A Novel Problem-solving Metric for Future Internet Routing Based on Virtualization and Cloud-computing

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Abstract

The Internet has evolved from an academic network to a broad commercial platform and become an integral and indispensable part of our daily life, economic operation, and society over forty years. However, many technical and non-technical challenges have emerged during this process. In order to address these challenges, we analyze the three features—pervasiveness, heterogeneity and intelligence that the future Internet possesses, and present a novel problem-solving metric for future Internet routing which can intelligently deal with the application requirements that current Internet cannot meet. The new routing metric possesses the capability of both Store-and-forward and service provider, the latter of which is introduced by us innovatively. Finally, we detail the routing metric which can provide a useful reference for the researches of future Internet routing.

Keywords: Future Internet, Network Architecture, Cognition, Cooperation；Cross-Layer, Virtualization, Cloud-computing.

1. Introduction

The Internet has evolved from an academic network to a broad commercial platform and become an integral and indispensable part of our daily life, economic operation, and society over forty years. However, many technical and non-technical challenges have emerged during this process.

In the aspect of flexibility, the Internet was originally designed for data transmission and its layers are toughly coupled. Its inner running state, parameter configuration and process method cannot be changed, but though the special interfaces, whereas the interfaces seldom change the information. Thus, traditional Internet is a kind of static network essentially, so it cannot configure Internet dynamically and meet various needs of dynamic service.

In the aspect of diversity, today's Internet builds around the "narrow waist" of IP, which makes it hard to change the IP layer to adapt for future requirements, but adapt various upper and lower layers protocols. With the multiplicity of Internet business and sharp expansion of user's requirements, the coexistence of different heterogeneous network is formed under the drive of technology innovation and application requirement. Thus, today's Internet can be seen as the logic combination of various network devices in different medium, frequency and space. To add a new application or service, the Internet needs to be modified correspondingly, which forms a messy structure of a forest of chimneys and severely restricts the sustaining development of Internet.

In the aspect of intelligence, the design pattern of traditional Internet is decoupling which is that a kind of network supporting a kind of main service. The Internet is a closed network running in static mode and lacks intelligent sensing and responding mechanism. Its network unit (e.g. host computers, routers, servers) cannot adjust automatically. However, intelligent network can sense changeable outer circumstance and business taken on to realize automatic adaptation. Therefore, the decoupling pattern which used to promote the rapid development of the Internet has become the key obstacle for development of future intelligent Internet.

The problems of traditional Internet make it face great innovation, especially in the network architecture which is the research focus of academy. In the United States, early research projects of future Internet mainly included Clean Slate 100*100[1], SING[2] and NGN[3]. Later, GENI[4]、FIND[5] plan were present. In 2009, the NSF started NetSE project which merged FIND, SING and NGNI, hoping to make breakthrough in future Internet architecture by the researches of crossing subject and domain. In 2010, the NSF start FIA plan[6] which includes NDN, MobilityFirst, NEBULA, and XIA projects. In European Union, the projects facing future Internet include FIRE[7] and FIA (EU) [8] which is a project group of FP7. Besides, Germany started G-Lab[9] project and France started RNRT[10] project. In Asia, Japan started NWGN[11] project and AKARI[12] project which is divided into three stages (JGN2、JGN2+、JGN3) to construct test bed. In 2003, the 973 project of China sponsored "the Research of Next-Generation Internet

Architecture" which is continuously sponsored by 973 of China in 2006. In the same year, 973 of China sponsored "the Research of Universal Trust Network and Pervasive Services Architecture". Besides, the 863, NSF and CNGI of China also sponsored a series of research projects facing to future Internet.

By analyzing the projects mentioned above, we find that the comprehension and research contents for future Internet of many countries are the same. There are two different approaches to future Internet research. One is based on the present Internet architecture and deals with the major technological problems through technology innovation. The other is to design new network architecture to settle the major technological problems from the beginning. Whatever approaches they adopt, researchers must acknowledge the technological kernel and successful experience of current Internet which are the root of the boom of the Internet over decades and the main contents of Internet architecture formed by long-term technical experiment, such as distributed architecture, packet switching, and extensible routing addressing.

