Society for Science and Education
United Kingdom

TNC Transactions on Networks and Communications

Volume 6, No. 4
ISSN: 2054 -7420

Exploring Network Softwarization and Virtualization by Applying SDN/NFV to 5G and IoT

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ABSTRACT

The development trends of networking and wireless communications technologies have evolved toward Open Networking (ON), Software Defined Networks (SDN), Network Function Virtualization (NFV), and Disaggregation. ON and SDN/NFV are playing the key roles for softwarization and virtualization (S&V) of next generation networks such as 5th Generation Communications and Networks (5G) and Internet of Things (IoT). This article explores the S&V of 5G & IoT and addresses the challenging issues related to applying SDN/NFV to 5G and IoT. These issues include system performance, end-to-end interoperability, software compatibility, global deployment, integration of SDN and NFV , and shortage of talents. In addition, we describe the research and development status of adapting ON architecture and applying SDN/NFV to 5G and IoT in Taiwan. Finally we report the collaboration between National Chiao Tung University (NCTU) and networking industry in the areas of programmable switches built on top of silicon with Programming Protocol-independent Packet Processor (P4) high-level script language and prototyping an OpenAirIntrface (OAI)-based M-CORD.

Keywords: 5th Generation Communications and Networks (5G), Internet of Things (IoT), Software Defined Networks (SDN), Network Function Virtualization (NFV), Programming Protocol-independent Packet Processor (P4), Central Office Re-architected Data center (CORD), Softwarization & Virtualization (S＆V), OpenAirInterface (OAI)

1 Introduction.

There has been a paradigm shift in the networking industry, from a proprietary networking with vendor-dependent software/hardware to vendor-independent open source and white-box switches, as illustrated in Figure 1. The white box is the commodity hardware which is available from network equipment ODM vendors. On the other hand, the open source software executed on the commodity hardware in the control plane can be very complex, which consist of controller (with various OSs, ONOS, ODL, RYU) [17][19], Network Function Virtualization (NFV), and Cloud OS. Not surprisingly, the software engineers involved in the realization of this paradigm shift often encounter various challenges, issues, or difficulties.

Besides the control plane of Software Defined Networking (SDN) as depicted in Figure 2(a), the software of data plane is also under rapid development. In particular, the new invention of switch programming language called Programming Protocol-independent Packet Processor (P4) that can be tightly coupled

DOI: 10.14738/tnc.64.4825
Publication Date: 17th July 2018
URL: http://dx.doi.org/10.14738/tnc.64.4825

with SDN controller, Open network (ON) architecture, and Tofino [16][23] system on chip (SoC) has brought lots of attention to the open networking community. Figure 2(b) shows the relationships among P4, Central Office Re-architected a Data Center (CORD), and Open Network Operating System (ONOS) based on a layered architecture. Among them P4 is a high-level programming language designed to configure/re-configure hardware, CORD is the architecture to transform telecommunications central offices to becoming data centers and ONOS [20] is the open networking OS developed by ONF. The ecosystem of this ON community includes network service operators, network equipment vendors, silicon providers, and white box ODM providers become so active. In the meantime, the next generation 5G communications system will be available within 2-3 years while the applications of IoT will appear in various industries.

The impacts of new ON architecture includes high speed network vendor (P4 switch), Rack solution provider (M-CORD), silicon provider (SoC/IC), commodity provider (white-box switches, servers, I/O blades), network service operators (services) are becoming quite significant. P4 switch provides high speed switch with highest programmability which capability is embedded in SoC/IC. CORD architecture will convert the central offices of telecommunications network to data center which can provide fast and rich services. Consequently, this conversion can reduce the capital expense (CAPEX) and operations expense (OPEX) for network service operator.

With the efforts of research and development related to SDN/NFV, open source for open networking, we have encountered and identified six challenging issues: performance, interoperability, compatibility, deployment, integration of SDN and NFV [4][5], and shortage of talents. In this paper, we will also address how to tackle these challenges.

