GEYSERS: A Novel Architecture for Virtualization and Co-Provisioning of Dynamic Optical Networks and IT Services

Eduard Escalona[1], Shuping Peng[1], Reza Nejabati[1], Dimitra Simeonidou[1], Joan A. Garcia-Espin[2], Jordi Ferrer[2], Sergi Figuerola[2], Giada Landi[3], Nicola Ciulli[3], Javier Jimenez[4], Bartosz Belter[5], Yuri Demchenko[6], Cees de Laat[6], Xiaomin Chen[7], Admela Yukan[7], Sebastien Soudan[8], Pascale Vicat-Blanc[8], Jens Buysse[9], Marc De Leenheer[9], Chris Develder[9], Anna Tzanakaki[10], Philip Robinson[11], Marc Brogle[11], T. Michael Bohnert[11]

[1]*University of Essex, United Kingdom*
[2]*i2CAT Foundation, Spain*
[3]*Nextworks, Italy*
[4]*Telefónica I+D, Spain*
[5]*Poznan Supercomputing and Networking Center, Poland*
[6]*University of Amsterdam, Netherlands*
[7]*Technical University of Braunschweig, Germany*
[8]*Lyatiss, France*
[9]*Interdisciplinary Institute for Broadband Technology, Belgium*
[10]*Athens Information Technology, Greece*
[11]*SAP, Switzerland*

Abstract: GEYSERS aims at defining an end-to-end network architecture that offers a novel planning, provisioning and operational framework for optical network and IT infrastructure providers and operators. In this framework, physical infrastructure resources (network and IT) are dynamically partitioned to virtual resources and then composed into a Virtual Infrastructure offered to operators as a service. The operator will be able to operate a virtual infrastructure with an enhanced Network Control Plane (NCP) able to offer coupled, optimized and dynamic on-demand Network and IT provisioning services (i.e., interconnections between multiple IT resources and end-users).The scope and novelty of the GEYSERS architecture is focused on the functional definition and description of two innovative layers, the enhanced Network Control Plane (NCP) and the Logical Infrastructure Composition Layer (LICL). The Service Middleware Layer (SML) and the physical layer (PHY) are part of the overall GEYSERS architecture but are based on existing developments that will be appropriately adapted or extended.

Keywords: IaaS, Network Control Plane, Virtualization, IT + Network provisioning.

1. Introduction

The ubiquitous presence of the Internet is driving network and IT infrastructure management, characterized by global services and delivery over generic infrastructures. Future Networks are required to provide new solutions in support of the Future Internet and its new emerging applications as the scale of information is increasing [1], [2]. This is becoming even more important considering the current development and technical enhancement of photonic networks, dynamic control planes, multi core processing, cloud computing, data repositories, and energy efficiency, which are driving profound transformations of networks and users capabilities. These technological advances are motivating the emergence of high-performance and high-capacity network based applications with strict IT (e.g., computing and data repositories) resource requirements, which the current best-effort Internet intrinsically cannot deliver. As a result, today's telecom operators are facing an increasing need for providing users with dynamic high-capacity and high-performance optical network connectivity services tightly bundled with IT resources. To realize this kind of networked-IT infrastructure service, envisioned to facilitate Future Internet, a next generation network architecture must be deployed before the current Internet reaches its limits. This new generation network architecture must seamlessly integrate optical network technologies with IT resources, and provide customized infrastructure provisioning services to facilitate a smooth integration of optical network segments and technologies.

This paper reports on the GEYSERS project concept. It aims at defining and implementing a novel service provisioning architecture, capable of provisioning optical network and IT resources for end-to-end service delivery. The GEYSERS vision is based on abstracting and partitioning the optical network and IT infrastructure to create specific virtual infrastructures composed by virtual optical network and IT resources (i.e., computing and data repositories), overcoming the limitations of network and domain segmentation. Each virtual infrastructure will be controlled by an enhanced Network Control Plane capable of provisioning Optical Network Services bundled with IT resources in an on demand basis.

