Phosphorus Grid-enabled GMPLS Control Plane (G^{2}MPLS): Architectures, Services and Interfaces

Georgios Zervas, Eduard Escalona, Reza Nejabati, Dimitra Simeonidou, University of Essex
Gino Carrozzo, Nicola Ciulli, Nextworks
Bartosz Belter, Artur Binczewski, Maciej Stroiński Poznan, Supercomputing and Networking Center
Anna Tzanakaki, George Markidis, Athens Information Technology

Abstract- G^{2}MPLS is a Network Control Plane (NCP) architecture that implements the concept of Grid Network Services (GNS). In the Phosphorus framework, GNS allows the provisioning of network and Grid resources in a single-step through a set of seamlessly integrated procedures. The implementation of GNS poses a number of requirements on the Control Planes of the underlying network infrastructure. This article describes the GNS requirements such as Grid resource discovery, service resiliency, Authorization Authentication Accounting (AAA), and advance reservation services, which are the main trigger factors of the G^{2}MPLS control plane architectures (Overlay and Integrated), services procedures and the Grid-enabled network interfaces provided by IST Phosphorus project.

Keywords: Optical networks, Grid computing, Grid Network Service, Network Control Plane, GMPLS, G^{2}MPLS

1. Introduction

The advent of Grid Computing and Optical Networks has necessitated the development of interoperable procedures for requesting and establishing dynamic network and non-network services between clients, applications and computational resources (e.g. CPUs, storage, etc.), all connected by the transport network[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, 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. G^{2}MPLS architecture is expected to expose interfaces specific for Grids and is made of a set of extensions to the standard ASON/GMPLS architecture. Therefore, G^{2}MPLS 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^{2}MPLS is driven by procedures, languages, and schemas standardized by Open Grid Forum (OGF) and OASIS and thus 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^{2}MPLS with standard GMPLS [4]. G^{2}MPLS 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^{2}MPLS 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^{2}MPLS 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. The main goal of this article is to provide a description of the two main Phosphorus architectural models (Overlay and Integrated) driven by requirements for Network Control Plane design in Photonic Grid Networks. Then, a description of service models which are the rationale for the G^{2}MPLS deployment following by a set of network reference points is identified and characterized in terms of available functionalities, along with the NCP components which are needed to provide the single-step control of Grid and network resources.

2. Requirements for Control Plane in Photonic Grid Networks

The implementation of Grid Network Services (GNS) [5] poses a number of requirements on the Control Planes of the underlying network infrastructure. In Phosphorus, GMPLS Control Plane has been evaluated as the more flexible and scalable solution for matching these requirements, even though the currently standardized GMPLS protocols are not natively suited to the Grid world and its mechanisms for service creation and management.
Specific requirements for the NCP for Photonic 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.)

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 [6]. Other solutions made available by ASON/GMPLS architecture, 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 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.

AAA

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

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

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

3. Phosphorus Network and Service Architectural Models

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.

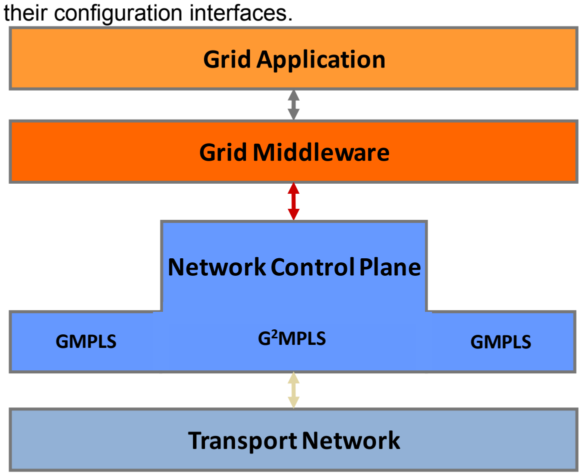

Figure 1: Phosphorus Network and Service architectural model.

The functionalities associated to each layer and the relationship between them constitutes the different Phosphorus architectural models, namely Overlay and Integrated. Note that despite this denomination is equal to the ones given by the IETF GMPLS deployment models, the scope differs as IETF is based on relationships between different Control Plane segments/domains. These models refer principally to the positioning between the Grid Service Layer and the Network Control Plane and require different capabilities of the G^{2}MPLS NCP.

