Abstract. FEDERICA is a European project started in January 2008 that created a scalable, Europe-wide, clean slate, infrastructure to support experiments on Future Internet. The key architectural principle is virtualization both in computer systems and in network equipment and circuits. The project “slices” its substrate to offer “virtual infrastructures” (slices) made of computing elements and network resources to researchers. The user may fully configure the resources, including the slice topology. The slices can be seen as “cloud infrastructures”, generalizing the concept of “cloud computing” and enhancing that of “Infrastructure as a Service”. A section elaborates on the main open issues: reproducibility, resource description, monitoring and mapping of virtual resources to the physical substrate.

Keywords: NREN, virtualization, Future Internet, FIRE, GEANT.

1 Introduction

The FEDERICA project [1] has been devised to provide support and research on current and Future Internet technologies and architectures. The project is linked to the European FIRE initiative [2] and the European Future Internet Assembly [3]. Other similar initiatives exist worldwide, e.g. GENI [4] in the United States, in Europe and AKARI [5] in Japan.

Such experimentation requires new environments that combine flexibility, a minimum set of constraint and full control of the environment for the researchers. A clean-slate approach has been advocated by the GENI, which initially planned to build a dedicated, new infrastructure.

The constant developments of technology in computing and in networks, coupled with the virtualization capabilities allow a new approach, which leverage existing infrastructures to create new ones. FEDERICA is built on top of the National Research and Education Networks (NREN [6]) in Europe, which in the last years created a strong multidomain hybrid network infrastructure with advanced capabilities. Virtualization technologies allow creating on this large physical footprint more than one infrastructure and each of them appearing independent and isolated, eventually to the wavelength level.
The project adds to the basic network resource (capacity) and network functionalities (e.g. switching, routing) computing elements to create virtual infrastructures with rich functionalities.

The paper describes the project architecture, its implementation and the challenges posed with particular emphasis to “cloud computing” developments.

2 The FEDERICA Project

The project [1] partners include a wide range of stakeholders on network research, European National Research and Education Networks (NRENs), DANTE, TERENA, academic and industrial research groups and vendors. In the following the architecture will be described as well as its current implementation.

2.1 Project Goals and Objectives

The FEDERICA project scope, as defined in the description of work, is to:
- Create an e-Infrastructure for researchers on Future Internet allowing researchers a complete control of set of resources in a “slice”, enabling disruptive experiments
- Support research in virtualization of e-Infrastructures integrating network resources and nodes capable of virtualization (V-Nodes). In particular on multi-(virtual)-domain control, management and monitoring, including virtualization services and user oriented control in a federated environment.
- Facilitate technical discussions amongst specialists, in particular arising from experimental results and disseminating knowledge and NREN experience of meeting users’ requirements.
- Contribute with real test cases and results to standardization bodies, e.g. IETF, ITU-T, OIF, IPsphere.

2.2 Architecture

2.2.1 Requirements

As the scope is focused on a research environment on new technologies, the following set of requirements for the infrastructure have been assumed:
- Be technology agnostic and neutral (transparent) to allow disruptive and novel testing, as to not impose constraints to researchers. The requirement is valid for all networking layers, not just the application layer and extends to the operating system used.
- Ensure reproducibility of the experiments, i.e. given the same initial conditions, the results of an experiment are the same. This requirement is considered of particular importance.
- Provide to the user complete control and configuration capabilities within the assigned resources
- Allow more than one user group to run experiments at the same time, without interference.
- Open to interconnect / federate with other e-Infrastructures and Internet. This last requirement plans for interoperability and migration testing.

2.2.2 Framework and Design.

The requirements suggest two key framework choices for the infrastructure, which are at the core of design:
- The simultaneous presence of computing and network physical resources. These resources form the substrate of the infrastructure.
- The use of virtualization technologies applied both to computing and network resources. Virtualization will allow creating virtual, un-configured resources.

Virtualization is defined as the capability to create a virtual version of a physical resource, both in the computing and network environment. The virtual resources (e.g. a virtual circuit, a disk partition, a virtual computer) are usually created by segmenting a physical resource. Virtualization may create un-configured (clean) virtual resources, e.g. an image of the hardware of a computing element on which (almost) any operating system can be installed, a point-to-point network circuit, a portion of disk space. Those resources can be then tailored to various needs and even moved from a virtualization-aware platform to another.

