Beyond the Clouds, How Should Next Utility Computing Infrastructures Be Designed?

The DISCOVERY Initiative

DIstributed and COoperative management of Virtual Environments autonomouslY

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Proposal Abstract:

The DISCOVERY initiative aims at exploring a new way of operating Utility Computing (UC) resources.

To accommodate the ever-increasing demand for Utility Computing (UC) resources, while taking into account both energy and economical issues, the current trend consists in building larger and larger data centers in a few strategic locations. Although such an approach enables to cope with the actual demand while continuing to operate UC resources through centralized software system, it is far from delivering sustainable and efficient UC infrastructures. We claim that a disruptive change in UC infrastructures is required: UC resources should be managed differently, considering locality as a primary concern. To this aim, **we propose to leverage any facilities available through the Internet in order to deliver widely distributed UC platforms that can better match the geographical dispersal of users as well as the unending demand. Critical to the emergence of such locality-based UC (LUC) platforms is the availability of appropriate operating mechanisms. We advocate the implementation of a unified system driving the use of resources at an unprecedented scale by turning a complex and diverse infrastructure into a collection of abstracted computing facilities that is both easy to operate and reliable.**

By deploying and using such a *LUC Operating System* on backbones, our ultimate vision is to make possible to host/operate a large part of the Internet by its internal structure itself: A scalable and nearly infinite set of resources delivered by any computing facilities forming the Internet, starting from the larger hubs operated by ISPs, government and academic institutions to any idle resources that may be provided by end-users. Unlike previous researches on distributed operating systems, we propose to consider virtual machines (VMs) instead of processes as the basic element. System virtualization offers several capabilities that increase the flexibility of resources management, allowing to investigate novel decentralized schemes that will enable to achieve the LUC infrastructure we target.

Consortium:
    Coordinator - Adrien Lèbre (Mines de Nantes, Inria Rennes Bretagne Atlantique, adrien.lebre@inria.fr)
    Inria Teams - Asap, Ascola, Avalon, Myriads
    External Partners - Orange R&D, Renater
    Envisioned and Ponctual Collaboration Members - BSC(Spain), CRS4(Italy), UniNe (Switzerland)
Web site: `http://beyondtheclouds.github.io`

Contributors: Marin Bertier, Thierry Coupaye, Frédéric Desprez, Laurent Gydé, Adrien Lèbre, Jonathan Rouzaud-Cornabas, Cédric Tedeschi

1 Context

1.1 Current Trends.

The success of Cloud Computing has driven the advent of Utility Computing. However Cloud Computing is a victim of its own success: In order to answer the ever-increasing demand for computing resources, Cloud Computing providers must build data centers (DCs) of ever-increasing size. Besides facing the well-known issues of large scale platforms management, these new DCs have to deal with energy considerations that limit the number of physical resources that a single location can host. As a consequence, several proposals suggest to build next generation DCs in strategical locations close to the polar circle. However, this approach is far from solving all issues. In addition to requiring the construction and the deployment of a complete network infrastructure to reach each DC, it exacerbates the inherent limitations of the Cloud Computing model:

- The externalization of private applications/data often faces legal issues that restrain companies from outsourcing them on external infrastructures, especially when located in other countries.

- The connectivity to the application/data cannot be ensured by centralized dedicated centers, especially if they are located in a similar geographical zone. The only way to ensure disaster recovery is to leverage distinct sites.[1]

- The unavoidable use of the Internet to reach distant platforms implies wasteful and costly overheads in addition to increase security flaws in several situations.

Although hybrid or federated Cloud solutions [AFG$^+$10] that aim at extending the available resource delivered by one Cloud with another one can partially tackle the two former points, the latter one requires a disruptive change in the way of managing UC resources. Deploying a broadcasting service of local events or an online service to order pizza at the edge of the polar circle leads to important overheads in terms of energy footprint, network exchanges as well as latency since it can be assumed that a vast majority of the users are located in the neighborhood of the event/the pizzeria. According to some projections of a recent IEEE report [Gro12], the network traffic continues to double roughly each year. Bringing the IT services closer to the end-users will become soon crucial to limit the energy impact of these exchanges and to save the bandwidth of some links. Similarly, this notion of locality is also critical for the adoption of the UC model by applications that should deal with a large amount of data as getting them in and out from actual UC infrastructures may significantly impact the global performance [Fos11].

