Architectural Approaches for the Integration of Service Plane and Control Plane on Optical Networks

Invited Paper

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Abstract – This paper presents some instantiations of novel application-aware network architectures for emerging IT services and future Internet applications. It proposes and analyses network architectures where the Control and Service Planes are closely and seamlessly interacting with the applications. In one instantiation, the Grid-GMPLS (G^2MPLS, as defined by the PHOSPHORUS project) is presented, which implements Network Control Plane (NCP) architecture for the support of Grid Network Services (GNS). The GNS allows the provisioning of network and HPC/Grid resources in a single-step through a set of seamlessly integrated procedures. In a second example of instantiation, a quite popular application signalling, i.e. the Session Initiation Protocol (SIP), is integrated with Optical Burst Switched (OBS) network technology. The SIP-enabled OBS network can be used to manage application sessions and provide network and IT services according to the application requirements. This paper investigates on the requirements that these new integrated architectures poses on supporting network Control and Service Planes, and technologies, and discusses their possible implementations.

Keywords: Network Control Plane; Service Plane; Grid-GMPLS; SIP; OBS

I. INTRODUCTION

Future Internet services aim to integrate and manage resources and services according to application requirements within distributed, heterogeneous, dynamic environments. The realization of this goal requires the disintegration of numerous barriers that normally separate application services, IT resources (computing systems), underplaying network. One of the key issues towards the realization of an application aware network environment is to provide solutions on bridging application layer and geographically distributed IT resources and services (e.g. supercomputers, data centers, IPTV) with emerging and promising optical transport network technologies. The optimal use of these networks infrastructures often implies a close interoperation of the application, service and control planes, in order to support seamless and harmonized operations for discovering, reserving and allocating IT and network resources.

On one side, evolving Grid applications developed by collaborative, virtual communities, are a hallmark of 21st century e-science. Many of the applications have requirements of one or more of these constraints: determinism (guaranteed QoS), shared data spaces, large transfer of data, and latency requirements that are often achievable only through dedicated optical bandwidth (lambdas). The advent of optical networking will soon not only be able to carry vast amounts of data, but software tools and frameworks addressing end-to-end users and applications. It will provision-on-demand bandwidth in coordination with other resources, such as CPU and storage [1,2,3]. The development of such procedures requires the definition of a Network Control Plane (NCP) able to support connectivity services through the transport network for Grid end-points, signaling protocols used to invoke the Grid and network services, and auto-discovery procedures to aid signaling. All these procedures are required to facilitate on demand as well as in-advance Grid and network services.

In the IST Phosphorus project, the solution adopted for the implementation of this Grid-enabled NCP considers a Grid evolution of GMPLS protocols [4], namely Grid-GMPLS (G^{2}MPLS). G^{2}MPLS seamless procedures serve Grid jobs by co-allocating and provisioning network and Grid resources in a single-step. The G^{2}MPLS is expected to provide generic applications with the ability to be aware of their Grid network resources (computational and networking) environment and capabilities, and to make dynamic, adaptive and optimized use of heterogeneous network infrastructures connecting various high end resources.

On the other side, an increasing number of multimedia and interactive applications today are using the Session Initiation Protocol (SIP) [18] for application-layer signalling. SIP is an agile protocol that works independently of underlying transport protocols and without dependency on the type of session that is being established. SIP does this by limiting itself to a modular philosophy and focusing on a specific set of functions and thus maximizing interoperability to existing and future protocols and applications. Last but not least SIP has been chosen as the signaling protocol for the IMS (Internet Multimedia Subsystem) [5] that promise to be the mobile pervasive network of the future, therefore it is likely to be a long lasting protocol.

Concerning the transport network technology to support these concepts, the OBS technology [6] is a suitable candidate for implementing a scalable network infrastructure to address the needs of these emerging IT networking services and future Internet applications [7,8]. Its transport format can be ideally designed to user's bandwidth requirements and can provide efficient use of network resources. Furthermore, the optical bandwidth can be reserved for a specified time slot, i.e. only for the duration of the burst. Therefore it can maximize efficiency of the transport service (i.e. connectivity, bandwidth) to application needs. It is also able to operate within G^{2}MPLS model by adapting the LOBS paradigm [9] or participate on hybrid OCS/OBS environments [10, 11] or even exist on independent domains and interoperate under heterogeneous network environment [12].

The remainder of this paper is organized as follows: Section II describes a case study on supporting Grid applications over

GMPLS controlled optical networks. It describes the High Performance Computing (HPC) application requirements and their impact on underlying network services. It then reports on PHOSPHORUS network architectures, services and interfaces. Section III reports on a different case study that investigates quad-play services, their requirements and how can be provided over different SIP-OBS network architectures. Section III concludes the paper.

II. CASE STUDY #1: GRID APPLICATIONS OVER GMPLS-CONTROLLED OPTICAL NETWORKS

G^2MPLS architecture exposes interfaces specific for Grids and is made of a set of extensions to the standard ASON/GMPLS architecture. Therefore, G^2MPLS results in a more powerful NCP solution than the standard ASON/GMPLS, because it complies with the needs for enhanced network and Grid services required by network "power" users/applications (i.e. the Grids). The enrichment of G^2MPLS is driven by procedures, languages and schemas standardized by Open Grid Forum (OGF) and OASIS; therefore, it is not conceived to be an application-specific architecture. Nevertheless, the requirements of standard users that only require the automatic setup and resiliency of their connections across the transport network are still supported by the backward-compatibility of G^2MPLS with standard GMPLS. G^2MPLS is aimed at providing part of the functionalities related to the selection, co-allocation and maintenance of both Grid and network resources in the same tier, guaranteeing service availability and tailoring to the user requirements.

