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Abstract

Current Internet has confronted many raised problems related to network security, scalability, performance, etc., mainly due to the rapid increase of end-users and various new service demands. Therefore, revolutionary Future Internet researches have come up with resolving the fundamental weakness of Internet while the importance of Future Internet testbed is growing faster for researchers to experiment and verify newly proposed Future Internet technologies on the experimental networks. Furthermore, the federation and management of distributed Future Internet testbeds is required to support reliable end-to-end researches over inter-domain networks, countries, and even continents. In this paper, we introduce the federated network operations and management experiments over global Future Internet testbeds based on DvNOC (Distributed Virtual Network Operations Center) and GMOC (GENI Meta Operations Center) [1][2]. We also take performance consideration on federated network operations into account for more efficient and scalable network management on Future Internet federation.

Keywords: Future Internet, Federated Network, Operations and Management

1. Introduction

Internet has been leading the global networks by designing and standardizing a single protocol named TCP/IP ever since the basic concept of packet switching and inter-networks was introduced. As WWW and lots of TCP/IP applications were positioned as the pivotal means to integrate global network and end-users, Internet has been growing rapidly and making significant success so far. From its beginning, Internet’s design principles and requirements include connectivity, survivability, support for multiple services, support for multiple physical layers, distributed management, cost effectiveness, and resource accountability [16]. In order to meet the design goals, the Internet was developed to support layering, packet switching, simple network and complex terminal, and end-to-end communication, which keeps network interconnected by simplifying network architecture and protocols.

However, there have been drastic changes over the past years in the Internet, compared to the earlier Internet designs. For instance, the number of end-users increases radically from the expert groups to massive general user groups, which makes it difficult to achieve reliable communications. Also, host-centric communication has been evolved into data-oriented communications as Internet expands dramatically [15]. There are two methods in general to cope with the new challenges and problems of the current Internet. While the evolutionary approach by IETF [4], etc. has been conducting successful researches and standardization on Internet for about 30 years, recently proposed revolutionary approach includes Future Internet development and research to figure out fundamental weakness of Internet. The revolutionary approaches are being researched and experimented by several major projects in the world, such as FIND [5] supported by NSF in the US, GENI [6], FP7 and EIFFEL [7] in Europe, NwGN [8] in Japan, and FIF (Future Internet Forum) [9] in Korea.

Revolutionary Future Internet approach aims to designing clean-state Internet in the long-term perspective. Therefore, experimental Future Internet testbed development is very essential for the tests and verification of the newly proposed Future Internet technologies. For example, the main objective of the GENI (Global Environment for Network Innovation) [6] is to deploy and develop global network testbed used for Future Internet research and development in the world. In addition, Future Internet
resource management technologies are actively being developed based on the network testbeds. For instance, GMOC [1] (GENI Meta Operations Center) is an operation system to monitor and manage meta data derived from GENI network testbeds including ProtoGENI [10], PlanetLab [11], ORBIT [12], etc., which was developed by Indiana University in the US.

In this paper, we introduce system design and experiment for federated network operations and management between GMOC and DvNOC (Distributed Virtual Network Operations Center). DvNOC is a resource management and operation system for the Future Internet testbeds in Korea, such as KREONET [14], K-GENI [19], etc., which is also enhanced to be capable of the federation experiment on Future Internet resource management with GENI.

The remainder of this paper is organized as follows. Section 2 describes the related works, and section 3 explains the architecture of DvNOC. The system implementation and experiment for the federated network operations between DvNOC and GMOC is introduced in section 4. Section 5 provides performance consideration for federated network operations, and we conclude this paper in section 6.

2. Related Works

GENI [6] differentiates itself with earlier network testbed projects focusing on specific technologies, in terms that it is developing testbeds based on diverse network technologies such as network virtualization, programmability, and federation in particular. GENI is designed to build virtual networks from upper layers (e.g. application layer) to lower layers (e.g. physical and control layers). Additionally, it pursues seamless migration and deployment process to have comparative and survived global technologies settled down for the future. Currently, GENI publishes GDD (GENI Design Document) that defines and explains requirement, specification, and experiment of various network equipments for testbed.