The concept of micro data centers at the edge of the backbone [GHMP08] may be seen as the complementary solution to hybrid platforms in order to reduce the overhead of network exchanges. However, the number of such micro data centers will stay limited and the question of how federating a large number of such facilities is still not solved.

At the same time, people are (and will be more and more) surrounded by computing resources, especially the ones in charge of interconnecting all IT equipments. Even though these small and medium-size facilities include resources that are sometimes barely used, they can hardly be removed (*e.g.* routers). As a consequence, several initiatives started investigating how they could be better leveraged to support the requirements and constraints of current IT usages. The concept of *data furnaces* [LGJ$^+$11] is one of the promising idea that seeks to mitigate the cost of operating network/computing resources by using them as sources of heat inside public buildings such as hospitals or universities.

1.2 Ubiquitous and Oversized Network Backbone.

Figure 1.2 is a snapshot of the network weather map of the IP service of RENATER[2], the network backbone dedicated to universities and research institutions in France. It reveals several important points:

- It clearly shows that most of the resources are barely used (only two links are used between 45% and 55%, a few between 25% and 40% and the majority below the threshold of 25%).

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[1] "Amazon outages – lessons learned", http://gigaom.com/cloud/amazon-outages-lessons-learned/ (valid on May 2013, the 25th).

[2] http://www.renater.fr

- The backbone has been deployed and is renewed according to the demand: the density of points of presence (PoP) of the network as well as the bandwidth of each link are more important on the edge of large cities such as Paris, Lyon or Marseille.

- The backbone has been deployed in order to face disconnections, *i.e.* 95% of the PoPs can be reached by at least two distinct routes.
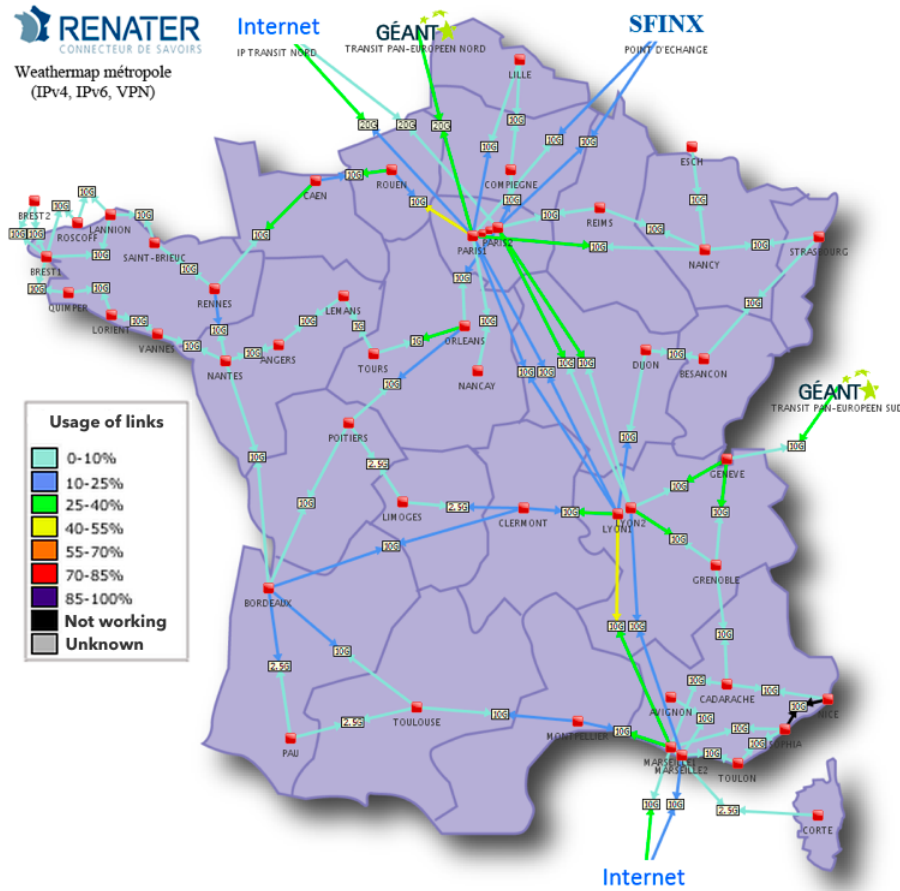