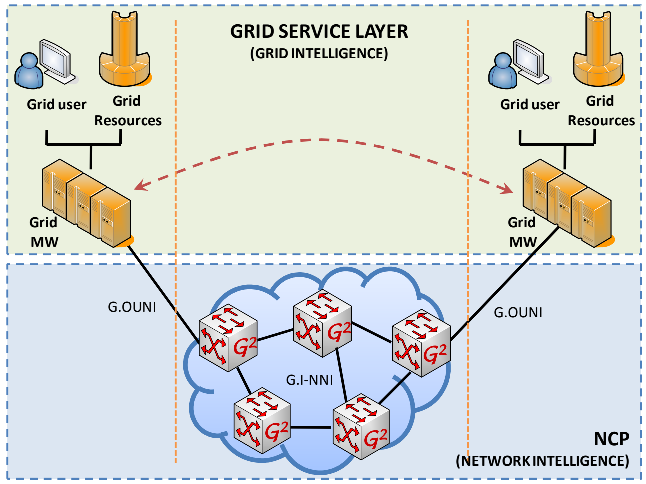

Figure 2: G^{2}MPLS Overlay Model

In G^{2}MPLS Overlay model, the Grid layer has both Grid and network routing knowledge (Figure 2). G^{2}MPLS provides automatic configuration just for the network service part; moreover, it acts as an information bearer of network and Grid resources. Therefore, in this context G^{2}MPLS basically implements the ASON Switched Connections (SC) and operates as a slave of the Grid layer (the Grid scheduler, in particular), which is the overall responsible for initiation and coordination of the (advance) reservation process through the participating Grid sites and the network. In G^{2}MPLS Overlay, the role of the network interfaces is mainly scoped to the Network Service creation, but they also piggyback opaquely and end-to-end Grid information concerning resource availabilities and site capabilities (routing) and job description data (signalling).

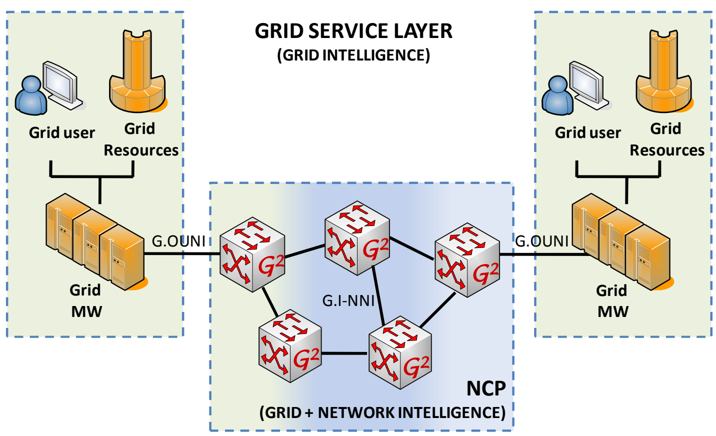

Figure 3: G^{2}MPLS Integrated Model

In G^{2}MPLS Integrated model, most of the co-allocation functionalities are moved to the Network Control Plane (Figure 3). G^{2}MPLS is responsible for scheduling and configuring all the job parts, those related to the Grid sites and those related to the network. The Grid scheduler functionality is still needed to coordinate workflow services, because G^{2}MPLS NCP is capable of managing just the workflow elementary unit, i.e. the Grid job. In this model, the role of the network interfaces is scoped to Grid Network Service creation, which implies that Grid information concerning Grid resource availability (routing) and job description data (signalling) become transparent at those interfaces in which a decision process needs to be provided: these are the G.OUNI, by which a G^{2}MPLS is entered, and the G.E-NNI, by which the border between domains is traversed.

G^2MPLS NCP architecture sets analogous reference points with respect to the ASON/GMPLS, with evolved network interfaces capable of managing and advertising the semantic of both Grid and network resources. Network interfaces in the scope of Phosphorus are detailed in Section 5.

4. Phosphorus Service provisioning

This section provides a comprehensive description of Grid-enabled GMPLS procedures.