PlanetLab [11] is a testbed project that experiments new ideas of computer networks and distributed systems led by Princeton University in USA, running more than 800 computers on PlanetLab researches in the world. As Future Internet expands, virtual and physical network resource management becomes significant for reliable and scalable network management based on end-users. GMOC [1] is a large-scale testbed resource management platform developed to operate GENI testbeds in the efficient, reliable, and sustainable manner. GMOC framework is composed of three functional entities: GMOC exchanger, GMOC translator, and GMOC data repository as shown in Figure 1.

![Figure 1. GMOC Framework](image)

- GMOC Exchanger: Receiving resource information from target nodes or substrates, and storing native information into GMOC Data Repository directly, non-native information into GMOC Data Repository after conversion
GMOC Translator: Conversing non-native resource information into native information and deliver the information to GMOC Data Repository
GMOC Data Repository: Centralized data storage based on GMOC database schema

3. Distributed Virtual Network Operations Center (DvNOC)

3.1. Architecture and Functions of DvNOC

Originally, DvNOC [17] is a virtual network management framework for hybrid research network that is a combination of circuit-oriented network and packet-switching network in order for providing both end-to-end dedicated lightpaths and layer-3 routed paths. Researchers and network operators may manage and operate their virtual network resources through DvNOC environment. Moreover, since recent advanced application requires global end-to-end network environment for their researches over many network domains and countries, NOC to NOC cooperation becomes very important between NOCs (Network Operations Centers) located on the different network domains. DvNOC provides the following functionalities to support collaborative efforts on multi-domain NOCs:

- Multi-domain Network Awareness: DvNOC pursues automatic resource exchanges between NOCs. Therefore, each DvNOC is aware of network knowledge of other NOCs (on DvNOC domain) such as network topology, status, utilization, etc.
- Efficient NOC-to-NOC Cooperation: DvNOC figures out inter-domain network problems more efficiently through visualized multi-domain network monitoring and management based on virtual NOC environment, while traditional NOCs use e-mail, phone, etc. to solve the same kind of cooperation issues.
- User-oriented Virtual Network Management: DvNOC provides a way to operate and manage virtual network resources that end-user created for their own application, researches, and experiments.

DvNOC incorporates resource repository in addition to the traditional NOC facilities so that the repository stores network resource information collected from local networks inside a network domain, ultimately in order to share the resource information with other NOCs on DvNOC domain. Each associated dNOC (distributed NOC) exchanges the operational dataset with others, interfacing with vNOC (virtual NOC). Figure 2 shows the overall architecture of DvNOC, where each dNOC connects to its corresponding vNOC, and there are secured connections between vNOCs for protected communication on dNOCs.
Figure 3 indicates that DvNOC has several more components for Future Internet management and federation, which are federation engine, data acquisition system, core schema, and user interface. ADN in the figure means autonomous distributed network, and it is an individual network testbed equipped with DvNOC facility.

Data acquisition system is designed to collect local network resources from intra-domain networks, e.g. operational status such as up/down/degraded state of node and link, performance information, and topology. In turn, the datasets are stored in the resource repository based on core schema of which purpose is scalable and adaptive exchange of network resource information between dNOCs (or ADNs). Since core schema represents essential resource datasets only for federation, each dNOC may apply the simplified schema into its existing network information registry or database in a very adaptive manner. Also, it is found that core set of resource information is small in number and amount, which means core schema may enable fast convergence and scalable data exchange when it comes to resource data sharing between dNOCs. Federation engine supports the integration and federation of exchanged network resource information for the purpose of end-to-end network monitoring and management over inter-domain networks. The collected and federated datasets are presented through visualized user interface for scientists, researchers, operators, and engineers in the end.