This novel vision is driven by the integrative nature of its architecture and a set of challenges which enforce the redefinition of the architecture of the Network of the Future and the services it provides such as scalability for high number of users, high bandwidth connectivity, security mechanisms, convergence of IT and network services, resources partitioning and virtualization, and automated and energy-efficient provisioning of network and IT resources. It will facilitate the emergence of new business models in the future telecom market, where current carrier roles can be split and extended into physical infrastructure providers and (overlay/customized) network operators. Thus, current carriers can also make profit from their infrastructure by carefully planning the allocation of resources to limit unused cycles or bandwidth, and minimizing the energy consumption by optimizing their resource usage and its efficiency.

The innovation that GEYSERS brings to these challenges is offered mainly by its novel layering architecture and the new business models that it facilitates.

2. GEYSERS Architecture

GEYSERS introduces a new architecture that re-qualifies the interworking of legacy planes by means of a virtual infrastructure representation layer for network and IT resources and its advanced resource provisioning mechanisms. The GEYSERS architecture presents an innovative structure by adopting the concepts of Infrastructure as a Service (IaaS) and service oriented networking to enable infrastructure operators to offer new network and IT converged services. On the one hand, the service-oriented paradigm and IaaS framework enable flexibility of infrastructure provisioning in terms of configuration, accessibility and availability for the user. On the other hand, the layer-based structure of the architecture enables separation of functional aspects of each of the entities involved in the converged service provisioning, from the service consumer to the physical ICT infrastructure.

Figure 1 shows the layering structure of the GEYSERS architecture reference model. Each layer is responsible to implement different functionalities covering the full end-to-end service delivery from the service layer to the physical substrate. Central to the GEYSERS architecture and focus of the project are the enhanced Network Control Plane (NCP), and the novel Logical Infrastructure Composition Layer (LICL). The Service Middleware Layer (SML) represents existing solutions for service management and at the lowest level there is the Physical Infrastructure layer that comprises optical network and IT resources from different Physical Infrastructure Providers. Each of these layers is further described below.

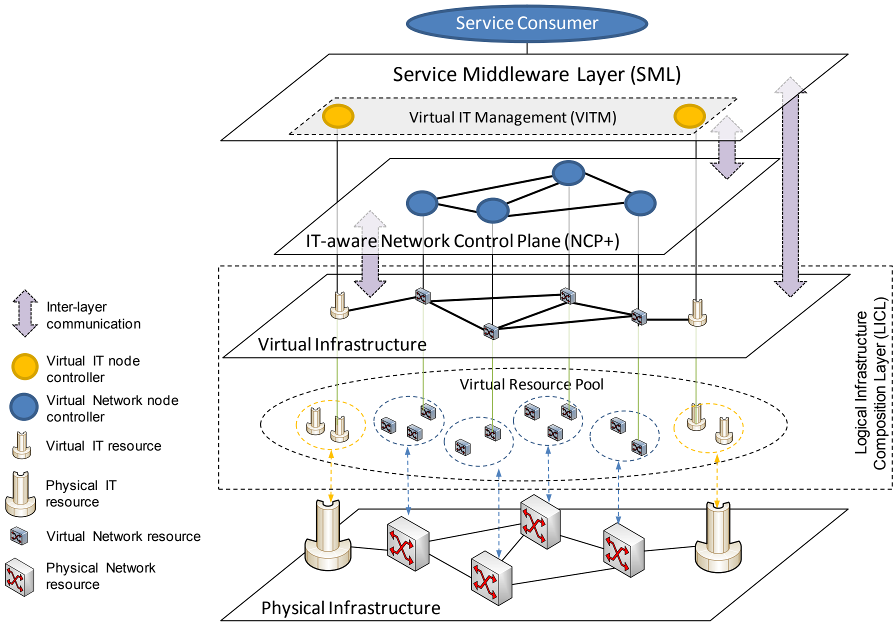

Figure 1: GEYSERS layered architecture

2.1 – Physical Infrastructure

The GEYSERS physical infrastructure is composed of optical network and IT resources. These resources may be owned by one or more physical infrastructure providers and can be virtualized by the LICL. The term infrastructure refers to all physical network resources (optical devices/physical links) used to provide connectivity across different geographical locations and the IT equipment providing storage space and/or computational power to the service consumer. From the network point of view GEYSERS will rely on the L1 optical network infrastructure. The GEYSERS architecture is expected to be generic enough to cover most of the technologies used in the existing optical backbone infrastructures offered by today's infrastructure providers/operators. Nevertheless, focus will be on Fiber Switch Capable (FSC) and Lambda Switch Capable (LSC) devices. From an IT point of view, IT resources are considered as service end-points to be connected to the edge of the network. IT resources are referred to physical IT infrastructures of IT such as computing and data repositories.

