User oriented Virtual Network Management based on dvNOC Environment

Dongkyun Kim

Cyber Network Infrastructure (CNI) Division Korea Institute of Science and Technology Information (KISTI) P.O. Box 122, Yuseong, Daejeon, Korea

Abstract – Distributed Virtual Network Operations Center (dvNOC) presents virtualized network management framework on hybrid research networks for both network operators and endusers (e.g. researchers) to monitor and manage their own virtual networks. Another purpose of dvNOC is to meet the network demands of advanced applications on hybrid research networks, e.g. very high bandwidth, no datagram loss, almost zero jitter with strict traffic isolation. Based on hierarchical architecture consisting of dNOC (distributed NOC) and vNOC (virtual NOC), users can acquire three functionalities, multi-domain network awareness, efficient NOC-to-NOC cooperation, and user-oriented virtual network management, which are essential elements to achieve automated and virtual network management based on users, over multi-national and inter-domain hybrid research networks.

Keywords – Distributed Virtual NOC, Network Management, Hybrid Research Network, Advanced Applications

I. INTRODUCTION

Hybrid research network has been deployed on almost all the advanced national research and educational networks (NRENs) worldwide, e.g. Internet2 and ESNet in USA, CANARIE Network (CA*net4) in Canada, GEANT2, SURFnet, Nordunet in Europe, KREONet2 in Asia [1-7], etc. Hybrid research network is required by variety of researchers with advanced applications demanding very high bandwidth (1Gbps ~ 100Gbps), no datagram loss, and almost zero jitter with strict traffic isolation [8]. The high performance network needs to be in place for the applications such as nuclear fusion energy science, high energy physics, astronomical data analysis, high definition video transmission, and so on. In order to provide required network performance, hybrid network is designed for layered network architecture that allows datagrams (or packets) to bypass layer 3 network, guaranteeing quality of services demanded by advanced applications. That is, hybrid research network infrastructure consists of two different types of environments, IP network and circuit-based network, to provision dedicated congestion-free network (lightpath) mostly based on layer 2 or layer 1 (e.g. gigabit Ethernet, STS channel, optical wavelength), as well as to provide limitless network reachability on layer 3.

In the mean while, network operation and management is a primary role of network operations center (NOC) that provides critical services for telecommunication networks, enterprise networks, campus networks, etc. Generally, NOC monitors and operates thousands of routers, switches, optical cross-connectors, etc., while it carries out its most important job to keep network very reliable. Regarding hybrid research networks, additional network services to above traditional facilities are necessary to have special type of requirements for advanced applications resolved. In particular, since advanced application experiments should frequently be performed based on dedicated lightpath provisioned between end users in the multi-domain global networks (e.g. between a research lab in USA and a university in the Netherlands), new research network services need to include not only hybrid networking technologies, but also global NOC-to-NOC collaboration.

In this paper, we suggest a framework for distributed and virtual network operations based on hybrid research networks and efficient cooperation between multi-domain hybrid networks, which aims to provide future network environment for high-end applications users in the long run. Two types of NOC schemes are proposed to meet the advanced application requirements, distributed NOC (dNOC) and virtual NOC (vNOC). Both schemes are integrated as dvNOC (distributed virtual NOC) with its basic framework as shown in Fig. 1, and Fig. 2 respectively. The main goals of dvNOC are as follows.

- Multi-domain network awareness: dvNOC pursues automated network resource exchange between NOCs so that each NOC can have complete network resource information (e.g. network topology) of other associated NOCs with dvNOC functionality. Such a multi-domain resource sharing makes it easier to monitor and manage inter-domain network and eventually to share network resources with end-users who want dedicated virtual networks worldwide for their research and experiment purposes.
- Efficient NOC to NOC cooperation: one NOC usually talks to other NOCs when it comes to multi-domain network failure recovery in particular. Traditional way of such communication is achieved via e-mail or phone call, but dvNOC will help each NOC handle network problem more efficiently based on visualized multi-domain network monitoring and virtual problem handling space. Multi-domain network awareness is a primary part for this NOC to NOC cooperation.
- User-oriented virtual network (UoVN) management: along with NOC to NOC cooperation designated to network operators or engineers, there is still an issue of end-user oriented network management. Once users create their own virtual network that is a set of lightpaths on hybrid research networks, it is necessary for them to monitor and manage their virtual network to ensure network quality and performance needed for their advanced applications and researches..