3.2. DvNOC-GMOC Federation

It is complicated to build up global-scale Future Internet testbed across national and domain boundaries because of massive cost and time consuming issues, although the testbed is critically necessary for Future Internet research and development. Furthermore, Future Internet should not be a local network inside one domain or country. It would rather be a global network for end-to-end researches over the world. This is why the federated network testbed construction and development are very important for the global collaborative efforts on Future Internet. So far, research communities in GENI, FIRE, and others have been working on their own autonomous Future Internet testbeds, while the similar activities have been applied to KREONET and K-GENI for Korean Future Internet testbed development. The requirement of federation increases to stitch and link those individual testbeds in the world into one globally connected network testbed which makes it possible to create, remove, and manage end-to-end virtual slices across GENI and KREONET, for instance.

In order to achieve the testbed federation, in advance, it is demanded to develop technologies for not only network resource management on each localized independent testbed, but also federated network operations and management over the virtually stitched global testbed. Therefore, suggested DvNOC system is federated with GMOC system in order to achieve international operational dataset exchange and sharing for federated operations and management. For the federation between DvNOC and GMOC,
GMOC-KR is implemented (Fig. 4) and federated in coalition with DvNOC, which is described more in detail in the next Section.

4. Experiment of Federated Network Operations on DvNOC and GMOC

4.1. Implementation of GMOC-KR

GMOC-KR is designed based on Redhat Linux and MySQL. Most of the running codes are implemented using Perl, and the internal data transfer unit adopts XML (Extensible Markup Language). GMOC-KR provides web-based visualized user interface that is composed of three user interfaces (tabs) shown in Figure 4.

![GMOC-KR Implementation and User Interface](image1)

**Figure 4. GMOC-KR Implementation and User Interface**

![SNAPP of GMOC-KR](image2)

**Figure 5. SNAPP of GMOC-KR**

First tab of user interface (UI) of GMOC-KR shows “Node/Slice” information that is node and slice resources described in the left table of the Figure 4. The table lists URN (Uniform Resource Name) of each node, time stamp, and slice information gathered at near real time. Second tab is about “Geographic/Logic” information. It indicates the topology and geographical location of particular aggregate and cluster on the global map. Zoom-in and zoom-out of the aggregate/cluster are adjusted with the buttons on the upper left in the map, while GMOC-KR manages several aggregate and clusters in the third tab (Aggregate/Cluster) such as “K-GENI,” “KISTI/K-GENI,” “ETRI/K-GENI,” “GMOC-US,” and “KR-US Federated.”
GMOC-KR acquires resource information using SNAPP (SNMP Network Analysis and Presentation Package), which is implemented by Indiana University and customized for GMOC-KR data acquisition module. GMOC-KR collects network resource information from GENI testbeds based on SNAPP in Fig. 5.

4.2. Design and Implementation of DvNOC

DvNOC is implemented with velocity and servlet for global and local views, MySQL for resource repository, tomcat for Web/WAS server, with Linux OS and Java program language. In addition, considering usability and public distribution, the application is developed under open source environment such as Spring and iBatis. UI of DvNOC is simplified and intuitive as shown in Figure 6 where two UIs are presented: “Global View” with federated network resource information between DvNOC and GMOC, and “Local View” with the local KREONET and K-GENI network resource information on Future Internet nodes such as OpenFlow nodes and layer-2 substrates for VLAN provisioning.

Based on the local views, Future Internet nodes with its status as well as localized network topology are provided with geographical information. In the left section of the map, there are an address query bar and a table that lists node and link information. It is identified by double-clicking each node and/or link on the table that operational and administrative status, utilization, and virtual network information are represented on the network topology. The network resource information is acquired from resource repository that adopts entities and attributes of core schema.
Table 1. Entity and Attribute List of DvNOC Resource Repository

