Invited Paper

A Distributed Optical Grid Network Infrastructure for Future Easy-to-Use Innovative Network Services

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ABSTRACT

Extending the researches on wavelength switched optical networks (WSON), efficient integration of the novel optical packet switching network and wavelength switching-based optical circuit switching network technologies which offers both best-effort packet delivery and QoS guaranteed lightpath services has been being studied. In addition, researches on the optical-layer transparent data processing, such as all-optical wavelength multicasting, all-optical 3R regeneration, etc, are conducted simultaneously. It is believed that future innovative optical network services (INSes) would be built on these novel future-proof technologies, and foster colorful applications in the new generation networks. Before the wide applications of INS in different fields, there would be a foreseeable strong requirement for INS firstly posed by pioneer grid applications, e.g., e-science, e-government, and e-banking, etc, which would require the high-performance underlying networks. Our research here is motivated to glue the optical networks and grid applications by integrating lightpath, geographically distributed INS systems and grid resources (e.g., computers, storages, instruments, etc.), and finally offering an easy-to-use high performance networked grid computing environment—optical grid network (OGN) to user applications. In this paper, we introduce our research activities of a distributed optical grid network infrastructure (OGNI), and the creation of the future easy-to-use INS based on OGNI. The proposals have been validated through field-trial experiments over a developed WSON testbed.

Keywords: lightpath, optical grid network, distributed control, innovative optical network service, wavelength-multicasting, integration

1. INTRODUCTION

It is believed that with the huge potential in cost-efficient computing, grid computing will infiltrate into different fields and bring huge impact to the human society in the future[1]. Currently, frontier scientific researches such as data-intensive particle physics experiments for the Large Hadron Collider (LHC), very long baseline interferometry (eVLBI), etc, and large-scale high performance distributed/parallel computing (HPC) applications which are enabled by grid computing rely on high performance communication environment to integrate the globally distributed grid resources (e.g. computers, storages, instruments, etc.).

As regards the high-performance underlying network, extensive research and standardization works on wavelength switched optical networks (WSON) can be found in literature[2,3]. Extending the researches on WSON, efficient integration of the novel optical packet switching network and wavelength switching-based optical circuit switching network technologies which offers both best-effort packet delivery and QoS guaranteed lightpath services has been being studied[4]. Lightpath service in WSON will enrich future applications by providing high performance communication environment to end users directly. Applications established on the grid computing and optical networking (i.e., lightpath) technologies are under research. There is a strong requirement for the automated construction of a high-performance multiple-lightpath optical networks for grid applications, namely, optical grid network (OGN), so as to dynamically integrate the distributed grid and optical network resources in the new generation network.[5-9].

In addition, researches on the optical-layer transparent data processing, such as all-optical wavelength multicasting, all-optical 3R regeneration, etc, are conducted simultaneously[10-14]. Future innovative optical network services (INSes)

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would be built on these novel future-proof technologies, and further foster colorful applications in the new generation networks. Before the wide applications of INS in different fields, pioneer large-scale grid applications e.g. for e-science researches would be the first and motivated to take the advantage of these innovative technologies for high performance and new capabilities.

On the other hand, at a primary stage of INS technology, most of INSes need requirement validations through wide applications (i.e., not only on a limited testbed) at first before standardization and deployment. Also due to the high cost and potential risk in investment, most of service providers might have no incentive to implement INS firstly. To construct INS-enabled value added optical grid networks (OGN) for first trial, certain optical network carrier might agree to integrate grid and INS resources in their single administrative domain, and might apply an integrated control plane for both grid and optical network control (e.g., introduced in the PHOSPHOROUS project[7]) with necessary extension for INS control. Meanwhile, by the nature of large international collaborations and large-scale distributed computation, grid applications are implemented on grid resources which are geographically distributed cross over multi-domain networks. However, it is hard for all the carriers to agree to support the non-standard services. Thus, it is almost impossible for INS being applied by applications in a wide range as the built-in service from underlying optical networks. Hence, a practical approach to the value-added OGN construction is required. Here, our research is motivated by the following concerns: (i) offer the high performance OGN to large-scale high-end grid applications over multi-domain WSONs, (ii) provide an approach to the validation of the emerging optical innovative network technologies through applications, (iii) ease the INS creation and encourage people to apply INS technology and provide INSes quickly.

In this paper, we introduce our research activities of a distributed optical grid network infrastructure (OGNI), and the creation of the future easy-to-use INS[16,17] based on OGNI. The proposals have been validated through field-trial experiments over a developed WSON testbed. The rest of the paper is organized as follows: Section 2 describes related works about OGN. Section 3 introduces the distributed OGNI. Section 4 describe the creation of the future easy-to-use INS with a four-wave mixing (FWM)-based wavelength selective multicasting as an example of INS. Section 5 presents some experimental results of field-trial over a developed WSON test bed to validate the integration of grid and INS. Section 6 summarizes this paper.

