. GinFlow relyies on an architecture where multiple service agents (SA) coordinate each others through a shared space containing the workflow description and current status. GinFlow allows the user to define several variants of a workflow and to switch from one to the other during run time.

- Participants: Cédric Tedeschi, Hector Fernandez, Javier Rojas Balderrama, Matthieu Simonin and Thierry Priol
- Partner: Université de Rennes 1
- Contact: Cédric Tedeschi
- URL: http://ginflow.inria.fr

6.2. PaaSage Adapter

KEYWORDS: Cloud computing - Dynamic adaptation - Cloud applications management

FUNCTIONAL DESCRIPTION: The purpose of the Adapter is to transform the current configuration of a cloud application into a target configuration in an efficient and safe way. The Adapter is part of PaaSage, an open-source platform for modeling, deploying and executing applications on different clouds in an optimal manner. The Adapter has the following responsibilities: (1) validating reconfiguration plans, (2) applying the plans to the running system, and (3) maintaining an up-to-date representation of the current system state.

- Contact: Nikolaos Parlavantzas
- URL: https://team.inria.fr/myriads/software-and-platforms/paasage-adapter/

6.3. SAIDS

self-adaptable intrusion detection system
KEYWORDS: Cloud - Security
FUNCTIONAL DESCRIPTION: SAIDS is a self-adaptable intrusion detection system for IaaS clouds. To maintain an effective level of intrusion detection, SAIDS monitors changes in the virtual infrastructure of a Cloud environment and reconfigures its components (security probes) accordingly. SAIDS can also reconfigure probes in the case of a change in the list of running services.

- Authors: Anna Giannakou and Jean-Léon Cusinato
- Contact: Christine Morin

6.4. SimGrid

KEYWORDS: Large-scale Emulators - Grid Computing - Distributed Applications
SCIENTIFIC DESCRIPTION: SimGrid is a toolkit that provides core functionalities for the simulation of distributed applications in heterogeneous distributed environments. The simulation engine uses algorithmic and implementation techniques toward the fast simulation of large systems on a single machine. The models are theoretically grounded and experimentally validated. The results are reproducible, enabling better scientific practices.

Its models of networks, cpus and disks are adapted to (Data)Grids, P2P, Clouds, Clusters and HPC, allowing multi-domain studies. It can be used either to simulate algorithms and prototypes of applications, or to emulate real MPI applications through the virtualization of their communication, or to formally assess algorithms and applications that can run in the framework.

The formal verification module explores all possible message interleavings in the application, searching for states violating the provided properties. We recently added the ability to assess liveness properties over arbitrary and legacy codes, thanks to a system-level introspection tool that provides a finely detailed view of the running application to the model checker. This can for example be leveraged to verify both safety or liveness properties, on arbitrary MPI code written in C/C++/Fortran.
NEWS OF THE YEAR: There were 3 major releases in 2018: The public API was sanitized (with compatibility wrappers in place). Th documentation was completely overhauled. Our continuous integration was greatly improved (45 Proxy Apps + BigDFT + StarPU + BatSim now tested nightly). Some kernel headers are now installed, allowing external plugins. Allow dynamic replay of MPI apps, controlled by S4U actors. Port the MPI trace replay engine to C++, fix visualization (+ the classical bug fixes and doc improvement).

- Participants: Adrien Lèbre, Arnaud Legrand, Augustin Degomme, Florence Perronnin, Frédéric Suter, Jean-Marc Vincent, Jonathan Pastor, Luka Stanisic and Martin Quinson
- Partners: CNRS - ENS Rennes
- Contact: Martin Quinson
- URL: https://simgrid.org/

6.5. DiFFuSE

Distributed framework for cloud-based epidemic simulations

KEYWORDS: Simulation - Cloud

FUNCTIONAL DESCRIPTION: The DiFFuSE framework enables simulations of epidemics to take full advantage of cloud environments. The framework provides design support, reusable code, and tools for building and executing epidemic simulations. Notably, the framework automatically handles failures and supports elastic allocation of resources from multiple clouds.

- Authors: Yvon Jégou, Manh Linh Pham, Nikolaos Parlavantzas and Christine Morin
- Contact: Nikolaos Parlavantzas
- Publication: hal-01612979/
- URL: https://team.inria.fr/myriads/software-and-platforms/diffuse/

7. New Results

7.1. Scaling Clouds

7.1.1. Fog Computing

Participants: Guillaume Pierre, Cédric Tedeschi, Arif Ahmed, Ali Fahs, Hamidreza Arkian, Mulugeta Tamiru, Mozhdeh Farhadi, Paulo Rodrigues de Souza Junior, Davaadorj Battulga, Genc Tato, Lorenzo Civolani, Trung Le.

Fog computing aims to extend datacenter-based cloud platforms with additional compute, networking and storage resources located in the immediate vicinity of the end users. By bringing computation where the input data was produced and the resulting output data will be consumed, fog computing is expected to support new types of applications which either require very low network latency (e.g., augmented reality applications) or which produce large data volumes which are relevant only locally (e.g., IoT-based data analytics).

Fog computing architectures are fundamentally different from traditional clouds: to provide computing resources in the physical proximity of any end user, fog computing platforms must necessarily rely on very large numbers of small Points-of-Presence connected to each other with commodity networks whereas clouds are typically organized with a handful of extremely powerful data centers connected by dedicated ultra-high-speed networks. This geographical spread also implies that the machines used in any Point-of-Presence may not be datacenter-grade servers but much weaker commodity machines.

We investigated the challenges of efficiently deploying Docker containers in fog platforms composed of tiny single-board computers such as Raspberry PIs, and demonstrated that major performance gains can be obtained with relatively simple modifications in the way Docker imports container images [12]. This work is currently being extended in a variety of ways: exploiting distributed storage services to share image among fog nodes, reorganizing the Docker images to allow them to be booted before the image has been fully downloaded, exploiting checkpoint/restart mechanisms to efficiently deploy application that have a long startup time. We expect a few publications on these topics in the coming year.

There does not yet exist any reference platform for fog computing platforms. We therefore investigate how Kubernetes could be adapted to support the specific needs of fog computing platforms. In particular we focused on the problem of redirecting end-user traffic to a nearby instance of the application. When different users impose various load on the system, any traffic routing system must necessarily implement a tradeoff between proximity and fair load-balancing between the application instances. We demonstrated how such customizeable traffic routing policies can be integrated in Kubernetes to help transform it in a suitable platform for fog computing. A paper on this topic is currently under review.

We investigated in collaboration with Etienne Riviere from UC Louvain the feasibility and possible benefits brought about by the *edgification* of a legacy micro-service-based application [31]. In other words, we devised a method to classify services composing the application as *edgifiable* or not, based on several criteria. We applied this method to the particular case of the ShareLatex application which enables the collaborative edition of LaTeX documents.

Thanks to the FogGuru MSCA H2020 project, five new PhD students have also started this year on various topics related to fog computing. We expect the first scientific results to appear in 2019.

7.1.2. Community Clouds

Participants: Jean-Louis Pazat, Bruno Stevant.

It is now feasible for consumers to buy inexpensive devices that can be installed at home and accessed remotely thanks to an Internet connection. Such a simple "self-hosting" paradigm can be an alternative to traditional cloud providers, especially for privacy-conscious users. We discuss how a community of users can pool their devices in order to host microservices-based applications, where each microservice is deployed on a different device. The performance of such an application depends heavily on the computing and network resources that are available and on the placement of each microservice. Finding the placement that minimizes the application response time is an NP-hard problem. We show that, thanks to well known optimization techniques (Particle Swarm Optimization), it is possible to quickly find a service placement resulting in a response time close to the optimal one. Thanks to an emulation platform, we evaluate the robustness of this solution to changes in the Quality of Service under conditions typical of a residential access network [30].

