Deployment and Interoperability of the Phosphorus Grid Enabled GMPLS (G^2MPLS) Control Plane

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***Abstract*—Grid-GMPLS (G^2MPLS) is conceived as a powerful Network Control Plane solution that enhances the standard ASON/GMPLS architecture providing single-step resource reservation, co-allocation and maintenance of both network and Grid resources. This paper identifies and discusses the main issues and considerations that arise by Network Research and Educational Networks and network operators in order to facilitate the dissemination of G^2MPLS Control Plane. Interoperability issues and backwards compatibility with existing Network Control Planes centre the scope of this study, which intends to demonstrate the feasibility of adopting the proposed architectures.**

***Index Terms*—High Performance Grid Network Services, Optical Networks, Network Control Plane, G^2MPLS**

I. Introduction

GRID resource management is crucial in High Performance Grid Networks. The advent of new applications that make use of distributed Grid resources and huge amounts of bandwidth necessitates an underlying transport network capable of supporting the requirements posed by this type of services [1]. Optical networks, which are able to cope with the bandwidth requirements, need a Network Control Plane (NCP) to control transport resources in a dynamic and efficient way [2]. The deployment of a distributed Grid enabled NCP entails thrilling challenges derived from the enhanced procedures and functionalities that implement the concept of Grid Network Services (GNS) [3].

In the IST Phosphorus project, the solution adopted considers a Grid evolution of GMPLS protocols, namely G^2MPLS, which seamlessly serves Grid jobs by co-allocating and provisioning network and Grid resources in a single-step. The enrichment of G^2MPLS 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^2MPLS with standard GMPLS [4]. 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.

This paper presents a high level description of the proposed G^2MPLS network and service architectural (or Grid-network layering) models developed in the Phosphorus framework. Deriving from these models a set of network reference points is identified and characterized in terms of available functionalities along with enhanced G^2MPLS procedures. Moreover, the compliance of 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. With this purpose, some possible network scenarios of GMPLS and G^2MPLS co-existence are introduced and an evaluation of the achievable levels of interworking in signalling and routing procedures is provided.

The rest of the paper is organized as follows: in Section II a description of the two main Phosphorus architectural models (Overlay and Integrated) is provided and a set of network reference points derived by these models is identified in Section III. In Section IV the main considerations that arise when deploying G^2MPLS in current network infrastructures are analyzed. In section V environments where the coexistence of G^2MPLS and GMPLS architectures are necessary or required by the network operators are identified and explored. Also possible network scenarios of such co-existence are analyzed aiming at providing an evaluation of the achievable level of interworking in routing and signalling procedures. Finally section VI concludes the paper.

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II. Service Architectural Models

The Phosphorus framework identifies two architectural models, namely Overlay and Integrated. These models refer principally to the positioning between the Grid Service Layer and the NCP and require different capabilities of the G^{2}MPLS NCP.

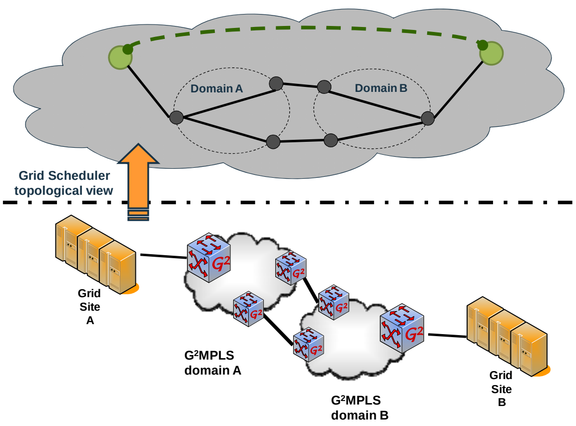

Fig. 1. G2MPLS Overlay Model.