2. RELATED WORKS

Users may construct OGNs by applying optical virtual private network services (i.e., addressed in the open grid forum (OGF)) that are provided by carriers. The standards for L1VPNs are emerging: ITU Y.1312 provides requirements, Y.11vpnarch provides the architecture, and RFC4847 and RFC5251 provide the control mechanism for Generalized Multi-Protocol Label Switching (GMPLS)-based networks. In a multi-domain WSON environment, which involves multiple carriers, with increased complexity, the control issues in L1VPN are out of the current scope of standardization bodies.

To achieve an efficient dynamic optical network construction for grid applications in terms of both grid and network resource utilizations, the architecture consisting of the grid resource management (GRM) system and the network resource management (NRM) system, and different approaches of collaboration between the GRM and the NRM have been presented in some representative researches[6-8]. One approach is that the NRM fulfils the exchange of information for both grid and network resources. A novel concept of an integrated control plane for both grid and optical networks was introduced in the PHOSPHOROUS project[7]. Another representative example was presented in the DRAGON project[8]. In the GRM the application specific topology (AST) is provided to the NRM. Within the network control plane, the OSPF-TE protocol is extended with authentication, authorization, accounting (AAA) concern. A network topology information aggregation scheme across multi-domain networks is presented for the optical network construction, as well. It should be noted that when the resources of the grid and network are entirely contained within an administrative domain, it is possible to maintain the complete resource availability information. Hence, these mechanisms for control and resource optimization will be applicable. While, in a multi-domain optical network environment including different carriers, with different policies on control plane usages, information disclosure and increased dynamic requests, it is difficult to support the required control plane extensions and maintain the complete resource availability information for the efficient resource optimization in OGN construction.

Another approach is that the GRM requests network information from the NRM via a specific interface. Such an interface has been addressed and implemented in the G-lambda project[6], where the information exchange is achieved through SOAP/HTTP-based communication. Moreover, a novel scheduling-based advance reservation scheme to avoid blocking of lightpath requests is presented.

In most of the previous representative researches such as that presented in the G-lambda projec[6] and the DRAGON project[8], centralized systems i.e. GRM and NRM are employed. This represents an approach to the management-based OGN creation, in which the control of OGN construction among grid resources is performed by management systems. Meanwhile, when the scale of grid systems increases, the load on the central management system will increase accordingly. Moreover, the reliability of the central management system turns to be extremely important, and assuring the reliability would be more costly. Therefore, to avoid a highly centralized control/management system, decentralized OGN control which decouples the OGN control from GRM, and performs the OGN creation in a distributed fashion would be beneficial.

To ease the usage of OGN, end-hosts' configuration such as the automatic IP address assignment/configuration is needed. In most of previous researches, L2 switches are connected with lightpaths, and all the end-hosts are connected to these L2 switches. There is the reachability among the end-hosts' data plane interfaces in L2 network. Thus, DHCP or the decentralized automatic IP address configuration scheme presented in RFC 3927 are applicable. However, with the utilization of end-to-end lightpaths, the L2 reachability is not necessarily assured among all the end-hosts in OGN. Hence, to take the advantage of end-to-end lightpaths reaching end-hosts directly (i.e., resulting in a simple network environment), without the L2 reachability among the end-hosts' data plane interfaces, a new end-host configuration scheme is required. In particular, a wavelength-oriented interface configuration scheme is necessary to enable users to employ the appropriate lightpaths of different wavelengths which are assigned by WSON dynamically.

3. OPTICAL GRID NETWORK INFRASTRUCTURE DESIGN

3.1 Target OGN Construction Scenario

In the future, interconnected WSONs will form a global optical lightpath service platform by providing high-quality end-to-end lightpath service crossover multiple domains. Users can take the advantage of the public lightpath service so as to enable their large-scale optical grid applications in a cost-efficient way. In this study, our target is to construct the end-to-end OGN reaching the end-host directly, where no L2/L3 switches are equipped between the end-hosts, resulting in a simple network environment. With respect to the OGN requests, in addition to an early scheduled OGN construction, which reserves lightpaths far in advance (i.e., the advance reservation presented in the G-lambda project[6]), some users may require a rapidly responded on-demand OGN construction. Here, the rapid-response on-demand OGN construction is our focus. Figure 1 outlines such an on-demand OGN construction scenario. When a group of allocated grid hosts are to be connected with an OGN, the host that received the OGN request is selected as the master node for initiating the OGN construction task. The other hosts are slave nodes for this task. Different tasks may require different hosts as the master nodes. In each task, the master node cooperates with the slave nodes to construct the OGN automatically in a distributed fashion.

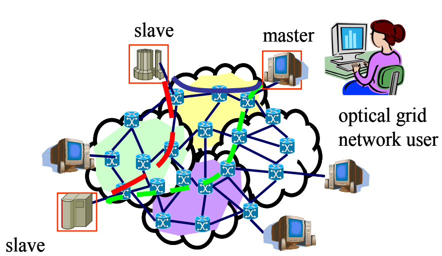


Figure 1. On-demand OGN construction over multi-domain WSONs.