7.1.3. Stream Processing

Participants: Cédric Tedeschi, Mehdi Belkhiria.

We investigated a decentralized scaling mechanism for stream processing applications where the different operators composing the processing topology are able to take their own scaling decisions independently, based on local information. We built a simulation tool to validate the ability of our algorithm to react to load variation. We plan to submit a paper on this topic by the end of 2018.

7.1.4. QoS-aware and Energy-efficient Resource Management for Function as a Service

Participants: Yasmina Bouizem, Christine Morin, Nikos Parlavantzas.

Recent years have seen the widespread adoption of serverless computing, and in particular, Function-as-a-Service (FaaS) systems. These systems enable users to execute arbitrary functions without managing underlying servers. However, existing FaaS frameworks provide no quality of service guarantees to FaaS users in terms of performance and availability. Moreover, they provide no support for FaaS providers to reduce energy consumption. The goal of this work is to develop an automated resource management solution for FaaS plaforms that takes into account performance, availability, and energy efficiency in a coordinated manner. This work is performed in the context of the thesis of Yasmina Bouizem. In 2018, we analysed the challenges of designing FaaS platforms and performed a detailed evaluation of three open-source FaaS frameworks, all based on Kubernetes, with respect to performance, fault-tolerance, energy consumption, and extensibility [13].

7.1.5. Cost-effective Reconfiguration for Multi-cloud Applications

Participants: Christine Morin, Nikos Parlavantzas, Linh Manh Pham.

Modern applications are increasingly being deployed on resources delivered by Infrastructure-as-a-Service (IaaS) cloud providers. A major challenge for application owners is continually managing the application deployment in order to satisfy the performance requirements of application users, while reducing the charges paid to IaaS providers. This work developed an approach for adaptive application deployment that explicitly considers adaptation costs and benefits in making deployment decisions. The approach relies on predicting the duration of reconfiguration actions as well as workload changes. The work builds on the Adapter system, developed by Myriads in the context of the PaaSage European project (2012-2016). We have evaluated the approach using experiments in a real cloud testbed, demonstrating its ability to perform multi-cloud adaptation while optimizing the application owner profit under diverse circumstances [25].

7.1.6. Adaptive Resource Management for High-performance, Real-time Embedded Systems

Participants: Baptiste Goupille-Lescar, Christine Morin, Nikos Parlavantzas.

In the context of our collaboration with Thales Research and Technology and Baptiste Goupille-Lescar's PhD work, we are applying cloud resource management techniques to high-performance, multi-sensor, embedded systems with real-time constraints. The objective is to increase the flexibility and efficiency of resource allocation in such systems, enabling the execution of dynamic sets of applications with strict QoS requirements. In 2018, we proposed an online scheduling approach for executing real-time applications on heavily-constrained embedded architectures. The approach enables dynamically allocating resources to fulfill requests coming from several sensors, making the most of the computing platform, while providing guaranties on quality of service levels. The approach was tested in an industrial use case concerning the operation of a multi-function surface active electronically scanned array (AESA) radar. We showed that the approach allows us to obtain lower execution latencies than current mapping solutions while maintaining high predictability and allowing gradual performance degradation in overload scenarios [22].

7.2. Greening Clouds

7.2.1. Energy Models

Participants: Ehsan Ahvar, Loic Guegan, Anne-Cécile Orgerie, Martin Quinson.

Cloud computing allows users to outsource the computer resources required for their applications instead of using a local installation. It offers on-demand access to the resources through the Internet with a pay-as-you-go pricing model. However, this model hides the electricity cost of running these infrastructures.

The costs of current data centers are mostly driven by their energy consumption (specifically by the air conditioning, computing and networking infrastructure). Yet, current pricing models are usually static and rarely consider the facilities' energy consumption per user. The challenge is to provide a fair and predictable model to attribute the overall energy costs per virtual machine and to increase energy-awareness of users. We aim at proposing such energy cost models without heavily relying on physical wattmeters that may be costly to install and operate.

Another goal consists in better understanding the energy consumption of computing and networking resources of Clouds in order to provide energy cost models for the entire infrastructure including incentivizing cost models for both Cloud providers and energy suppliers. These models will be based on experimental measurement campaigns on heterogeneous devices. Inferring a cost model from energy measurements is an arduous task since simple models are not convincing, as shown in our previous work. We aim at proposing and validating energy cost models for the heterogeneous Cloud infrastructures in one hand, and the energy distribution grid on the other hand. These models will be integrated into simulation frameworks in order to validate our energy-efficient algorithms at larger scale.

Finally, a research result dating from 2015 was finally published after a long review and publication process [4]: to help the energy-aware co-design of IaaS and PaaS platforms, we conducted an extensive experimental evaluation of the effect of a range of Cloud infrastructure operations (start, stop, migrate VMs) on their computing throughput and energy consumption, and derived a model to help drive cloud reconfiguration operations according to performance/energy requirements.

7.2.2. End-to-end Energy Models for Internet of Things

Participant: Anne-Cécile Orgerie.

The development of IoT (Internet of Things) equipment, the popularization of mobile devices, and emerging wearable devices bring new opportunities for context-aware applications in cloud computing environments. The disruptive potential impact of IoT relies on its pervasiveness: it should constitute an integrated heterogeneous system connecting an unprecedented number of physical objects to the Internet. Among the many challenges raised by IoT, one is currently getting particular attention: making computing resources easily accessible from the connected objects to process the huge amount of data streaming out of them.

While computation offloading to edge cloud infrastructures can be beneficial from a Quality of Service (QoS) point of view, from an energy perspective, it is relying on less energy-efficient resources than centralized Cloud data centers. On the other hand, with the increasing number of applications moving on to the cloud, it may become untenable to meet the increasing energy demand which is already reaching worrying levels. Edge nodes could help to alleviate slightly this energy consumption as they could offload data centers from their overwhelming power load and reduce data movement and network traffic. In particular, as edge cloud infrastructures are smaller in size than centralized data center, they can make a better use of renewable energy.

We investigate the end-to-end energy consumption of IoT platforms. Our aim is to evaluate, on concrete use-cases, the benefits of edge computing platforms for IoT regarding energy consumption. We aim at proposing end-to-end energy models for estimating the consumption when offloading computation from the objects to the edge or to the core Cloud, depending on the number of devices and the desired application QoS, in particular trading-off between performance (response time) and reliability (service accuracy). This work has been published in [10].

7.2.3. *Exploiting Renewable Energy in Distributed Clouds*

Participants: Benjamin Camus, Anne-Cécile Orgerie.

The growing appetite of Internet services for Cloud resources leads to a consequent increase in data center (DC) facilities worldwide. This increase directly impacts the electricity bill of Cloud providers. Indeed, electricity is currently the largest part of the operation cost of a DC. Resource over-provisioning, energy non-proportional behavior of today's servers, and inefficient cooling systems have been identified as major contributors to the high energy consumption in DCs.

In a distributed Cloud environment, on-site renewable energy production and geographical energy-aware load balancing of virtual machines allocation can be associated to lower the brown (i.e. not renewable) energy consumption of DCs. Yet, combining these two approaches remains challenging in current distributed Clouds. Indeed, the variable and/or intermittent behavior of most renewable sources – like solar power for instance – is not correlated with the Cloud energy consumption, that depends on physical infrastructure characteristics and fluctuating unpredictable workloads.