Figure 1: The RENATER Weather Map on May the 27th, around 4PM.
Available in real-time at: http://www.renater.fr/raccourci

Instead of building and deploying dedicated facilities, we claim that next UC infrastructures should be tightly coupled with any facilities available through the Internet, starting from the core routers of the backbone, the different network access points and any small and medium-size computing infrastructures that may be provisioned by public and private institutions. Although it involves radical changes in the way physical and virtual resources are managed, locating and operating computing and data on facilities close to the end-users is the only way to deliver highly efficient and sustainable UC services.

From the physical point of view, network backbones such as the RENATER one provide appropriate infrastructures, that is, reliable and efficient enough to operate UC resources spread across the different PoPs. In a perfect model, UC resources may directly take advantage of computation cycles available on network servers, *i.e.* the one in charge of routing packets. However, leveraging network resources to make external computations may lead to important security concerns. Hence, we propose to extend each network hub with a number of servers dedicated to host VMs. As we can expect that the distribution between network traffics and UC demands would be proportional, larger network hubs will be completed by more UC resources than the smaller ones. Moreover by deploying UC services on relevant PoPs, a LUC infrastructure will be able to natively confine network exchanges to a minimal scope, minimizing both the energy footprint of the network as well as the latency impact.

From the software point of view, the main challenge is to design a complete distributed system in charge of turning a complex and diverse network of resources into a collection of abstracted computing facilities that is both reliable and easy to operate.

2 The DISCOVERY IPL Objectives

The main target of this *INRIA Project Lab* is the definition of a complete distributed system in charge of turning a complex and diverse network of resources into a collection of abstracted computing facilities that is both easy to operate and reliable.

2.1 Overview

By designing an advanced system that offers the possibly to operate in a unified manner a large number of UC resources spread throughout distinct sites, ISPs as well as academic and private institutions in charge of operating a network backbone will be able to build an extreme-scale LUC infrastructure with a limited additional cost. Instead of redeploying a complete installation, they will be able to leverage IT resources and specific devices such as computer room air conditioning units, inverters or redundant power supplies that are already present on each hub of their backbone.

The DISCOVERY initiative aims at making significant advances towards such a LUC operating system with the ultimate goal of allowing end-users to launch virtual environments (VEs), i.e. users' working environments, throughout a DISCOVERY infrastructure as simply as they are used to launch processes on a local machine, i.e. without the burden of dealing with resources availability or location.

In addition to consider *Locality* as a primary concern, the novelty of the LUC OS proposal is a new way of designing systems to operate UC resources. Unlike existing research on distributed operating systems that consider processes as the basic object they manipulate, a LUC OS will manipulate VMs throughout a federation of widely distributed physical machines. Virtualization technologies abstract hardware heterogeneity, and allow transparent deployment, preemption, and migration of VEs.

By dramatically increasing the flexibility of resource management, virtualization allows to leverage state-of-the-art results from other distributed systems areas such as autonomous and decentralized-based techniques.

2.2 Scientific/Technical Challenges

Similarly to traditional operating systems (OSes), a LUC OS will be composed of a significant number of mechanisms. Trying to identify all of them and establishing how they interact is an on-going work that will be finalized during the first months of the project. However, in order to reach the goal of delivering a unified system in charge of operating a complex and diverse infrastructure into a LUC platform, we have already identified that the following objectives should be considered when designing a LUC OS:

- Scalability: a LUC OS must be able to manage hundreds of thousands of virtual machines (VMs) running on thousands of geographically distributed computing resources, including small and medium-sized computing facilities as well as any idle resource that their owner would make available. These resources might be highly volatile, especially if the LUC infrastructure allows to include resources hosted by end-users.

- Reactivity: To deal with the infrastructure's dynamicity, a LUC OS should swiftly handle events that require performing particular operations, either on virtual or on physical resources, with the objective of maximizing the system utilization while meeting QoS expectations of VEs. Reconfiguring VEs over distributed resources, sometimes spread across wide area networks, or moving VMs, while preserving their active connections, are examples of operations that should be performed as fast as possible.

