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A Survey on New Architecture Design of Internet

Hongyu Hu, Jun Bi, Tao Feng, Sen Wang, Pingping Lin, You Wang
Network Research Center, Tsinghua University, China
4-204, FIT Building, Beijing, China
huhongyu@cernet.edu.cn, junbi@tsinghua.edu.cn, fengt09@mails.tsinghua.edu.cn,
swangfly@vip.qq.com, {linpp, wangyou}@netarchlab.tsinghua.edu.cn

***Abstract*—The current Internet, which is based on TCP/IP architecture, exposed its inherent shortcomings increasingly in recent years, such as: network management is difficult to deploy, network security issues become more serious, "best effort forwarding" strategy cannot provide QoS that a user needs, and new applications are difficult to deploy, etc. All of these problems cannot be resolved satisfactorily by "putting-patch" way. It is time to redesign and reconstruct the architecture of Internet. Now some new design ideas about future Internet architecture have been put forward. In this paper, some representatives of these ideas are introduced, and their advantages and defects are analyzed. After these analyses, the possible direction for future Internet design in our opinion is pointed out.**

Future Internet; Architecture; OpenFlow; NDN; GENI

I. INTRODUCTION

After thirty years' development, current Internet which is based on TCP/IP architecture has achieved great success and become one of the essential infrastructures for people's work, study and daily life. However the initial design principle of Internet, that is "Keeping the simplicity of network while leaving the complex processing tasks to hosts", forms an embarrassing situation: software in application layer has got rapid development and functions in application layer have been greatly enriched because protocols in application layer on host side can be easily and conveniently modified and deployed; in contrast, protocols in network layer lack scalability and can not be easily and conveniently modified and deployed. The result of this strange framework is: on the one hand, some fatal flaws or serious leakages of Internet network layer are difficult to get fixed in a long time, such as: network management is difficult to deploy, network security issues become more serious, "best effort forwarding" strategy cannot provide QoS that a user needs, and new applications are difficult to deploy, etc.; on the other hand, new protocols and services are difficult to be applied because they need to make changes to network layer, such as: the transition from IPv4 to IPv6 is difficult to deploy, large-scale network is facing routing scalability issues, cloud computing and content distribution applications put forward new requirements to forwarding efficiency of the network, etc. Vinton G. Cerf, the father of TCP/IP, pointed out that Internet should do better in network security and reliability.

To resolve current problems and embarrassment of Internet, deep discussion, analysis and renovation for network architecture level should be made to meet the future challenges and opportunities of the 21st century.

The network layer, which is the core of Internet, is hard to be expanded and improved. The revolution to the core of Internet is almost in stagnation. The architecture of Internet is facing redesign and reconstruction. New ideas about how to design future Internet architecture are put forward successively. Internet is at the crossroads of revolution. There are many factors that will influence Internet's evolution. Everyone in this revolution process has opportunities to create new things and make success. But there is a long way for Internet evolution.

This paper will introduce and analyze some representatives of current new design points and ideas for future Internet architecture.

II. REPRESENTATIVE RESEARCH RESULTS OF FUTURE INTERNET

A. *Representative of Open Ideas -- OpenFlow[1]*

Nowadays, Stanford University and Juniper Company walk in the front of the research of open network. Stanford University's OpenFlow technology and Juniper's JUNOS SDK technology represent the research results and progress on open network both in academia and industry.

In 2007, professor Nick McKeown of Stanford University proposed a new network operation mode with open devices and centralized control -- OpenFlow[1-3]. OpenFlow is composed by three parts：Open network equipment (OpenFlow Switch), centralized control (OpenFlow Controller) and communication protocol (OpenFlow Protocol). The basic idea of OpenFlow is to separate the fast packet forwarding part (data plane) from the logical routing computing part which is resident in devices in traditional network, and leave data plane in the devices while take control plane out of the devices to a centralized control server (OpenFlow Controller), and both parts communicate with each other through an standardized message interface (OpenFlow Protocol). Meanwhile, in the data plane, a new hardware is designed -- FlowTable, which is a miniature of the data plane and provide a unified way for the outside logic to use and control; in the control plane, computing logic is centralized and control commands to network devices is

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send by standard messages, which can realize all basic functions of traditional distributed computing mode, such as packet reception and forwarding, updating FIB and acquiring devices status, etc.