<table>
<thead>
<tr>
<th>Entity Name</th>
<th>Function</th>
<th>Associated Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>PoP</td>
<td>Point of Presence (PoP) is a place where network nodes are physically located</td>
<td>pop_id, pop_name, location_id, network_id</td>
</tr>
<tr>
<td>Location</td>
<td>Information related physical address, etc.</td>
<td>location_id, longitude, latitude, address, city, zipcode, country</td>
</tr>
<tr>
<td>Organization</td>
<td>Administrative and operational groups and institutions.</td>
<td>org_id, org_name, URL, location_id, contact_info_id</td>
</tr>
<tr>
<td>Contact_Info</td>
<td>Contact information of the related entities such as organization, etc.</td>
<td>contact_info_id, first_name, last_name, email_addr</td>
</tr>
<tr>
<td>Network</td>
<td>Network information that organization, and physical links are connected</td>
<td>network_id, network_name, organization_id, contact_info_id</td>
</tr>
<tr>
<td>Physical_Node</td>
<td>Physical network device information, which connects to physical links</td>
<td>p_node_id, node_name, model, vendor, domain_name, CPU_util, memory_util, upper_node_id, state_type_id</td>
</tr>
<tr>
<td>Physical_Link</td>
<td>Physical link or circuit information, which connects to physical nodes and physical network ports</td>
<td>p_link_id, link_name, reserved_bw, vlan_id, channel_name, state_type_id</td>
</tr>
<tr>
<td>Physical_Interface</td>
<td>Physical interface or port information on physical nodes, which connect to physical links or circuits</td>
<td>p_int_id, interface_name, IPv4_address, IPv6_address, mac_address, channel, mtu_size, contracted_bw, traffic_util, error_rate, state_type_id</td>
</tr>
<tr>
<td>Virtual_Node</td>
<td>Virtual or logical network device information, which has virtual or logical links connected</td>
<td>v_node_id, node_name, domain_name, CPU_util, memory_util, state_type_id</td>
</tr>
<tr>
<td>Virtual_Link</td>
<td>Virtual or logical link information, which connects to virtual nodes</td>
<td>v_link_id, link_name, reserved_bw, state_type_id</td>
</tr>
<tr>
<td>Virtual_Interface</td>
<td>Virtual interface information on virtual nodes, which is connected to virtual links</td>
<td>v_int_id, interface_name, IPv4_address, IPv6_address, mac_address, channel, mtu_size, contracted_bw, traffic_util, error_rate, state_type_id</td>
</tr>
<tr>
<td>P_V_Node_Map</td>
<td>Mapping information between physical nodes and virtual nodes</td>
<td>v_node_id, p_node_id, timestamp</td>
</tr>
<tr>
<td>P_V_Int_Map</td>
<td>Mapping information between physical interfaces and virtual interfaces</td>
<td>v_int_id, p_int_id, timestamp</td>
</tr>
<tr>
<td>L_E2E_Virtual_Network</td>
<td>End-to-end path or network identifier inside a local network domain</td>
<td>v_network_id, v_node_id, v_int_id, org_id, contact_info_id</td>
</tr>
<tr>
<td>G_E2E_Virtual_Network</td>
<td>End-to-end path or network identifier of globally stitched virtual network</td>
<td>g_network_id, v_network_id, org_id, contact_info_id</td>
</tr>
<tr>
<td>State</td>
<td>State/status information on network topology</td>
<td>state_type_id, state</td>
</tr>
<tr>
<td>Type</td>
<td>Type information of nodes, interfaces, and links on virtual/physical networks</td>
<td>state_type_id, type</td>
</tr>
</tbody>
</table>

Table 1 indicates entity name, its function, and associated attributes based on core schema, and there is a FDD (Functional Dependency Diagram) of the core schema in Figure 7. The FDD shows how the entities are related with each other using relational database modeling. For example, if you have a network identifier, it is easily recognized that organization identifier and any associated attributes such as organization name, URL, etc. are searched out by the network identifier. And, in a similar way, you can find the location of the organization coupled with the network identifier, which is an attribute of location entity based on Figure 7 and Table 1.
Those attributes of the core schema are network resource information retrieved from local network infrastructure, to be exchanged with inter-domain and international network entities. Therefore, it is required to show globally federated network resources including the above two types of information in an integrated UI called “Global View” which is described below.