In G^{2}MPLS Overlay model (Fig. 1 the Grid layer has both Grid and network routing knowledge. G^{2}MPLS acts as an information bearer of network and Grid resources and provides automatic configuration just for the network service part. In this context, the Grid layer (specifically the Grid scheduler) takes the leading role, being responsible for initiation and coordination of the reservation process through the participating Grid sites and the network. The Grid layer topological view needs to be augmented with the network topological view, so the Grid scheduler can send detailed connection requests towards the G^{2}MPLS (e.g. by specifying the ingress and egress network attachment points or possibly the explicit route to follow).

This model is intended to be a short-term evolution of state-of-the-art, because it improves knowledge and capabilities of the Grid layer, relies on advanced GMPLS features (e.g. advance reservations) that are still missing, but it does not provide the aimed one-step co-allocation of Grid and network resource yet. In fact, the two layers (i.e. Grid and network) remain asymmetrically aware of each other, and the level of awareness much depends also on the capability of the Grid layer – and the Grid scheduler in particular – to compute service distributions based on the details of network topology retrievable from the interface between Grid Clients and network (G.OUNI) [5].

In G^{2}MPLS Integrated model (Fig. 2), most of the functionalities for resource advance reservation and co-allocation are moved to the NCP. G^{2}MPLS is responsible for scheduling and configuring both the job parts related to the Grid sites and to the network. Grid sites are modeled as special network nodes with specific additional Grid resource information. The resulting topology is flat and integrated with respect to the positioning of the Grid layer against the network layer. The Grid scheduler functionality is still needed in this model to coordinate workflow services. In fact, the elementary unit of service managed by the G^{2}MPLS Control Plane is the Grid job, which is a component of the workflow.

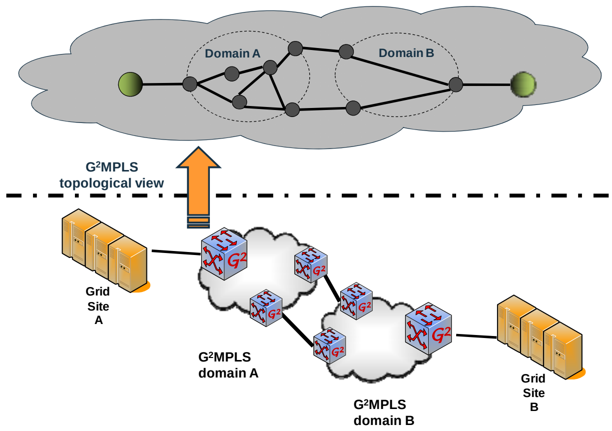

Fig. 2. G^{2}MPLS Integrated Model.

Due to the impact of the model on the existing Grid middleware and the advanced functionalities to be implemented by the G^{2}MPLS Network Control Plane, the Phosphorus integrated model could be considered a mid/long-term deployment solution for the Grid and network co-allocation.

III. G^{2}MPLS Network Reference Points

G^{2}MPLS 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. G^{2}MPLS 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 [6], but also provides a seamless and single-step control of both Grid and network resources.

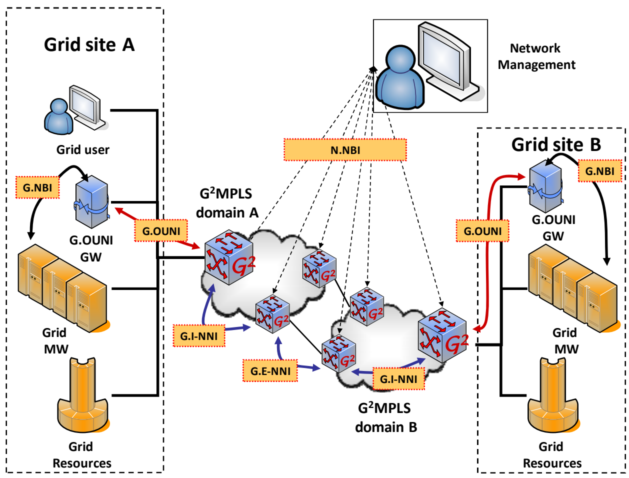

Fig. 3. G^{2}MPLS Interfaces.