The initial aim of OpenFlow is to allow researchers to run their experiments in actual production network such as campus network to get more realistic information. But its reformation to network black box (router) makes the innovation to network become easy and possible and promotes OpenFlow's application in a wider scale. Now, OpenFlow has been widely used to data centers (such as Google) and other high self-control private network for user-defined network reconstruction. We believe that OpenFlow's effects and contributions to the innovation and evolution of Internet is huge and enormous. Its influences include two aspects:

First, OpenFlow introduces open and standardized thinking to reconstruct network and network devices. Its open and standardized thinking is reflected in three levels, as shown in Figure 1. (1) In data forwarding plane, the design of FlowTable realizes the standardization, simpleness, and openess of hardware resources and network devices. In traditional network, network device is a black box, and the internal design details and processing are opaque. Manufactors refuse to open the internal implementation details of devices and the internal implementation details from different manufacturers are different. This causes the internal structure and processing of devices are complicated, overlapped and various, which is bad to the stability, error correction and evolution of devices; (2) The design of OpenFlow messages realizes standardized access means to hardware resources of network devices. This is the openness and standardization in access interface level; (3) In control plane, NOX -- a centralized control platform is designed. NOX provides standardized interfaces that are NOX components to add new control logic for users, by which user-defined control logic can be added to the platform to share the hardware resources in network equipments in a united way.

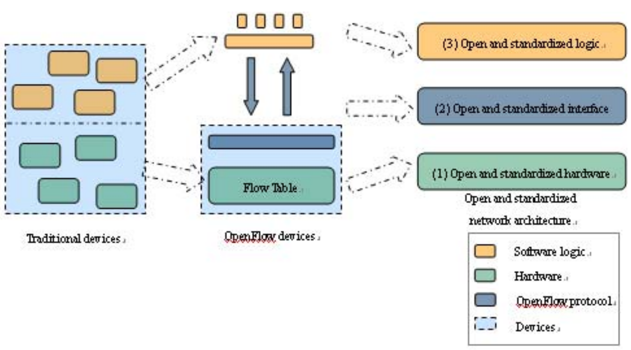

Figure 1. OpenFlow's innovation to the network.

Secondly, the centralized computing mode is another important feature of OpenFlow, and it can be treated as a supplement for the traditional network's distributed computing mode which is in troubles in some applications which need global information of network. Centralized computing mode can get global information and improve computing efficiency. This feature can easily realize the applications and services which require global information and has not be resolved satisfactorily in long-term in traditional IP distribution computing mode, such as QoS routing, multicast routing, and traffic engineering, etc. Obviously, the centralized computing and control mode is based on OpenFlow's first feature -- "openness and standardization".

Of course, OpenFlow has its shortcomings, such as: additional hardware resources is needed to add to devices--FlowTable which will add the cost of the devices, openness of hardware resources are not adequate and can not fully meet user requirements, centralized control mode has control efficiency issue in some cases, and its scalability (e.g. extending to the global world) is weak.

B. *Representative of New Narrow Waist Ideas -- NDN[4]*

The initial design goal of current Internet architecture is to realize the interconnection of the existing networks effectively, in which "end" device (or IP address) is the center and "end to end" connection is the main services Internet provides for users. However, with the development of Internet, Internet is gradually evolving to a "content distribution as the main service" network, in which people are concerned about the "content" instead of "content's location". This "content-centric" application mode is profoundly affecting the use and evolution of Internet.

In 2006, Van Jacobson and his colleagues in U.S. PARC laboratory recognized the importance of the "content-centric" application model for Internet and recognized that the traditional Internet architecture built on "end to end" communications exposed many problems when supporting "content-oriented" application, such as: the content cannot be effectively identified, stored and reused, there are a large number of retransmissions and large amounts of bandwidth are consumed, and special conversion mechanism from the "find content" to "find the IP address of content " is needed which will cause the reduction of network efficiency, etc. Therefore Van Jacobson and his colleagues designed a new network routing model based on the "content-centric distribution"-- NDN (Named Data Networking).

NDN uses hierarchical and human-readable name structure to name the content which is directly used for data search, data transmission and data storage in NDN network. As the data name is accordant with the data content, so NDN network equipments can recognize and understand the content in data packets by the analysis to the data name in the packets, and then NDN equipments can do some advanced and intelligent functions, such as caching "hot" data content according the request number of the content, registration a request instead of forwarding it, which will reduce the duplicate transmission of contents in the core network and improve network data transfer efficiency.