Path Computation Issues

A proposed approach of the Phosphorus control plane for the inter- and intra-domain path computation based on specified constraints is the introduction of a separate component in each domain, which will be responsible for the path computation issues. This component can be identified as an application (different building block) residing within or externally to a network node, providing optimal routes and interacting with the control plane for the establishment of the proposed paths. The Path Computation Element (PCE) [7] is an entity (component, application or network node) that is capable of computing a network path or route based on a network graph and applying certain constraints during the computations [8]. The PCE could represent a local Autonomous Domain (AD) that acts as a protocol listener to the intra-domain routing protocols e.g. OSPF-TE, and is also responsible for inter-domain routing. PCEs peer across domains and exchange abstract or actual topology information to enable inter-domain path computation and also utilize a modified version of OSPF-TE to share a link state database between domains

Advance reservations

Advance reservation is a reservation scheduled for future (non-instantaneous) execution. Advance reservations in Grids are needed to cope with a guaranteed service at the time of execution of the job. Therefore, when the connection service is requested there is a need to specify the start and end time of the circuit.

In order to provide feasibility of advance reservations in G^2MPLS, partitioning of the Transport Network resources is needed distinguishing the resources to be used for bookings from those that could be used for immediate reservations (e.g. by standard ASON/GMPLS users). As reservations are scheduled for the future, it is required to have a calendar instance for maintenance of resource bookings. Such calendars must be scalable and open solutions in order to schedule various types of resources, including not only network parameters (like bandwidth, VLAN ids, SDH time slots, etc.) but also typical Grid attributes (number of processors, amount of memory, etc.). The calendar may be kept centralized for single or even multi-domain environment, but it may be also distributed.

"Grid-fast" circuits set-up

Apart from advance reservation setup procedures there are also on-the-fly path establishing procedures. These mechanisms have to create a path between Grid resources as fast as possible taking into consideration the switching time associated with the optical data plane. The "Grid-fast" circuit setup is done by the standard GMPLS exchange of the path setup messages between ingress and egress nodes.

Beyond point-to-point services

A typical usage of bandwidth reservation is the creation of point-to-point (p2p) network connections, but there is an emerging request from specific group of users to progress beyond this service. For example there are specific applications where a number of distributed users are simultaneously sending a large amount of data to a single computation point for hardware correlation. Also Grid tasks that are executed on separated cluster environments may require high bandwidth connections between each other to synchronize computation data. In the G^2MPLS architecture, there are three types of connections with more than two end points: (a) point-to-multipoint, (b) multicast and (c) anycast.

Wavelength-agility

Wavelength agility provides a very fast mechanism to select or change the wavelengths used to carry services between endpoints. There are two possible scenarios for wavelength agility either one wavelength corresponds to one TE link or many wavelengths correspond to one TE.

G^2MPLS transport service modifications

To reach optimal Grid and network utilization and fulfil dynamic requirements of some Grid tasks G^2MPLS has to support transport service modifications. There are three main scopes of network and Grid parameter modifications including parameter decrease (it is the easiest modification and can be done "on the fly"), parameter increase (in some cases difficult to serve,- decision may need to be made with MW consultation) and relocation (the most complicated case as new resource reservation process must be performed).

G²MPLS recovery

The concept of recovery refers to the required actions taken to maintain or retrieve the correct functioning of the network upon the detection of a failure. These actions consist of notification, fault isolation, repair of the failure and reconfiguration using survivability mechanisms (protection and restoration). An important feature provided by the use of G^2MPLS integrated model is the availability of recovery functionalities, which are the native realm of GMPLS. In case of failure occurrence on a working LSP, these recovery procedures have to be fast enough not to disrupt the application's data connections.

Depending on the significance and impact of the occurring network fault, it could be impossible for the Network Control Plane to recover the service. In such case an escalation from the network layer to the Grid layer may be needed, triggered by timely fault notifications across the G.OUNI. The G^2MPLS integrated model allows the definition of new escalation strategies, which could start recovering the network connection. In case of a failure the recovery procedure moves to the selection of new job performers – if not strictly specified by the application/middleware – and/or move to the notification towards the Grid layer/user that could take the final decision on releasing all already used resources, re-scheduling the job and sending a new request to the G^2MPLS Control Plane.