The G^2MPLS NCP can bring to an innovation in this field, because of its faster dynamics for service setup in the same time-scale of the NCP ones, availability of well-established procedures for traffic engineering, resiliency and crankback and uniform interface (G.OUNI) for the Grid-user to trigger Grid & network transactions not natively dependent on a specific Grid middleware. Moreover, the compliance of the G^2MPLS to the ASON/GMPLS architectures foster for the possible integration of Grids in real operational networks, by overcoming the current limitation of Grids operating as stand-alone networks with their own administrative ownership and procedures.

A HPC requirements with impact on underlying network services

High Performance Computing (HPC) applications uses services and functions defined by OGSA and specified by OGSI along with Grid infrastructure to accomplish specific work-related tasks that solve business and technical problems. In general, a HPC application is a collection of work items or jobs that carry out a complex computing task by using Grid network resources. It usually remains private and largely under the developers control. HPC applications run in a dynamic, sometimes loosely defined and heavily networked environment. The integration of HPC and Network services under the Grid Network Service paradigm poses a number of requirements, mainly to the Network Control Plane of the underlying optical network infrastructure. In Phosphorus, GMPLS Control Plane has been evaluated as the more flexible and scalable baseline for matching these requirements. Evolution of GMPLS to G^2MPLS is the result of this requirement identification and analysis.
Specific requirements for the NCP for Optical Grid Networks are discussed in the remainder of this section, trying to highlight the rationale behind the definition of Grid-enabled GMPLS (G^2MPLS). Many "standard" ASON/GMPLS requirements about signalling, routing, link management, addressing and Signalling Communication Network (SCN) are not presented here, as

they are completely shared by Photonic Grid Networks. Therefore, just those requirements with a direct impact by Grid layer will be described.

Grid service discovery

Grid Service discovery is essential for any NCP solution supporting GNS. The NCP must provide mechanisms for the negotiation of Grid and network services, configurable across the interface between the Grid user/site and the network. The service discovery mechanism includes network specific resources and operation modes (e.g. types of signals, protocols, routing diversity, permeability modes for the information coming from the network, etc.) and Grid specific capabilities (e.g. types of CPU, storage, OS, etc.)

Grid Resource discovery

The NCP must provide mechanisms for learning and advertisement of the Grid (e.g. amount of CPU, storage, etc.) and network (e.g. amount of bandwidth, connectivity, etc.) resource availability at the Grid user site. Depending on the type and amount of routing information that the Grid user and the Network Operator are able to manage for GNS purposes, different levels of permeability may be negotiable at the User-Network Interface (UNI), in order to cope with different scenarios at the Grid layer:

- Pre-configured and static reachability information about the remote Grid sites;
- Dynamic reachability information on the remote Grid sites with a dynamic learning;
- Full Grid routing information and summarized network routing information for resolving the service/job endpoints and some loose connecting route (e.g. in case of inter-domain route),

Full Grid and network routing information for resolving the service/job endpoints and the exact connecting routes.

This requirement and its permeability implications are mostly originated from the Network Operator side, because of the different levels of dissemination for the core topology information via Control Plane (i.e. from an overlay to a full peer-to-peer approach).

Connection management

The NCP must support Switched Connections (SC) through the G.OUNI [[13]]. Other solutions made available by ASON/GMPLS architecture [14], like Soft Permanent Connections (SPC) and Permanent Connections (PC), are not essential for the Photonic Grid Network. Moreover, the majority of network connections required by Grid applications are unidirectional point-to-point connections due to its better suitability for the asymmetric nature of Grid traffic (e.g. several clients against one server model). However, bidirectional point-to-point connections may be possibly required by some computational Grid applications in which a main stream direction cannot be identified. Unidirectional point-to-multipoint connections are not used in state of the art Grid applications, but represent an upcoming enhancement for faster and effective data replication services. The same future perspective applies for anycast point-to-point connections, which could be intended as routing data to the "nearest" or "best" destination as viewed by the routing topology at that stage.

Flexible bandwidth allocation for GNS services

The GNS-es [[15]] related to the execution of a complex Grid job should be dynamic (i.e. medium lived connections instead of long lived connections) and tailored to the bandwidth needs (i.e. with a guaranteed bandwidth as requested). A range of signal types (and thus bandwidth granularities) needs to be available for building a GNS, ranging from Gigabit Ethernet up to SDH-SONET TDM hierarchies and 10 Gigabit Ethernet, in optical or electrical technologies where possible.

Advance reservations for GNS services

The Grid layer should be able to ask at a given time for a future service setup of Grid and network resources, by specifying start time and duration of the required service. This implies an immediate processing and reservation of the selected Grid and network resources for that task in that timeframe and a later "service activation" tier just before the execution of the task.

Service resiliency

The guarantee of the required service during the execution of a task might be compromised by some possible faults of the involved network or Grid resources. The NCP should provide means for faulty condition detection and reaction, as well as mechanism for diverse routing between the failing path and its backups, for intra and inter-domain connections. A coordination and escalation of recovery strategies between the Grid layer and the network layer is also necessary, depending on the significance and impact of the occurring network fault. This will be carried out by triggering timely fault notifications across both layers.

Authentication and Authorization

AuthZ/AuthN provides means to authenticate check authorization and account for the service usage. In the NCP scope, AuthZ/AuthN mechanisms basically focus on:

- the interfacing towards external AuthZ/AuthN infrastructures,
- the internal mechanisms to forward session credentials along the signalling path.

The challenge raised from the Photonic Grid Network environment is to integrate AuthZ/AuthN infrastructures for network with those for Grids, towards a unified and generalized infrastructure granting access to both Grid and network resources.

B G^{2}MPLS reference network and service models

From a user's perspective, G^{2}MPLS enables a real node-to-node deployment of on-demand Grid services, because it exposes specific interfaces towards the Grid layer. Part of the middleware functionalities related to selection, co-allocation and maintenance of both Grid and network resources are provided through these interfaces.

From a network operator perspective, G^{2}MPLS is a means for the integration of Grids and automated network control plane technologies in real operational networks. This allows on one side to use well established solutions for setup, recovery and crankback of network connections spanning multiple domains and matching traffic engineering objectives; on the other side, G^{2}MPLS allows to overcome the current limitation of Grids that operate as stand-alone overlaid infrastructures upon research networks with different administrative ownership and uncorrelated procedures.