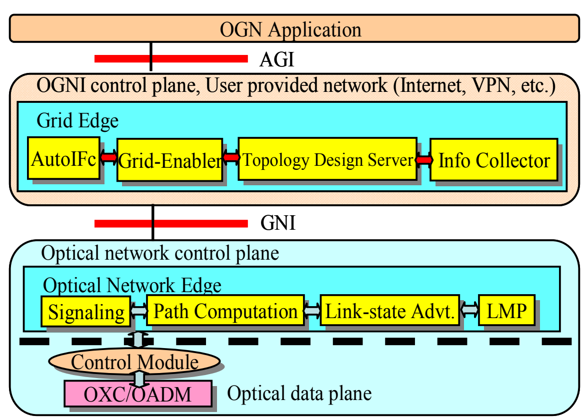


Figure 2. Edge node architecture in OGNI design.

3.2 System architecture design of each node

The OGN is constructed in a totally distributed manner by OGN edge nodes, which are the hosts equipped with optical network interfaces for data communication purposes. Figure 2 shows a schematic diagram of the OGN edge system architecture in OGNI. The OGN edge consists of two edge subsystems: grid edge and optical network edge. The grid edge deals with the setup and release of OGNs. It consists of four components: grid enabler, topology design server, info collector, and automatic interface configuration tool (AutoIFc). Grid enabler provides signaling functionality for OGN construction based on OGN topology specification. Topology design server calculates such a topology of OGN for application if the topology is not specified by applications. Information collector disseminates both grid-host related information (e.g., availability of CPU power, memory, storage, DWDM optical network interfaces), and lightpath related information (e.g., price and estimated delay of lightpaths between nodes, etc.). AutoIFc performs end-host configuration (e.g., automatic address assignment and wavelength-oriented network interface configuration). Due to the space limitation, the details of individual components are omitted hereinafter. The readers are referred to the literature[9] therein. In the OGNI design, the optical network edge employs a suite of protocols, for signaling, path computation, link-state advertisement, and link management. In OGNI implementation, GMPLS is employed for the currently available control technology. OGN applications (or a remote management system) interact with the grid edge in node by sending/receiving OGN requests/results through the application/grid edge interface (AGI). The grid edge interacts with the optical network edge through the grid edge/optical network edge interface (GNI) so as to conduct the lightpath services of WSON and receive the result (e.g., indicating one of the following statuses: waiting, success (i.e., indicated by the assigned wavelength number when setup a lightpath), failure (i.e., blocking in lightpath creation)). Basically, this GNI defines the same interactions as those in the standard user/network interface (UNI) for the normal non-grid systems that can use lightpath services.

3.3 Overlay model and simple GNI concern

In the multi-domain WSON scenario, as carriers may have different policies on resource information disclosure and control message exchanging, it is difficult for all carriers to implement the OGNI protocols within their control planes. Thus, the OGNI protocols are implemented in an independent control plane, e.g., using a pre-established L2/3 VPN or the Internet, which is outside the carriers' control plane networks. In this overlay model, the grid system providers or users see the optical networks as a black box. The optical networks provide well-defined lightpath services to clients. This overlay approach conceals the architecture of the underlying heterogeneous optical network systems for grids. It provides grid service providers or users the flexibility to establish composite lightpath network services to crossover a complex multi-domain network environment, and build high-level services to enable colourful applications and enrich the optical networks as well. In fact, this architecture does not exclude an integrated grid/optical network system in a single administrative domain scenario. In this case, GNI can be extended to support more complicated interactions for the jointed control of grid and optical network.

3.4 Protocol of OGN construction

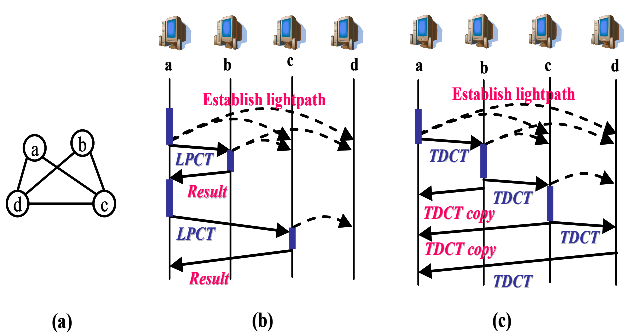


Figure 3. Tokens in LPCT and TDCT signaling.

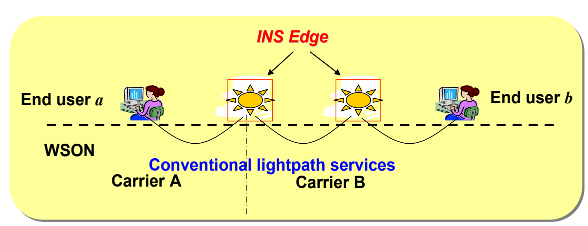


Figure 4. On-demand value-added OGN construction for grid/INS users over the multi-domain WSONs.