Manuscript received October 5, 2008 Manuscript revised October 20, 2008

There are several related projects. PerfSONAR [9] is research network monitoring platform designed for multidomain global networks. Basically it adopts service oriented architecture (SOA) and provides its functionalities for NOCs and PERTs (Performance Response Teams). That is, PerfSONAR provides various network performance analysis tools including end-to-end lightpath monitoring between multiple hybrid research NOCs. However, PerfSONAR doesn't support layered topology visualization and monitoring on multi-domain networks. In addition, network resource sharing and trouble recovery efficiency need to be taken into consideration as well.



Figure 1. Overal Architecture of dvNOC

Coalition Network Management System (CNMS) [10] is a multi-national NOC environment focused on network policies for each network. CNMS is designed to hand over its network controls to another network domain's NOC from its NOC when a network failure happens on interdomain network. In other words, a network domain A has a problem, but NOC A doesn't have a good condition to handle the problem (e.g. night time, or short of network engineers), NOC B can take over network control permission from NOC A and investigate the problem. This network control exchange is based on strict policy rule definition between NOCs. CNMS is, though, not flexible in terms that it doesn't have reasonable architecture considering expansion of NOC-to-NOC cooperation. When a NOC newly added, it is necessary to apply a complicated policy rules and create a new relationship to every other associated NOCs.

UCLPv2 [11] is designed to create APNs (Articulated Private Networks), developed by CANARIE [12]. APN is a virtual network consisting of network resources and computational resources requested by end-users across different network domains using web services. Each user who acquired an APN can allocate resources without limitations inside the APN for own researches and experiments. Meanwhile, the resources reservations for an APN need to be allowed by relevant NOCs mainly because of security reasons and resource management on each network domain. That is, one NOC should talk to another NOC either manually or automatically to have an APN generated and operated without any interruption e.g. due to firewall regulations. dvNOC adopts the concept of virtual network and web services introduced by UCLPv2 to come up with cooperative virtual NOC framework, considering NOC-to-NOC communications before actual user-oriented virtual networks are in place for global researches.

NDL (Network Description Language) [13] introduces a way to express network resources of NRENs and GOLEs (GLIF Open Lightpath Exchanges) [14] by describing nodes, cross-connects, node-to-node connections, etc. TL1 toolkit [15] released through GLIF uses this language to visualize international and inter-domain networks particularly in terms of lightpath provisioning. dvNOC uses NDL as well to write network resource information and exchange it with NOCs. Furthermore, dvNOC expands NDL to query availability of lightpath, other network resources such as nodes and interfaces, and additional information such as contacts, applications, network provisioning period, etc.

GLIF produced failure recovery procedure [16], explaining structural approaches to recover problems possibly happening over lightpath provisioning and operations between international hybrid research NOCs and GOLEs. dvNOC follows up this procedure basically, while it adopts virtual controls suggested by CNMS and virtual network developed by UCLPv2. dvNOC allows each NOC to take controls of specific network resources on interdomain environment with a time or permission limit based on pre-defined network policies between hybrid research NOCs beforehand.

The remainder of this paper is organized as follows. Section II describes the basic framework of dvNOC, and section III explains the dvNOC architecture and core systems. User oriented virtual network (UoVN) is introduced in section IV. Finally we conclude this paper in section V.

II. BASIC FRAMEWORK OF DVNOC

dvNOC framework consists of two core elements, distributed NOC (dNOC) and virtual NOC (vNOC). By introducing hierarchical model that logically divides dNOC and vNOC, we categorized network functions based on traditional NOCs with a few additional requirements, and new virtual overlay architecture for collaborative network operations between hybrid research NOCs and eventually end-users. Fig. 1 shows the overall architecture of dvNOC where depicts how dNOC and vNOC interoperates with each other.

Basically, a dNOC provides network information base as well as general NOC services maintaining each hybrid research network domain. Traditional network operations include management of equipment change, network trouble, device installations, wiring, etc. Network information base is added to this general NOC's functionality. Network information base of dNOC is a repository of network resources that is a collection of data acquired from various types of network gears using management protocols such as SNMP, TL1, and CLI (Command Line Interface). Having network resource information stored in network information base, dNOC can exchange the data with its corresponding vNOC.