The following network interfaces are identified in the G^{2}MPLS NCP (Fig. 3):

- 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^2MPLS 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.
- NBI, i.e. the Northbound Interface that groups two interfaces towards upper layers: one towards the Grid layer (G.NBI) and one towards the NSP (including NRPS, N.NBI).

In G^2MPLS Overlay model, 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).

On the other hand, the role of the network interfaces in G^2MPLS Integrated model 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^2MPLS is entered, and the G.E-NNI, by which the border between domains is traversed.

A. 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^2MPLS 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) 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 used to describe IT Resources (both capability and availability) is translated to routing messages (OSPF-TE) in order to publish resource information through G^2MPLS NCP.

B. 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 its functionalities through numerous routing and signalling messages for intra-domain and inter-domain communication. G.E-NNI can communicate with the standardised E-NNI in a downgraded configuration where only network functionalities are supported. The interfaces support Grid and network resource announcement, Grid and network resource discovery, Network Service requests, Grid Network Service requests, Network Service status enquiry and Network Service status notifications.

C. North-bound Interfaces

Grid Northbound interface (G.NBI)

Grid Network Service requires interaction and coordination of procedures supported both by Grid Middleware and G^2MPLS 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. The use of the G^2MPLS northbound interface by an NRPS and/or the NSP limits to network only the services exportable by that interface. Therefore, in this context G^2MPLS 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.

IV. G^2MPLS DEPLOYMENT CONSIDERATIONS

The deployment of G^2MPLS in existing network infrastructures raises some issues associated with the support of the offered Grid services. A number of these issues and required actions are introduced in this section focusing mainly on some management considerations.

A. Integration of Grid and Network AAA Mechanisms

Phosphorus proposes two approaches in order to extend the authentication authorization infrastructure (AAI) of existing infrastructures to support Grid Services:

- Full integration of Grid and network AAI systems,
- Separated services with information exchange.

The first approach assumes that there is a single AAA mechanism used for both network and Grid. This may potentially cause problems with maintenance of users and privileges database due to the large number of database entries. Network AAA systems do not usually include a large number of users, as it is limited to system administrators and operators but this is not the case with Grid where users may also be virtual such as projects, groups, etc. The most important advantage of this approach however, is full single sign-on, where users logged into Grid systems, are automatically authenticated to access network resources.

In the second approach, Grid and network AAA services are separated and an information exchange channel exists. In this case a single user must authenticate twice in order to get access to Grid and network resources. To avoid this problem users should authenticate only for Grid services and allow the Grid service to represent the users for network purposes (i.e. users will transparently have access to network services). Here, the network AAA must be aware of just the Grid services that will be authenticated. As this authentication is performed automatically, users are not forced to log in twice. The advantage of this approach is that Grid and network AAA are kept separately under management of specific administrators, who are not crossing responsibilities. On the other hand, there are two databases which must be kept consistent causing a maintenance problem and complicate charging issues.

B. SLA Operation and Maintenance

Service Level Agreement (SLA) as a part of AAA system is generally an administrative contract and does not contain technical service specification. The technical details like QoS requirements or traffic characteristics are described through Service Level Specification (SLS) allowing the support of a number of procedures like advance reservations. In general the SLA management system proposed for GMPLS can be extended to service the G^{2}MPLS architecture but several modifications are still required. The main extensions to the SLA template include the description of grid resource requirements and job specifications. SLA maintenance and scheduling procedures also require in advance synchronization of grid and network resource access and reservation to ensure reliable job execution.

The process of SLA negotiations can be split into two depended steps. First, network SLS is processed according to the rules defined for the G^{2}MPLS architecture along with grid constraints. If network negotiations are finished the grid resource reservations procedure is triggered. When the required grid resources are available in the local domain the grid SLS record is performed locally and if the resources belong to some other domain the grid part of the SLA is sent to the next peer domain towards the grid domain. Negotiations are successfully accomplished and the SLA is accepted only if both network and grid parts, requirements, dependencies and constraints can be fulfilled.