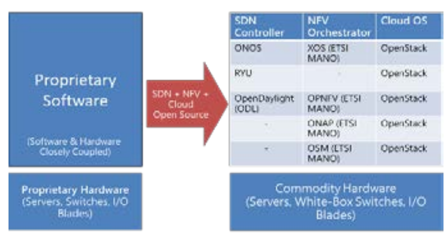


Figure 1 Open Networking Trend

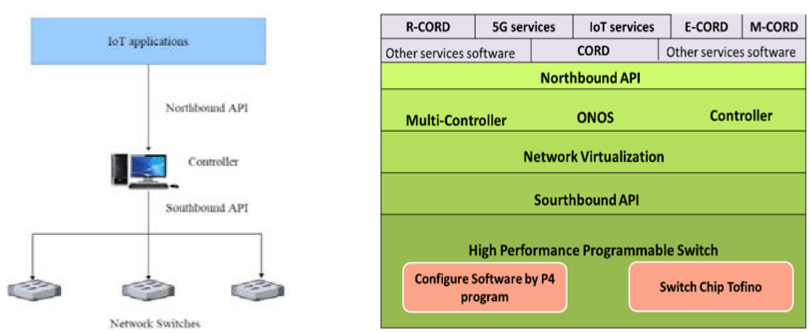


Figure 2(a) SDN Architecture

Figure 2(b) SDN Layered Architecture based on P4/ONOS/CORD

Figure 2 SDN layered architecture based on P4/CORD/ONOS

2 Network Softwarization & Virtualization

There are several papers [1][2][7][8] pay much attention to realize SDN for IoT and virtualization of network functions of network elements of IoT. The other papers [6][9][10][11]are investigating how to take care of 5G or mobile broadband. In this paper, we address both of IoT and 5G from softwarization and virtualization point of view.

SDN sets the standards for converting a network based on propriety hardware/software into a software defined network based on commodity hardware and open source. SDN defines a network with the separation of control plane (controller) and a data plane (switch). Figure 2 shows the SDN layered Architecture where the control of network switches is separated out and moved to SDN controllers such as ONOS via defining southbound API such as OpenFlow. Also, the P4 programming language is defined to enable the data plane programmability of SDN switches. Via P4 an SDN controller can configure and re-configure switches during runtime.

On the other hand, NFV provide the ways to virtualize the network elements by software components or modules. According to NetSoft 2018 conference statement [26] and ONF (Open Networking Foundation), SDN, NFV, and Cloud Edge computing have been driving a paradigm shift in the telecommunications and ICT industries. Network softwarization and programmability promise to reduce OPEX and to provide better flexibility and bring new services to their customers sooner [21].

3 P4 and CORD Becoming Popular and Their Impacts

Since ONOS is available, the P4 and CORD are becoming popular in the ON community. This creates significant impacts to the SDN ecosystem including high speed network vendor (P4 switch), Rack solution provider (M-CORD box) silicon provider (SoC/IC), commodity provider (white box switch, server, storage I/O, blade), and network service operator (services)

3.1 P4 as an SDN Switch Programming Language

P4 [12][13][14][15] is a re-configurable, multi-platform, protocol and target independent, packet processing language which is used to facilitate dynamically programmable, extensible, packet processing in the SDN data plane. In SDN, a switch uses a set of “match+action” flow tables to apply rules for packet processing and P4 provides an efficient way to configure the packet processing pipelines to achieve this goal. Specifically a packet consists of a packet header and payload, and the header includes several fields defined by the network protocol. A P4 program describes how packet headers are parsed and their fields are processed by using the flow tables where matched operations may modify he header fields of packet or the content of metadata registers.

Figure 3 shows how P4 make SDN switch more flexible and programmable [12][13]. Figure 3(a) shows SDN switch without supporting P4 while Figure 3(b) with P4 support.

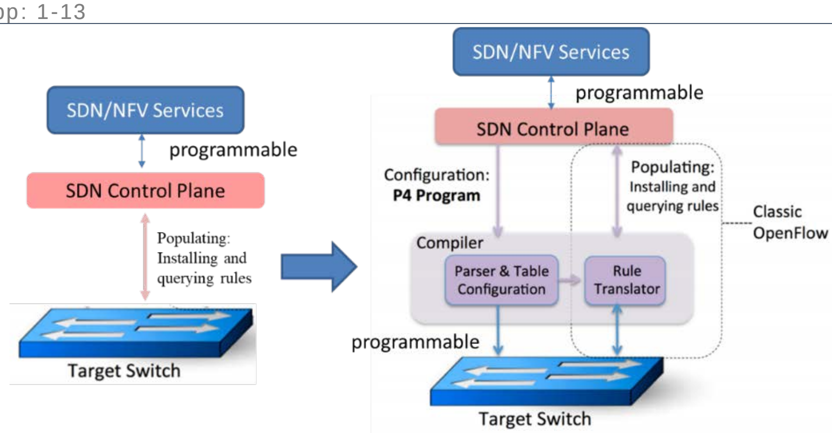


Figure 3(a) Switch without P4 support   Figure 3(b) Switch with P4 support

Figure 3 SDN Switch with/without P4 support

We have conducted the P4 switch system performance evaluation by developing two applications :

(1) Traffic Classification for Dynamic QoS Control based on P4 Switch[24]
(2) Dynamic Load Balancing and Congestion Avoidance based on P4 Switch [25]

Figure 4(a), 4(b), and 4(c) show the topology of experiment, architecture, and the sample percentage of applications distribution respectively for the traffic classification for dynamic QoS control based on P4 switch, Figurer 4(d) and 4(e) illustrates the two topologies and the architecture respectively for dynamic load balancing and congestion avoidance based on P4 switch.