- Resiliency: In addition to the inherent dynamicity of the infrastructure, failures and faults should be considered as the norm rather than the exception at such a scale. The goal is therefore to transparently leverage the underlying infrastructure redundancy to (i) allow the LUC OS to continue working despite node failures and network disconnections and (ii) to provide snapshotting as well as high availability mechanisms for VEs.

- Sustainability: Although the LUC approach natively reduces the energy footprint of UC services by minimizing the network impact, it is important to go one step further by considering energy aspects at each level of a LUC OS system and propose advanced mechanisms in charge of making an optimal usage of each source of energy. To achieve such an objective, data related to the energy consumption of the VEs and the computing resources as well as the environmental conditions (computer room air conditioning unit, localization of the site, etc.) should be taken into account by the system.

- Security and Privacy: Similarly to resiliency, security affects the LUC OS itself and the VEs running on it. For the LUC OS security, the goals are to (i) avoid attacks on the P2P layers, (ii) create trust relationships between different locations, (iii) include security decision and enforcement points in the LUC OS and (iv) make them collaborate to provide a secured infrastructure. For the VEs security, we need to provide users with a way to express their security requirements. The LUC OS security decision and enforcement points will collaborate to enforce these requirements.

In addition to the aforementioned objectives, targeting a distributed system where VM is the elementary granularity requires to deal with important issues regarding the management of the VM images. Managing VM images in a distributed way across a WAN is a real challenge that will require to adapt state-of-the-art techniques such as replication and deduplication. Also, several mechanisms of a LUC OS must take into account VM images' location, for instance to allocate the right resources to a VE or to request VM images prefetching to improve deployment performance or VM relocations.

Amongst the numerous scientific and technical challenges that should be addressed, the lack of a global view of the system introduces a lot of complexity. In order to tackle it while addressing the above-mentioned challenges, we claim that internal mechanisms of a LUC OS should be based on decentralized mechanisms specifically designed for it. These techniques should provide mechanisms which are fully decentralized and autonomous, so to allow self-adapting control and monitoring of complex large-scale systems. Simple locality-based actions by each of the entities composing the system can lead to the global emergence of complex and sophisticated behaviors, such as the self-optimization of resource allocation, or the creation of decentralized directories. These techniques are starting to be used in well-known large systems. As an example, the Amazon website relies on its Dynamo service [DHJ+07], based on fully-decentralized mechanisms, to create massive scale distributed indexes and recover from data inconsistencies. Facebook's Cassandra massive scale structured store [LM10] also leverages P2P techniques for its core operation. In a LUC OS, decentralized and self-organizing overlays will enable to reflect the current state of both virtual and physical resources, their characteristics and availabilities. Such information is mandatory to build higher mechanisms ensuring the correct execution of VEs throughout the whole infrastructure.

2.3   Background

Several generations of UC infrastructures have been proposed and still co-exist [FK11]. However, neither Desktop, nor Grid, nor Cloud Computing platforms provide a satisfying UC model. Contrary to the current trend that promotes large offshore centralized DCs as the UC platform of choice, we claim that the only way to achieve sustainable and highly efficient UC services is to target a new infrastructure that better matches the Internet structure. Because it aims at gathering an unprecedented amount of widely distributed computing resources into a single platform providing UC services close to the end-users, a LUC infrastructure is fundamentally different from existing ones. Keeping in mind the aforementioned objectives, recycling UC resource management solutions developed in the past is doomed to failure.