We proposed NEMESIS: a Network-aware Energy-efficient Management framework for distributEd cloudS Infrastructures with on-Site photovoltaic production. The originality of NEMESIS lies in its combination of a greedy VM allocation algorithm, a network-aware live-migration algorithm, a dichotomous consolidation algorithm and a stochastic model of the renewable energy supply in order to optimize both green and brown energy consumption of a distributed cloud infrastructure with on-site renewable production. Our solution employs a centralized resource manager to schedule VM migrations in a network-aware and energy-efficient way, and consolidation techniques distributed in each data center to optimize the Cloud's overall energy consumption. This work has been published in [15] and [38].

7.2.4. *Smart Grids*

Participants: Anne Blavette, Benjamin Camus, Anne-Cécile Orgerie, Martin Quinson.

Smart grids allow to efficiently perform demand-side management in electrical grids in order to increase the integration of fluctuating and/or intermittent renewable energy sources in the energy mix. In this work, we consider a distributed computing cloud partially powered by photovoltaic panels as a self-consumer that can also benefit from geographical flexibility: the computing load can be moved from one data center to another one benefiting from better solar irradiance conditions. The various data centers composing the cloud can then cooperate to better synchronise their consumption with their photovoltaic production.

We aim at optimizing the self-power consumption of a distributed Cloud infrastructure with on-site photovoltaic electricity generation. We propose to rely on the flexibility brought by Smart Grids to exchange renewable energy between data centers and thus, to further increase the overall Cloud's self-consumption of the locally-produced renewable energy. Our solution is named SCORPIUS: Self-Consumption Optimization of Renewable energy Production In distribUted cloudS. It optimizes the Cloud's self-consumption by trading-off between VM migration and renewable energy exchange. This optimization is based on an original Smart Grid model to exchange renewable energy between distant sites. This work has been published in the distributed computing community [14] and in the electrical engineering community [37].

7.2.5. *Involving Users in Energy Saving*

Participants: David Guyon, Christine Morin, Anne-Cécile Orgerie.

In a Cloud moderately loaded, some servers may be turned off when not used for energy saving purpose. Cloud providers can apply resource management strategies to favor idle servers. Some of the existing solutions propose mechanisms to optimize VM scheduling in the Cloud. A common solution is to consolidate the mapping of the VMs in the Cloud by grouping them in a fewer number of servers. The unused servers can then be turned off in order to lower the global electricity consumption.

Indeed, current work focuses on possible levers at the virtual machine suppliers and/or services. However, users are not involved in the choice of using these levers while significant energy savings could be achieved with their help. For example, they might agree to delay slightly the calculation of the response to their applications on the Cloud or accept that it is supported by a remote data center, to save energy or wait for the availability of renewable energy. The VMs are black boxes from the Cloud provider point of view. So, the user is the only one to know the applications running on her VMs.

We explore possible collaborations between virtual machine suppliers, service providers and users of Clouds in order to provide users with ways of participating in the reduction of the Clouds energy consumption. This work will follow two directions: 1) to investigate compromises between power and performance/service quality that cloud providers can offer to their users and to propose them a variety of options adapted to their workload; and 2) to develop mechanisms for each layer of the Cloud software stack to provide users with a quantification of the energy consumed by each of their options as an incentive to become greener. This work was explored in the context of David Guyon's PhD thesis (defended on December 7, 2018). For 2018, it resulted in one publication in the International Journal of Grid and Utility Computing [8] and two publications in conferences: IC2E [23] and SBAC-PAD [24].

7.3. Securing Clouds

7.3.1. *Security Monitoring in Clouds*

Participants: Christine Morin, Louis Rilling, Amir Teshome Wonjiga, Clément Elbaz.

In the INDIC project we aim at making security monitoring a dependable service for IaaS cloud customers. To this end, we study three topics:

- defining relevant SLA terms for security monitoring,
- enforcing and verifying SLA terms,
- making the SLA terms enforcement mechanisms self-adaptable to cope with the dynamic nature of clouds.

The considered enforcement and verification mechanisms should have a minimal impact on performance.

After having proposed a verification method for security monitoring SLOs [33], we have worked on defining security monitoring SLOs that are at the same time relevant for the tenant, achievable for the provider, and verifiable. Indeed the experiments done when studying verification showed the costs of verying the configuration of an NIDS, in time and in network overhead on the tenant's virtual infrastructure. This allows us to propose trade-offs in the verification part of an SLO. In order to allow a provider to propose achievable SLOs, we also propose methods to predict metrics of evaluation for an NIDS configured according to the specific needs of a tenant. These predictions are based on measurements done on a set of basic setups of the NIDS, the basic setups covering together the variety of NIDS rules that may interest tenants. Finally we propose extensions to an existing cloud SLA language to define security monitoring SLOs. These results will be submitted for publication in beginning of 2019.

To make security monitoring SLOs adaptable to context changes like the evolution of threats and updates to the tenants' software, we first studied the economic feasibility for a provider to guarantee new threats mitigation in SLAs. Our study of 3 years on the lifecycle of public vulnerabilities from their publication to the publication of mitigations (either as intrusion detection rules or as software patches) shows that there is room for providers to propose profitable SLAs. The results of this study incite us to investigate in two directions: how to incite tenants to apply security patches on the software they manage, and how to mitigate new threats during time window in which no intrusion detection rule exist and no security patch is applied yet (if available).

Our results were published in [33], [34], [20], [21].

A demo of SAIDS, our prototype of self-adaptable network intrusion detection systems was also presented at FIC 2018, Lille, France in January 2018.

7.4. Experimenting with Clouds

7.4.1. Simulating Distributed IT Systems

Participants: Toufik Boubehziz, Benjamin Camus, Anne-Cécile Orgerie, Millian Poquet, Martin Quinson.

Our team plays a major role in the advance of the SimGrid simulator of IT systems. This framework has a major impact on the community. Cited by over 900 papers, it was used as a scientific instrument by more than 300 publications over the years.

This year, we pursued our effort to ensure that SimGrid becomes a *de facto* standard for the simulation of distributed IT platforms. We further polished the new interface to ensure that it correctly captures the concepts needed by the experimenters. To that extend, we also added several complex applications to our Continuous Integration (CI) testing framework, to ensure that we correctly cover the needs of our existing users. We also worked toward our potential users by reworking the documentation, and by proposing new pedagogical resources. Making SimGrid usable in the classroom should greatly increase its impact. A publication on this effort was recognized as Best Paper in the Workshop on Education for High-Performance Computing [17].

The work on SimGrid is fully integrated to the other research efforts of the Myriads team. This year, we added the ability to co-simulate IT systems with SimGrid and physical systems modeled with equational systems [16]. This work, developed to study the co-evolution of thermal systems or of the electic grid with the IT system, is now distributed as an official plugin of the SimGrid framework.

7.4.2. Formal Methods for IT Systems

Participants: The Anh Pham, Martin Quinson.

The SimGrid framework also provide a state of the art Model-Checker for MPI applications. This can be used to formally verify whether the application entails synchronization issues such as deadlocks or livelocks [7].

This year, we pursued our effort (in collaboration with Thierry Jéron, EPI SUMO) to improve the reduction techniques proposed to mitigate the state space explosion issue. We are leveraging event folding structures to improve the performance and accuracy of dynamic partial ordering reduction techniques. We plan to submit a publication on this work by the beginning of 2019.