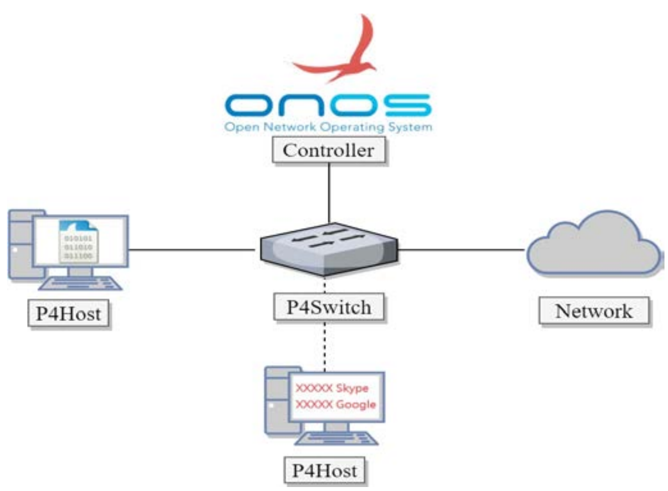


Figure 4(a) Topology of Experiment for Traffic Classification for Dynamic QoS Control

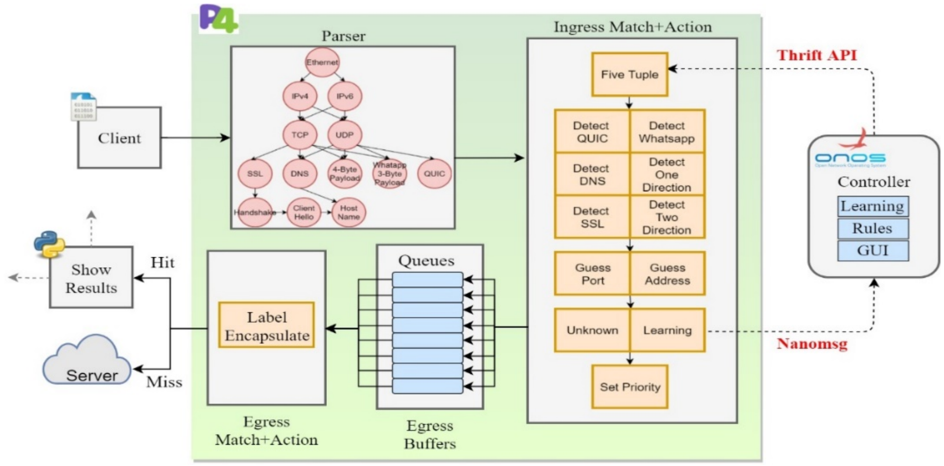


Figure 4(b) Architecture of P4-based Traffic Classification for Dynamic QoS Control

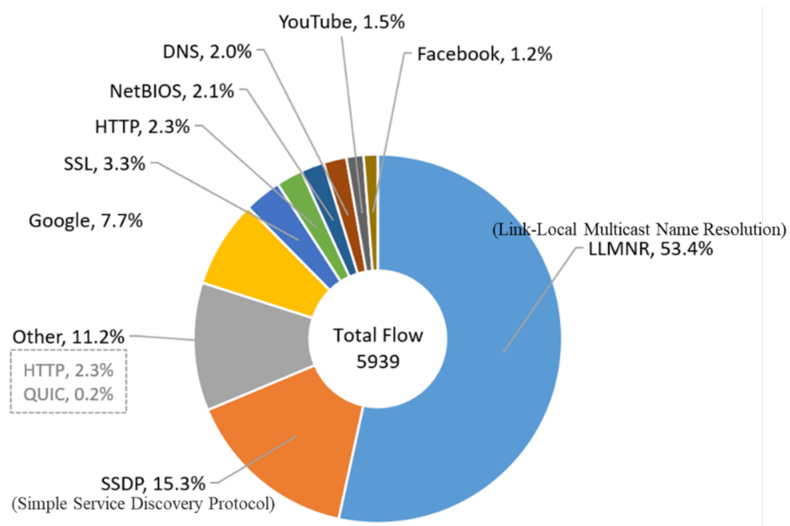
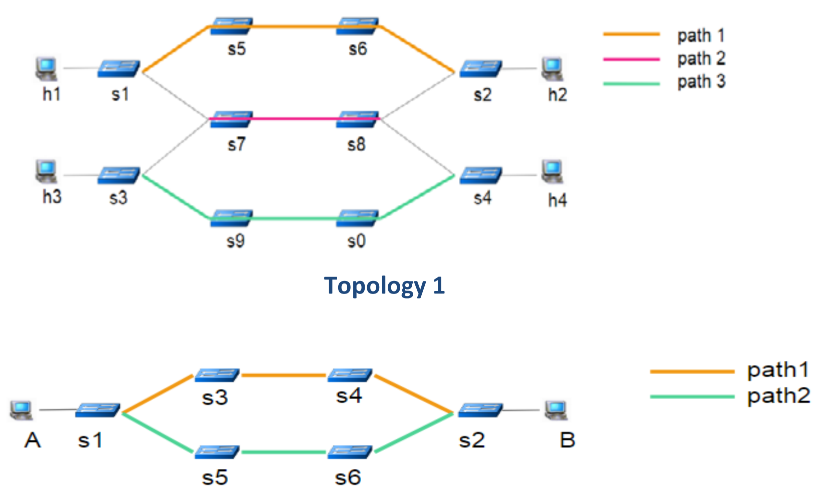