As previously mentioned, our vision significantly differs from hybrid Cloud Computing solutions. Although these research activities address important concerns related to the use of federated cloud platforms such as the standardization of the interfaces for supporting cooperation and resource sharing over Cloud federations, their propositions are incremental improvements of the existing UC models. From our point of view, hybrid and cloud federation investigations are comparable in some ways to previous works that have been done for Grids and where, the purpose of the Grid middleware is to interact with each resource management system composing the Grid [BRC10, RBL+09, ZYT+12]. By taking into account network issues in addition to traditional computing and storage concerns in Cloud Computing systems, the European SAIL project[3] is probably the one which targets the biggest advances in comparison with previous works on Grid systems. Concretely, this project investigates new network technologies in order to provide end-users of hybrid/federated Clouds with the possibility to configure and virtually operate the network backbone that interconnects the different sites they use [MSS+12]. More recently, the *Fog Computing* concept has been proposed as a promising solution to applications and services that cannot be put into the cloud due to locality issues (mainly latency and mobility concerns) [BMZA12]. Although it might look similar to our vision as they propose to extend the Cloud Computing paradigm to the edge of the network, *Fog Computing* does not target a unified system but rather proposes to add a third party layer (*i.e.* the

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[3]http://www.sail-project.eu

Fog) between cloud vendors and end-users. In our vision, UC resources (*i.e.* Cloud Computing ones) should be repacked in the different network hub of backbones and operated through a unified system, *i.e.* the LUC OS. As far as we know, the only system that investigated whether a widely distributed infrastructure can be operated by a single system, was the XtreemOS Project [Mor07]. Although this project was sharing some of the goals of the LUC OS, it did not investigate how the geographical distribution of resources can be leveraged to deliver more efficient and sustainable UC infrastructures.

To sum up, we argue for the design and the implementation of a distributed OS, manipulating VEs instead of processes and considering locality as a primary concern. Referred as a LUC Operating System, such a system will include most of the mechanisms that are common to actual UC management systems [clo, nim, opea, opeb, Low11, MVML12]. However, each of them will have to be rethought in order to leverage P2P algorithms. While largely unexplored for building operating systems, P2P/decentralized-based techniques have the potential to achieve the scalability required for LUC systems. Using all these technologies for establishing the foundation mechanisms of massive-scale distributed operating systems will be a major breakthrough from current static, centralized or hierarchical management solutions.

3 Work Program

3.1 A Mutli-Agent Peer to Peer System

The DISCOVERY system will rely on a multi-agent peer-to-peer system deployed on each physical resource composing the LUC infrastructure. Agents are autonomous entities that collaborate to efficiently use the LUC resources. In our context, efficiency means that a good trade-off is found between satisfying user's expectations, ensuring reliability, reactiveness as well as availability of the services while limiting the energy consumption of the system and providing scalability. We propose thus to leverage P2P techniques, that allow self-* properties, such as self-adaptation and self-repairing of overlays. To reduce the management complexity as well as the design and the implementation of the different mechanisms that are mandatory, we strongly support to use micro-kernel concepts. Such an approach should enable to design and implement services at higher level while leveraging P2P mechanisms at the lower ones. Furthermore, to address the different objectives and reduce the management complexity, we also underline that self-* properties should be present at every level of the system. We think that relying on a multi-agent peer-to-peer system is the best solution to cope with the scale as well as the network disconnections that may create temporary partitions in a LUC platform.

In DISCOVERY, each agent has two purposes: (i) maintaining knowledge based on the LUC platform composition (ii) ensuring the correct execution of the VEs. Concretely, the knowledge base will consist of overlays that will be used for the autonomous management of the VEs life cycle. This includes the configuration, deployment and monitoring of VEs as well as the dynamic allocation or relocation of VMs to adapt to changes in VEs requirements and physical resources availability.

3.2 Work Packages

Designing and implementing the DISCOVERY system will require a clear organization of the work as there are strong dependencies between the different mechanisms of the system. To avoid any fruitless development and to ensure the maximal usability of the work achieved within the project, we propose to build the system by successive steps following a bottom-up approach driven by five scientific/technical work packages:

- Mechanisms related to physical resource localization and monitoring,

- Mechanisms related to VEs management,

- Mechanisms related to the VM images management,

- Mechanisms related to reliability,

- Mechanisms related to security and privacy.

To prevent any deviation and limit the problems that might occur if a specific element of the work plan should fail to deliver its promises, we will leverage an additional work package dedicated to the design of the

architecture, its integration and the API that will be exposed to the applications so that they can benefit from the LUC infrastructure.