7.4.3. Executing Epidemic Simulation Applications in the Cloud

Participants: Christine Morin, Nikos Parlavantzas, Manh Linh Pham.

In the context of the DiFFuSE ADT and in collaboration with INRA researchers, we transformed a legacy application for simulating the spread of Mycobacterium avium subsp. paratuberculosis (MAP) to a cloud-enabled application based on the DiFFuSE framework (Distributed framework for cloud-based epidemic simulations). This is the second application to which the DiFFuSE framework is applied. The first application was a simulator of the spread of the bovine viral diarrhea virus, developed within the MIHMES project (2012-2017). Using both the MAP and BVDV applications, we performed extensive experiments showing the advantages of the DiFFuSE framework. Specifically, we showed that DiFFuSE enhances application performance and allows exploring different cost-performance trade-offs while supporting automatic failure handling and elastic resource acquisition from multiple clouds. These results are described in a journal article under submission. In 2018, we also released the fist major version of the DiFFuSE software (v1.0) under the CeCILL-B licence.

7.4.4. Implicit locality awareness of Remote Procedure Calls evaluation

Participants: Javier Rojas Balderrama, Matthieu Simonin.

Cloud computing depends on communication mechanisms implying location transparency. Transparency is tied to the cost of ensuring scalability and an acceptable request responses associated to the locality. Current implementations, as in the case of OpenStack, mostly follow a centralized paradigm but they lack the required service agility that can be obtained in decentralized approaches. In an edge scenario, the communicating entities of an application can be dispersed. In this context, we focus our study on the inter-process communication of OpenStack when its agents are geo-distributed regarding two key metrics: scalability and locality. Scalability refers to the ability of the communication middleware to handle a massive number of clients while consuming a reasonnable amount of resources. Locality refers to the ability of the communication middleware to serve requests as localy as possible while mitigating long-haul data transfers.

Results show that scalability and locality are very limited when considering the traditionnal broker-based approaches [28]. Novel solution such as router-based communication middleware offers better scalability and a good level of implicit locality. This work is an initial step towards building locality-aware geo-distributed systems.

7.4.5. Tools for the experimentation

Participant: Matthieu Simonin.

In collaboration with the STACK team and in the context of the Discovery IPL, novel experimentation tools have been developed. In this context experimenting with large software stacks (OpenStack, Kubernetes) was required. These stacks are often tedious to handle. However, practitioners need a right abstraction level to express the moving nature of experimental targets. This includes being able to easily change the experimental conditions (e.g underlying hardware and network) but also the software configuration of the targeted system (e.g service placement, fined-grained configuration tuning) and the scale of the experiment (e.g migrate the experiment from one small testbed to another bigger testbed).

In this spirit we discuss in [19] a possible solution to the above desiderata. We illustrate its use in a real world use case study which has been completed in [28]. We show that an experimenter can express their experimental workflow and execute it in a safe manner (side effects are controlled) which increases the repeatability of the experiments.

8. Bilateral Contracts and Grants with Industry

8.1. Bilateral Grants with Industry

8.1.1. Thales Research and Technology (2016-2018)

Participants: Baptiste Goupille-Lescar, Christine Morin, Nikos Parlavantzas.

Our collaboration with Thales Research and Technology focuses on the development of distributed Cyber-Physical Systems, such as those developed by Thales to monitor and react to changing physical environments. These systems need to be highly adaptable in order to cope with the dynamism and diversity of their operating environments. Notably, they require distributed, parallel architectures that support dynamic sets of applications, not known in advance, while providing strong QoS guarantees. The objective of this collaboration is to explore adaptive resource management mechanisms for such systems that can adapt to changes in the requirements and in the availability of resources. This contract funds Baptiste Goupille-Lescar's PhD grant.

9. Partnerships and Cooperations

9.1. Regional Initiatives

9.1.1. INDIC - Cybersecurity Pole of Excellence (2014-2020)

Participants: Christine Morin, Louis Rilling, Amir Teshome Wonjiga, Clément Elbaz.

Our study carried out in the framework of a collaboration with DGA-MI aims at defining and enforcing SLA for security monitoring of virtualized information systems. To this aim we study three topics:

- defining relevant SLA terms for security monitoring,
- enforcing and evaluating SLA terms,
- making the SLA terms enforcement mechanisms self-adaptable to cope with the dynamic nature of clouds.

The considered enforcement and evaluation mechanisms should have a minimal impact on performance. The funding from DGA funds the PhD of Anna Giannakou (defended in 2017) and Amir Teshome Wonjiga. Clément Elbaz is partially funded by the Brittany Regional Council in the PEC framework.

9.2. National Initiatives

9.2.1. ADEME RennesGrid

Participants: Anne Blavette, Benjamin Camus, Anne-Cécile Orgerie, Martin Quinson.

The aim of the RennesGrid project is to design and implement a large-scale preindustrial microgrid demonstrator in the territory of Rennes Metropole to organize the shared self-consumption of a group of photovoltaic panels coupled to stationary storage devices. Traditional approaches to power grid management tend to overlook the costs, both energy and economic, of using computers to ensure optimal electricity network management. However, these costs can be significant. It is therefore necessary to take them into account along with the design of IT tools during studies of optimal energy management of smart grids. In addition, telecommunication networks are generally considered to have an ideal functioning, that is to say they can not negatively affect the performance of the electricity network. However, this is not realistic and it is necessary to analyze the impact of phenomena such as congestion, latency, failures related to computer equipment or impact on the batteries of sensors, etc. on strategies for optimal management of the electricity network. In this project, we closely collaborate with Anne Blavette (CR CNRS in electrical engineering, SATIE, Rennes) and co-supervise the post-doc of Benjamin Camus who started in April 2018 on evaluating the impact of the IT infrastructure in the management of smart grids.

9.2.2. Inria ADT SaaP (2016-2018)

Participants: Toufik Boubehziz, Martin Quinson.

The SaaP technological development action (SimGrid As A Platform) funded by INRIA targets the refactoring of SimGrid to make it ready to use in production and teaching contexts. Our ultimate goal is to sustain the development of the framework by involving 5 to 10 companies that are using it internally. Our target of the teaching context is thus an intermediate goal, as we think that the best solution to ensure the adoption of our tool by the industrial engineers is that they discover the tool during their studies.

The technical actions envisioned for this ADT are the complete re-factoring of the software (to make it easier to script a new model within the tool kernel) and a reorganization of the interfaces (for a better integration in the Java and python language). This work is lead by Toufik Boubehziz in collaboration with the whole SimGrid community, which provide valuable feedback.

9.2.3. Inria ADT DiFFuSE (2017-2018)

Participants: Nikos Parlavantzas, Christine Morin, Manh Linh Pham.

The DiFFuSE technological development action (Distributed framework for cloud-based epidemic simulations) funded by INRIA focuses on the DiFFuSE framework developed by Myriads in the context of MIHMES (2012-2017). MIHMES was a 5-year collaborative multidisciplinary project funded by ANR under the Investments for the Future Program, and led by BIOEPAR, INRA, ONIRIS. DiFFuSE is a framework that provides design support, reusable code, and tools for building and executing epidemic simulations in the cloud. The main objectives of this ADT were to improve the usability and robustness of DiFFuSE, to provide support to scientists for applying the framework to a new epidemic simulations as well as to provide a thorough evaluation of the framework using two case studies.

9.2.4. Inria IPL Discovery (2015-2019)

Participants: Ehsan Ahvar, Anne-Cécile Orgerie, Matthieu Simonin, Genc Tato, Cédric Tedeschi.