Figure 4(c) Percentage of applications for a sample traffic flow



Topology 2

Figure 4(d) Topology1&2 for Dynamic Load Balancing and Congestion Avoidance

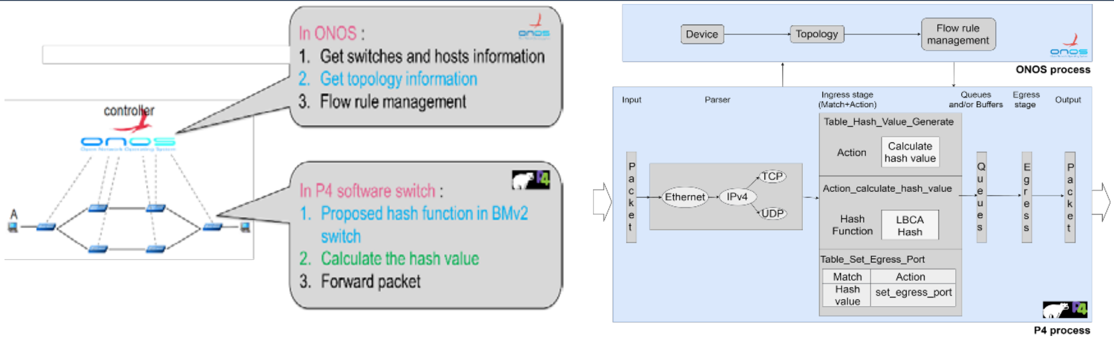


Figure 4(e) Architecture for Dynamic Load Balancing and Congestion Avoidance

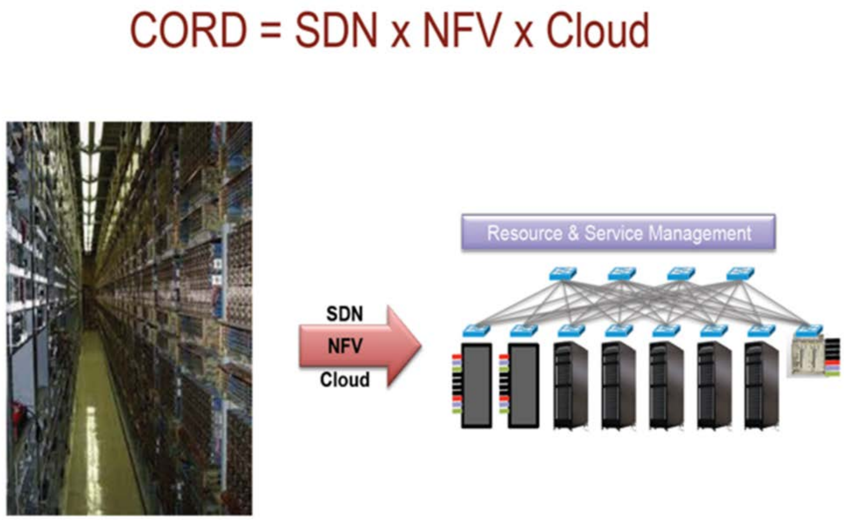


Figure 5 Basic CORD Architecture [18] [20]