4.3. Federation and Experiment on DvNOC and GMOC-KR

Federation is very important for the operational dataset sharing [20] and the operational rules modeling [21] between networks in terms of the integrated global view and user-specified network view with the management facilities on. In Figure 8 and Figure 9, federated datasets are presented in the form of globally assembled network view and end-to-end user-oriented virtual network view respectively.

Regarding federation between GMOC-KR and DvNOC, the global view of DvNOC indicates federated network resource information that is gathered and assembled from Future Internet domains in Korea and USA. Figure 8 shows that federation between two individual systems successfully works by putting together GENI and Korean Future Internet testbed resources. In order to experiment the federation, a wrapper is implemented and applied on the federation engine of DvNOC to conform data exchange specification derived from GMOC. We also implemented a prototype for end-to-end virtual network management as shown in Figure 9. It presents one virtual network path with associated state information from one end (Jeju) in Korea to the other end (Seattle) in USA. The virtual path is composed of three physical circuits and corresponding network nodes.
5. Performance Consideration for Federated Network Operations

From the computational point of view, a federated network operation is considered as a set of tasks performed and federated in and between various network domains. Therefore, the number of task completed as function of time is given by the following equation:

\[
  n(t) = \sum_{i \in N} \left( P_N i \left| \frac{t}{T_i} \right| \right) + V_N \left| \frac{t}{T} \right| \tag{1}
\]

where \(P_N\) and \(V_N\) are the number of tasks of resource \(i\) in a network domain \(N\), representing physical network node as \(P_N\), and virtual network node as \(V_N\) respectively.

The following formula defines the performance of the system (tasks completed per time) on actual network operations with a finite number of tasks:
Based on the above equations, it is considered that we can optimize the maximum completion time criterion (such as shortest operational dataset convergence on federated network), $C_{\text{max}}$, when the following condition is met assuming each network domain is fully connected on federated network (i.e. full-mesh network connections with the interconnected links $l$ on federated network $FN$):

$$C_{\text{max}} = \max_{i \in FN} r(i) \cdot \frac{l(l-1)}{2}$$

(3)

This problem can be formulated as an integer linear programming problem as follows: There are $T$ tasks to be processed where each task can be processed in the federated network $FN$. We assume that each federated network can perform $t_i$ tasks.

$$\text{minimize} \quad C_{\text{max}}$$

$$\text{subject to}$$

$$\sum_{i \in FN} t_i - T = 0;$$

$$t_i \geq 0 \quad \forall i \in FN$$

(4)

This optimization problem is applied for performance consideration of federated network operations. Based on the above definition, it is noted that the factors influencing performance on local network domains are operational dataset acquisition delay, data storing delay, the number of nodes for acquisition and repository, the number of datasets of each node, and the number of datasets to be stored, etc. In addition, we can take it into consideration that the factors of federation performance are involved with the number of total tasks to be processed on federated network, which is mainly affected by operational dataset exchanges and process overheads.

6. Conclusion and Future Works

In this paper, we introduced DvNOC system that is designed and developed to manage network resources on domestic and international Future Internet testbeds such as KREONET and K-GENI. It is also informed that the federation of localized testbeds is experimented for end-to-end Future Internet researches and collaborative works across national boundaries. The international federation experiment is conducted based on DvNOC and GMOC that manages network resources over GENI and KREONET/K-GENI of which purpose is reliable federated network operations of the global-scale Future Internet testbed.

Besides, the performance consideration on federated network operations in this paper indicates that applying core schema on federated network presents performance enhancement by reducing task completion time with convergence delay decreased. Our future works include researches on more scalable and reliable federated network management supporting faster convergence and higher performance when it comes to federate and operate autonomous Future Internet testbeds.

7. References

[18] RELAX NG, URL: http://relaxng.org