Such framework brings to a design in which the infrastructure is considered made of two in two distinct levels (see Fig. 1 for a pictorial representation):
1. The virtualization substrate. The physical infrastructure which contains all the hardware and software capable to create the virtual resources;
2. The level containing all virtual infrastructures. Each containing the virtual resources and the initial network topology connecting them.

The virtualization substrate is a single administrative domain. The virtual infrastructures (VI or “slices”) may be in principle unlimited, in practice a large number, restricted by the physical resources available and the requested characteristics for the slice.

Two basic resource entities are defined:
1. Connectivity. In form of a point to point circuit with or without assured capacity guarantees and with or without a data link protocol (a “bit pipe”)
2. A computing element, offering the equivalent of a computer hardware containing at least RAM, CPU and one network interface, mass storage is optional, although usually available. The computing element is capable of hosting various operating systems and also perform functionalities (e.g. routing)

To minimize the load on the physical resources and the interference between virtual resources, the network topology has a high level of meshing. Where virtualization is not available in hardware, as on most of network interfaces for computers, more hardware is installed. As a design principle, the infrastructure would favour testing of functionalities, protocols and new ideas, rather than providing a laboratory for very high performance studies.
Following the framework outlined above, FEDERICA is designed in two layers. The lower layer is the substrate and it’s made of physical resources, both network and computing elements, each capable of creating “virtual” resources of their kind. The resource sets, or slices, managed by the user, compose the upper layer.

Given the sophisticated NREN network architecture, a distributed infrastructure can be engineered, with various Points of Presence on the top of the GÉANT [7] backbone, interconnecting several NRENs in Europe. Figure 1 depicts pictorially the design of the infrastructure built on top of the existing NREN and GÉANT production environment. The virtual infrastructures (slices) are shown on the top of the picture. More than one slice is active at the same time.

![Figure 1: Pictorial representation of FEDERICA](image)

The figure represents the slice in vertical format for sake of clarity and to show that there is no dependency or hierarchy between them. Each slice may contain a virtual resource coming from any part of the substrate. The same physical node, as an example, can provide virtual systems to more than one slice. A virtual router can be created in a Juniper node (ensuring complete independence between the virtual routers) or by a virtual system running the routing suite.

### 3 The Infrastructure Implementation

The infrastructure is built using:

- A mesh of one Gigabit Ethernet circuits provided by the GEANT2 backbone. The circuits are initially at one Gbps as this capacity allows slicing to still high-speed links and it is still affordable as contribution by the participating NRENs. Most of the circuits are created over SDH using generic framing procedure and virtual concatenation. Fig. 2 represent the current topology.

- Network equipment. Programmable high-end routers/switches: Juniper Networks MX480 with dual CPU and 1 line card with 32 ports at 1Gb Ethernet.
The MC functionalities include virtual and logical routing, MPLS, VLANs, IPv4, IPv6. The MX 480 are installed in four core Points of Presence and 2 MX480 are equipped with Ethernet line cards with hardware QoS capabilities. Smaller multi-protocol switches (Juniper EX series) are installed in non-core PoPs.

- Computing equipment. PC-based nodes (V-Nodes) running virtualization software, capable of implementing e.g., open source software routers and emulating end-user nodes. Each PC contains 2 x Quad core AMD running at 2 GHz, 32GB RAM, 8 network interfaces, 2x500GB disks. The V-Nodes are connected to the Juniper routers.

The initial choice of the virtualization software for the V-Nodes is VMware [8], the free version of ESXi. This choice has been done after a review of other virtualization software (e.g. XEN). In particular it has been evaluated the Application Programming Interface, the availability of usage examples and expertise and an upgrade path to better management using not-for-free version of the software. The capabilities and performance of the free version have been adequate for the current requirements.

These building blocks of the substrate pose very few constraints to the user. In the current status of the infrastructure the most significant one is that the data link layer is fixed to Ethernet framing. Future development of FEDERICA may permit access to optical equipment to overcome this limitation.

2.3.1 Topology
The topology is composed of 13 physical sites. Of these points of presence (PoP) a full mesh of four is equipped with MX router/switches and it is considered the core. The 9 non-core nodes are equipped by EX switches. The core nodes are equipped by 2 V-Nodes the non-core PoPs host one node each. The FEDERICA physical topology is depicted in Figure 2.

The design placed particular importance on the resiliency and load balancing of the network, based on GEANT2’s infrastructure, and resources availability at partners’ locations.
The FEDERICA substrate is configured as an IPv4 and IPv6 Autonomous System with both public and private addresses. The infrastructure is connected to Internet using the Border Gateway Protocol and receives full routing tables in the four core PoPs.