3.2 CORD as CO Re-architected Data Center

The basic CORD architecture [18] [20] transforms telecommunications Central Office (CO) to Data Center (DC)as illustrated in Figure 5. This transformation will change the CO with properity hardware/software to DC with white-box commodity and open source. Based on this CORD architecture, many possible applications may apply SDN/NFV and Cloud (local cloud and remote cloud) to telecommunications networks, including:

a) Mobile/Wireless network – M-CORD
b) Residential/wireline network – R-CORD
c) Enterprise network – E-CORD

4 Why 5G and IoT ?

5G is the next generation communications networks which provides very high data rate (throughput) with very low latency. SDN, NFV, and mm-wave are claimed as 3 key ingredients for 5G. In this article, we are trying to find out that 5G is capable of handling various requirements of IoT applications and services. The IoT applications may generate big data or small data and services may be mission critical. 5G network architecture is designed to handle these IoT applications and services properly.

The international standard organization, Next Generation Management Network (NGMN) has proposed three real and existing categories of network slicing for 5G including smart phones, autonomous driving, and massive IoT as shown in Figure 6. To zoom into massive IoT category, it can be further divided into as many network slicing as shown in Figure 7. Figure 8 indicates the realization of 5G network slicing [22] by SDN/NFV technology through the virtualization of RAN and EPC

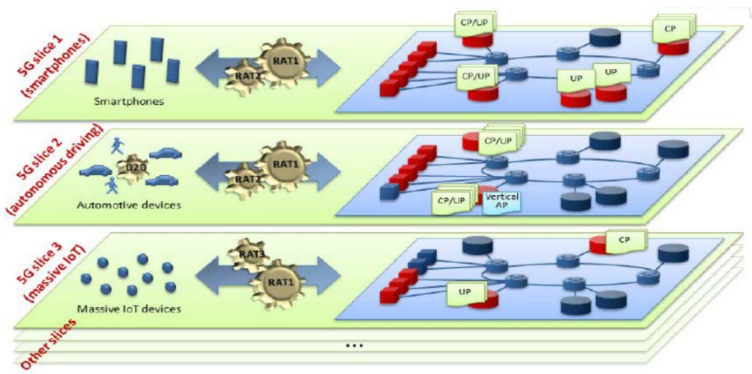


Figure 6 NGMN proposes three categories of network slicing

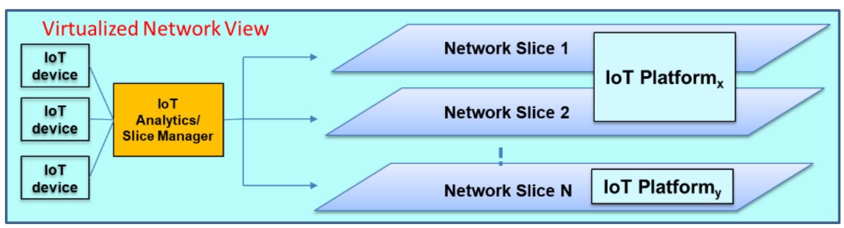


Figure 7 Appling SDN/NFV to IoT Services to realize dynamic deployment of IoT services

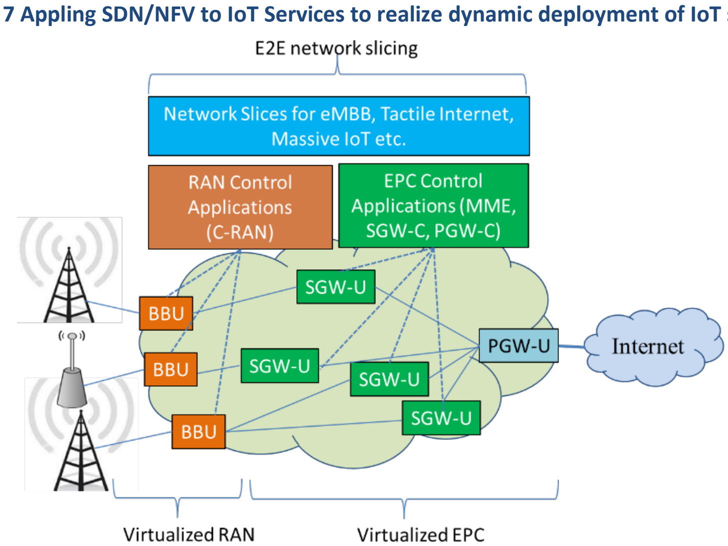


Figure 8 Realizing 5G network slicing by SDN/NFV

5 Challenges and Technical Issues

Through the joint Research and Development of SDN/NFV technology between CHT-TL and NCTU, we have discovered and identified six technical and human resource issues [3] [4] [8]. In the section, we also address how to resolve those issues.