Crankback applied to set-up and restoration

Path setup can be blocked by links or nodes without sufficient resources if e.g. information used to compute a path is out of date. In the crankback scheme, failure information is returned from the point of failure to some ingress LSR (repair point) where a new path setup is found to avoid the blocked resources. In particular conditions, there may not be any available way to send a new path message to the same egress node (destination node). In this case escalation to middleware or selection of a new Grid node to which the path will be send could be considered. In the first scenario, the Grid middleware is probably responsible for sending a new job request to the G^2MPLS Control Plane. The second scenario is possible if the Grid middleware used the implicit service identification and the Traffic Engineering Database (TED) in the G^2MPLS Control Plane nodes contains alternative Grid resources. Crankback operation could be repeated a few times. When the number of retries is exceeded the path-making efforts will be ended and the job error response is sent to the middleware.

Auto-discovery procedures

The auto-discovery mechanism is a very important feature, which allows finding quickly available resources or acquiring updates when resources become available or unavailable in the domain. The result of auto-discovery is the identification of connectivity between the client and the network and the available network services.

GNS Discovery

The GNS Discovery Agent (G-SDA) is the functional entity responsible for discovering Grid and network capabilities between a Grid site attached to the G.OUNI (client side) and the G^2MPLS network control plane. Discovery of capabilities is generally referred to as service discovery, and this functional entity is conceived as an extension of the standard service discovery functionality.

G-SDA main actions comprise:

- Standard service discovery, which includes
    - Negotiation of the signalling protocol and its version to be used across the G.OUNI,
    - Correlation of the service attributes of all the transport links connecting the Grid site to the network (e.g. encoding type, signal types, etc.),
    - Discovery of network capabilities (e.g. transparency in case of SONET/SDH, diversity routing capability)
- GNS specific discovery, which includes
    - Discovery of Grid site capabilities (e.g. type of CPUs, storage, OS, etc.)

Service (network & Grid) capability

Service discovery is the process by which a client device obtains information on available services from the transport network and the transport network obtains information on the client UNI signalling (i.e. UNI-C) and port capabilities. To make a service discovery mechanism useful in the G^2MPLS functional architecture, this definition should be extended to support Grid capabilities offered by Grid sites attached to the G.OUNI.

In the G^{2}MPLS architecture, the service discovery process will be supported by a component called GNS Service Discovery Agent (G-SDA). The G^{2}MPLS DA will be designed to have the same interfaces as the ASON DA. However, in addition to ASON's functionality, G^{2}MPLS DA will be also responsible for discovering and verifying Grid resources available at Grid sites attached to the G.OUNI, thus the exposed interfaces should be extended accordingly.

5. G^{2}MPLS Interfaces

The deployment of the enhanced G^{2}MPLS NCP sets analogous reference points with respect to the ones defined by ASON/GMPLS. 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 also provides a seamless and single-step control of both Grid and network resources.

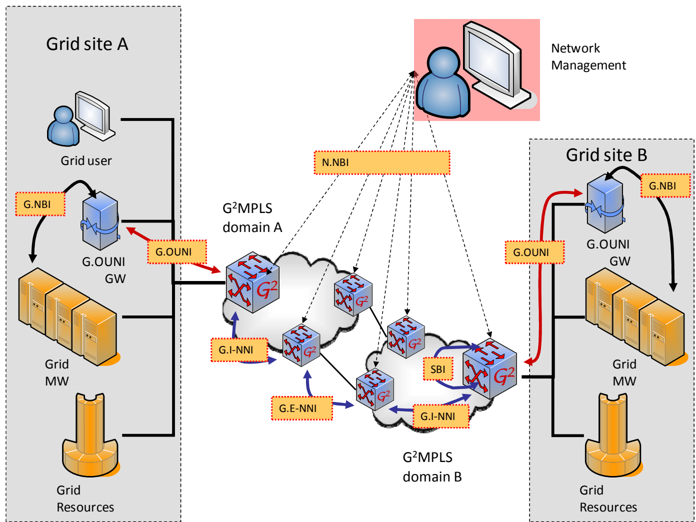

Figure 4 G^{2}MPLS interfaces.

