Design and Development of a Large-scale Network Testbed on a Research and Education Network

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***Abstract*—As the Internet continues to grow in width and depth, its very architecture presents challenges when it comes to implementing innovations. For testing new developments, networking developers need an environment for evaluating their ideology and practicality. The testing environment is required to emulate a production network, and it also has to operate in the private area without real-world interference. Under these circumstances, the network testbed provides such a platform for the developers. This paper presents the TaiWan Advanced Research and Education Network testbed, a large-scale, as well as multi-layer network testbed, constructed for network research, and designed to orchestrate and aggregate resources of different testbed sites for supporting the conduction of experiments. The paper aims to share the building experience of this network testbed, introducing the key development points and future work.**

Keywords-Network Testbed; Virtualization; SDN; Cloud; Resource Control.

I. INTRODUCTION

The Internet has become a critical infrastructure in modern society [1] even though its design choices could not be used to anticipate the current needs [2]. While the scope of the Internet continues to grow at a fast pace, its architecture makes implementing innovations difficult. Therefore, before new approaches and concepts can be implemented to the actual global network, they need to be evaluated in a bench-scale environment first. A testbed enables new technologies to be tested experimentally with realistic and reproductive scenarios. Thus, network developers are able to verify their new ideas without the fear of interfering with the real environment. For the reasons above, recently, many institutes [3][4][5] have been designing and developing testbeds to satisfy research requirements.

Since the Software-Defined Networking (SDN) [6] has been proposed to improve the programmability of network architecture, it is commonly applied in network provision. There are also several testbed projects using SDN in their designs. For example, the Global Environment for Network Innovations (GENI) [7], is supported by National Science Foundation of the United States, and RISE [8] is a large-scale testbed with nation-wide network infrastructure for research and academic use. Furthermore, OFELIA [9] project financially supported by European Union is a testbed which using SDN to integrate various sites as a large-scale network testbed in Europe. OF@TEIN [10] is another project to utilize production network to constructed a collaborated testbed with cloud services and SDN techniques. The common point of these network testbeds is that they integrate underlay infrastructure, access networks and computing resources for supporting testbed purposes, providing such a platform to explore new network inventions for network researchers.

In Taiwan, the TaiWan Advanced Research and Education Network (TWAREN) [11] operated by the National Center for High-performance Computing (NCHC) [12] is an academic network in Taiwan, providing variety services and applications for research and education purposes. In order to support more advanced experiment of the Future Internet researches, a plan of building a SDN-enabled testbed on TWAREN has been proposed. The design goal of the testbed is to extend the software-defined controllability into TWAREN. By doing this, the testbed users are able to have more flexibility on conducting their experiments. This testbed is also designed to aggregate geographically distributed resources from different providers, and testbed users are able to use the cloud resources of participated providers in distributed testbed sites. To manage these resources, a resource control software is also developed. The design goal of this testbed is to provide a flexible environment to sustain innovative researches of Taiwan’s academic and research institutes.

While the testbed is still under verification and improvement, in this paper, we present our experience for building this SDN network testbed on TWAREN (i.e., TWAREN testbed), and several on-going progress steps are also introduced. The remainder of this paper is organized as follows. The background and related work are introduced in Section 2. The concerns, design and development issues are described in Section 3. The initial performance measurement is presented in Section 4. Finally, the conclusions and future work are provided in Section 5.

II. BACKGROUND AND RELATED WORK

A. *Software-Defined Networking*

With the advancement of network technologies, many ideas and implementations have sprouted in recent years. However, due to the architecture of the legacy network, new innovation may be limited by existing policies and rules. The SDN is recognized as a new architecture to enhancing the network programmability for fulfilling requirements. Two of the most significant characteristics of SDN is the centralized control and softwarized management. By using the SDN controller, network devices are able to change behaviors according to upper layer instructions. Nowadays, the most well-known SDN protocol is OpenFlow [13]. It is a SDN solution to improve the controllability and scalability on network provision. In an OpenFlow network, there are three basic components: switch, controller and application. The switch is used to handle traffic transmission, and controller is responsible for managing the switch operation. The application is able to tell the controller what is the required network behavior for the upper layer.

In the beginning, the SDN research was focusing mainly on layer 2 and layer 3 networks [6]. However, to enhance the network control ability, there is a trend to extend the controllability into underlay network. For example, Mambretti et al. [14] proposed their research about using an experimental control-plane architecture to achieve Light-path provisioning dynamically. Filer et al. [15] also introduced their experience on observing network infrastructure in a cloud system, discussing the impact of elasticity on network capacity and flexibility. Moreover, Channegowda et al. [16] made a discussion on their OpenFlow testbed, which is allowing seamless operation across heterogeneous optical and packet transport domains. Larrabeiti et al. [17] also presented their research of building a large-scale network testbed with both packet-switched and circuit-switched services. As described above, it can be found that the software-defined mechanism is becoming more and more popular in network design, development and implementation in network innovation.