The physical infrastructure should provide interfaces to the equipment to allow its operation and management, including support for virtualization (when available), configuration and monitoring. Depending on the virtualization capabilities of the actual physical infrastructure, physical infrastructure providers may implement different mechanisms for the creation of a virtual infrastructure. In terms of optical network virtualization, GEYSERS considers optical node and optical link virtualization. Moreover, the virtualization methods include partitioning and aggregation.

- Optical node partitioning: It entails dividing an optical node into several independent virtual nodes with independent control interfaces by means of Software and Node OS guaranteeing isolation and stability.

- Optical node aggregation: It entails presenting an optical domain or several interconnected optical nodes (and the associated optical links) as one unified virtual optical switching node with a single/unified control interface by means of Software and Control/Signalling Protocols. The controller of the aggregated virtual node should manage the connections between the internal physical nodes and show the virtual node as a single entity.
- Optical link partitioning: It entails dividing an optical channel into smaller units. Optical fibres can be divided into wavelengths and wavelengths into sub-wavelength bandwidth portions that can be performed e.g. using advanced modulation techniques. The latter is a very challenging process especially when the data rate per wavelength is >100Gbps.
- Optical link aggregation: Several optical wavelengths can be aggregated into a super-wavelength with aggregated bandwidth ranging from wavelength-band, to fibre or even multi-fibre level.

After partitioning and aggregation, optical virtual nodes and links are included in a virtual resource pool used by the LICL to construct virtual infrastructures; thus, multiple virtual infrastructures can share the resources in the optical network. This means that isolation between the partitioned virtual resources has to be guaranteed at both data (physical isolation) and control level.

2.2 Logical Infrastructure Composition Layer (LICL)

The LICL is a key component in the GEYSERS architecture. It is located between the physical infrastructure and the upper layers, NCP and SML. The LICL is responsible for the creation and maintenance of virtual resources as well as virtual infrastructures. In the context of GEYSERS, infrastructure virtualisation is the creation of a virtual representation of a physical resource (e.g., optical network node or computing device), based on an abstract model that is often achieved by partitioning or aggregation. A virtual infrastructure is a set of virtual resources interconnected together that share a common administrative framework. Within a virtual infrastructure, virtual connectivity (virtual link) is defined as a connection between one port of a virtual network element to a port of another virtual network element.

The LICL utilizes a semantic resource description and information modelling mechanism for hiding the technological details of the underlying physical infrastructure layer from infrastructure operators. Consequently, the LICL acts as a middleware on top of the physical resources and offers a set of tools that enable IT and Optical Network resource abstraction and virtualization. Moreover, the LICL allows the creation of virtual infrastructures using the virtualized resources and a dynamic on-demand re-planning of the virtual infrastructure composition. The LICL manages the virtual resource pool where virtual resources are represented seamlessly and in an abstract fashion using a standard set of attributes, which allows the enhanced Control Plane to overcome device dependency and technology segmentation. The LICL also brings the innovation at the infrastructure level by partitioning the optical and IT resources belonging to one or multiple domains. Finally, LICL supports the dynamic and consistent monitoring of the physical layer and the association of the right security and access control policies. LICL mainly supports the following functionalities:

- Physical resource virtualization
- Semantic resource description and resource information modelling
- Physical/virtual resource synchronization and monitoring
- Virtual infrastructure composition and management
- Virtual infrastructure planning/re-planning

- Security handling

  The LICL requires privileged access to the physical infrastructure resources in order to implement isolation in an efficient manner. It also works as a middleware that forwards requests and operations from the NCP to the physical infrastructure native controllers. This is achieved by using a Virtual Infrastructure Management System (VIMS) that is a set of tools and mechanisms for control and management of its resources (Figure 2).