C. Resource Partitioning and virtualization

G^{2}MPLS as an enhancement to the ASON/GMPLS control plane architecture inherits the rights for full usage of the Transport Plane (TP) resources assigned to its ownership. In this case, the Management Plane (MP) entities (e.g. pre-existing Network Management Systems (NMS)) which could possibly compete with G^{2}MPLS for transport network (TN) resources, can modify the resources exported by the Control Plane and manage them as virtual resources according to the G^{2}MPLS information model. Moreover, the existence of advance reservation services in G^{2}MPLS entails a problem of resource partitioning due to the temporal dimension of TP resources. Therefore, it is interesting to have a disjoint partition of the available network resources under the authority of the G^{2}MPLS Control Plane and maintaining some others under the management plane (including NRPSs), as shown in Fig. 4.

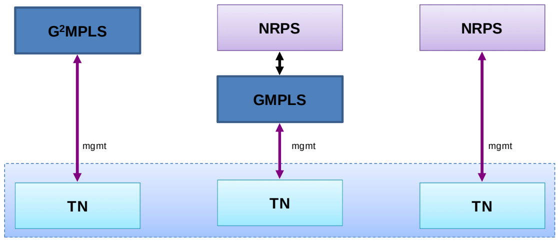

Fig. 4. Resource partitioning among G^{2}MPLS, NRPS with GMPLS and NRPS.

The simplest partitioning scheme that can be implemented in this case selects resources to be used for bookings from a disjoint set with respect to those that could be used for immediate reservations. This approach simplifies routing and signalling operations of the respective connection modes by guaranteeing a uniform semantic for resource availability specification in time and the creation of complete and coherent set of resources. The latter, is particularly needed in case of non-label swapping for specific connections (i.e. non timeslot interchange in TDM networks, non wavelength conversion in DWDM networks). In this case, a label is completely available either for advance or for immediate reservations and the existence of a solution for the non-label swapping problem along the designated path could exist just in one of two disjoint solutions spaces (i.e. the advance or the immediate).

More complex partitioning schemes might include resource re-partitioning in time. The definition of these schemes and procedures relies mainly on the Network Operator policies for offering connection services and depends on the expected connections requests.

D. Integration of G^{2}MPLS management in existing NMS

Network operators, willing to deploy G^{2}MPLS NCP, will probably require using the existing Management Plane, composed of an NMS. These expectations will motivate the introduction of GMPLS functionalities and the Grid related extensions into NMS, which should give the ability to monitor Grid resource localization, capability, availability and usage. This knowledge will be gathered and provided to the MP by the Grid site adjacent CP entities, and used during the failure localization and reparation processes. Besides, the MP will have the information about grid and network resource binding which exists in relation to particular GNS requests.

V. Coexistence/Interoperability of GMPLS and G^{2}MPLS NCP

The G^{2}MPLS NCP derives from the ASON/GMPLS architecture and has been defined as a superset of the original ASON/GMPLS functions and procedures in support of the specific functionalities required by Grids. The study of the relationships between G^{2}MPLS and GMPLS domains is an interesting use-case, from which an evaluation of the achievable levels of interworking in signalling and routing procedures can be derived.

A. Applicability of the network reference points

The ASON architecture is built around the identification and description of network reference points (i.e. UNI, I-NNI, E-NNI), which represent a convergence point for the main architectural features and protocol actions. G^2MPLS inherits these reference points and elaborates on them in order to provide the required extensions in support of Grids, thus, defining a G.OUNI, G.I-NNI, G.E-NNI. Any evaluation of the coexistence issues between G^2MPLS and ASON/GMPLS domains should consider compatibility and possible interworking between the two sets of network interfaces.

This section describes the problem under two perspectives, i.e. the intra-domain and the inter-domain, being these the main frameworks for a complete analysis of the co-existence of two different Network Control Planes.