5.1 Performance for Network based on ON/Open Source vs. Propriety

The network performance comparison is an issue between approach with ON & open source verse approach with propriety hardware & software. But if the network scalability and programmability are the requirements, then ON/open source approach or solution is a better choice. Also, the network performance of ON/open source approach continuous to improve automatically while the propriety approach needs to pay more to buy a new model with better capacity and capability.

5.2 End-to-End Interoperability

The choice of SDN popular controller's OSs includes ONOS, Open DayLight (ODL), RYU. The available switches from various vendors built on top of different SoC/IC solutions. How to test the end-to-end interoperability among SDN of north Taiwan Universities and to connect to global are shown in Figure 9. It indicates the network topology, controller OS of each site and various brands of switches of each site:

a) NCTU SDN controller runs ONOS as its OS with switches by PICA 8, Edgecore, and Broadcom,
b) CHT-TL (CHT: Taiwan top one telecom operator) controller runs RYU as its OS and with Switches by NEC
c) NTHU's controller runs ODL as its OS with switches by PICA 8
d) Kreonet and AmLight are global links to South Korea and to Florida then to South America

Through those intensive exercises and experiments following the successful global deployment led by the lab team of ONF, the issue of interoperability is resolved.

5.3 Global Deployment

To deploy SDN global peering, NCTU team worked together with ONF Lab Team (used to call ON.LAB). There are 8 cities around 5 Continents participated in this global SDN-IP Peering. The result was demo at Open Network Summit (ONS) went very well. Figure 10 and Figure 11 provide two screens shown during the demo.

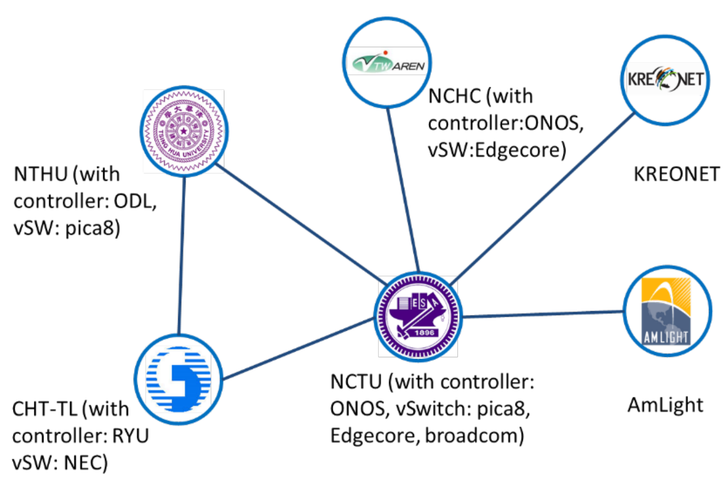


Figure 9 Network Topology in North Taiwan (Link to Global)