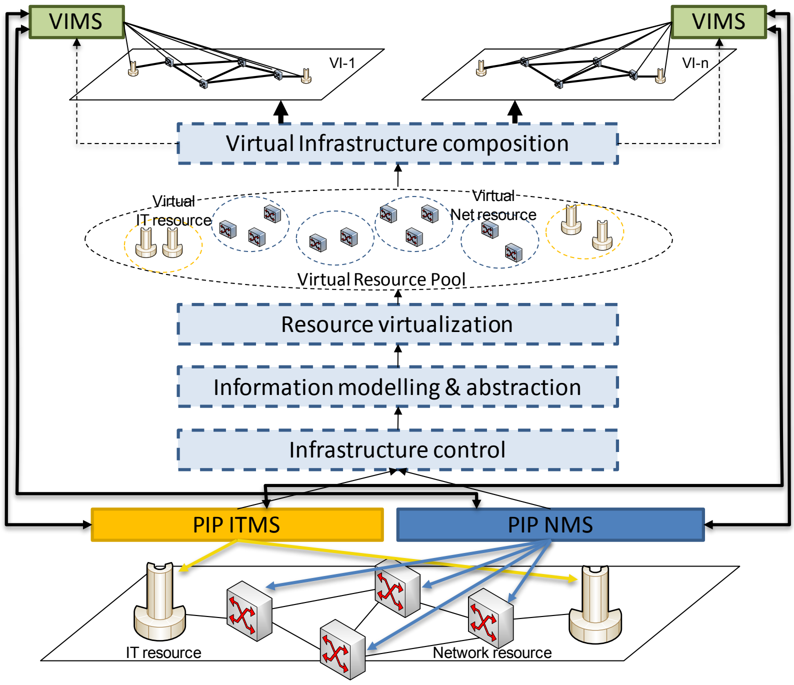

Figure 2: LICL basic functional decomposition

2.3 Network + IT Control Plane (NCP+)

The GEYSERS network and IT control plane (NCP+) operates over a virtual infrastructure, composed of virtual optical network and IT resources, located at the network edges. The virtual infrastructure is accessed and controlled through a set of interfaces provided by the LICL for operation and re-planning services. The NCP+ offers a set of functionalities towards the SML, in support of on-demand and coupled provisioning of the IT resources and the transport network connectivity associated to IT services.

The combined Network and IT Provisioning Service (NIPS) requires the cooperation between SML and NCP+ during the entire lifecycle of an IT service. This interaction is performed through a service-to-network interface, called NIPS UNI. Over the NIPS UNI, the NCP+ offers functionalities for setup, modification and tear-down of enhanced transport network services (optionally combined with advance reservations), monitoring and cross-layer recovery.

The GEYSERS architecture supports several models for the combined control of network and IT resources. The NCP+ can assist the SML in the selection of the IT resources providing network quotations for alternative pairs of IT end points (assisted unicast connections). Alternatively the NCP+ can select autonomously the best source and destination from a set of end points, explicitly declared by the SML and equivalent from an IT perspective (restricted anycast connections). In the most advanced scenario, the NCP+ is also able to localize several candidate IT resources based on the service description provided by the SML, and computes the most efficient end-to-end path including the selection of the IT end-points at the edges (full anycast connections). This is a key point for the optimization of the overall infrastructure utilization, also in terms of energy efficiency, since the IT and network resources configuration is globally coordinated at the NCP+ layer. The NCP+ is based on the ASON/GMPLS [3] and PCE [4] architectures, is enhanced with routing and signalling protocols extensions and constraints based route computation algorithms designed to support the NIPS and, on the other hand, to optimize the energy efficiency for the global service provisioning. Particularly the NCP layer implements mechanisms for advertisement of the energy consumption of network and IT elements as well as computation algorithms which are able to combine both network and IT parameters with energy consumption information to select the most suitable resources and find an end-to-end path consuming the minimum total energy. Figure 3 shows a high-level representation of the NCP+: the routing algorithms at the PCE operate over a topological graph created combining network and IT parameters with "green" parameters, retrieved from the SML (IT side) and the LICL (network side).