B. *SDN-enable Network and Testbed Development*

For conducting a large-scale network experiment, the main problem is to access the required resources for building the testing environment. Therefore, many large-scale network researches are often supported by network operation institutes or enterprises. Following are the three typical instances:

- **Internet2 and GENI Testbeds:** GENI is a project to build a national resource control framework and provide a testing environment for experiments and verifications [3]. The testbed network of GENI is based on the Internet 2 [18] backbone. Internet 2 provides GENI testbeds with a multi-layer resources including optical facility, layer 2 service and IP route. By deploying computing resources and network control systems [19] [20], GENI testbeds have an open, large-scale, realistic network environment for researchers to evaluate their ideas and explore network research.
- **JGN and RISE Testbed:** The Japan Gigabit Network (JGN) [21] is a nationwide network supported by the National Institute of Information and Communication Technology in Japan. The Research Infrastructure for large-scale network Experiments (RISE) testbed is using this network infrastructure to virtualize the physical network as logical network for experimental purposes [8]. By assigning a number of logical networks called Existing Virtual Networks (EVNs) for creating private experiment networks, the testbed users of RISE are able to operate their desirable topologies in parallel and reduce the time spent in the experiment deployments.
- **TEIN and OF@TEIN Testbed:** The Trans-Eurasia Information Network (TEIN) is a network which connects more than fifty countries in Europe and Asia [22]. TEIN plays an important role of inter-continental traffic exchanges among Europe and Asia countries, and it is also actively being used for international joint researches and education purposes. The OpenFlow at TEIN (OF@TEIN) collaboration community was established in 2012, and its career is to carry out the SDN research issues. The OF@TEIN testbed [10] is using distributed architecture, deploying testbed sites at the domestic collaborators, and making site-to-site connection through the TEIN.

C. *Research and Education Network in Taiwan*

The TWAREN was initiated to construct a fundamental network for research and education in Taiwan. The infrastructure of TWAREN backbone consists of four core nodes. All these nodes are connected with spare dark fibers for redundancy. There are also many GigaPOPs (Point of Presence) located at regional network centers. These GigaPOPs are the communicating entities among the TWAREN backbone and local networks. In initialization, most GigaPoPs are using dark fibers with SDH technique to connect to the core nodes [23]. By using SDH, the TWAREN Optical network is able to divide multiple light-paths between two GIgaPOPs for different purposes. For upper layer connection, the GigaPoPs provide layer 2 entrance to stitch the network. By using this infrastructure, TWAREN facility provides various kinds of networking services [23]. For example, the TANet is a logical network based on TWAREN backbone. It is used to serve the academic institutes for network access. For another, TWAREN VPLS VPN is a network service to establishing point-to-point connections among branches of research institutes. The proposed testbed in this paper also uses this method to create logical and isolated networks to support user experiments.

III. SYSTEM DESIGN

In this section, we present our experience on building a large-scale, as well as multi-layer network testbed on