The purpose of this organization is to group similar concerns together. First, it clearly states the contact point for each expertise area, in order to improve interactions within the project. Second, it will allow to address each WP in an independent way once the basic architecture of the whole system and the different APIs will have been defined. However, due to the strong dependencies between WPs and in order to limit the problems that might occur if a specific element of the work plan should fail to deliver its promises, the design of the DISCOVERY system will not be a linear process. Instead, it will include several iterations between WP1 and the other ones, to evolve from a basic solution to a complete one. Figure 2 shows this organization.
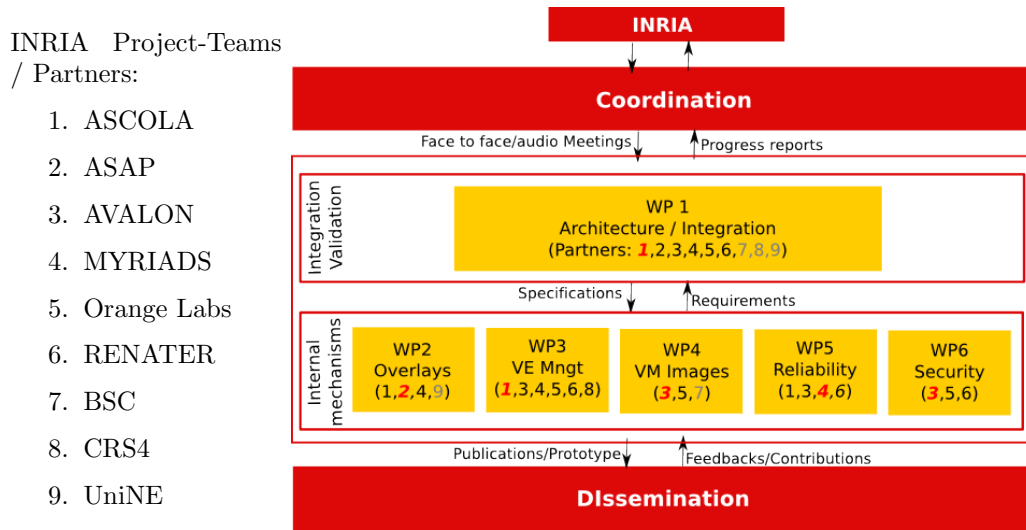
INRIA Project-Teams / Partners:

1. ASCOLA
2. ASAP
3. AVALON
4. MYRIADS
5. Orange Labs
6. RENATER
7. BSC
8. CRS4
9. UniNE

Figure 2: Work Package Organization
(Number in bold denotes the team in charge of leading the WP while number in gray refers to an external partner)

3.3 Consortium as a Whole

The DISCOVERY consortium is composed of 4 INRIA Project-Teams from two INRIA centers (Rennes Bretagne Atlantique and Rhône-Alpes) and two external partners that are in charge of operating large network backbones (Orange Labs and RENATER). In addition to this core consortium, three european partners will punctually take part to some working sessions as they have been taking part to the preliminary investigations of the DISCOVERY system. This geographic pluralism coupled with the privileged relationships the participants in the project enjoy with the different communities guarantee a wide dissemination of the DISCOVERY results.

From the scientific point of view, the consortium gathers the expertise of well-recognized research groups dealing for several years with Cluster/Grid/Cloud and P2P Computing challenges as well as the potentials of young researchers who have clearly demonstrated their ability in their respective areas (virtualization, large-scale systems, security and energy).

In Table 1, we summarize the complementary expertise of participants and we point out that the consortium has the complete knowledge necessary to reach the objectives of DISCOVERY project. This association of strong research groups and major network partners assures prime scientific results to the DISCOVERY project while securing a wide possible exploitation impact.

Finally, it is worth nothing that most of the members are used to collaborate directly around formal or informal collaborations. A co-supervision of a PhD between ASCOLA and AVALON has been started in October 2012, it aims at defining the foundations of the DISCOVERY system. Another PhD co-supervision between MYRIADS and ASCOLA about energy concerns in data-centers will be started next October in the context of the COMinLab LABEX project. The ASAP and MYRIADS teams explore the interest of new programming paradigm and P2P technics to address large scale concerns since 2010, these collaborations have lead to several publications. From the industrial point of view, ASCOLA and Orange Labs have been collaborating for several years around the ANR projects Selfware, SelfXL and more recently the OpenCloudware FSN project. Regarding