The Inria IPL Discovery officially started in September 2015. It targets the design, development and deployment of a distributed Cloud infrastructure within the network's backbone. It will be based upon a set of building blocks whose design will take locality as a primary constraint, so as to minimize distant communications and consequently achieve better network traffic, partition management and improved availability.

Its developments are planned to get integrated within the OpenStack framework. Myriads is involved in the design of new overlay networks for such environments so as to support efficient messaging and routing. Myriads is also involved in the energy/cost benefit analysis of distributed edge-cloud architectures.

9.2.5. Inria IPL CityLab (2015-2018)

Participants: Subarna Chatterjee, Christine Morin.

The Inria Project Lab (IPL) CityLab@Inria (http://citylab.inria.fr) studies ICT solutions toward smart cities that promote both social and environmental sustainability. A strong emphasis of the Lab is on the undertaking of a multi-disciplinary research program through the integration of relevant scientific and technology studies, from sensing up to analytics and advanced applications, so as to actually enact the foreseen smart city Systems of Systems. City-scale experiments of the proposed platforms and services are planned in cities in California and France, thereby learning lessons from diverse setups.

Myriads investigates advanced cloud solutions for the Future Internet, which are critical for the processing of urban data. It leverages its experience in cloud computing and Internet of services while expanding its research activities to the design and implementation of cloud services to support crowd-Xing applications and mobile social applications.

In 2017, Christine Morin was involved in the preparation of a SPOC entitled "Technological challenges of participatory smart cities", which is proposed in the framework of the EIT Digital professional school. She prepared seven sequences on cloud-based urban data management. This SPOC is the English version of the MOOC entitled *"Défis technologiques des villes intelligentes participatives"* run on the FUN platform in Spring and Fall 2017.

In 2017, we also conducted a comparative experimental evaluation of data stream processing environments executed on clusters and clouds. We compared the performance and energy consumption of Heron, Storm and Flink frameworks with three data streaming representative applications.

9.2.6. Inria IPL Hac Specis (2016-2020)

Participants: Anne-Cécile Orgerie, Martin Quinson, The Anh Pham.

The goal of the HAC SPECIS (High-performance Application and Computers: Studying PErformance and Correctness In Simulation) project (http://hacspecis.gforge.inria.fr/) is to answer methodological needs of HPC application and runtime developers and to allow to study real HPC systems both from the correctness and performance point of view. To this end, we gather experts from the HPC, formal verification and performance evaluation community.

During his second year of PhD thesis, The Anh Pham proposed a new algorithm to mitigate the state space explosion problem, using event folding structures to efficiently compute how to not explore equivalent execution traces more than once. This work, co-advised by Martin Quinson with Thierry Jéron (team SUMO, formal methods), was important to bridge the gap between the involved communities. The work will be submitted in the near future.

During her first year of PhD thesis, Dorra Boughzala studied the energy consumption of GPU and the simulation tools of the literature related to this aspect. Her work is co-advised by Laurent Lefèvre (Avalon team, Lyon), Martin Quinson and Anne-Cécile Orgerie.

9.2.7. COSMIC PRE (2016 - 2018)

Participants: Benjamin Camus, Anne-Cécile Orgerie, Martin Quinson.

The distributed nature of Cloud infrastructures involves that their components are spread across wide areas, interconnected through different networks, and powered by diverse energy sources and providers, making overall energy monitoring and optimization challenging. The COSMIC project aims at taking advantage of the opportunity brought by the Smart Grids to exploit renewable energy availability and to optimize energy management in distributed Clouds. This PRE, led by Anne-Cécile Orgerie also involves Fanny Dufossé from Datamove team (Inria Grenoble), Anne Blavette from SATIE laboratory (electrical engineering, Rennes), and Benjamin Camus, who finished a 18 months post-doc in March 2018 in the context of this project. Several paper on this project have been presented this year: ACM SIGSIM PADS 2018 [16], SBAC-PAD 2018 [15], IEEE Cluster 2018 [14], IEEE PES ISGT 2018 [37], and one book chapter [38].

9.2.8. SESAME ASTRID project (2016-2019)

Participants: Pascal Morillon, Christine Morin, Matthieu Simonin, Cédric Tedeschi, Mehdi Belkhiria.

The Sesame project (http://www.agence-nationale-recherche.fr/Project-ANR-16-ASTR-0026) led by IMT Atlantique aims at develop efficient infrastructures and tools for the maritime traffic surveillance. The role of Myriads is to define a robust and scalable infrastructure for the real-time and batch processing of vessel tracking information.

In 2018, we investigated the dynamic, decentralized scaling of stream processing applications. Also, we collaborated with the Inria OBELIX team to scale and deploy a machine learning application they developed to build a model of a *normal* vessel trajectory.

9.2.9. PIA ELCI (2015-2018)

Participant: Anne-Cécile Orgerie.

The PIA ELCI project deals with software environment for computation-intensive applications. It is leaded by BULL. In the context of this project, we collaborate with ROMA and Avalon teams from Lyon: we co-supervise a PhD student (Issam Rais) funded by this project on multi-criteria scheduling for large-scale HPC environments. Issam successfully defended his PhD in September 2018. This collaboration has led to two publications in 2017: two journal articles published in IJHPCA [3] and CCPE [11] and two conference papers presented at HPCS [26] and ICA3PP [27].

9.2.10. CNRS GDS EcoInfo

Participant: Anne-Cécile Orgerie.

The EcoInfo group deals with reducing environmental and societal impacts of Information and Communications Technologies from hardware to software aspects. This group aims at providing critical studies, lifecycle analyses and best practices in order to improve the energy efficiency of printers, servers, data centers, and any ICT equipment in use in public research organizations.

9.3. European Initiatives

9.3.1. FP7 & H2020 Projects

9.3.1.1. FogGuru

Participant: Guillaume Pierre.

Title: MSCA ITN EID

Program: H2020

Duration: September 2017 - August 2021

Coordinator: Guillaume Pierre

Participants:

University of Rennes 1, France (coordinator)

Technisch Universität Berlin, Germany

Elastisys AB, Sweden

U-Hopper srl, Italy

EIT Digital Rennes, France

Las Naves, Spain

FogGuru is a doctoral training project which aims to to train eight talented PhD students with an innovative and inter-sectoral research program to constitute the next generation of European Cloud and Fog computing experts. Besides their scientific and technical education, FogGuru's PhD students will receive extensive training in technological innovation and entrepreneurship as well as soft skills. These combined skills will enable them to fully master the innovation process stemming from fundamental research towards invention and development of innovative products and services, and to real-life deployment, experimentation and engagement with beta-testers.

9.3.2. Collaborations in European Programs, Except FP7 & H2020

Program: EIT Digital

Project acronym: DriveTrust

Project title: AI-Powered Driving Evaluation

Duration: January 2019 - December 2019

Coordinator: University of Rennes 1

Other partners:

Eurapco, Switzerland

Achmea, the Netherlands

Imec, Belgium

Abstract: This project aims to develop and commercialize an AI-powered dash cam with short range V2X and LTE communication capabilities. The product uses the newest AI capable hardware for real-time object detection. The device can detect street signs, traffic lights, other cars, and pedestrians. Combined with sensor data from the accelerometer, GPS and weather data from the cloud we use the data to calculate different dimensions of driving profiles. In addition the V2X and object detection capabilities allow us to warn the driver in real-time about dangers on the road.