For OGN construction, within the grid edge, the grid enabler coordinates between different components and performs signaling of OGN construction with peer grid enablers in other OGN nodes. Here, the signaling is different from that in the network control plane, such as RSVP-TE in GMPLS. The signaling described here represents the high layer functionality for OGN construction in a P2P fashion. We present two token-based signaling designs: lightpath provisioning control token (LPCT) and topology design control token (TDCT) signaling. Both of these signaling systems work in a distributed fashion. Figure 3(a) shows an example of the desired topology (i.e., specified by users or solved by the topology design server described later). Figures 3(b) and 3(c) depict the OGN construction schemes for LPCT and TDCT, respectively. An OGN construction task has one master node (node *a*) and all the other nodes involved in the task are slave nodes (nodes *b*, *c*, and *d*).

In LPCT signaling, an OGN topology profile is inputted first for OGN construction. When the OGN topology is not specified by users, the grid enabler conducts the OGN topology blueprint design service executed by the topology design server. According to the OGN topology, the grid enabler issues lightpath provisioning control tokens to the slave nodes; these slave nodes are the ingress nodes of the required lightpaths. The candidate node is selected according to the out-degree in the un-constructed OGN topology; the node with the large degree is selected first. The necessary information for lightpaths provisioning (e.g., the OGN control plane node IDs of the source, destinations, corresponding to the ingress node ID and the egress node ID in the optical network i.e. WSON control plane, etc.) and the setup/release actions are encapsulated into the lightpath provisioning control tokens. The grid enabler at each slave node interacts with the local optical network edge through GNI to execute the lightpath provisioning actions by conducting the signaling functionality in the optical network control plane (e.g. RSVP-TE in GMPLS). The route of the lightpath is computed by the path computation functionality within the underlying optical network. Results of the path IDs and wavelength numbers of successfully established lightpaths and failed lightpaths which are received from local optical network edge (i.e. through GNI) should be returned back to the master node. Upon receiving the results, the grid enabler at the master node updates the un-constructed OGN topology by pruning the successfully established lightpaths, and decides whether the OGN construction processes should be continued or not. When no failure occurred in lightpath provisioning, the construction process is continued, and the next node with a large degree in the un-constructed OGN topology is selected. In OGNI implementation, in order to avoid wavelength resource contentions among concurrent lightpath requests of the same task, a sequential LPCT transmission approach is adopted. It should be noted in Fig. 3 that the setup of each lightpath is fulfilled by employing the signaling protocol of the WSON control plane (e.g., RSVP-TE). For simplicity, the details of RSVP-TE signaling processes and path computation in the underlying optical network control plane are not shown in Fig. 3(b) and Fig. 3(c). The setup process of each lightpath is summarized with the broken-line. The protocol of LPCT and TDCT are highlighted and illustrated with the solid-lines.

In TDCT signaling, OGN construction is achieved by negotiating among all the grid enablers involved in the same task. For each node, after establishing a group of lightpaths starting from itself (e.g., one part of the user-specified OGN topology), it is possible to commit the entire OGN construction task to other nodes by sending the topology design control tokens. The topology design token includes the completed context for the OGN construction task. If the topology design is required, even optimization tools (e.g., the code itself or a URL indicating the location where the code can be retrieved) can be included so that each node can run the same optimization code to solve the partial OGN topology. In Fig. 3(c), the OGN construction with specified topology using TDCT is depicted. After lightpath provisioning at each node, the next source candidate is selected. Finally, when the TDCT comes back to the master node, the OGN construction task is completed. Although TDCT provides a flexible means for negotiation and load balancing during OGN construction among different nodes, the TDCT itself is more complicated compared to the lightweight LPCT.

As that mentioned above, the signaling and the path computation of each lightpath are implemented within the underlying optical network. This overlay concern is based on the assumption that different optical network carriers have different policies on the network resource information disclosure. No details of resource information would be shared among them. Hence, grid edge cannot specify the route of the lightpath. However, when the grid and optical network resources are within the same administrative domain, the detailed network resource availability information can be provided to grid edge through an extended GNI. In this case, the route of each lightpath can be calculated by the grid edge during the OGN topology design for optimal resource utilization, and the explicit route can be specified in the request of lightpath which is conveyed by LPCT or TDCT. LPCT and TDCT can be extended to carry such explicit route information of the multi-hop lightpath (i.e., spanning multiple fibre links in the underlying WSON) specifying the sequence of intermediated nodes along the path.