DND's basic principles are as follows: publish/subscribe model and two types of packets (Interest packet and Content packet) are designed and used in data transmission. Consumers of content will issue an Interest packet to request content. NDN routers forward an Interest packet according to the name in the Interest packet and record all Interest packets they forwarded. Routers or hosts which receive an Interest packet may check whether they have the corresponding contents requested by the Interest and send back the content by Response packet if they have. Content packets will go back along the path that the Interest packet has passed, so routers need not to look up route tables for the content packets. Compared with traditional IP router, two new storage hardware parts are added to NDN router except FIB: the content buffer (or content cache) and PIT (Pending Interest Table). NDN routers use Content buffer to cache the contents passing through them and use PIT table to record the Interests which have been forwarded while have not received the responding Content. When an Interest packet comes in, a router will first look up in the Content buffer whether there is a Content satisfying the Interest. If no corresponding Content exists, router will look up in the PIT table whether the same Interest has been forwarded. If same Interest exists in PIT, router will not forward the Interest but add some information about the request user in the response PIT table entry. If no same Interest exists, router will look up in the FIB table for the corresponding forwarding ports.

NDN's advantages are as follows: the use of hierarchical name avoiding the IP address scalability problems in IP network; novel forwarding mechanism providing good foundation to solve the multi-path routing and policy routing problems; inherent support for network traffic balance and multicast transmission; realizing the security and integrity of the content through the signature of content (that is a kind of data-oriented security mechanism); and providing support to mobile network and delay tolerant network [5]. Additionally, NDN is compatible with today's Internet architecture and has a clear progressive evolution strategy [6] because NDN layer can run upon IP layer while IP layer can also run upon NDN layer. This feature makes NDN becomes a new "narrow waist" naturally instead of IP in new architecture of future Internet, as shown in Figure 2. With these features, NDN can resolve many problems which are all challenges for today's TCP/IP network architecture.

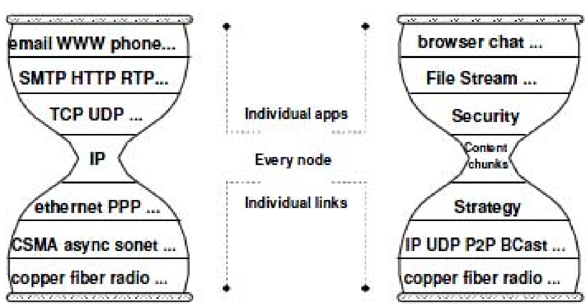

Figure 2. NDN becomes the new "narrow waist" instead of IP.

We also believe that there are some shortcomings in NDN: First, NDN routing mode is designed for content distribution services initially and its advantages are obviously in these content services. Whether this mode is suitable for all other application services, and whether this mode can get route efficiency increase for all other application services (such as instant messaging services), and whether network routing efficiency can be improved totally, all of these problems need rigorous analysis and improvement. Second, NDN routing mode wants to replace IP routing mode as a new "narrow waist" upon IP, which needs understand and support from end-users and network operators. Third, NDN's research is still in starting stage and it is still an empty framework without implementation details such as how to achieve efficient and scalable name spaces, the designs for routing/forwarding mechanism and network storage strategies are also in blank and there is no large-scale experimental network of NDN, all of which need more deep research work.

C. Representative of Testbed Ideas -- GENI[7]

In January 2005, 30 Internet experts of United States organized a seminar "Across the barriers of innovation of network". The seminar was initiated and organized by Tom Anderson and other experts. After the meeting they submitted a proposal to NSF (National Science Foundation) signed jointly. The main ideas of this proposal are as follows: The design and research of a new Internet architecture is important and urgent, while any new ideas about future Internet architecture need a rigorous and large-scale network simulation testing, demonstration and test-run before their actual practical use and apllication. So to design a global network simulation platform for researchers has become an important issue. Based on this report, a project which aims to support the reconstruction of Internet and the building of corresponding test bed is formed -- GENI. In August 2005, GENI published its goal that is to set up a new distributed architecture for Internet which will support incremental and revolutionary innovation of Internet. In February 2006, GENI changed its name from the "Global Environment for Networking Investigations" to "Global Environment for Network Innovations". This change reflects GENI revolutionary objects more clearly.