The Phosphorus framework identifies different layering solutions with respect to the positioning between Grid Services layer and Network Control Plane. Layers involved and illustrated in Figure 1are:

- Grid layer,
- Network Control Plane,
- Transport Plane.

The Grid layer comprises Grid users/applications, Grid resources, and Grid middleware. Within the Phosphorus perspective, the relevant aspect of this layer is the functionalities exported to/by the underlying network Control and Management Planes.

The NCP takes different roles depending on the architectural model chosen. Finally, the Transport Plane (TP) is the basic layer comprising all the data bearing equipments and their configuration interfaces.

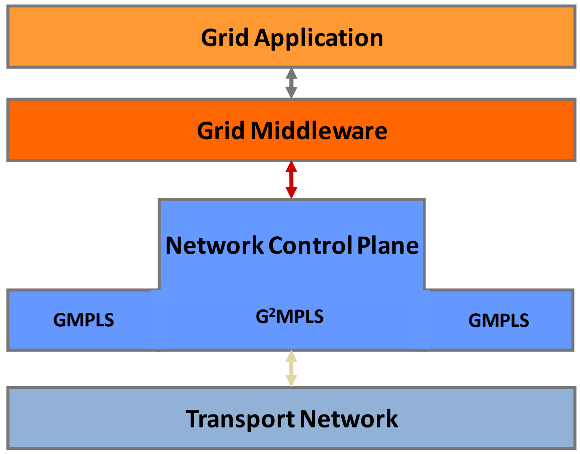

Figure 1: Phosphorus Network and Service architectural model.

G^2MPLS is aimed to provide part of the functionalities related to the selection, co-allocation and maintenance of both Grid and network resources. This goal translates in:

- Discovery and advertisement of Grid capabilities and resources of the participating Grid sites;
- Service setup
    - Coordination with those parts of the Grid middleware needed for the local configuration of the Grid job (i.e. the local job scheduler in particular)
    - Configuration of the deriving network connections among the sites participating to the Grid job.
    - Management of resiliency for the installed network services and possible escalation of recovery actions
    - Advanced reservations of Grid and network resources, aimed to guarantee connection availability at job execution time by providing users with a priori information about start, wait and completion times.
- Service monitoring
    - Retrieving of the status of a Grid job and the related network connections.

Two Control Plane models are defined for the G^2MPLS architecture:

- G^2MPLS Overlay
- G^2MPLS Integrated

These models concern the layering of grid and network resources. Thus, they have a different meaning and scope with respect to the IETF definitions for GMPLS Overlay, Augmented and Peer/Integrated models. A description of G^2MPLS Control Plane models is provided in the following subsections.

G^2MPLS Overlay model

In the G²MPLS Overlay model, the Grid layer is supposed to have Grid and network routing knowledge in order to provide Grid resource configuration and monitoring (as in its standard behaviour) plus network resource configuration and monitoring. G2MPLS acts as an information bearer of network and Grid resources and as a configuration "arm" just for the network service part (ref. Figure 2).

Most of the computational and service intelligence is maintained on the Grid layer and, upon the occurrence of a Grid job request from a user, it is up to the Grid scheduler to initiate and coordinate the reservation process through a sequence of phases, including:

- localization of resources in an Index Service available at the Grid middleware;
- negotiation with the selected resources (local and remote Grid plus network in the middle) of a common timeframe for allocating the respective job parts;
- initial advance reservation of the agreed service segments, which implies a temporary booking of the service segment;
- final commit of the advance reservation, which results in the final booking of resources on the different service segments after all the initial booking have been positively acknowledged and correlated.

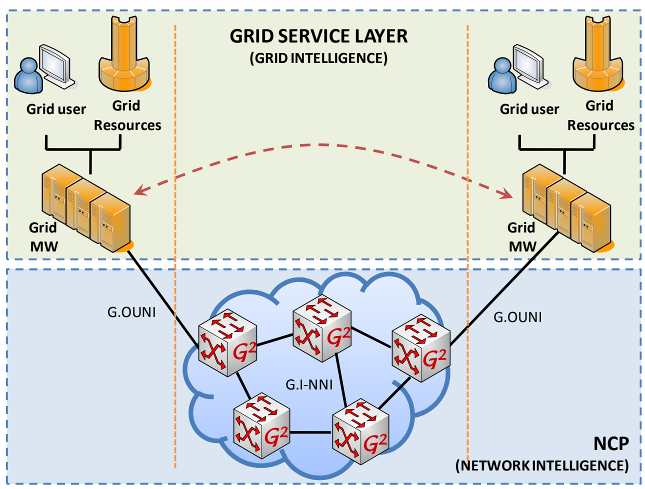

Figure 2: G²MPLS Overlay Model

Each involved Grid site is responsible for scheduling, configuring and monitoring of the job part to be run on its resources. This functionality is provided by the Local Resource Management System (LRMN).

The G²MPLS is responsible for scheduling, configuring and monitoring of the job part related to the network, thus implementing advance reservations, recovery and connection monitoring mechanisms.

G²MPLS Integrated model

In the G²MPLS Integrated model, most of the functionalities for resource advance reservation and commit are moved to the G²MPLS Network Control Plane and G²MPLS is responsible for selecting the job segment providers and coordinating the co-allocation process (ref. Figure 3).

Each involved Grid site is still responsible for scheduling, configuring and monitoring of the job part to be run on its resources. This functionality continues to be provided by the Local Resource Management System (LRMN).

On the contrary, G^2MPLS is responsible for scheduling and configuring all the job parts, those related to the Grid sites and those related to the network. Therefore, Grid and network resources are seamlessly allocated in one step, under the coordination of the G^2MPLS NCP.