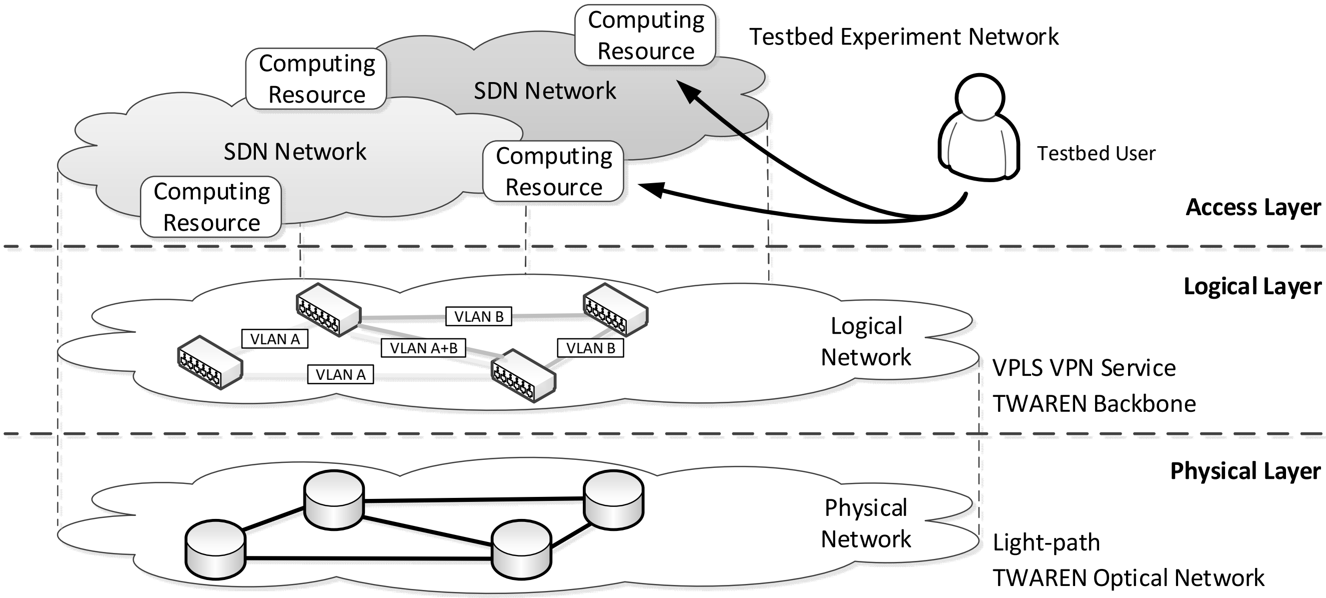

Figure 1. The architecture overview of TWAREN testbed.

TWAREN. The introduction includes concerns, system architecture, and system deployment. Several key development issues in testbed construction are also discussed.

A. *Testbed Architecture*

To explain the TWAREN testbed design, the overview of the TWAREN testbed is shown in Fig. 1. The testbed system can be categorized in three parts: the physical layer, the logical layer and the access layer.

- **Physical Layer:** The physical layer is provisioned with optical transport solutions in TWAREN [23]. It uses a monolithic infrastructure to create virtual networks for supporting different purposes. The light-paths are configured with SDH SNCP protection, preventing single point failure occurred. The devices in this layer are the fundamental hardware of TWAREN infrastructure.
- **Logical Layer:** The logical layer is the middle layer for integrating the other two layers. It consists of numerous layer 2 devices and enabled VLAN to separate virtual networks. For building site-to-site connection among TWEAREN testbed sites, each connection is assigned with a unique VLAN ID. By doing this, the network traffic of each connection is isolated, operating as a virtual links for deploying testbed network.
- **Access Layer:** The access layer is the one appearing to the testbed users. The computing devices (e.g., server and storage) are located here, and layer 3 devices are deployed to establish the network connection among the resources and testbed users. There is also a resource control software in this layer provides the front-end GUI to testbed users. It is the interface bridge for connecting the testbed system with users. Testbed users can request resources (e.g., virtual machines and virtual networks) at the front-end interface first. After that, the resource control software allocates sliced resources to build testing environments. When the experiments are finished, testbed users can notify the testbed system to free the resources and make them re-useable.

B. *Network Resource Control*

The optical infrastructure of TWAREN is shared by testbed network and production network. Therefore, to avoid the interference, these two networks must be separated logically. There is a management mechanism [24] built on TWAREN for light-path control. It supports circuit and equipment protection. Therefore, we use existing light-paths to create multiple VLANs. By enabling QinQ [25] tunnel, each site-to-site link can be divided into as many slices as needed, and the slices are restructuring as virtual paths for traffic delivery. The packet switching is made by a SDN controller. By using VLAN tag-translation [26], the controller is able to manage the site-to-site flows in transmission.

C. *Computing Resource Control*

In anticipation, the institutes participating in TWAREN testbed would share their computing resources for the others, and a control software would be used to take control. For unifying computing resources, currently, the virtual machine is representing the smallest unit in computing resource. Currently, the XenServer [27] is used to manage virtual machines. The received instructions of the XenServer will be converted to create virtual machine. By doing this, the control software sends instruction to each resource site to setup sufficient virtual machines for serving testbed users. With the integration of network and computing resources,

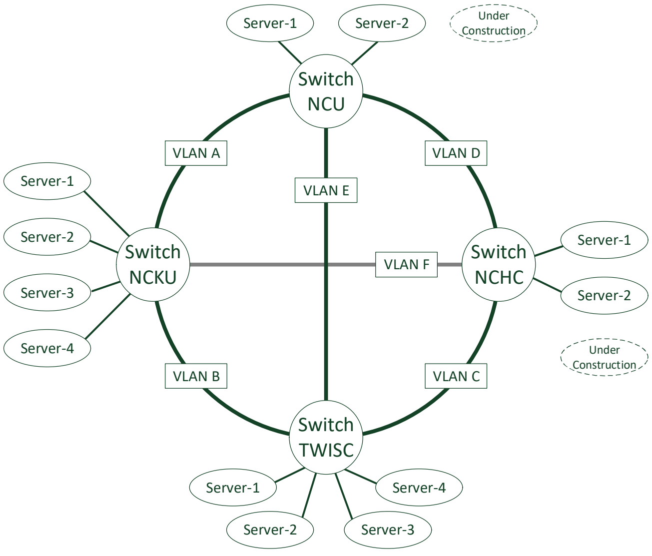

Figure 2. The virtual link among TWAREN testbed sites.

the TWAREN testbed is able to provide a private space for testbed users to conduct their experiments.