Partners \ Expertise	Software Engineering	Virtualization Technology	Data Management	Distributed Algorithms	Network Management	Security	Reliability	Energy
ASAP			S	P			S	
ASCOLA	P	P	S	S		S		S
AVALON	S	P	S	S		P		S
MYRIADS		P		S			P	P
ORANGE R&D		S	P	S	P	P		S
RENATER					P	S	S	
BSC			P					S
CSR4	P	S			S			
UNINE				P				

Legend: Red = Primary expertise (P), Yellow = Secondary expertise (S)

Table 1: Participant/Research Group Expertise

RENATER, several members of the consortium are used to interact with the main technical leaders through the Grid'5000 project. At the European level, ASCOLA and BSC have been taking part the European Marie Curie Initial Training Network SCALUS, SCALing by means of Ubiquitous Storage since 2009. In (Lèbre, et al. March 2011), ASCOLA with CRS4 conducted a prospective study that sketch out the premises of the current DISCOVERY proposal. Figure 3 shows the existing collaborations and the ones that will result from the DISCOVERY initiative. All these fruitful collaborations are excellent indicators for the successfully achievement of the DISCOVERY project.
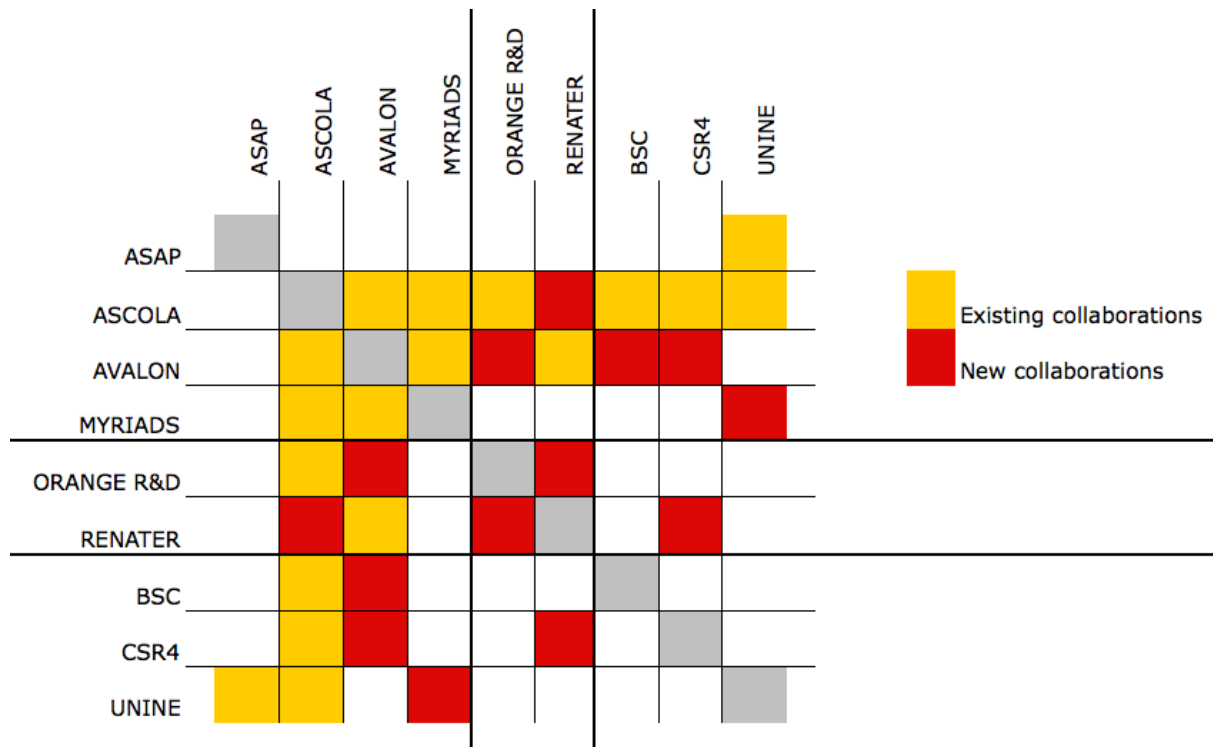
Figure 3: Existing and future collaborations between the teams.

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