For G^2MPLS purposes, Grid sites are modelled as network nodes with specific additional Grid resource information. Therefore, these nodes are available in the network topology and can be used for the localization of resources (network and Grid remote) upon the occurrence of a service request. Different routing behaviour could be possible for these Grid end-nodes, i.e. they could not participate in the routing protocol instance or be silent listeners or be full peering entities. This behaviour depends on the network model used while running the G^2MPLS.

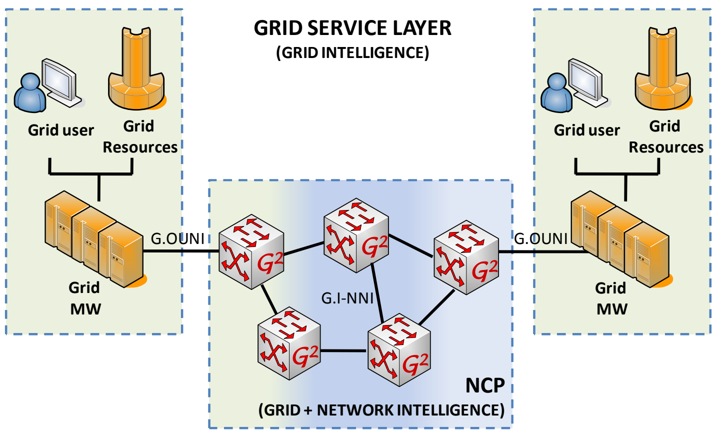

Figure 3: G^2MPLS Integrated Model

The Grid and network localization service is included in G^2MPLS integrated model, in order to have knowledge of the capability and availability of all the resources that can be involved in Grid Network Services instantiations. The Grid middleware/application could just declare the identity of the Grid site involved in the job, while it is up to the G^2MPLS to resolve the network attachment end-points for these sites. However, it could be possible for some applications to declare just an anonymous service requirement (e.g. an amount of storage or CPU) despite its location. In this case G2MPLS is responsible also for localizing the best resource candidate for that service and the best network attachment point.

For all these purposes, routing computations and advertisements are basic enablers of the G^2MPLS integrated model, as well as all the signalling procedures for the different network reference points (G.OUNI, G:I-NNI and G.E-NNI). The two schemas that can be used as reference for the Grid-extension of the G^2MPLS NCP can be identified in:

- Job Submission Description Language (JSDL) [16], for the job submission and description
- Grid Laboratory Uniform Environment (GLUE) schema [17] for the resources description.

C G^2MPLS network reference points

The deployment of the enhanced Grid-GMPLS Control Plane sets analogous reference points with respect to the ASON/GMPLS ones. The resulting network interfaces are a Grid-aware evolution of the standard interfaces (UNI, I-NNI, E-NNI), with a set of procedures that maintains the backward compatibility with the original ASON references, but provides also the seamless and one-step control of both Grid and network resources.

Five network interfaces are identified in the G^2MPLS Network Control Plane (**Figure 4**):

- G.OUNI, i.e. the Grid Optical User-Network Interface that supports Grid and network signalling and discovery between the Grid site and the G2MPLS domain.
- G.I-NNI, i.e. the Grid Internal Node-Node Interface (G.I-NNI) that supports the routing and signalling procedures between adjacent nodes.
- G.E-NNI, i.e. the Grid External Network-Network Interface that propagates Grid and network topology information across different Control Plane domains and supports the inter-domain signalling mechanisms.
- SBI, i.e. the Southbound Interface that retrieves resource status from the specific Transport Plane and translates Control Plane actions into appropriate configurations of those resources.
- NBI, i.e. the Northbound Interface that groups two interfaces towards upper layers: one towards the Grid layer (G.NBI) and one towards the Network Service Plane (including NRPS, N.NBI).

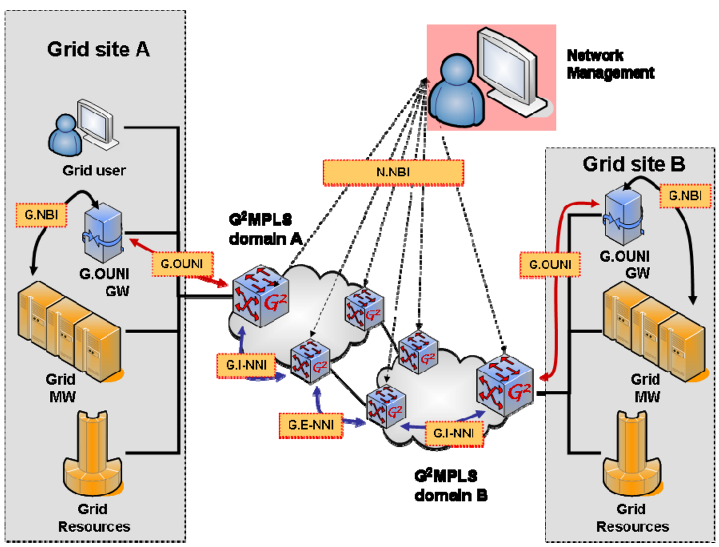

Figure 4: G^2MPLS network reference points.

III. CASE STUDY #2: SIP APPLICATIONS OVER OBS NETWORKS

An application aware optical network, in addition to an efficient network transport technology (such as OBS) needs an application layer signaling protocol to help users in the actions of presenting their needs and resource providers in the actions of making them known and reachable to users. In this work we have assumed that these actions may be supported by a session management protocol. The concept of service session, is well known in networking, and also in more general real life, and is related to a set of activities performed by a user that can be logically correlated. In networks, several exchanges of information (either in parallel or series and possible referring to different media) may be part a single session. The session may be manipulated by the user or the network according to the needs, for instance a session may be suspended, retrieved etc. This paper assumes that the users requests for "communication services" can be mapped into "communication sessions" independently of the networking environment and the effective location of the service resources, and wants to show how session manipulation functions can be used to announce network and non network resources with various degrees of pervasiveness or session management may be used to attach/detach resource to a specific communication service. To implement these concepts in the test-bed here presented we have chosen the Session Initiation Protocol (SIP) [18] since it is the most popular session manipulation protocol in the Internet.