Intra-domain Coexistence

Intra-domain is generally related to the Internal Node-to-Node Interface between NCP performers. ASON/GMPLS I-NNI is a standardized network reference point in which GMPLS-controlled equipments by different vendors could establish peering relationships. G^2MPLS requires a complex set of extensions to the base GMPLS protocols for Grid purposes, both in terms of routing (e.g. advertisement of Grid capabilities and information permeability at the G.OUNI) and of signalling (e.g. procedures for the setup and maintenance of Grid Network Services through GNS transactions). While routing extensions rely on OSPF Opaque LSAs and could be just forwarded – though neglected – by standard GMPLS controllers, part of the signalling extensions cannot be ignored by pure GMPLS nodes and could lead into unsupported operational conditions resulting in a final block of signalling.

However, the use of the G^2MPLS architecture and controllers in a mode reduced to standard (i.e. for the implementation of just standard connection services as per ASON and GMPLS architectures) does not raise any interworking problem between G^2MPLS and ASON/GMPLS nodes in terms of architectural design and protocol behaviours. In fact, G^2MPLS is defined to be backward compatible and down-gradable to standard GMPLS just by cutting off new Grid-specific services (e.g. advance reservations and time limited bandwidth reservations) and resource advertisements.

The most convincing future scenario for an intra-domain coexistence of G^2MPLS and ASON/GMPLS controllers seems to be that of a multi-region domain, in which G^2MPLS controllers are used to provide NCP capabilities to equipment currently lacking it (e.g. carrier Ethernet switches or similar). In this scenario, the main envisaged role of the GMPLS NCP is to set up and maintain Forwarding Adjacencies (FA) across the served TN section in an automatic, highly dynamic and adaptive way. On the other side, G^2MPLS just uses these FAs in the technology layer/region under its control.

Coexistence across different domains

In the Inter-domain coexistence of G^2MPLS and ASON/GMPLS scenario a reduction of the information set carried out through the G.E-NNI occurs with routing and signalling purpose. In a G^2MPLS domain both Grid and network resources are under the same control, while in an ASON/GMPLS domain only network resources are controlled.

Concerning E-NNI routing, the G^2MPLS advertisement process (TE + Grid) is designed to be based on OSPF Opaque LSAs as in standard ASON/GMPLS and, thus, any node in these domains must be an opaque-capable router that generates and floods LSAs towards its neighbour. A real issue in the G.E-NNI routing applicability is the detail of network topology exported by each domain towards its peers, which has a direct impact on path computation and advance reservation capabilities. However, this issue rises also in case of homogeneous G^2MPLS vs. G^2MPLS interfacing and has different solutions with different levels of optimality and scalability. Some possible solutions are ranged in:

- Advertisement of just domain capabilities,
- Advertisement of domain border nodes and inter-domain links,
- Advertisement of domain border nodes, inter-domain links and a summarization of virtual TE-links among the border nodes (intra-domain links),
- Coordination with signalling means such as crankback.

Concerning E-NNI signalling, the main architectural problem which limits the applicability of the two E-NNI models relies on new G^2MPLS concept of destination end-point, which, in the anycast case, could be unspecified in terms of network attachment point but detailed in terms of Grid capabilities. In fact, the destination network attachment point is mandatory for an ASON/GMPLS call. A possible solution in this case could be to limit this G^2MPLS behaviour in a single domain, or to run the Grid resource localization process and bind to a network attachment point in the first G^2MPLS domain traversed.

B. Network scenarios

Two relevant scenarios are described here to summarize the models for coexistence of G^2MPLS and ASON/GMPLS NCPs. Services initiated in a GMPLS domain and terminating or traversing a G^2MPLS domain cannot be modified in G^2MPLS Network Services (e.g. with advance reservation), but must stick to the only service mode defined in ASON (eg. immediate and long-living calls/connections.)

Two-parties scenario

In this scenario a GMPLS and a G^2MPLS domain are directly interfaced (Fig. 5). Grid users and resources, wrapped by the Grid middleware, result localized just in the G^2MPLS domain. Both Phosphorus Overlay and Integrated models are possible for establishing the GNS transactions.