A pair of dNOC and vNOC is working as dvNOC on one hybrid research network domain. Supposing there are several other network domains adopting dvNOC architecture, we call them members of dvNOC association. One member can communicate with other members based on virtual overlay networks made by vNOCs. Based on a dNOC element, its corresponding vNOC talks to other vNOCs (on different hybrid research network) to share network resource information, and eventually to provide virtual collaborative network operation services between all members of dvNOC association.

In our scheme, every resource repository at each dNOC is designed to acquire complete set of information base of all the hybrid research NOCs in the end, so that, for instance, each dNOC can keep global network topology of members of dvNOC association. Furthermore, dvNOC can provide rich data set and services based on resource information of hybrid research NOCs.



Figure 2. Basic Framework of dvNOC

As shown in Fig. 2, dNOC includes two more functional elements, layered network management system, and dynamic lightpath provisioning system. Layered network management system performs network monitoring, measurement, and management based on different network layers, e.g. layer 0 thru layer 3. Layered network management is necessary for hybrid optical and packet network infrastructure, since dNOC needs to manage both routed path and lightpath. While Layered network management system is focused on visualizing and analyzing hybrid network resource states, dynamic lightpath provisioning system carries on allocating and controlling network resources. It requires inputs about lihgtpath from network engineers or end-users on demand or scheduling basis. Those inputs include requested time frame, connecting end-points (A and Z), user information, protocols, etc. Dynamic lightpath provisioning system uses the inputs to control network devices in a domain, provisioning end-to-end lightpath, and computing optical paths, based on the control protocols such as GMPLS and TL1. Layered network management system and dynamic lightpath provisioning system stores network states into resource repository regarding network monitoring, measurement, management, and lightpath, so that a dNOC can operate a stateful network domain. Eventually the network information stored in resource repository is used for a vNOC to share network information with other vNOC domains. Therefore resource repository is a very important part of dvNOC when it comes to open and shared architecture for NOC-to-NOC cooperation. It keeps network resource information from physical nodes and circuits to lightpath monitoring states, user contact information, etc. Detailed schema of resource repository is described in chapter III.

In Fig. 2, there are four functional elements and three interfaces in vNOC. Among the functional elements, vRES plays a role of sharing network resource information stored in the local network resource repository. Resource queries can be made both by network operators/engineers and end users. For example, network operators want to find performance measurement data such as packet loss and delay during a certain time frame, while end users need to see if there are available network resources (e.g. bandwidth) between two end institutes. Note that properties of performance measurement data are only shared by vRES, rather than data archives. vMAN provides a way to share monitoring, measurement, and management information with other vNOC domains, as vLIGHT provisions multi-domain end-to-end lightpaths. vCON is designed to exchange trouble ticket information and give a specific time window to control network resources for end-users or network operators based on very strict policy.

III. DVNOC ARCHITECTURE AND CORE SYSTEMS

A. Distributed NOC Architecture and Functions

The principle of dNOC is to build distributed network information base using a defined set of system which includes network resource repository, layered network monitoring & management system, and dynamic lightpath provisioning system. Based on these systems, each dNOC keeps its local information base, and gathers other dNOC's resource information by interfacing with vNOC facility. For instance, resource repository at dNOC starts to collect and maintain its own NOC's network resource information such as network devices, interfaces, ports, connections, etc. Then, it tries to gather other NOC's resource information as well which is retrieved from its correspondent vNOC. The vNOC communicates with other vNOC entities to receive and transmit resource information required by one another. Eventually every resource repository at each dNOC has a complete picture of information base of all the NOCs in a distributed manner. In addition to the network resource information, dNOC's resource repository is designed to store user information, so vNOC can share and maintain end-to-end connections between users. Table 1 shows an example of data schema for network resource repository.

Layered network management system (LNMS) is required to monitor the status and performance of hybrid networks at near real time on layer 1 thru layer 3, and eventually manage the whole layered network infrastructure such as OXCs, SONET/SDH muxes, ethernet switches, and routers. Fig. 3 indicates layered network management framework that provides a way to manage routed path and lightpath by reading or recording over network resource repository, being used by end-users as well as network operators/engineers.