9.3.2.1. NESUS

Participant: Anne-Cécile Orgerie.

Program: ICT COST

Project acronym: NESUS

Project title: Network for Sustainable Ultrascale Computing (ICT COST Action IC1305)

Duration: 2014 - 2018

Coordinator: Prof. Jesus Carretero, University Carlos III of Madrid, Spain, http://www.nesus.eu

Other partners: 33 COST countries and 11 non-COST countries

Abstract: Ultrascale systems are envisioned as large-scale complex systems joining parallel and distributed computing systems that will be two to three orders of magnitude larger that today's systems. The EU is already funding large scale computing systems research, but it is not coordinated across researchers, leading to duplications and inefficiencies. The goal of the NESUS Action is to establish an open European research network targeting sustainable solutions for ultrascale computing aiming at cross fertilization among HPC, large scale distributed systems, and big data management. The network will contribute to gluing disparate researchers working across different areas and provide a meeting ground for researchers in these separate areas to exchange ideas, to identify synergies, and to pursue common activities in research topics such as sustainable software solutions (applications and system software stack), data management, energy efficiency, and resilience. Some of the most active research groups of the world in this area are members of this proposal. This Action will increase the value of these groups at the European-level by reducing duplication of efforts and providing a more holistic view to all researchers, it will promote the leadership of Europe, and it will increase their impact on science, economy, and society. Anne-Cécile Orgerie is co-responsible of the focus group on metrics, monitoring, instrumentation and profiling in the Working Group 5 on Energy Efficiency. A joint paper has been accepted in 2018 on this topic at the Elsevier journal on Sustainable Computing [2]. In the context of this COST action, we closely collaborate with Pascal Felber's research group from University of Neuchâtel (Switzerland) on energy efficiency in Clouds and in particular on the design of energy cost models for virtual machines. A joint journal paper has been accepted in 2018 for publication in Sustainable Computing: Informatics and Systems, Elsevier [9].

9.4. International Initiatives

9.4.1. Inria International Labs

Inria@SiliconValley

Associate Team involved in the International Lab:

9.4.1.1. DALHIS

Title: Data Analysis on Large Heterogeneous Infrastructures for Science

International Partner (Institution - Laboratory - Researcher):

Lawrence Berkeley National Laboratory (United States) - Data Science and Technology department - Deb Agarwal

Start year: 2016

See also: https://project.inria.fr/dalhis/

Data produced by scientific instruments (large facilities like telescopes or field data), large-scale experiments, and high-fidelity simulations are increasing in magnitude and complexity. Existing data analysis methods, tools and infrastructure are often difficult to use and unable to provide the complete data management, collaboration, and curation environment needed to manage these complex, dynamic, and large-scale data analysis environments. The goal of the Inria-LBL DALHIS associate team involving the Myriads (PI) and Avalon Inria project-teams and the Data Science and Technology (DST) department at Lawrence Berkeley National Laboratory (LBL) is to create a collaborative distributed software ecosystem to manage data lifecycle and enable data analytics on distributed data sets and resources. Specifically, our goal is to build a dynamic software stack that is user-friendly, scalable, energy-efficient and fault tolerant. Our research determines appropriate execution environments that allow users to seamlessly execute their end-to-end dynamic data analysis workflows in various resource environments and scales while meeting energy-efficiency, performance and fault tolerance goals. We engage in deep partnerships with scientific teams (Fluxnet in environmental science and SNFactory and LSST experiences in cosmology) and use a mix of user research with system software R&D to address specific challenges that these communities face. This associate team ended in 2018.

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

9.4.2.1. FogCity

Title: QoS-aware Resource Management for Smart Cities

International Partner (Institution - Laboratory - Researcher):

IITKGP (India) - Department of Computer Science and Engineering - Sudip Misra

Start year: 2018

See also: https://www.inria.fr/en/associate-team/fogcity

The FogCity associate team proposal concerns a collaboration between the Myriads project-team and a research team at Indian Institute of Technology Kharagpur led by Dr. Sudip Misra. The proposal focuses on a smart city scenario in which data from static and mobile sensors is routed to appropriate fog data centres based on application QoS requirements. The main goal of the research is to select suitable nodes within the fog data centers to optimize the QoS of the applications in terms of latency. The two teams have complementary expertise in theoretical research (Indian partner) and system research (Inria Myriads project-team) and share a strong research interest in IoT and Fog Computing.

9.4.3. Inria International Partners

9.4.3.1. Informal International Partners

We collaborate with Prof. Etienne Riviere from UC Louvain on legacy application edgification. Genc Tato spent six month at UCL.

We collaborate extensively with Prof. Gene Cooperman from Northeastern University, USA. One of his students, Onesphore Ndayishimiye, visited us for a three-month visit. Conversely, Arif Ahmed visited Northeastern University for three months as well. These informal collaborations are the basis of a proposal for a joint Inria team.

We collaborate with Dr. Djawida Dib (Tlemcen University, Algeria) on energy-efficient and fault-tolerant resource management in containerized clouds. Christine Morin and Nikos Parlavantzas are co-advising Yasmina Bouizem, who is enrolled in both Tlemcen University and University of Rennes 1.

We collaborate with Prof. Hector Duran-Limon (University of Guadalajara, Mexico) on cloud resource management. Nikos Parlavantzas co-advised Carlos Ruiz Diaz, a PhD student enrolled in the University of Guadalajara, who defended his thesis in January 2018.

9.5. International Research Visitors

9.5.1. Visits of International Scientists

9.5.1.1. Internships

- Onesphore Ndayishimiye (PhD student from Northeastern University) spend three months in the Myriads team.
- Lorenzo Civolani (master student from Bologna University) spent three months in the Myriads team.

9.5.2. Visits to International Teams

9.5.2.1. Research Stays Abroad

- Amir Teshome Wonjiga did a 3-month research internship in the Data Science and Technology department of the Lawrence Berkeley National Laboratory from January to March 2018. He worked with Sean Peisert, staff scientist, on the follow-up of his previous internship in 2017 about ensuring data integrity in the workflow of high performance applications.

- Arif Ahmed spent three months from September to December 2018 at Northeastern University. He worked with Gene Cooperman, Professor, on combining Docker cache sharing (developed in the Myriads team) with checkpoint-restart (developed at Northeastern University) to speed up the starting time of Docker containers.

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Scientific Events Organisation

10.1.1.1. General Chair, Scientific Chair

- Guillaume Pierre was General Chair of the 19th ACM/IFIP Middleware conference which took place on December 10-14th 2018 in Rennes. The event attracted more than 200 participants (a record number for this conference), including 70% from abroad.

10.1.1.2. Member of the Organizing Committees

- Anne-Cécile Orgerie was a member of the Organizing Committee of the 3rd GDR RSD and ASF Winter School on Distributed Systems and Networks.
- Anne-Cécile Orgerie was a member of the Organizing Committee of the E3-RSD Research school for early stage researchers on Energy Efficiency of Networks and Distributed Systems.
- Maryse Fouché and Julie Montégu were members of the organizing committee of ACM/IFIP Middleware 2018.
- Anne-Cécile Orgerie was Student activities co-chair for ACM/IFIP Middleware 2018.
- Christine Morin was Sponsor chair for ACM/IFIP Middleware 2018.
- Benjamin Camus was Publicity co-chair and Web and social media chair for ACM/IFIP Middleware 2018.