D. *Testbed Site Deployment*

In the initial phase, we establish four resource sites in the TWAREN testbed. The TWAREN facility provides 6 VLANs to setup virtual links between two sites. These links are constructed as a mesh topology for connecting testbed sites, which is shown as Fig 2. Each resource site is deployed with an OpenFlow switch, and there is a shared controller (with out-of-band connection) used to manage all the switches.

IV. INITIAL EVALUATION

The implementation of the testbed is still work in progress, while the four testbed sites are ready for initial evaluation. Currently, four available sites in TWAREN testbed are located at NCU, NCKU, NCHC and TWISC, and more sites are anticipated to join in the near future. For verification, we limit the site-to-site bandwidth to 1Gbps initially. By using the iperf [28], the result shows that each link is able to reach the line rate speed. The ping [29] availability test also shows a good response time. Furthermore, for long-term monitoring, we use a Cacti [30] system to collect and present traffic statistics.

For the initial evaluation, an experiment scenario with video broadcasting in 4K resolution is conducted [31]. The streaming VMs are allocated at NCU, NCKU and TWISC sites. By using video player, the receiver is able to get the streaming from broadcasting VMs, which is shown as Fig 3. In our observation, the video traffic for serving one receiver is about 20-24 Mbps. To conduct the stress-test on broadcasting VMs, we use flazr [32] to simulate numerous receivers for acquiring large traffic. Furthermore, due to the fact that each site-to-site connection is limited to 1Gbps, for processing oversubscribed traffic without conjunction, we let the SDN controller select available paths in mesh topology. For example, the traffic flow from NCU to NCKU can be divided in two available routes: NCU → NCKU and NCU → TWISC → NCKU. As a result, the monitoring traffic from NCU to NCKU site has a merged throughput, which is shown in Fig 4. The result of the initial evaluation shows that the testbed system is able to conduct simple network experiments, and the SDN controller is able to manage OpenFlow switches in the testbed for controlling network traffic.

Figure 3. The received 4K streaming on PC.

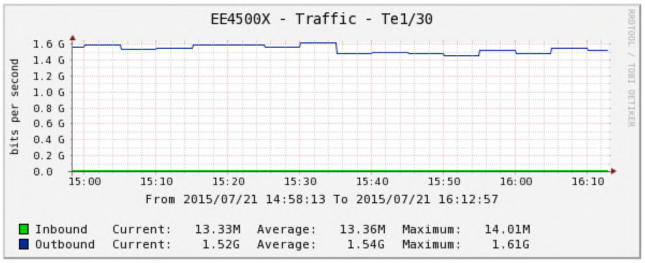

Figure 4. The monitoring result made by MRTG [33] tool.

V. CONCLUSIONS AND FUTURE WORK

This paper describes the experience of designing and implementing a network testbed to support innovative research in Taiwan. The design principle of this testbed system includes several concepts for achieving virtualization. The network of this testbed fully supports the OpenFlow protocol. For managing various resources in the testbed, a resource control software is implemented to allocate resources among different resource sites. The whole implementation of the testbed is still in progress, while the prototype has been verified. When fully completed, the testbed is expected to orchestrate and aggregate the various resources of domestic academic institutes in support of large-scale network researches.

Since testbed users may need various kinds of networking environments within which they can emulate the actual environment. Therefore, making network functions to be a service on the testbed is essential. The following works are expected to enhance the emulation functionality of TWAREN testbed:

- **Enhancement of Programmability in Underlay Network:** Owing to one of the characteristics in SDN is to enhance the programmability on the network, how to extend the controllability to underlay network becomes an important issue. For example, Belter et al. [34] introduced their experience on building GEYSERS, a multi-domain testbed for testing and validating cloud-oriented technologies. The extended controllability is expected to have more flexibility and adaptation on physical network. More testbed operations, such as optical route switching and light-path protection, can be controlled by softwarized methods for supporting advanced network research.
- **Resource Aggregation:** Because many testbed collaborators may have their own cloud solutions, for managing variety resources, making collaboration on these resource is a rapid way for extend the testbed scale. Currently, the TWAREN testbed only supports Xen-based virtual machine. If there is a standard protocol for integrated resources with control software of TWAREN testbed, it would be possible to serve more users to conduct large-scale experiments that are geographically distributed.
- **High-speed Network Infrastructure:** Nowadays, many scientific research projects on TWAREN generate massive amounts of traffic. As a consequence, at present, the TWAREN backbone has reached its limited bandwidth capacity, and the transmission performance of OpenFlow research network may be affected by the available capacity of TWAREN backbone. There is an ongoing plan for deploying 100G infrastructure of TWAREN. The capacity promotion is expected to achieve the ability of traffic engineering on delivering large traffic generated by possible killer applications on the testbed.

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