The infrastructure is centrally managed and monitored by a Network Operation Centre. The NOC has also the task to create the slices. The infrastructure (substrate) is a single domain that contains all the physical resources (point to point circuits, nodes) in all PoPs. The domain does not contain the optical equipment of GÉANT used to transport the circuits between PoPs.

### 2.3.2 Resource Virtualization and Slice Creation

The process to create a virtual system is rather straightforward and can be based on an image provided by the user or on template of various operating systems. The virtualization capabilities in the network are also evolving, as described in [9]. The article reviews the current research in a Network Virtualization Environment (NVE) and the many challenges associated. The initial choice in FEDERICA is to use VLANs and use QoS techniques for circuit virtualization; MPLS may be applied when needed.

The slice creation procedure definition is constantly developed and may change slightly to incorporate the feedback received after the first user feedback. The slice creation includes a manual step to map the virtual resources to the physical substrate. The step is manual to ensure that the mapping ensures the best reproducibility of the behaviour of the virtual resources.

The current slice creation process consists of the following steps. First, the researcher that wants to perform an experiment over the FEDERICA infrastructure is required to provide the NOC with the desired topology, including requirements for the nodes and the network (each V-node RAM size, CPU power, mass storage space, topology and bandwidth between the V-Nodes, routing or switching functionalities, protocols). The request may be for un-configured resources, that the user will configure directly, even substituting protocols, or resources with a n initial configuration, e.g. IP routing.

Once the NOC receives the slice description and resource requirements, the NOC maps the logical topology requested on the physical topology of the substrate and chooses the sites (PoPs) from which physical resources will be allocated. Besides instantiating all the resources requested by the user, the NOC needs to instantiate an extra virtual machine, that act as a gateway between Internet and the slice: the Slice Management Server. Access control of the Slice Management Server is performed by means of identity credentials managed by a RADIUS server.

The next step for the NOC is to instantiate Ethernet VLANs to connect the slice resources and create the topology required by the researcher. Finally, the NOC needs to setup the Slice Management network for the user that will connect the Slice Management Server to the management interface of each one of the managed resources in the slice (V-Nodes, logical routers, software routers). The connection is performed creating virtual interfaces in all resources and one in the Management Server in the same IP subnet (usually private) and creating an additional VLAN.
linking them. This subnet is initially the only IP path for the user to connect to the slice resources when accessing from Internet the Management server.

### 2.3.3 User Access And Support

When the NOC has finished the slice creation process, they inform the researchers that the slice is ready to use. The following information needs to be included: the public IP address of the Virtual Slice Management Server plus the credentials to access it, the credentials for accessing the Juniper logical routers and/or the software routers, and finally the IP addressing scheme of the Virtual Slice Management Network. Now the user is ready to access his slice through the Virtual Slice Management Server.

![Diagram](Image)

**Fig. 3:** Researcher accessing a simple FEDERICA slice

In the example in Figure 3 the user has requested a simple slice consisting of two virtual servers connected through a Juniper logical router. The NOC has already setup these three resources, connected them through a VLAN (black line at the bottom of the Figure), instantiated the Virtual Slice Management Server and created the Slice Management Network (cloud at the centre of the Figure). The researcher connects to the Virtual Slice Management Server using the credentials provided by the NOC, and is authenticated against the FEDERICA Authentication RADIUS Server. If the authentication is successful, the user can access all his/her nodes via the management IP interfaces.

Besides remote access to the resources, another complimentary mechanism is under investigation. VMware virtual machines can be configured to be accessed
through remote VNC connections (the virtual machine clients would connect to a special port of the physical machine where VMware is installed). By exploiting this mechanism users would have access to the console of their virtual servers, but they would also be able to interact with graphical user interfaces and to even access the BIOS of the server; i.e. they would have full control of the virtual machine.

During the initial FEDERICA operation, all the steps explained in these two sections will be performed either manually or using a heterogeneous set of tools (web portal for users, VMware Infrastructures application, the remote console of the devices, VNC clients, monitoring tools). However, a tool bench that provides a unified environment to operate the FEDERICA infrastructure and use the FEDERICA slices is being developed, and will be progressively deployed and used by the NOC and the FEDERICA users.