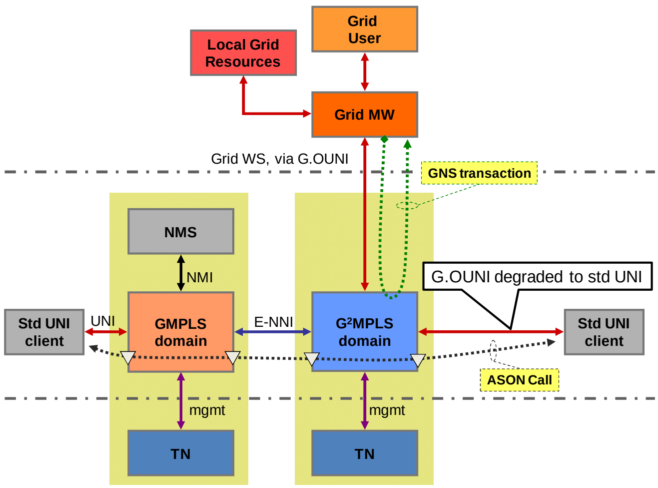

Fig. 5. Two-parties interworking between G^{2}MPLS and ASON/GMPLS.

The G.OUNI interface conveys the Grid WS semantic from the middleware towards the G^{2}MPLS for establishing the GNS (Integrated case) or just the network part of it (Overlay case). However, the G.OUNI could "degrade" to a standard UNI for standard ASON call services. The G.E-NNI is not needed in this scenario and thus it "degrades" to standard E-NNI. ASON call is segmented according to the ITU recommendations into connections (LSP), with the end-points briefly sketched in Fig. 5 (reverse grey triangle).

Three-parties scenario

In this scenario two G^{2}MPLS domains are "bridged" by a GMPLS domain (Fig. 6). Grid users and resources on both sides are locally managed by the Grid middleware components. Both Phosphorus Overlay and Integrated models are possible for establishing the GNS transactions, with the limitation of explicit indication of the destination end points, in order to create calls and connections in the GMPLS domain with standard signalling session descriptors.

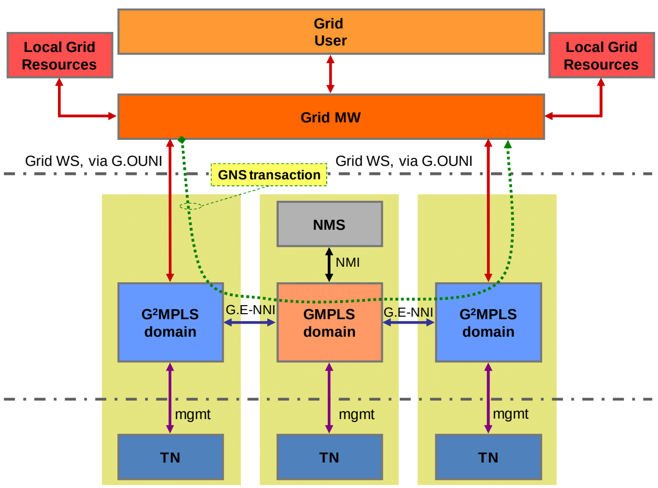

Fig. 6. Three-parties interworking: ASON/GMPLS in the middle.

VI. Conclusions

The two proposed deployment models of Phosphorus G^{2}MPLS Control Plane (Overlay, Integrated) provide a high level discussion of the identified network reference points and procedures required to implement the concept of Grid Network Services. In this paper, case studies toward the deployment of G^{2}MPLS Control Plane and network scenarios dealing with the coexistence of GMPLS and G^{2}MPLS architectures have been presented.

Moreover, issues like AAA functionality and resource partitioning under the G^{2}MPLS Control Plane have been also investigated. The compliance of G^{2}MPLS and ASON/GMPLS architectures 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, which enables an easy adaptation of G^{2}MPLS in current research networks.

Acknowledgment

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