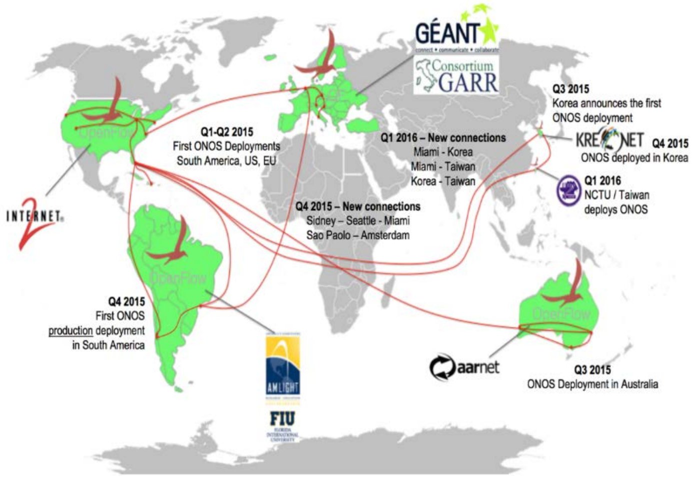


Figure 10 SDN-IP Global Peering Deployment with 5 Continents

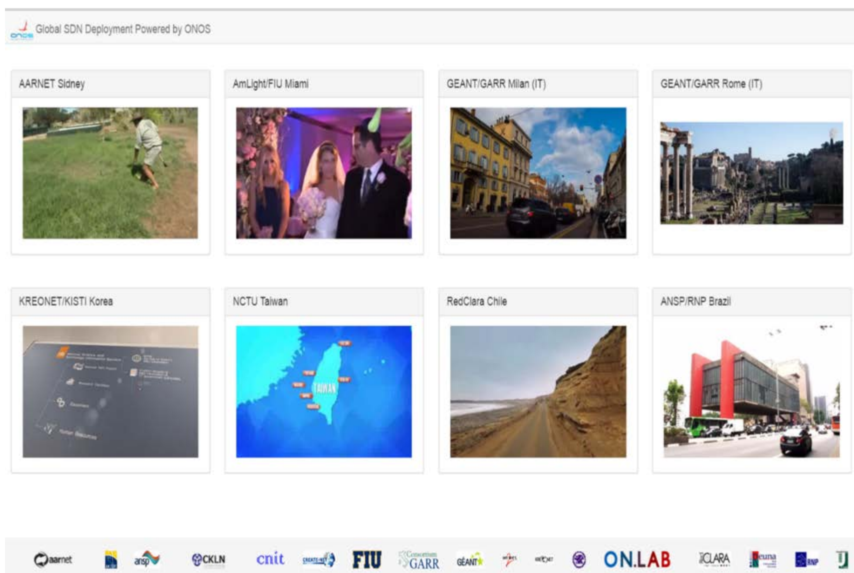


Figure 11 Video Shown from 8 Cities and Regions during SDN-IP Global Deployment

5.4 Software Compatibility

To get familiar with the availability and functionality of the proper version released open source software and tools in particular related to open networking software is essential to resolve the incompatible issue. The version control and development methodology are also very important.

5.5 Vertical Integration

The challenge of integration of SDN and NFV was addressed by several papers [3][4]. By creating vertically-integrated stack as SDN distribution. The software and tools of open source related to SDN will continue to update or revise and the virtualization of network elements defined in NFV may change or update time to time. The case In Figure 12 shows a successful vertically integrated as SDN distribution.

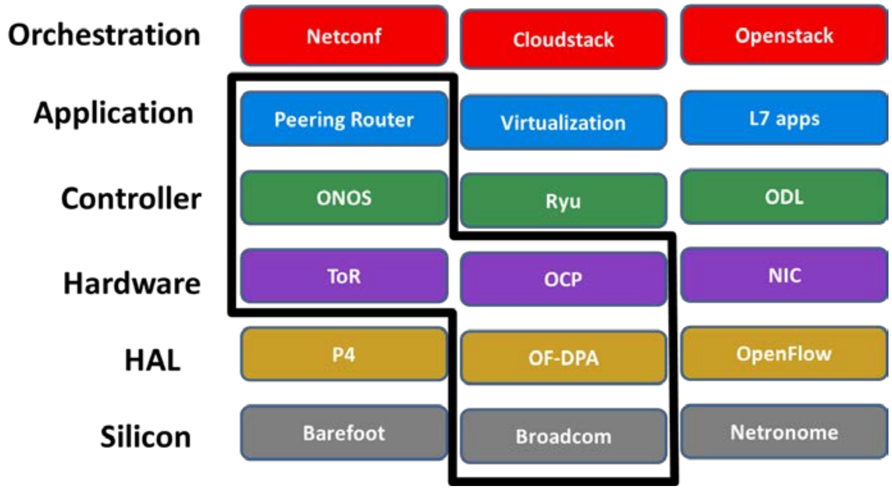


Figure 12 Solution: Vertically Integrated Stack as SDN Distribution

5.6 Human Resource – Shortage of Talents

The talents who have the knowledge of P4, ONOS, CORD, and the familiarity of open source for open networking are limited. The technical training and practice are needed. Also, the global collaboration by work together with famous organization with good reputation by sending the motivated people as interns and/or contributors. NCTU experiences working with ONF (Lab Team) in the areas of P4 and CORD Is quite successful. For this collaboration, NCTU has sent several graduate students to ONF Lab Team (US) as interns and participates in the ambassador roles and brigade team. Also, NCTU's PhD students have participated in EURECOM (France) OpenAirInterface (OAI) open networking project and they have contribute significantly in the area of virtual Radio Access Network (vRAN) performance improvement.

6 R&D Status of P4 Switch and M-CORD at NCTU

6.1 Tested of P4 Switches and Applications Development

At NCTU, we have done the performance measurements based on the testbed of P4 switches designed by Edge-core (in Figure13, Inventec, or WNC can be the other choice) with two applications as described in Section 3. Today we open this P4 testbed to the universities and research institutes (with proper agreement) who are interested in P4 switches related research & technology exploration and P4 applications development.