Five network interfaces are identified in the G^{2}MPLS NCP (Figure 5):

- G.OUNI, i.e. the Grid Optical User-Network Interface that supports Grid and network signalling and discovery between the Grid site and the G^{2}MPLS 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).

5.1. Grid Optical User Network Interface (G.OUNI)

Grid Optical User Network Interface (G.OUNI) comprises a number of procedures to facilitate on demand as well as in-advance access to Grid services over G^{2}MPLS NCP. G.OUNI is conceived also to interface with current GMPLS transport network in a limited downgraded configuration, by acting as a standard O-UNI. Interoperable procedures between Grid users/resources (e.g. storage, processor, memory) and optical network for agreement negotiation and Grid service activation have to be developed. In Phosphorus G.OUNI, Job Submission Description Language (JSDL) [9] documents sent by the user using WS-Agreement procedures towards the network are mapped to signalling messages (RSVP-TE) at G.OUNI-C. Similarly, GLUE schema [10]used to describe IT Resources (both capability and availability) is translated to routing messages (OSPF-TE) in order to publish resource information through G^{2}MPLS NCP.

A more visionary approach reported in OGF [11] and initiated by Phosphorus, describes a generic G.OUNI that could connect directly Grid users/applications/resources or any type of Grid Middleware (e.g. Globus, UNICORE, gLite, etc.) with any type of service provisioning system (e.g. NRPS, GMPLS, OBS) as illustrated in Figure 5. The goal of this work is to describe G.OUNI requirements driven from GNS use cases (i.e. Phosphorus [12], Enlightened [13], G-Lambda [14], 3TNET) and in turn provide specific G.OUNI capabilities to meet these requirements.

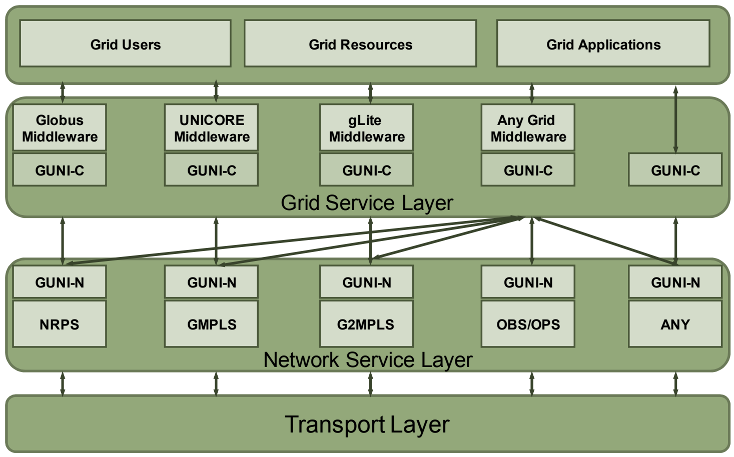

Figure 5: Grid User Network Interface with Grid End points as well as Grid middleware with Network Provisioning Systems

5.2. Grid Internal Network-Network Interface (G.I-NNI) and Grid External Network-Network Interface (G.E-NNI)

The G.I-NNI and G.E-NNI interfaces have knowledge of the GNS semantic and implements the following functionalities through numerous routing and signalling messages for intra-domain and inter-domain communication. The interfaces support:

- Grid & network resource announcement: Flooding of local and learned Grid resource capabilities (e.g. type and quantity of CPU, storage, etc.) and network resources (TE links, etc.)
- Grid & network resource discovery: Flooding of local and learned Grid resource availabilities in the same manner.
- NS request: Just network call/connections requests. Issued in case of explicit specification of the network attachment points.
- GNS request: Grid + network requests. Issued in case of implicit specification of the network attachment points.
- Network Service status: Status enquiry for a given network connection.
- Network Service notify: Notification message sent autonomously to indicate a change in the status of a given network connection (e.g., un-restorable connection failure).

5.3. North-bound Interfaces

Grid Northbound interface (G.NBI)

Grid Network Service requires interaction and coordination of procedures supported both by Grid Middleware and G^{2}MPLS NCP in order to provision network and Grid resources in a single step. A G.NBI interface with knowledge of the Grid semantics is required to support all messages transactions between the Grid Middleware and G.OUNI-C to support GNS integrated procedures (e.g. resource reservation and co-allocation).