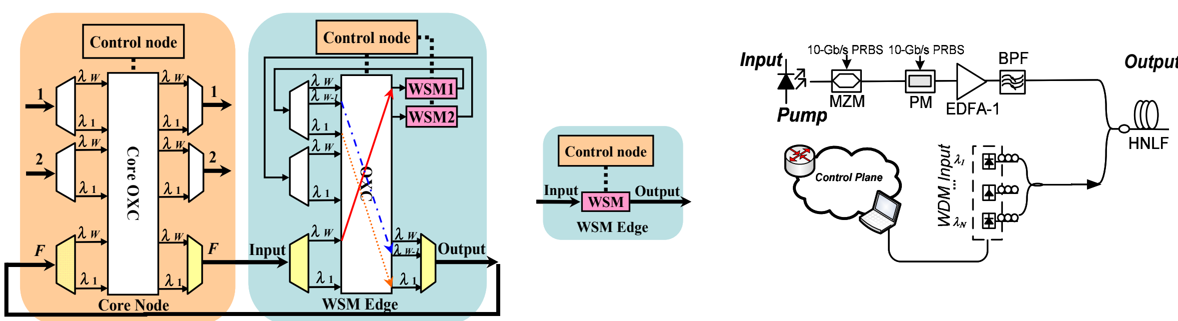
4. WAVELENGTH SELECTIVE MULTICASTING INNOVATIVE OPTICAL NETWORK SERVICE: A COLORFUL-LIGHT-TREE

4.1 An overlay approach to the value-added OGN with WSM: a colorful-light-tree

In the future, grid users can take advantage of the commercial available lightpath service in WSON to enable their OGN applications in a cost-efficient way. In addition, pioneer grid users are the first and motivated to take advantage of optical INSEs for further high performance and new capabilities. As mentioned above, to ease the application of new INS for grid applications, we practice an overlay approach to the integration of grid and INS resources establishing value-added OGNs automatically. Figure 4 illustrates such an on-demand value-added and INS-enabled OGN construction scenario. Lightpaths are established between desired grid hosts and INS systems. To focus on the construction of the value-added OGN, hereinafter, the grid and INS resources selection is assumed to be done before the OGN construction.

4.2 INS-edge and flexible INS leverage

It is believed that from the view point of network carriers, the new-born INS technologies might have a high inventory-cost and risk at the primary stage. Moreover, without standardization both in hardware interface and control system interface, these new technologies would be hardly integrated into the core networks to provide widely used services to society, therefore no service no users. In consequence, without broad applications at user side, it is difficult for vendors and service providers to manufacture and leverage INSEs. With respect to the INS implementation, the integration of INS within core node systems will be beneficial to conceal the complexity to the outside. However, the future non-blocking core optical switch itself will have a large scale therefore a large complexity, further integrating INSEs into core switches will face to the scale limitation due to the drastically increased complexity of new core switching system [10].



(a) (b) (c)

Figure 5. Edge-mode implementation of INS. (a) WSM edge; (b) a lightweight WSM edge; (c) structure of the WSM unit.

To prevent the core node system from serious scalability problem, new-born INSEs might not be expected to integrate into the core system directly. Hence, in this research, we introduce a concept of INS edge and present an edge-mode approach which leverages INS technologies and provide INSEs at a special edge node, e.g., close to the core switch, to reduce the complexity of future large-scale core optical switch node. In such a kind of INS edge, for example, all optical wavelength conversion-capable multicasting[10-12], all-optical 3R (O-3R)[13-14], modulation format conversion, future faster or special optical signal processing (e.g. for improving speed or quality of transmission which might need transparent lightpath services) etc, or further efficient integration of these capabilities can be equipped. As one instance of INSEs, we implement a multi-function wavelength selective multicasting (WSM) unit as mentioned previously. Figure 5 depicts this edge-mode WSM INS, which is introduced at edge and using a fibre port (multiplexing/demultiplexing W numbers of wavelengths) e.g. port F of core optical cross-connect (OXC). By establishing one input unidirectional lightpath (e.g. λ_w) and multiple output unidirectional lightpaths (e.g. λ_1 and λ_{w-1}), WSM INS can be provisioned to users by INS service providers. Figure 5(a) depicts a possible WSM edge structure with the flexibility for WSM extension. For instance, more WSM modules e.g. WSM2, WSM3 can be appended into one WSM edge. For further WSM extension extra WSM edge nodes can be equipped, as well. By appropriately configuring the OXC various optical signal processing functionalities can be integrated into high-level value-added INS and offered to users easily and quickly. The basic functional elements in INS edge can be reused to build up new service, resulting in the great cost-saving. In addition to these highly integrated INSEs in a single INSEs box, various relatively small-scale INS service providers can individually build up their own simple INS edges which might be of different functions over WSON. These functionalities then can be further dynamically integrated over WSON flexibly, forming colorful optical services. In Fig. 5(b) a simple INS edge with only one WSM unit is illustrated. To validate grid and WSM INS integration, in the implementation of field trial experiment shown later, we utilize this simple WSM edge. Figure 5(c) illustrates the structure of the WSM unit[16]. It should be noted that, with this edge-mode, new optical INSes (e.g. WSM INS) can be introduced as network services flexibly. In particular, it is beneficial for network to upgrade supporting new capabilities or change the locations of INS edges to where the function is desired without interfering other ongoing lightpath services.