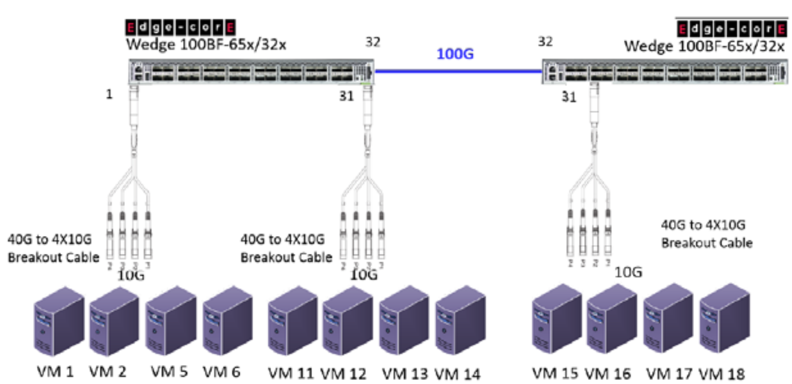


Figure 13 Topology of P4 testbed at NCTU

6.2 6.2 M-CORD architecture, Prototype, and Applications

Figure 14 shows a 4G OAI-based M-CORD Prototype at NCTU. This prototype consists of two components: one is USRP X310 (RRU+BBU)as OAI eNB, the other is CORE-in-a-box as OAI EPC with ONOS as SDN controller(MME) and P4 switches (S+P GW)+ HSS

The M-CORD-in-a-box and M-CORD Prototype at NCTU in Figure 16 is prepared to be ready for 5G UE-eNB as RAN/C-RAN.

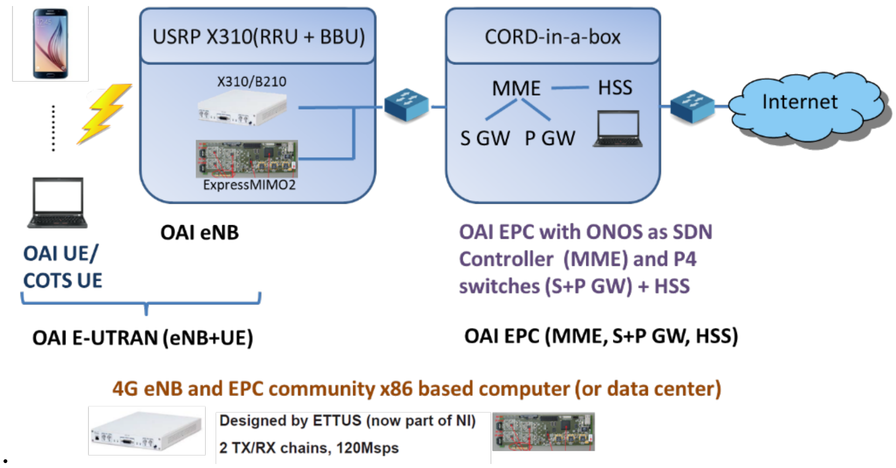


Figure 14 An OAI-based M-CORD Prototype at NCTU

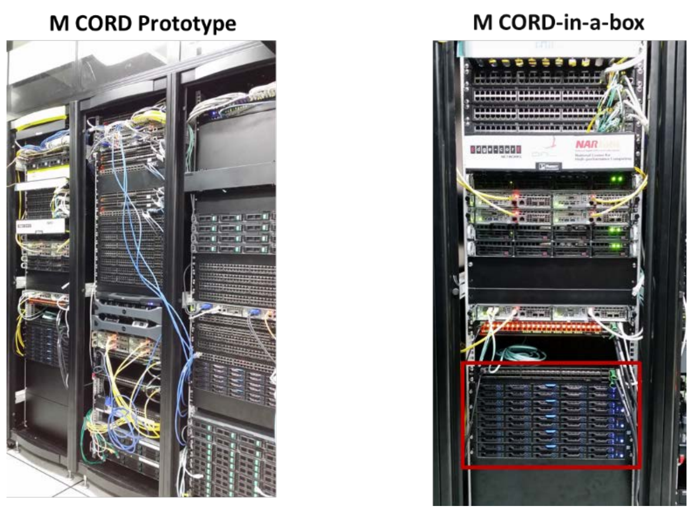


Figure 15 M-CORD-in-a-box and M CORD Prototype at NCTU

7 Conclusion

This paper addresses the discovery of the challenges/issues of network softwarization and virtualization and to find out the possible solutions. The impacts of new open networking architectures and open source, ONOS, P4 and CORD of SDN/NFV to the software defined networking industry ecosystem includes high speed network vendor (P4 switch), Rack solution provider (M-CORD box) silicon provider (SoC/IC), commodity provider (white box switch, server, storage I/O, blade)

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ACKNOWLEDGEMENTS

The work as supported by the Ministry of Science and Technology (MOST) of Taiwan and National Chiao Tung University under grants: 106-2221-E-009 -008, 105-2622-8-009-008 and NCTU-ICTL 194Q707.

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