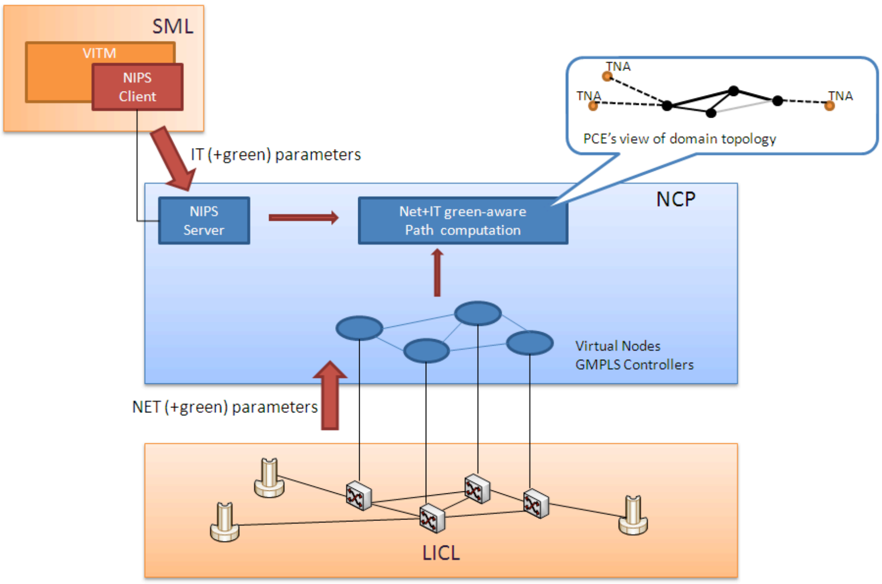

Figure 3: NCP – Network and IT energy-aware service provisioning

Finally, another key element for NCP+ is the interaction with the LICL in order to trigger the procedures for the virtual infrastructure dynamic re-planning on the network side. In case of inefficiency of the underlying infrastructure, the NCP+ requests the upgrade or downgrade of the virtual resources in order to automatically optimize the size of the virtual infrastructure. The involved algorithms take into account current network traffic, forecasts for resource availability and utilization in the medium and long terms, as well as specific SLAs established between provider and operator for dynamic modifications of the rented virtual resources.

2.4 Service Middleware Layer (SML)

The Service Middleware Layer (SML) is a convergence layer for coordinating the management of IT resources that belong to an aggregate service (AS). An AS is a collection of heterogeneous services from different providers used to deliver a single capability to a specific customer or a market segment. GEYSERS primarily focuses on the Infrastructure as a Service (IaaS) concept when referring to services that support specific applications. The SML is hence responsible for the following tasks from an application-level perspective, where applications are deployed by Service Consumers:

- Matching application requests to infrastructure resources as specified in Service Level Agreements (SLAs).

- Monitoring and maintaining a “landscape model” of the infrastructure and applications under the management of the SML instance. A landscape model is a specification of a collection of managed elements and their associations. These managed elements can include software, data-base instances, virtual machines and physical machines.
- Triggering the infrastructure provisioning process with application deployment or adaptation requests. These requests contain properties and constraints to be satisfied by resources.
- Accounting of resource usage on a customer or application basis.
- Authentication and authorization processes for access to virtual resources on a customer or application basis.

The SML exposes an interface to application providers and customers, such that the complexity of network and IT provisioning is transparent to them. Business objectives for a specific application scenario are declared to the SML and translated into provisioning requests understood by a Virtual IT Manager (VITM). The VITM is in charge of the end-to-end IT service management and the virtual IT resource configuration. The SML also maintains a registry of assets (local physical or virtual infrastructure), IT infrastructure providers and network providers. The registration entry for each of them includes the path to the respective control planes of these resources (VITM for IT and NCP for network). For example, the SML maintains entries of network providers, including information about the service access points of their respective NCP, such that networking resources can be reserved for the purpose of the application.

2.5 Service consumer or application

In the GEYSERS architecture the service consumer or application is the user of a virtual infrastructure. A virtual infrastructure can be offered to a single application or user (super user) or can be shared among several users or applications.