4.3 Distributed optical grid/INS network infrastructure (OGINI)—extension from OGNI

Based on the INS edge concern, for efficient integration of grid and INS resources, we first extend the scope of grid resource to include the INS resource in a broad meaning. We can consider that both the traditional grid resource and INS resource are over optical networks. They all can be abstracted as information processing nodes. For instance, grid resource operates information logically, optical INS resource also operates information but in a physical layer. Hence, generally speaking, based on this similarity on information processing, INS resource could be treated as a special type of grid resource. With this unification, we see the grid/INS integration problem as an extended OGN construction problem, which sets up multiple lightpaths to connect geographically distributed grid/INS resources, and performs individual local configurations at each node to build the final communication environment. Different types of grid resources require different configurations. Extending the architecture of OGNI, we introduce a unified platform—optical grid/INS network infrastructure (OGINI) for resource integration. Figure 6 shows a schematic diagram of the OGN edge node architecture in OGINI. In OGINI there are two types of end-node configuration modules, namely grid-cf (i.e., AutoIFc) and INS-cf. They are for grid's network interface configuration, INS component configuration, respectively.

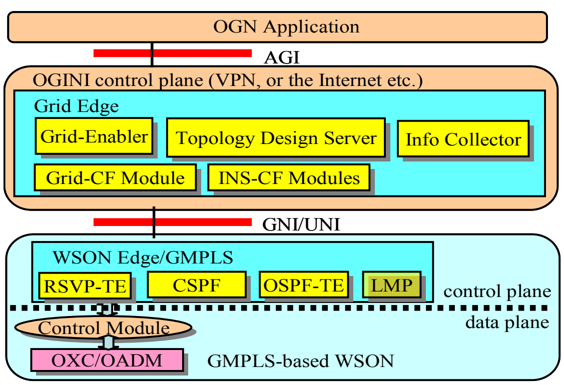


Figure 6. OGINI architecture.

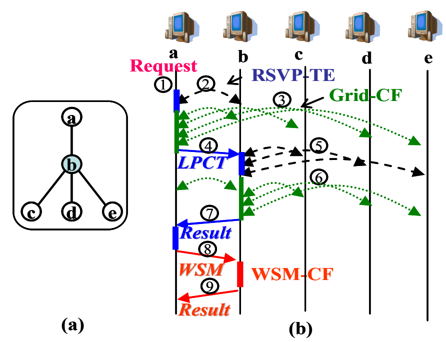


Figure 7. A tree construction example: (a) a specified tree, (b) protocol.

4.4 Construction of Value-added OGN with WSM

Figure 7 depicts a multicast tree provisioning example with a logical tree specification shown in Fig. 7(a), with source host *a*, and destination hosts *c, d* and *e,* where *b* is the INS node equipped with WSM. When no topology is specified, topology design server optimizes a logical topology (i.e. without routing and wavelength assignment (RWA) of individual lightpaths) within given grid and INS nodes set. A desired topology the protocol for provisioning is shown in Fig. 7(b). (1) One grid application sends a tree topology request to the grid edge at node *a* via the application/grid edge interface (AGI). (2) Grid enabler at node *a* sends lightpath setup requests to the optical edge via GNI/UNI to setup a unidirectional lightpath terminated at node *b.* RWA of lightpath is solved within WSON. (3) Upon receiving the assigned wavelength information via GNI/UNI, grid-enabler trigger grid-cf to negotiate with all other involved nodes to assign a unique IP address for the local interface which is attached to the selected wavelength. (4) Grid-enabler selects the branch nodes (here it is node *b*) and sends it a lightpath request set (i.e. the lightpaths started at that branch) with lightpath provisioning control token (LPCT) message. (5) Grid-enabler at node *b* sequentially issues three unidirectional lightpath requests to the local optical edge via GNI/UNI to establish lightpaths terminated at node *c*, *d* and *e*, respectively. (6) Upon receiving the assigned wavelength information grid-cf is triggered to assign unique IP addresses and configure the local interfaces at node *c*, *d* and *e*. (7) The results including three lightpath IDs and wavelength numbers of the lightpaths (i.e. started from node *b* and terminated at node *c*, *d* and *e*) are sent back to node *a*. (8) Upon receiving these results grid-enabler at node *a* triggers WSM-cf to send WSM configuration request to each branch node (here, node *b*) with WSM message indicating: the dynamically assigned wavelength numbers of inputted and outputted lightpaths at each branch node. Then WSM-cf at each branch issues WSM laser configuration command to the attached WSM unit to enable and tune the lasers to the desired wavelengths according to the input and output wavelength information. (9) After WSM unit configuration, branch nodes (here, node *b*) send results to node *a* for confirmation. Upon receiving confirmation, source node *a* initiates application and sends contents to destinations in the optical light tree. Thanks to the integrated wavelength conversion capability in WSM, no global multicast-tree RWA solution is needed prior to the tree construction. In stead, the RWA problem of light tree is decomposed into individual RWA of lightpaths. These can be solved independently and dynamically within WSON, resulting in a drastically decreased complexity and increased flexibility in optical multicast tree construction especially in a multi-domain WSON environment.