SIP was first introduced to link applications and OBS networks in [19]. Two SIP-enabled control plane architectures, the overlay and integrated, where proposed, and the first one was also implemented. [20] makes a step further and proposes the use of the SIP protocol to support Grid networking over an OBS network. Grid-aware SIP Proxy (GSP) is referred to as a network component that is able to satisfy the communication requests of Grid applications by exploiting the SIP protocol over the OBS network. Extensions to existing SIP protocols (PUBLISH, SUBSCRIBE, NOTIFY) are introduced to map Job Subscription Description (JSDL) documents used to describe job requirements into communication sessions. SIP is then proposed to give Grid middleware the capability to exploit the network-oriented features on one side and the rich semantic of application oriented languages such as JDSL on the other. Up to that point implementation of the SIP-enabled OBS where limited to overlay architecture, where SIP messages where transported over IP layer and OBS control plane was used in the traditional way to reserve and establish network connectivity. In [21] first experimental results of a partially-integrated architecture where demonstrated.

Here we extensively analyze and compare three architectural models, overlay, partially-integrated and fully-integrated and describe their deployment considerations. Furthermore, end-to-end SIP-OBS protocols are described to realize such solution. Three different approaches -localized, distributed, centralized - of publishing computational resources to SIP-OBS network environment are introduced and the first two were implemented. Each provides different level of control to service providers and different level of scalability. Depending on the service level agreements (SLAs) a service provider can choose the most appropriate approach for its own domain. The level of scalability required must be considered on deciding among these approaches. Initial experiments on the SIP proxy level have been conducted to provide some scalability incentives of this approach. Complete description of SIP-enabled OBS Edge and Core routers has also been provided for possible deployment considerations. Overall, the enrichment of OBS control plane with SIP messages was used to provision sessions and connections in a single step. Coordination of network and IT services according to the application requirements was demonstrated by implementing the partially-integrated architecture.

A. Quad-play service requirements with impact on underlying network services

The provisioning of specialized end-user experience, better billing systems, enhanced security mechanisms, better mobility management (roaming), improved quality of service and, most importantly, the integration of various services are some of the quad-play service requirements. The IMS architecture is able to support such requirements and also be a key enabler to delivering a converged IPTV/quad-play service such as extension of voice (e.g. caller ID, telephony click-to-call, video call) and data (e.g. information sharing, chat) services into the TV environment and TV services into the wireless environment. The ultimate aim of is to provide a unified and consistent service experience to customers by utilising service enablers listed below [22, 23]:

Single Subscriber Authentication

It enables a user to log onto a service using one device and continue the session on another device without having to sign in again. This capability is made possible by a master database managed through a Home Subscriber Server (HSS) element in the IMS core network.

Unified Session Control

It enables sessions to be handed off between devices, such as when an IPTV viewing session is started on a TV and then continued on a mobile device. This function is accomplished from a Call Session Controller (CSC) element in the IMS core network.

Service enablers

Presence and Network Buddy List, can be extended to any network device via the IMS core network, enabling features to be delivered in the same manner to a PC, mobile device or IPTV set-top box.

Application ubiquity

It refers to the way the IMS application layer applies to multiple access networks. New applications and services can be extended from one access/device type to another with relative ease.

Resource control

It ensures that the required resources for a service are established among different access types. This IMS element manages policies for service by access type, and makes sure the specific access network can deliver the required attributes. IMS provides a core network foundation allowing a service provider to deliver a personalized multimedia experience beyond basic IPTV.

Service control

It plays a major role in IMS Service Provisioning due to the fact that it allows the synchronization needed for session establishment and Quality of Service (QoS) management. In this way the end-users can have a predictable experience at a reasonable charge as compare to present 3G networks. Service control also allows the service platform to be reusable by allowing proper control and management of complex functions such as service filtering, triggering and interaction. The main enablers for service control are Quality Control, Mobility Management, Security and Billing, as described below.

SIP-Network message handling

It handles all the messages that are necessary to control a long lasting communication session (e.g. authentication, presence discovery)

Information management

It supports information exchanges that are required for the management of any network and IT service (e.g. resource reservation messages)

Dynamic service provisioning

It facilitates end-to-end dynamic service provisioning across heterogeneous optical network infrastructures

Session-based connections

Provide session-based, high speed, “short lived” or “long lived” connections based on GMPLS or OBS control protocols.

B SIP-enabled OBS network reference architectures

The Session Initiation Protocol (SIP) is an IETF application layer protocol used for establishing sessions in an IP network. SIP has been developed purely as a mechanism to establish sessions, it does not know about the details of a session, it just initiates, terminates and modifies sessions. In other words, SIP does not provide services. Rather, SIP provides primitives that can be used to implement different services. For example, SIP can locate a user and deliver an opaque object to his current location [18]. It is transport protocol neutral; can run over reliable TCP, TSL and unreliable UDP channels, and can have request routing based on direct (performance) or proxy-routed (control). This simplicity means that SIP scales, it is extensible, and it sits comfortably in different architectures and deployment scenarios.

Optical Burst Switching [24,25] combines the best of the coarse-grained optical wavelength switching and the fine-grained optical packet switching while avoiding their deficiencies. Its transport format can be ideally tailored to user’s bandwidth requirements and can therefore provide efficient use of network resources. Here we propose network architectures that take advantage of abovementioned technologies by bridging them together.

In order to exploit SIP protocol over OBS Network there is a need of a middleware to couple them at Edge OBS and/or Core OBS routers. This middleware can be embedded in the OBS router hardware and is made of three main blocks:

1. Interface required to interpret the applications requests related to the sessions supporting user/applications requests (e.g. parsing and processing resource description documents);
2. Parsing engine which translate the application requests into network related communication instances.
3. Interface required to forward SIP protocols to the OBS control plane (encapsulate/decapsulate SIP messages over Burst Control Headers)

To realize possible deployment of SIP and OBS on a boarder scale, different network architectures have been studied, analyzed and compared throughout the next three paragraphs. The architectures proposed are divided in three models, overlay, partially integrated and fully integrated.