Network Service Plane Northbound interface (N.NBI)

Network Resource Provisioning System (NRPS) and the Network Service Plane (NSP) operate just in the network domain and are used by the Grid layer as a meta-Grid service [15]. The use of the G^{2}MPLS northbound interface by an NRPS and/or the NSP limits to network only the services exportable by that interface. Therefore, in this context G^{2}MPLS is used as standard GMPLS Control Plane. The N.NBI is used only to request/tear down network connections and to retrieve topology and connection status information. This interface is based on a simple request/response model, which abstracts and generalizes transactions between NSP and GMPLS.

6. Conclusions

In this paper we have described the requirements, architectures, service models and interfaces for a Grid-enabled GMPLS control plane. 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. Moreover, the compliance of the G^2MPLS to the ASON/GMPLS architecture foster for the possible integration of Grids in existing operational networks, by overcoming the current limitation of Grids operating over dedicated networks with their own administrative ownership and procedures. All these features have been defined by the Phosphorus project and will be implemented and demonstrated by the experimental activities on the project Testbed.

Acknowledgements

This work has been supported by European Commission through the IP PHOSPHORUS project in the Sixth Framework Programme, contract number 034115.

References

[1] D. Simeonidou, R. Nejabati (Editors), “Optical Network Infrastructure for Grid”, GFD-I-036, http://forge.gridforum.org/projects/ghpn-rg/, August 2004.
[2] Dimitra Simeonidou, Reza et. al,"Dynamic Optical Network Architectures and Technologies for Existing and Emerging Grid Services", IEEE Journal of Lightwave Technology (JLT), Volume 23, Issue 10, Page(s):3347 – 3357, Oct. 2005
[3] A. Jukan, G. Karmous-Edwards, “ Optical Control Plane for the Grid Community”, Communications Surveys & Tutorials, IEEE, Vol. 9, Issue: 3, pp. 30-44, Third Quarter 2007
[4] E. Mannie (Ed.), “Generalized Multi-Protocol Label Switching (GMPLS) Architecture”, IETF RFC 3945, October 2004.
[5] G. Clapp, T. Ferrari, D.B. Hoang, A. Jukan, M.J. Leese, P. Mealor, F. Travostino, “Grid Network Services”, draft-ggf-ghpn-netserv-2, Grid High Performance Networking Research Group working draft, May 2005.
[6] ITU-T G.8081/Y.1353 Recommendations, “Definitions and Terminology for Automatically Switched Optical Networks (ASON)”, 2004.
[7] A. Farrel J.-P. Vasseur, J.Ash, “A Path Computation Element (PCE) – Based Architecture”, IETF RFC 4655, August 2006.
[8] G. Clapp, T. Ferrari, D.B. Hoang, A. Jukan, M.J. Leese, P. Mealor, F. Travostino, “Grid Network Services”, draft-ggf-ghpn-netserv-2, Grid High Performance Networking Research Group working draft, May 2005.
[9] A. Savva (Ed.), “Job Submission Description Language (JSDL) Specification, Version 1.0”, GFD.056, http://forge.gridforum.org/projects/jsdl-wg, November 2005.
[10] S. Andreozzi (Ed.), “GLUE Schema Specification – version 1.3”, Draft 3 – 16 Jan 2007, http://glueschema.forge.cnaf.infn.it/Spec/V13.
[11] G. Zervas, et al., “Grid Optical User Network Interface (GOUNI),” Open Grid Forum Draft, https://forge.gridforum.org/sf/docman/do/listDocuments/projects.ghpn-rg/docman.root.current_drafts, Feb 2007
[12] http://www.ist-phosphorus.org/
[13] http://enlightenedcomputing.org/
[14] Atsuko Takefusa, et. al, “G-lambda: coordination of a grid scheduler and lambda path service over GMPLS Source”, Future Generation Computer Systems ,Vol.22 , Issue 8, pp. 868 – 875, October 2006
[15] S. Figuerola, N. Ciulli, M. de Leenheer, Y. Demchenko, W. Ziegler, and A. Binczewski, PHOSPHORUS: single-step on-demand services across multi-domain networks for e-science, Proc. SPIE 6784, 67842X, (2007)