Figure 3. Layered Network Management Framework

Table 1. Network Resource Repository Schema Example

	Filed Name	Format	Description
User Infor- mation Base	Org-ID	Text(10)	Organization ID
	Org-name	Text(20)	Organization name
	Apps	Text(20)	Applications
	Contacts	Memo	Contact information
	IPv4-addr-block	Text(30)	IPv4 address block
	IPv6-addr-block	Text(50)	IPv6 address block
	ConnectedTo-ID	Text(10)	Upper network ID
	ConnectedTo	Text(40)	Upper net:gear:port
	Acc-bw	Float(20)	Access bandwidth
	Acc-gear-ID	Text(10)	Access gear ID
	Acc-gear-name	Text(20)	Access gear name
	Acc-port	Text(15)	Access gear port
	Acc-port-type	Text(15)	Access port type
Network Infor- mation Base	Net-ID	Text(10)	Owner network ID
	Net-name	Text(20)	Owner network name
	Contacts	Memo	Chief engineer info.
	Gear-ID	Text(10)	Gear ID
	Gear-name	Text(20)	Gear name
	ConnectedTo-ID	Text(10)	Connected net ID
	ConnectedTo	Text(40)	Cntd net:gear: port
	Port	Text(15)	Gear port
	Port-type	Text(10)	Type of port
	Port-bw	Float(20)	Bandwidth
	Xconnected-port	Text(20)	Cross-connected port
	Port-IPv4	Text(30)	Port IPv4 address
	Port-IPv6	Text(50)	Port IPv6 address

Dynamic lighptath provisioning system is an integral part of dNOC, because congestion-free path needs to be provisioned for the demands of advanced applications on demand or on scheduling-basis. Currently there are several dynamic lightpath provisioning systems being developed or deployed [17]. Therefore dNOC can simply choose one of them, but it is strongly advised that every associated vNOC uses a standard interface for lightpath provisioning so that the lightpath can be efficiently built on inter-domain and multi-national characteristics of global hybrid research networks, ensuring lightpath compatibility. Dynamic lightpath provisioning systems refers to the information that resides on network resource repository to have the proper lightpath across global network. Standard interface of multi-domain lightpath provisioning is proposed in the section B.

B. Virtual NOC Architecture and Functions

vNOC is designed to distribute and share network resource information between dvNOC domains, based on network operators and end-users. vNOC framework needs secured web service architecture to share the network resource information in a highly protected manner. Using web services, locally collected network information at each dNOC is converted into XML format to be shared between vNOCs. Eventually, every network resource data can be equally distributed between dvNOCs. Building information sharing infrastructure using web service is a basic and primary work for vNOC framework, so that virtual spaces can be generated with specific network instances. One issue for the data distribution is fast convergence between dvNOCs, which is not described in this paper.

vNOC framework proposes four functional entities, vRES (Virtual Network Resources), vMAN (Virtual Network Management), vLIGHT (Virtual Lightpath Provisioning), and vCON (Virtual Network Trouble Controls). It also requires three interfaces such as graphical user interface, data handling and control handling interfaces. GUI of vNOC provides a first-contact for users or operators to choose specific services and interact with functionalities listed below. Data and control messages are exchanged based on secured web services between vNOCs.

vRES is related to network resource exchange, resource query, and integrated topology generation with visualization interfaces to LNMS in dNOC. Converted XML messages from NRR (Network Resource Repository) Data Schema are exchanged between vRESs through secured web service interfaces, and in turn, they are stored into each NRR to be queried by both end-users and network operators. In other words, each vRES on its dvNOC domain communicates with other domains' vRESs to acquire complete available network resources over virtual connections by exchanging locally gathered data. Data exchange modules use XML resource specifications. Note that XML resource specification needs to include available resources at specific time window because end-users and network operators generally want to use lightpath(s) with designated time period. Following XML specification example suggests what kind of information is exchanged to find available network resources over dvNOC system.



Above example includes reserved resource information for a lightpath provisioned between two network domains which are a part of the multi-national end-to-end lightpath. That is, a part of lightpath information is assembled with other parts of lightpaths, and each dvNOC domain has the full information of end-to-end lightpath after all. The example references NDL (Network Description Language) [13] that is being deployed on GLIF network playground [14] over the world.