Overlay Model

The overlay approach keeps both physical and logical separation between the SIP (session) layer and the optical network. The non-network resources (e.g. computing and storage) and the optical layer resources are managed separately in an overlay manner. An IP legacy network carries the SIP signals and the OBS network carries the data: the slow network (based on legacy technology) is used for the signalling while the fast network (optical OBS) is used only for data transmission. The SIP proxies are placed into the edge routers only and use a legacy electronic connection to forward the SIP signals to the other SIP proxies (Figure 5). They negotiate the sessions and are composed by registrar, location and proxy servers in order to provide all the functions of a SIP network. The users (i.e. the application) use the SIP protocol to negotiate the IT communication session. When the session is set the middleware is responsible to request a data path between the edge routers involved in the session to the optical network control plane. Then the session data cut through the OBS network and the SIP layer is only involved to modify or tear down the session.

The main advantage of this approach is to use the various technologies for what they do best. The well-established legacy technology based on the current Internet is used to carry the signalling, i.e. low speed and rather low bandwidth data transmissions while the high speed OBS network is used to carry vast amount of data.

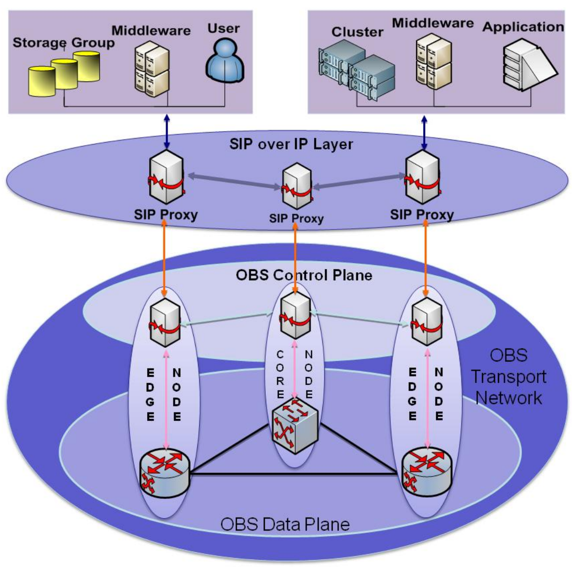

Figure 5 SIP-OBS overlay model.

Partially Integrated Model: Integrated Control Plane – Overlay Logical Plane

The partially integrated approach (Figure 6) enriches the optical control plane with SIP functionalities, to realize a pure OBS network that interwork with the SIP protocol to negotiate the application sessions and by OBS to control the connection management functions. No legacy networks are into play any more and signalling and data share the same networking infrastructure. Since the signalling and the data plane share the same network infrastructure, all OBS node must at least have the capacity to read and forward a SIP message.

The SIP proxies in the edge nodes are full functional and logically identical to those mentioned before. On the other hand the

SIP proxies in the core nodes can be equipped with a subset of functionalities, to satisfy the best performance/complexity trade-off. On one side the SIP functionalities could be limited to a light proxy with forwarding functions only. In such a way most of the intelligence of the SIP layer can still be segregated at the boundaries of the OBS network. On the other side the OBS core nodes could be equipped with full functional SIP proxies and therefore could take part in the operations of managing the application requests, for instance actively participating in the resource discovery process.

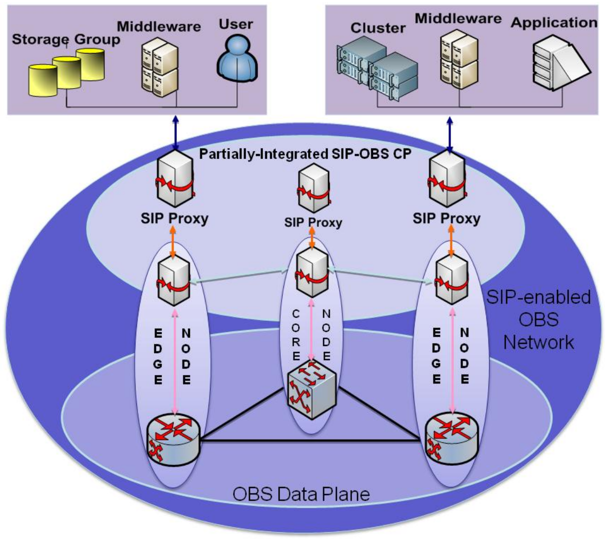

Figure 6 Partially-Integrated SIP-OBS model

Fully Integrated Model

The ultimate goal is to have a fully integrated architectural mode (Figure 7) where there is both logical and physical unification of SIP (proxies and protocols) with OBS (routers and control plane). This integration can occur by hardware embedding the SIP proxy and OBS router to a Field Programmable Gate Array (FPGA) equipped with PowerPC processors. The SIP stack can run on the PowerPC processor and the OBS router functionalities on the FPGA part. The advantages of such development are the following:

1. Integration of application and transport plane (single step session and connection initiation);
2. Hardware interaction of SIP and OBS mechanisms provides node and network flexibility, agility and scalability (due to hardware programmability and reconfigurability);
3. Faster protocol parsing, forwarding both for session and connection mechanisms (due to combination of FPGA and PowerPc processor enhanced performance);
4. Optimization of Quality of Service (QoS) and IT Differentiated Service (DiffServ) provisioning.
5. Faster response and recovery mechanisms.