5. FIELD-TRIAL: ON-DEMAND WSM INS FOR GRID APPLICATIONS

5.1 Prototype overview

Figure 8 depicts the OGINI prototype network topology, which consists of optical grid hosts, WSM INS node and the underlying WSON. Five optical grid hosts (i.e. Kog1, Kog3, Ot1, Ot2, Hk1) and one WSM INS node (i.e. Kog2) at three sites (Koganei, Otemachi, and Hakusan) are connected with the underlying optical network, which is within the metropolitan of Tokyo. In the WSON test bed, one pair of ITU-T G.652 single-mode optical fibres (SMF) provided by JGN2-Plus[15] in both the Koganei-Otemachi segment (about 50 km, within 20 dB insertion loss at 1550 nm band) and the Otemachi-Hakusan segment (about 12 km, within 10 dB insertion loss at 1550 nm band) are employed. Four wavelengths—1548.5, 1549.3, 1550.1, and 1550.9 nm—compliant with the 100 GHz interval ITU-T G.694.1 are employed. In the grid systems, the optical grid hosts have multiple Ethernet interfaces and media converters (MC) equipped with DWDM and 1000 Base-T SFP modules. In this prototype, the three sites employ JGN2-Plus L2 service to set up the physical network for OGINI and WSON control planes. The OGINI control plane uses 192.168.0.0/16 network and the GMPLS-based WSON control plane uses 10.10.0.0/16 network. It should be noted that this WSON test bed implementation has one domain. As the focus in this paper is the practical overlay approach for easy value-added OGN construction with simple GNI/UNI, the underlying WSON is only required to provide simple and commercial available end-to-end lightpath services in the future, for OGINI validation, both single-domain and multi-domain test beds are applicable. Figure 9 shows the experimental setup for the WSM unit. It includes a four-channel tunable laser array, a tunable optical filter, two EDFA amplifiers, a piece of nonlinear fiber, and control software through GPIB bus.

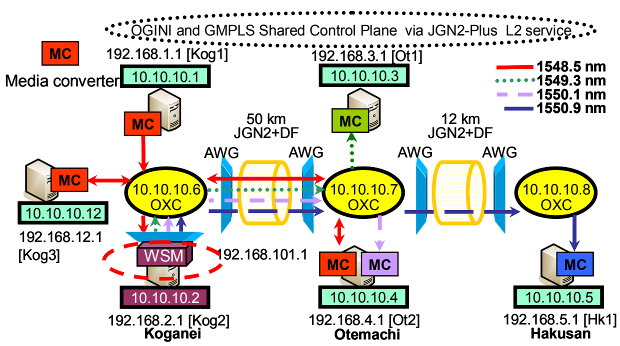


Figure 8. OGINI prototype built on WSON testbed.

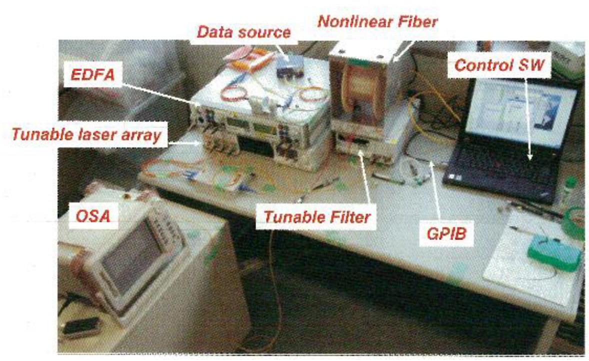


Figure 9. Experimental setup of the WSM.

5.2 Demonstration—On-demand integration of grid and innovative WSM resources with OGINI

In this field trial, we demonstrate a grid application scenario, in which host Kog1 initiates an optical multicast tree OGN request (i.e. specifying source Kog1, WSM branch Kog2, destinations Ot1, Ot2 and Hk1), and then sends data to destination hosts Ot1, Ot2 and Hk1 simultaneously taking advantage of WSM service implemented at Kog2. In particular, to verify the flexibility of multicast tree construction in a dynamic WSON environment, in which the wavelength availability might be dynamically changed because of the unpredictable lightpath requests, one concurrent lightpath request between host Kog3 and Ot2 was inserted during multicast tree construction. The wavelength assignment for each lightpath is shown in Fig. 8. Figure 10 depicts the control planes' message sequence (including both OGINI and GMPLS control planes messages) monitored at the segment within Koganei site. After the WSM OGN construction, an application (here, a network performance-test software "IPERF" was employed) started to send multicast traffic targeting at 239.1.1.1. The destination hosts Ot1, Ot2 and Hk1 received the same data simultaneously. In Fig. 10 the data plane multicast traffic (i.e. message group no.12) was monitored as well by splitting and receiving partial energy of optical signals at wavelength 1550.9 nm in the fibre from Koganei to Otemachi, which was assigned to the lightpath originated from Kog2 and targeted at Hk1. This message sequence numbered on the right-hand side of Fig. 10 is summarized as follows:

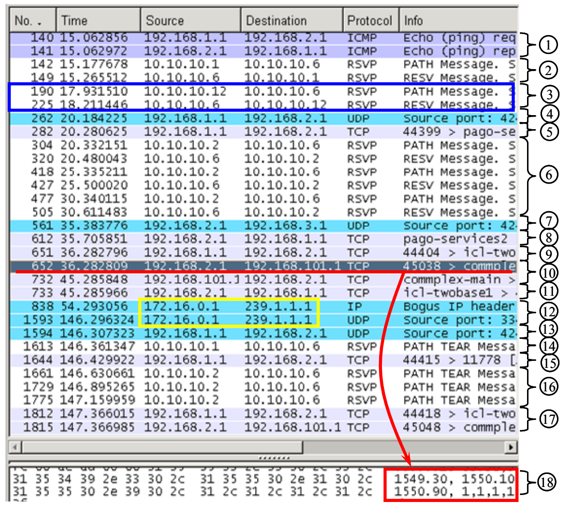


Figure 10. Control planes message sequence and data plane traffic.

(1) Ping messages, a starting sign of the tree OGN setup;
(2) Major RSVP-TE messages for dynamic lightpath provisioning along the shortest path between Kog1 and Kog2 by employing a RSVP-TE extension for distributed wavelength assignment[11]. The RSVP-TE signaling time is less than 100 msec;
(3) One concurrent lightpath request for other users' usage is inserted between Kog3 and Ot2;
(4) At Kog1, grid-cf is triggered to negotiate with grid-cf in Kog2 for consistent IP address assignment and network interface configurations at two ends of the first light-path mentioned above (2) in the tree OGN. Here, the first grid-cf message is presented for simplicity. IP address configurations in WSM are not necessarily executed;
(5) LPCT message is sent from Kog1 to branch node Kog2 for a set of lightpath provisioning targeting at Ot1, Ot2 and Hk1, respectively;
(6) A set of RSVP-TE messages originated from Kog2 targeting at Ot1, Ot2 and Hk1 are issued;
(7) The first grid-cf message for IP assignments and configurations for Ethernet interfaces using three lightpaths established in (6);
(8) The provisioning results indicating the wavelength numbers for three branch lightpaths are returned from Kog2 to Kog1;
(9) Kog1 initiates WSM-cf to branch node Kog2 for WSM configuration indicating the wavelength numbers of lightpaths inputted to and outputted from the WSM attached to Kog2;
(10) Kog2 sends the lasers tuning commands to the attached WSM (details are presented in (18)). Then the configuration results are returned to the WSM control node Kog2. For the stableness of component tuning (e.g. lasers, and EDFAs), a longer tuning time about 9 sec are employed in the implementation;
(11)The WSM configuration results are returned from Kog2 to Kog1 to confirm the end of tree OGN construction;
(12)Kog1 executes application to send 100 sec traffic (i.e. using IPERF) targeting at a multicast address 239.1.1.1 with the local IP of 172.16.0.1 which is assigned by grid-cf mentioned above;
(13) Release IPs among the nodes by triggering grid-cf;
(14) Kog1 releases the lightpath between Ko1 and Kog2 by using RSVP-TE signaling;
(15) Kog1 sends a set of path release commands to Kog2;
(16) A group of path tear messages issued by Kog2;
(17) Kog1 sends WSM configuration command for turning laser and EDFA off;
(18) The monitored WSM configuration command (here, only the outputted wavelengths at WSM are shown).

Through the field trial experiments, the results successfully verified the efficient integration of grid and INS resources with the unified platform—OGINI. Using this platform, various INS service providers can individually build up their own simple INS edges which might be of different functions over WSON. These functionalities then can be further dynamically integrated flexibly, forming colorful optical services on WSON to users. In consequence, both service providers of WSON, INS, grid, third-party vendors and users can join into the opened field, efforts from different perspectives will foster new applications and inspire the creation of new technologies for the future.

6. Conclusion

To enable the network-wide applications of INS in large-scale high-end grid computing for both high-performance communication and the validation of new emerging optical innovative network technologies, we adopt an overlay approach to integrate the grid and emerging INS resources for establishing the value-added OGN flexibly cross over multi-domain WSONs. The well-validated INSes through quick applications could be selected to merge into the WSON as built-in services in the future. We introduced an edge-mode approach which leverages new multi-function wavelength selective multicasting as an INS at a special edge. This edge mode approach would bring significant flexibility for introducing new colorful capabilities. To integrate grid and INS resources efficiently, we introduced a unified platform—OGINI. Through field trial experiments over a developed metropolitan-scale WSON test-bed, we verified the feasibility of the WSM scheme in the optical transmission systems and the totally automated colorful-light-tree OGN constructions supported by OGINI successfully. WSM is beneficial because it effectively reduces the implementation cost and enhances the flexibility of the sub-system in terms of the wavelength assignment. The investigation of further functionality requirements are considered as the future works.

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