In addition, vRES is designed to generate layered topologies with network management interfaces so that network users can easily check and detect what is currently undergoing on entire multi-domain networks with granular layered network information. vMAN is closely related to vRES in the management context. vMAN collects management data from NRR, and bind the data to vRES to represent visualization of layered networks with management and monitoring information such as link up and down, status of traffic and performance, etc. The topology visualization is also combined with vLIGHT and vCON in terms of shared end-to-end lightpath information and trouble tickets respectively. Fig. 5 shows how these systems are associated with each other.



Figure 4. Layered Network Topology and Interactions

vLIGHT is a virtual lightpath provisioning system of local lightpath provisioning systems (as is "a system of systems"). There are about a dozen number of dynamic provisioning systems such as DCN, DRAC, HPDM, G-Lambda, LambdaStation, UCLP, etc.[17]. Therefore, vLIGHT needs to provide a virtual space not only to share lightpath resource information but to exchange control messages of multi-domain lightpath provisioning with simplified and standardized method defined among the local lightpath provisioning systems.

Fig. 5 indicates how vLIGHT manipulates data generated from its local dNOC facilities. In this figure, vLIGHT consists of five functional elements. User interface receives queries for available resources during specific time frame as well as lightpath provisioning requests. Fig. 5 shows how the queries are processed with network resource repository and other vLIGHT elements, while lightpath requests go to resource handler which interacts with dNOC's local lightpath provisioning system using web service interfaces or native configuration commands such as TL1. Resource handler also interacts with XML translator & parser to store new requests into resource repository. Eventually resource handler sends the request to other dvNOC's vLIGHT, through data/control handler and secured web interface of vNOC.

Regarding vCON, generally there are NOCs that control their own nodes for international connections as well as their NRENs in each country. In terms of international connections, each NOC maintains and controls its international node connected to other member's networks that are operated by their traditional NOC(s). Every NOC easily detects and figure out any problems that happen on its node(s), but when the problem happens at other NOCs' nodes connected to its own, there is no way but waiting after several e-mails or phone calls until the problem is gone away (or sent back). This kind of work flow is usually performed when it comes to traditional NOC to NOC (international) cooperation so far.



Figure 5. vLIGHT Data Flow Diagram

vCON is designed to issue and assign trouble ticket(s) for network troubles, and to control international networks in a distributed way among dvNOC domains, excluding several exceptional hardware related breakdowns such as network OS failure, interface card crash, fiber cut, etc. In order to do the distributed operations, first, it is required that vCON acquire network resource information. It mainly relies on vRES and vMAN for the information. vRES provides layered topology information to allow each dvNOC domain to figure out which layer of network incurs the trouble at a certain location of hybrid research networks. In the mean while, vMAN gives a way for network engineers to analyze the status of network, traffic, performance, etc. They can recognize how much traffic is utilized, and who generates the traffic on a specific link on international paths. Also, each dNOC's pre-deployed monitoring tools such as ping, traceroute, MRTG, etc. give clues for any other network troubles such as BGP routing anomaly.

Based on the monitoring results from all above systems, network engineers detect a problem. Once the detection done, the first detector reports the problem to vCON to issues a trouble ticket that is, in turn, delivered to all other dvNOC domains. The first detector can locate the problem at its own dvNOC, or can do that at any other dvNOCs. Then, vCON checks out (pre-registered) available human resources and working hours to assign the ticket to a proper engineer. When a ticket is assigned, trouble control broker invokes AAA functionality and provides access to the problematic node(s) according to pre-defined level of access permission of the engineer in charge. One important thing to provide the access for a node(s) is that control path should be arranged under vCON's control, because access control needs to be done through secured connection, and data path is possibly down due to the problem.

Eventually, vCON assigns a control window to a specific network engineer (or an end-user) on one of dvNOC domains. That is, the engineer or end-user controls all the available network resources using CLI, SNMP, and TL1 with defined access policy during a certain time frame generated by vCON. When the problem is removed within the time frame, the generated ticket will be closed by the assigned user. Otherwise, the trouble ticket holds and will be assigned to another user with the vCON work flows described above.