10.1.2. Scientific Events Selection

10.1.2.1. Chair of Conference Program Committees

- Anne-Cécile Orgerie was Co-chair of the Track on Cluster and Cloud Computing for Euro-Par 2018.
- Anne-Cécile Orgerie was Co-chair of the Special Track on Big Data/Smart Cities and IoT for IEEE BigData Congress 2018.
- Guillaume Pierre was vice-PC chair of the short paper track at the IEEE ICDCS 2018 conference.

10.1.2.2. Member of the Conference Program Committees

- Anne-Cécile Orgerie was a member of the Workshop committee and Poster committee at ACM/IEEE Supercomputing Conference 2018 (SC'18).
- Anne-Cécile Orgerie was a member of the program committee for IEEE Cluster Conference 2018.
- Cédric Tedeschi was a member of the program committee for ICCS 2018.
- Cédric Tedeschi was a member of the program committee for ICWS 2018.
- Cédric Tedeschi was a member of the program committee for Compas 2018.
- Cédric Tedeschi was a member of the program committee for SBAC-PAD 2018.
- Cédric Tedeschi was a member of the program committee for IEEE CSE 2018.
- Guillaume Pierre was a member of the program committee for ICACNI 2018.
- Guillaume Pierre was a member of the program committee for ISORC 2018.
- Guillaume Pierre was a member of the program committee for CloudCom 2018.
- Guillaume Pierre was a member of the program committee for IEEE/ACM UCC 2018.

- Guillaume Pierre was a member of the program committee for mF2C 2018.
- Nikos Parlavantzas was a member of the program committee for IEEE ISPDC'2018.
- Nikos Parlavantzas was a member of the program committee for Euro-Par 2018.
- Nikos Parlavantzas was a member of the program committee for IEEE/ACM UCC 2018.
- Nikos Parlavantzas was a member of the program committee for IEEE CloudCom 2018.
- Nikos Parlavantzas was a member of the program committee for IEEE CSE 2018.
- Nikos Parlavantzas was a member of the program committee for CrossCloud 18.
- Nikos Parlavantzas was a member of the program committee for VHPC'18.
- Nikos Parlavantzas was a member of the program committee for CLOSER 2018.

10.1.3. Journal

10.1.3.1. Reviewer - Reviewing Activities

- Nikos Parlavantzas served as a reviewer for IEEE Computer.
- Nikos Parlavantzas served as a reviewer for JSS.

10.1.4. Invited Talks

- Anne-Cécile Orgerie gave a presentation Entretiens Jacques Cartier, Lyon, France, November 12, 2018.
- Anne-Cécile Orgerie gave a keynote at GreenDays@Toulouse, Toulouse, France, July 3, 2018.
- Anne-Cécile Orgerie gave a seminar organized by France Stratégie, Paris, France, March 13, 2018.
- Guillaume Pierre gave an invited talk at the Fog Placement meeting, Grenoble, June 19-20th 2018.
- Guillaume Pierre gave a keynote at the Journées Cloud, Troyes, September 12-13th 2018.
- Martin Quinson gave a presentation at the spring school "Algorithmique et programmation" for secondary teachers, Luminy, May 11th 2018.
- Martin Quinson gave a presentation to the seminar of the "Large Scale System" department of IRISA, Rennes, November 23th 2018.
- Martin Quinson gave a presentation to the seminar of the DGD-T of Inria, Rennes, October 18th 2018.

10.1.5. Leadership within the Scientific Community

- Anne-Cécile Orgerie is co-chair of the Green axis of the CNRS GDR RSD (Network and Distributed Systems working group).
- Anne-Cécile Orgerie is vice-chair of the ASF: the French chapter of ACM SIGOPS.
- Cédric Tedeschi is member of the steering committee of the Compas conference.

10.1.6. Scientific Expertise

- Jean-Louis Pazat is the coordinator of experts in Information Technology for the evaluation of international bilateral collaborations at the ministry of research and education.

10.1.7. Research Administration

- Anne-Cécile Orgerie is an officer (chargée de mission) for the IRISA cross-cutting axis on Green IT.
- Martin Quinson is the leader of the "Large Scale Systems" department of IRISA.

10.2. Teaching - Supervision - Juries

10.2.1. Teaching

License: Jean-Louis Pazat, Introduction à la programmation, L1, Département STPI, INSA de Rennes.

License: Guillaume Pierre, Systèmes Informatiques, L3 MIAGE, Univ. Rennes 1.

License: Guillaume Pierre, Systèmes d'exploitation, L3 Informatique, Univ. Rennes 1.

License: Jean-Louis Pazat, Calcul Hautes Performances, Département Informatique L3, Insa Rennes.

License: Jean-Louis Pazat, Calcul Hautes Performances, Département Mathematiques L3, Insa Rennes.

Licence: Martin Quinson, Architecture et Systèmes, 60 hETD, L3 Informatique, ENS Rennes.

Licence: Martin Quinson, Pedagogy, 15 hETD, L3 Informatique, ENS Rennes.

Master: Anne-Cécile Orgerie, Cloud & Big Data, 30 hETD, M1, ENS Rennes.

Master: Anne-Cécile Orgerie, Green ICT, 4.5 hETD, M2, Telecom SudParis Evry.

Master: Anne-Cécile Orgerie, Green ICT,3 hETD, M2, ENSSAT Lannion.

Master: Anne-Cécile Orgerie, Green ICT, 22.5 hETD, M2, IMT-Atlantique Nantes.

Master: Cédric Tedeschi, Concurrency in Systems and Networks, M1, Univ. Rennes 1.

Master: Cédric Tedeschi, Service Technology, M1, Univ. Rennes 1.

Master: Cédric Tedeschi, Parallel Programming, M1, Univ. Rennes 1.

Master: Guillaume Pierre, Distributed Systems, M1, Univ. Rennes 1.

Master: Guillaume Pierre, Service technology, M1, Univ. Rennes 1.

Master: Guillaume Pierre, Techniques de développement pour le cloud, M2, Univ. Rennes 1.

Master: Guillaume Pierre, Advanced Cloud Infrastructures, M2, Univ. Rennes 1.

Master: Jean-Louis Pazat, Parallel Computing, M1 Département Informatique Insa Rennes.

Master: Jean-Louis Pazat, Internet Of Things, M1 & M2 Département Informatique Insa Rennes.

Master: Nikos Parlavantzas, Clouds, M1, INSA Rennes.

Master: Nikos Parlavantzas, Performance Evaluation, M1, INSA Rennes.

Master: Nikos Parlavantzas, Project in Large-Scale Systems, M2, INSA Rennes.

Master: Nikos Parlavantzas, Big Data and Applications, M1, INSA Rennes.

Master: Martin Quinson, Préparation à l'Agrégation de Science Industrielle (Programming and Software Engineering, 20h ETD; Operating Systems and C programming, 20 hETD; Networking, 20h ETD), ENS Rennes.

Master: Martin Quinson, Scientific Outreach, M2, 30 hEDT, ENS Rennes.

10.2.2. Supervision

PhD: Issam Rais, Multi criteria scheduling for large scale High Performance Computing environments, defended on September 28th, 2018, Anne-Cécile Orgerie, Anne Benoit (ROMA), Laurent Lefèvre (Avalon).

PhD: David Guyon, Supporting energy-awareness for cloud users, defended on December 7th, 2018, Anne-Cécile Orgerie, Christine Morin.

PhD in progress: Paulo Rodrigues De Souza Junior, "fog computing service roaming techniques", started in December 2018, advised by Guillaume Pierre and Daniele Miorandi.