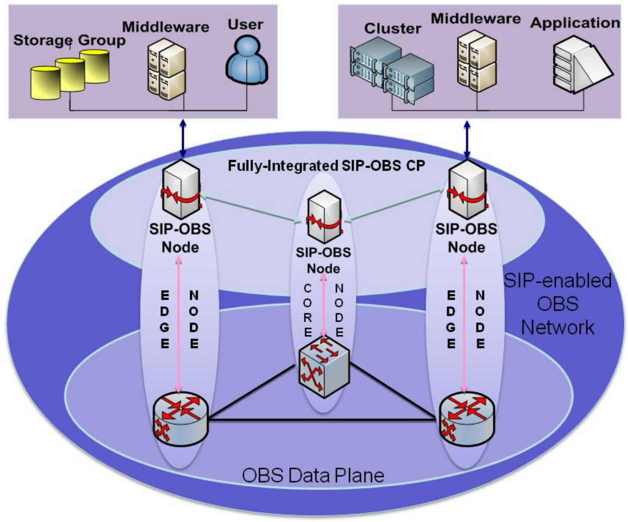

Figure 7 Fully-Integrated SIP-OBS model.

C. SIP-ENABLED OBS TESTBED

Functionalities of the proposed SIP enabled OBS network architecture and the proposed aforementioned networking scenarios have been validated with a test-bed. The test-bed architecture is based on OBS network technology utilizing SIP-enabled OBS routers and JIT-SIP signaling protocol as shown in .

The test-bed comprises two SIP-enabled edge routers, one SIP-enabled core router and JIT-SIP control protocol as described below. The SIP-enabled edge OBS router is utilizing PowerPC processor and FPGA (Field Programmable Gate Arrays) and is able to process, classify and differentiate application layer sessions according to their network (bandwidth) and non-network (computing) resource requirements [26,27]. It can aggregate jobs according to their resource requirements into bursts and allocate a suitable wavelength and Burst Control Header (BCH) to them. The SIP-enabled core OBS router is comprises a fast switch. It utilizes network processor and FPGA and it can process application layer information on the fly to allocate switch resources. The proposed JIT-SIP protocol utilizes SIP functionalities to negotiate and manage the application sessions (i.e. non-network resource discovery and allocation) and JIT signaling to reserve optical network resource and manage the physical layer connections. In the proposed architecture, SIP messages are carried in the optical domain with JIT signalling. In this network architecture the SIP functionalities are handled by SIP proxies that are coupled with OBS edge nodes. On the other hand SIP-enabled core OBS routers, where the processing speed is critical, are equipped with a light subset of SIP functionalities to provide the best performance for the proposed network in terms of resource discovery and connection

The OBS test-bed operates at 2.5 Gbps for both the data plane and control plane. All routers utilize a Xilinx high-speed and high-density VirtexII-Pro FPGA with embedded network processor. The OBS control channel is transmitted on dedicated wavelength channel in the same fibre using the proprietary Optical Burst Ethernet Switched (OBES) transport mechanism [28]. The data plane transports variable sized bursts with variable time intervals and operates in bursty mode. Edge Router (ingress side) utilizes a SIP engine and one fast and widely tunable SG-DBR laser.

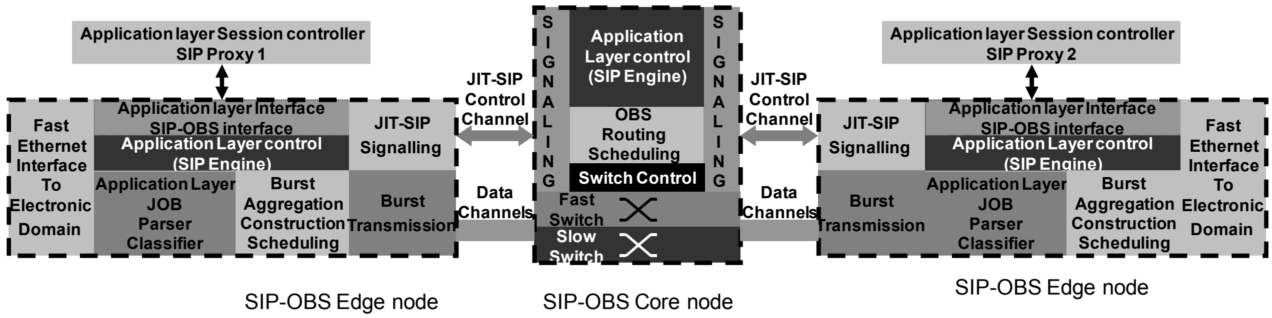

Figure 8 Functional block diagram of the SIP-enabled OBS network.establishment. The SIP Proxy is based on a SIP stack called pjsip [29] and runs on a PC.

D. DEMONSTRATION RESULTS

The message-timing flow is presented in Figure 10, where only the messages related to the dialog between the OBS edge nodes are reported, and the flow of SIP messages between the clients and the proxies is not shown. Such flows include exactly the same messages as those between the two proxies and therefore do not add any significant information. After the INVITE message is processed at SIP proxy 2 the user is informed about the results of the resource discovery, with either a positive or negative reply, depending on whether resources are available or not. In the experiment a positive reply is the 200 OK message, that is received by SIP proxy 1 T_{S1} = 14.45 ms (experimentally measured) after sending the INVITE message, as indicated in Figure 10. In this case SIP proxy 1 forwards the OK message to the client and triggers the application to sent the job. At the same time a computational resource reservation signalling (ACK) message is sent to SIP proxy 2 (after T_{S2} = 17.95 ms).