IV. USER ORIENTED VIRTUAL NETWORK MANAGEMENT

dvNOC scheme is originally designed for network engineers and operators as well as researchers and developers who want to manage their own virtual networks. When an end-user wants to use the view of its own virtual network, the user can acquire the same virtual space as network operators can. Only does one difference lie between two of them, which means end-users can have limited network resource information and access permission on virtual NOC space for their own virtual networks, while network operators have almost limitless network access controls. However network operators or engineers still have the constrained access or use of virtual networks by the permitted level when it comes to other dvNOC domain's network resources. More importantly, very strict policy is required to give resource controls to end users. One of virtual network example is shown in Fig. 6, which is a useroriented virtual network for medical applications between Norway and Korea, which is a dedicated congestion-free network guaranteeing very high performance, e.g. no data1gram loss, zero jitter, optimized delay, etc. However, this type of virtual network still requires specified operations and management based on users. Fig. 7 shows a performance analysis result for network bandwidth on 1Gbps IP network path from a node in Daejeon, Korea to another node in Seattle, USA, showing sudden bandwidth drops during UDP data transmission. Therefore, it is advised to have virtual networks configured and managed particularly by end-users, guaranteeing a certain level of quality and performance for high-end applications.



Figure 6. Norway-Korea Virtual Network on Hybrid Research Networks

V. CONCLUSIONS AND FUTURE WORKS

Given the increasing complexity of the underlying infrastructure and the increasing demand for both advanced and basic network services, dvNOC is designed to adopt decentralized model of multi-domain hybrid research network management. A collaborative and distributed virtual model that is characterized by cooperation among hybrid research networks that insist on maintaining their autonomy and control, can also contribute for researchers and other end-users to manage and operate their own virtual networks within dvNOC's sphere. Future works of dvNOC will include more detailed resource specifications derived, but optimized from current research works, design of adaptation manager to interact with the developed NOC tools (e.g. PerfSONAR), development of strict policy control algorithm among hybrid research networks, fast convergence of network resource information, and so on.

- [16] Rene Hatem et al. "The ordering and fault resolution process for multi-domain Lightpaths across hybrid networks," GLIF Technical WG, July 2006.
- [17] Erik-Jan Bos et al., "Optical Networking : GLIF," CCIRN Annual Meeting, May 2008.



Figure 7. Network Performance Analysis Result between Korea and USA

References

- [1] The Internet2 Network, URL : http://www.internet2.edu/network/
- [2] Tom Lehman et al., "Hybrid Network Control Plane Interoperation Between Internet2 and ESnet," ESCC/Internet2 Joint Techs Summer Meeting, July 2007.
- [3] Andrew K. Bjerring, "Towards an Intellengent-Infrastructure for R&E in Canada," Ontario R&E Summit, June 2004.
- [4] Hybrid Network in GEANT2, URL : http://www.geant2.net/server/show/nav.2140
- [5] World-wide distribution of Large Hadron Collider data through SURFnet and NetherLight, URL : http://www.surfnet.nl/en/nieuws/Pages/WorldwidedistributionofLargeHadronColliderdatathroughSURFnetandNeth erLight.aspx
- [6] Lars Fisher, "Lambda Networking," 2nd Chinese-Nordic Network Workshop, April 2007
- [7] Dongkyun Kim, "Hybrid Network Initiative in Korea : KREONet2," 7th Global Lambda Grid Workshop, September 2007.
- [8] Harvey Newman, "LHC: A New Window on the Universe Frontiers of HEP & Cyberinfrastructure," 8th Gobal Lambda Grid Workshop, October 2008.
- [9] PerfSONAR, URL : http://www.perfsonar.net/
- [10] Scott Shyne et al., "Distributed Multi-National Network Operation Centres," IEEE MILCOM 2004, November 2004.
- [11] Grasa, E et al., "UCLPv2 : A Network Virtualization Framework built on Web Services [Web Services in Telecommunicatios, part II]," IEEE Communications Magazine, March 2008.
- [12] CANARIE, URL : http://www.canarie.ca
- [13] Jeroen van der Ham et al., "A Distributed Topology Information System for Optical Networks Based on the Semantic Web," Optical Switching and Networking 5 (2-3), June 2008.
- [14] GLIF Open Lightpath Exchange Resources, URL : http://www.glif.is/resources/
- [15] TL1 Toolkit, URL : https://noc.sara.nl/nrg/TL1-Toolkit/