If you think GENI is only a super testbed and has no relationship with future Internet architecture, you are totally wrong. GENI has a close and complex relationship with the future Internet architecture, which is mainly reflected in two aspects: 1) GENI is a distributed platform and will support multiple protocol stacks which need to run upon GENI and get demonstration and test, and each protocol stack can be treated as an independent network architecture. So GENI will be a test platform for future network; 2) Multiple network architectures will be test and run upon GENI (a unified platform). It will generate two possible results: a. one of the network architectures will win ultimately and gain large-scale use and deployment, so the contribution of GENI is a testbed platform for the winner architecture; b. multi architectures of future Internet will survive ultimately. The survival architectures can be treat as the sub-architectures, and GENI can be treat as the father-architecture. So GENI distributed architecture will be a bottom platform and will be a de facto and critical part of the future Internet architecture.

One important goal of GENI is: to support a variety of network experiments to run simultaneously, and to provide a high-confidence, robustness, and secure platform which can avoid some errors caused by experiments or experiments users and isolate these errors from another experiments users. For this goal, GENI uses network virtualization technology to build an isolated, secure virtual sub-network for a specific experiment to form their "test bed" and to support multi kinds of networks exist simultaneously. So actually GENI is a "test bed" behind these virtual "test bed". To build a virtual "test network", virtual node, virtual link, virtual network construction and virtual resource release etc. techniques will be used in GENI.

A concrete building process of virtual experiment network is described as follows: the laboratory personnel sends request to the GENI resources exchange and control center (which is called as ClearingHouse) "Is there any appropriate and sufficient resources for us to do experiment now?", ClearingHouse then sends the available "resources" list to the laboratory personnel, and laboratory personnel bases on the given "resources" list to build their own topology to form a virtual network. Virtual network is a slice of the total network resources of GENI. After a Slice is successfully established, the laboratory personnel can run and execute their own experiments in the Slice. The Slice can be expanded with resources and reduced, or even be halted when in use process by the administrators.

Another important goal of GENI is to support wider and more revolutionary network experiments. GENI will not be limited to the connection of PlanetLab PCs (which actually are virtual soft routers) all over the world, but will support the interconnection of more types of nodes, such as routers, switches, PCs, optical fiber etc., and will expose the connection of lower network layers. At the same time, GENI will use the experiences of PlanetLab testbed to realize its global platform that is to utilize an alliance way to form hierarchical Clearinghouses to realize network resources allocation and reconstruction across Clearinghouses. Clearinghouse from different countries can be connected, which is the foundation to realize global network research and science activities.

The disadvantage of GENI in our opinion is that: virtualization technology, which is used to build sub-network (Slice) for experiments, will consume some network resources (such as CPU, bandwidth, etc.), and will reduce the utilization rate of network, and the virtual process will increase the complexity, difficulty and error rate of network.

In 2008, The leader of GENI project got to know OpenFlow project and recognized that the campus experimental network environment built by OpenFlow has the similar goal with the GENI global experimental network test environment, so OpenFlow project became a sub-project of GENI and is funded by GENI.

III. POSSIBLE DIRECTIONS OF FUTURE INTERNET

Internet is like a huge monster. Its impact is enormous but its architecture is mechanical and awkward. We need to change the architecture of Internet, give it more flexility and scalability to support new business and services rapidly with low costs for development and maintenance. About how to redesign the future Internet architecture, there has occurred many points of view both from academic and from industry, but none of them has got widely understood and fully accepted, which is mainly due to two reasons: one is that the future direction of network development is not very clear, and we can not determine what technology can represent the future development mainstream of Internet. Another is that we lack the appropriate approaches to evolve smoothly from the current Internet architecture to the new one. Therefore, for the future Internet architecture development, open and smooth network evolution mode should be used to ensure smooth evolution of the Internet.

In our opinion, “Giving him a fish is not better than teaching him how to fish”. So open network devices and open networks will be valuable and useful and is an important research direction for the future network architecture research. Furthermore, in open network architecture, the standardization and simplification of equipments and the modularization of software functions and the standardization of development, testing, deployment process will help to realizes the rapid implementation, application and deployment of new protocols, functionality and business of network layer with low cost in the network, and will help to strengthen the flexibility capacity and innovation capacity of Internet, and promote Internet to provide better services to mankind and create greater glory.

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