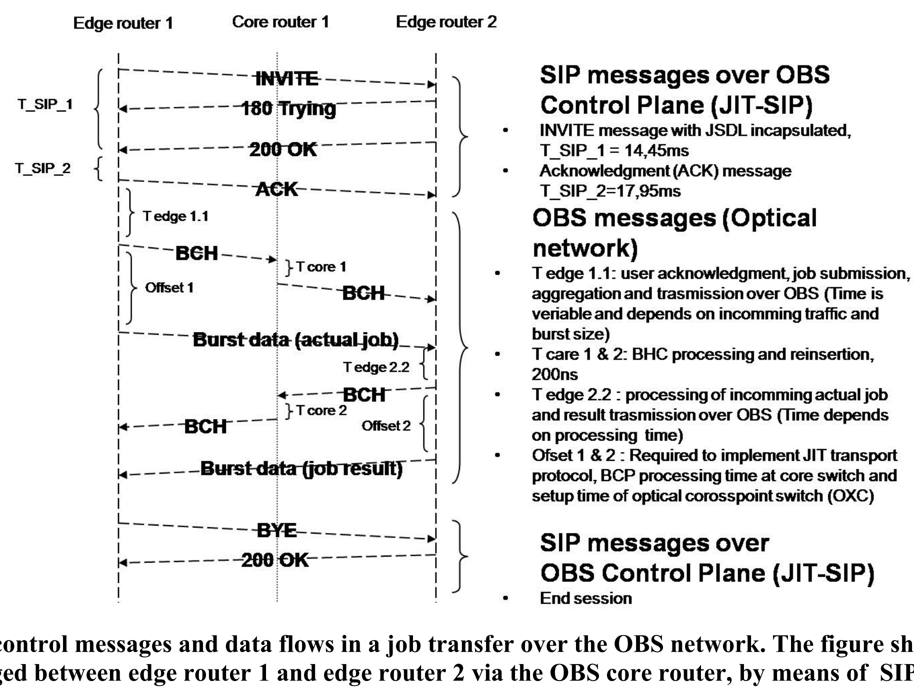

Figure 9 Session control messages and data flows in a job transfer over the OBS network. The figure shows the messages exchanged between edge router 1 and edge router 2 via the OBS core router, by means of SIP - OBS test-bed

This is for acknowledging the session establishment. The time elapsed between the arrival of the OK message and the departure of the ACK is due to the signalling between SIP proxy 1 and the client (not reported in the figure) and for triggering the application to transfer the data referring to the communication session under negotiation.Concerning the scalability of the proposed SIP-OBS approach for publishing (PUBLISH), discovering (SUBSCRIBE), and reserving (INVITE) resources, the processing time of these single messages and the total amount of time required to forward messages to the neighbour proxies is one of the main issues. The results shown in Figure 10 project the time between the request of a User Agent and the proxy's processing time to forward the message to all neighbour Proxies, thus the total amount of time to broadcast a message into the network. The tests were performed with a single dual 2.4 Ghz Xeon PC with 2 Gbyte of RAM virtualizing neighbour proxies. In addition to this, table 1 shows the processing time between the request of a User Agent (UA) and the proxy response for all possible SIP messages on stand alone proxy

Messages	Time (ms)
UA (Req) INVITE -> Proxy (Res) 404	0.201
UA (Req) PUBLISH -> Proxy (Res) 200	0.2102
UA (Req) SUBSCRIBE -> Proxy (Req) NOTIFY	0.29175
UA (Req) UNSUBSCRIBE -> Proxy (Res) 200	0.1805

Table 1. Timing results of SIP message results on a single Proxy.

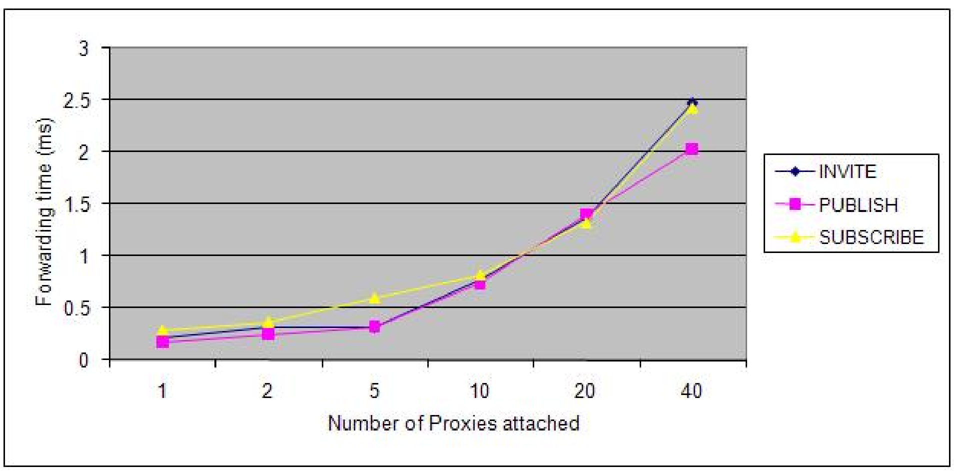

Figure 10 SIP proxy forwarding (broadcasting) timing results with regards to the number of proxies attached for PUBLISH, SUBSCRIBE, and INVITE protocols.

IV. CONCLUSIONS

In this paper we have reported two distinct use cases that integrate service and network control plane in order to support a broad range of applications. In the first use case, the requirements, architectures, service models and interfaces for a Grid-enabled GMPLS control plane is reported. This work aims to address some of the key technical challenges to enable on-demand and in-advance end-to-end Grid Network Services across multiple domains in a seamless and efficient way. The G^2MPLS NCP is an innovate approach, because of its faster dynamics for service setup in the same time-scale of the NCP ones, availability of well-established procedures for traffic engineering, resiliency and crankback and uniform interface (G.OUNI) for the Grid-user to trigger Grid & network transactions not natively dependent on a specific Grid middleware. All these features have been defined by the Phosphorus project and will be implemented and demonstrated by the experimental activities on the project testbed. In the second use case, requirements, architectures and implementation of a SIP-OBS network environment able to support quad-play services is described. The proposed architectures integrate the application layer SIP protocol with OBS control and signaling (JIT) for enabling the optical network to use application layer information (e.g. computational resource requirements) for establishing and managing connectivity between users and resources/applications. The JIT-SIP protocol utilizes SIP functionalities to negotiate and manage the application sessions (i.e. non-network resource discovery and allocation) and JIT signaling to reserve optical network resource and manage the physical layer connections. In the proposed architecture, SIP messages are carried in the optical domain with JIT signaling. These sub-systems and protocols are realized and integrated into a test-bed to demonstrate a fully functional application aware OBS network. The results of the demonstrator prove the feasibility and effectiveness of the suggested solution.

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