PhD in progress: Davaadorj Battulga, "Scalable data pipelines for fog computing applications", started in September 2018, advised by Cédric Tedeschi and Daniele Miorandi.

PhD in progress: Mulugeta Tamiru, "Automatic optimization of autonomous management systems", started in September 2018, advised by Guillaume Pierre and Erik Elmroth.

PhD in progress: Mozhdeh Farhadi, “Fog computing-enabled IoT situation-aware services”, started in June 2018, advised by Guillaume Pierre and Daniele Miorandi.

PhD in progress: Hamidreza Arkian, “Stream processing operator placement”, started in June 2018, advised by Guillaume Pierre and Erik Elmroth.

PhD in progress: Mehdi Belkhiria, Dynamic Stream Processing for Maritime Traffic Surveillance, started in December 2017, advised by Cédric Tedeschi.

PhD in progress (*co-tutelle*): Yasmina Bouizem, Energy-efficient, fault-tolerance mechanisms for containerized cloud applications, started in December 2017, Didi Fedoua (Tlemcen University, Algeria), Djawida Dib (Tlemcen University, Algeria), Christine Morin, Nikos Parlavantzas.

PhD in progress: Ali Jawad Fahs, “Decentralized Fog Computing Infrastructure Control”, started in October 2017, Guillaume Pierre.

PhD in progress: Clément El Baz, Reactive security monitoring in clouds, started in October 2017, Louis Rilling, Christine Morin.

PhD in progress: Loic Guegan, Simulating Internet of Things, started in October 2017, advised by Martin Quinson and Anne-Cécile Orgerie.

PhD in progress: The Anh Pham, Dynamic Formal Verification of High Performance Runtimes and Applications, started in November 2016, Martin Quinson, Thierry Jéron.

PhD in progress: Arif Ahmed, “Scalable Decentralized Edge Cloud Infrastructures”, started in October 2016, Guillaume Pierre.

PhD in progress: Baptiste Goupille-Lescar, Designing agile, distributed cyber-physical systems with advanced collaboration capabilities, started in January 2016, Eric Lenormand (Thales), Christine Morin, Nikos Parlavantzas.

PhD in progress: Pernelle Mensah, Security policy adaptation driven by risk evaluation in modern communication infrastructures, started in December 2015, Samuel Dubus (Alcatel-Lucent), Christine Morin, Guillaume Piolle (Cidre), Eric Totel (Cidre).

PhD in progress: Genc Tato, Locality-aware Lazy Overlay Networks for WANS, started in December 2015, Marin Bertier, Cédric Tedeschi.

PhD in progress: Amir Teshome, Definition and enforcement of Service-Level Agreements for Cloud security monitoring, started in October 2015, Louis Rilling, Christine Morin.

PhD in progress: Bruno Stevant, Resource allocation strategies for service distribution at the Internet edge to optimize end-to-end latency, started in December 2014 (part-time), Jean-Louis Pazat.

10.2.3. Juries

- Anne-Cécile Orgerie was preliminary examiner (equivalent to external reviewer) for the PhD of Kashif Khan, Aalto University, Finland, March 2018.
- Guillaume Pierre was an external reviewer in the PhD committee of Alejandro Tomsic, Sorbonne Université, April 20th 2018.
- Guillaume Pierre chaired the PhD committee of Yacine Taleb, Univ. Rennes 1, October 2nd 2018.
- Guillaume Pierre was a member in the PhD committee of David Guyon, Univ. Rennes 1, December 7th 2018.
- Guillaume Pierre was an external reviewer in the PhD committee of Ye Xia, Université Grenoble Alpes, December 17th 2018.

10.3. Popularization

10.3.1. Internal or external Inria responsibilities

Martin Quinson is on the scientific board of the Blaise Pascal foundation, boosting the scientific outreach in the domains of Maths and Computer Science.

10.3.2. Articles and contents

- Anne-Cécile Orgerie participated to the radio program La methode scientifique by Nicolas Martin with Jean-Marc Jancovici, France Culture, October 17, 2018.
- Anne-Cécile Orgerie was interviewed by Agnes Rougier, Radio France Internationale, September 26, 2018.
- Anne-Cécile Orgerie was interviewed by Laure Cailloce for the Journal of CNRS, May 2018.

10.3.3. Education

- L codent L créent - An outreach program to send PhD students to teach Python to middle school students in 8 sessions of 45 minutes. Tassadit Bouadi (Univ. Rennes 1), Camille Maumet (VisAGeS) and Anne-Cécile Orgerie (Myriads) are coordinating the local version of this program, initiated in Lille. The first session in Rennes is planned for April 2019. The program is currently supported by: Fondation Blaise Pascal, ED MathSTIC, Inria and Fondation Rennes 1.
- Anne-Cécile is a member of the Jury for the Agrégation de Sciences Industrielles, an examination for future secondary teachers of engineering
- Martin Quinson is a trainer for the Agrégation de Sciences Industrielles.
- Martin Quinson is in charge of a M2 lecture on scientific vulgarization at ENS Rennes. The students are asked to come up with new activities (or improve existing ones) on their research field.
- Martin Quinson was a trainer during the SIF summer school on "Scientific Vulgarization in Computer Science", held in Toulouse, June 6th-8th 2018.

10.3.4. Interventions

- Anne-Cécile Orgerie and Martin Quinson participated in the organization of a day for middle school student to deconstruct computer science-related stereotypes http://emergences.inria.fr/2018/newsletter-n53/l53-informaticiennes.
- Martin Quinson presented various unplugged activities to primary and secondary students over the year.
- Anne-Cécile Orgerie and Martin Quinson hosted 2 secondary students during one week (17th-21th december 2018).

10.3.5. Creation of media or tools for science outreach

- Martin Quinson initiated a new unplugged activity with Philippe Marquet (EPI Dreampal – Lille) and Corentin Ferry (student at ENS Rennes) called M999 to explain the internal behavior of a CPU. This activity is still to be tested live with pupils.
- Martin Quinson helped the M2 students of ENS Rennes to create or improve unplugged activities on their research topics. Activities on Classification, Image Reconstruction, Modeling, Cryptographic Protocols, Map-Reduce or Verifications are still incubating at this point.

11. Bibliography

Publications of the year

Doctoral Dissertations and Habilitation Theses

[1] D. GUYON. *Supporting energy-awareness for cloud users*, Université Rennes 1, December 2018, https://tel.archives-ouvertes.fr/tel-01973083

Articles in International Peer-Reviewed Journals

[2] F. ALMEIDA, M. DIAS DE ASSUNCAO, J. BARBOSA, V. BLANCO, I. BRANDIC, G. DA COSTA, M. F. DOLZ, A. C. ELSTER, M. JARUS, H. KARATZA, L. LEFÈVRE, I. MAVRIDIS, A. OLEKSIAK, A.-C. ORGERIE, J.-M. PIERSON. *Energy Monitoring as an Essential Building Block Towards Sustainable Ultrascale Systems*, in "Sustainable Computing : Informatics and Systems", March 2018, vol. 17, pp. 27-42 [*DOI :* 10.1016/J.SUSCOM.2017.10.013], https://hal.inria.fr/hal-01627757

[3] A. BENOIT, L. LEFÈVRE, A.-C. ORGERIE, I. RAÏS. *Reducing the energy consumption of large scale computing systems through combined shutdown policies with multiple constraints*, in "International Journal of High Performance Computing Applications", January 2018, vol. 32, n^{o} 1, pp. 176-188 [*DOI :* 10.1177/1094342017714530], https://hal.inria.fr/hal-01557025

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