3. Challenges

3.1 Real vs. Virtual

The reproducibility and the stability of the behaviour of the virtual resources is a fundamental requirement for quantitative evaluations of new ideas. As an example, a virtual circuit may not be capable of offering a constant, fixed amount of bit per second, and a virtual computer image may not provide a constant CPU usage.

The quality of a virtual resource can then be defined as a function of the difference between the behaviour of the virtual and the physical resource. The difference is due to two main independent causes:
- Sharing of the physical resource with other virtual resources
- The virtualization technology itself, usually a layer placed between the physical resources and the virtual ones

Hardware assistance for virtualization has been introduced recently to reduce such a difference. Since 2005 the main CPU manufacturers have added virtualization-friendly extensions, in particular related to protection rings.

QoS is considered in both resource types: connectivity and computing element.

Computing elements in FEDERICA have been chosen to provide specific functionalities in hardware, like virtualization-aware CPUs. Some circuits are connected to Quality of Service capable line cards in the Juniper MX. In other cases, where hardware was not available, the resources have been adequately increased, to avoid any overbooking and minimize contention. It is possible then to create a slice with a set of resources, which exhibits, singularly, a known behaviour in all conditions.

Virtual resource performance measurements are ongoing in FEDERICA.

Assuring the QoS of a set of connected resources is more complex and under evaluation. While for a single virtual computer or link it is possible to carefully configure its performance, the complexity increases with the number of resources involved. The classic problem of guaranteeing an end-to-end quality of service of an
IP flow exemplifies the issue. In case of virtual infrastructures, as in the case of Internet traffic, probably most of the resources do not require strict guarantees, but rather "best effort" behaviour.

In the particular case of a geographically distributed set of resources, the resource synchronization is more complex due to the longer delay, making the issue harder to solve.

3.2 Virtualization service definition and automation of procedures

A service to create “virtual infrastructures” (i.e. slices) needs more dynamic and automated procedures. Such a service opens the possibility to federate with other infrastructures and to develop new business models with the user virtual infrastructure extending in many domains. To achieve these goals a standardisation of resource description is required. The design of FEDERICA identified two basic entities (computer and point-to-point circuit) each with a set of characteristics and a set of relationship between them.

The most complex step in automating the service is the definition of the logic and the rules to map virtual resources to physical resources in such a way that the use of the substrate is fair and that the resources comply with a service level agreement, when requested.

3.3 Complexity

The complexity of the systems based on virtualization, in particular when coupling network and computing resources, increases fast with the increase of number of resources. The complexity may actually reduce the reliability and the quality of the system, increasing its operational cost for management and problem resolution.

It is worth underling that virtualization is not restricted to a single layer, but allows recursivity. Multiple virtual networks stacked on the same physical infrastructure may be recursively created, as an example. Such advances require better ad-hoc support in the hardware and the development of new standards for virtual resource interaction. In particular the need is for a more rich information system, which tracks the relationships between entities (virtual or real).

4. Conclusions And Next Steps

An infrastructure substrate based on virtualization both on computing and network resources is a novel approach to provide an ideal environment for innovative research and services. The substrate can create virtual infrastructures containing any combination of the basic, “raw” fundamental virtual resources in arbitrary topologies and hosting any operating system and application type. Such virtual infrastructures are decoupled from their physical location, albeit exhibiting the requested functionalities, appearing as “cloud infrastructures".
The initial experience of the FEDERICA project with its users is that:

- There are very few constraints, except the amount of physical resources available in the substrate when reproducibility is requested.
- It’s possible to easily interconnect the slices with the current Internet. Two “cloud infrastructures” can be connect through Internet to validate the behaviour of application in real-life environment;
- A slice may allow the user to fully control and configure almost all communication and computing layers;
- A “Cloud Infrastructure” can be reconfigured in a very short time, even manually. Resources can be added, subtracted or restarted also in a short time.
- The presence of computing capabilities in the infrastructure enables new usage models and service. In particular increases resiliency, as functionalities and even whole “infrastructures” may move in the substrate continuing to work.

The main challenges are related to the reproducibility of the behaviour of the virtual resources and to the complexity of the overall system, in particular the substrate. The current size of FEDERICA is still well manageable and does not present issues. Management and control of distributed, parallel, virtual infrastructures, which may communicate among them and with the open Internet, are also key functions in the next generation networks. The FEDERICA project will continue to develop experience and draft a model for managing and using virtual infrastructures as a combination of networks and systems.

5. Acknowledgments

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6 References

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