3. GEYSERS Service Delivery Framework

The GEYSERS Service Delivery Framework (SDF) includes two main services: Virtual Infrastructure (VI) provisioning and on-demand network + IT service provisioning (Figure 4). The former comprises the process of requesting and creating a VI, whilst the latter deals with the provisioning of the connectivity required between the different virtual IT elements involved in a specific application landscape. Both services are part of the whole GEYSERS lifecycle, which is comprised of five phases:

1) Service requests and SLA negotiation
2) Planning/design
3) Deployment/Configuration
4) Operation
5) Decommission

The functions in each phase vary concomitantly with specific VI provisioning cases, while the on-demand provisioning service takes place during the operation phase. As a general starting point in the GEYSERS lifecycle, one or more physical infrastructure providers expose their owned physical resources to enable its virtualization and subsequent leasing. The full set of virtualized resources constitute a virtual resource pool, from which VIs can be created during the planning/design phase according to negotiated SLAs. Once the VI is deployed, the enhanced NCP controllers are installed and configured. At this point, a virtual infrastructure operator is ready to serve on-demand provisioning requests during the operation phase. In contrast to the VI provisioning, the on-demand service provisioning is offered to the customers of the VI with the objective of providing a landscape for their applications. Finally, the decommissioning phase is triggered whenever a VI is no longer in operation; then the virtual resources are detached from the virtual infrastructure and become available again at the virtual resource pool.

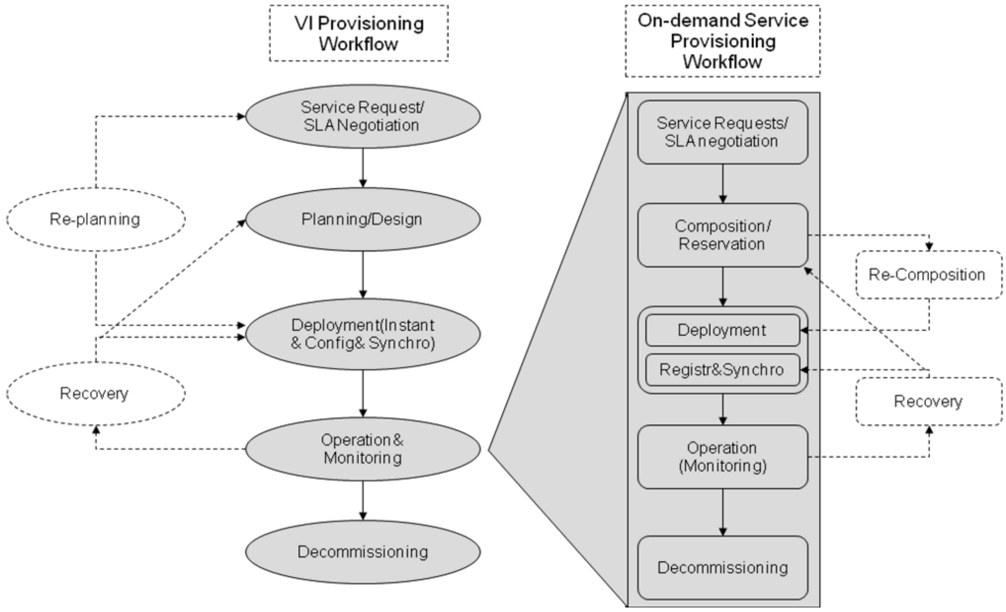

Figure 4: Workflow chart of GEYSERS lifecycle

4. Conclusions

The GEYSERS vision is to qualify optical infrastructure providers and network operators with a new architecture, to enhance their traditional business operations. GEYSERS enables the composition of virtual infrastructures and its control through the novel LICL and NCP layers. The LICL is able to perform the infrastructure virtualization by abstracting, partitioning and interconnecting physical infrastructure resources, while the NCP is able to run cost-efficient, dynamic and mission-specific networks supporting optical network and IT resource provisioning in a seamless and efficient way.

Acknowledgement

The work in this paper has been funded by the European Union through the project GEYSERS (FP7-ICT-248657).

References

[1] M. Handley, “ Why the Internet only just works”, BT Technology Journal, Vol. 24, Nr 3,July 2006
[2] B. Swanson, G. Gilder, “Estimating the Exaflood”, http://www.discovery.org/a/4428.
[3] ITU-T G.8080/Y.1304 Recommendations, “Architecture for the Automatic Switched Optical Network (ASON)”, 2001
[4] A. Farrel, J.P. Vasseur, J. Ash, “A Path Computation Element (PCE) – Based Architecture”, IETF RFC 4655, August 2006