Based on the investigation on the popular researches of future Internet, we consider that the problems of future Internet should be solved not through designing a completely new network but through improving current networks The reasons are that the time cost and economical cost are gigantic for overthrowing a huge existent network, such as constructing new infrastructure, designing new applications, and training users' habits. Thus, we present a novel routing metric based on current various technologies to provide a helpful reference for the research of future Internet routing technology.

2. Description of Future Internet

We consider that future Internet should include three important characteristics according to investigation and analysis.

(1) Pervasiveness

Future Internet is a pervasive network and can realize convenient and fast access at anytime and anywhere for any devices. Because of the following technologies, the pervasiveness of the future Internet is possible.

Intelligent terminal: it is the basic medium to achieve ubiquitous characteristic.

Mobile access: it provides convenient and efficient access mode at anytime and anywhere for intelligent terminals.

Cloud-computing: it provides technological support to the pervasiveness.

Pervasive service: it provides pervasive computing service for intelligent terminals.

Network security: it guarantees users' rights.

(2) Heterogeneity

The future Internet will be a heterogeneous network with the coexistence of various access technologies. Because of the following technical diversity, the heterogeneity of future Internet will exist in a long term.

Communication protocol and link: different communication protocols and links are adopted from end-edge network, access network to core network.

Wireless protocol: there are various wireless communication protocols, such as 2G/3G, WiFi, Bluetooth and Zigbee.

Access link: there are various access links, such xDSL, xPON, Ethernet, Cable and private communication system. Besides, various networks differ in authentication mode, QoS, configurable capability, and application interface.

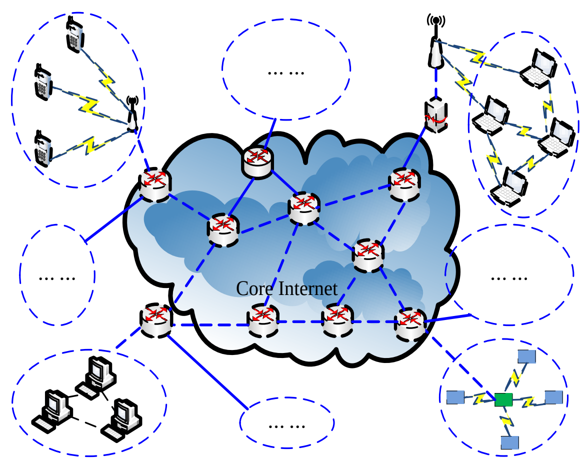


Fig. 1 Sketch map of topology for future Internet

(3) Intelligence

Future Internet also should be an intelligent network. The researches facing the intelligence of future Internet include cognitive wireless radio, cognitive network, self-adaptive network, autonomic network, bio-inspired network, multi-agent network, etc. Those researches aim to improve the intelligence of future Internet which is the main feature distinguishing from traditional Internet.

According to the above discussion, we believe that the future Internet is a complicated distributed network with the coexistence of various technologies and devices. In order to avail for our discussion, we propose the topology of future Internet which is shown in Fig. 1. The topology includes the main components of future Internet, such as computers, intelligent devices, routers, and servers.

3. Challenges and Meeting Technologies for Future Internet

The future Internet will emerge new challenges in the network connection of lower layer, data transmission of middle layer and intelligent service of upper layer.

(1) Network Connection

Heterogeneous interconnection: because heterogeneous network and devices are always the main components of Internet, heterogeneous interconnection mechanism is a challenge of the future Internet.

Information perception: the acquirement, transmission, storage and process of information are also a challenge of the future Internet in physical/logical sensing units deployed in a large scale.

Ubiquitous access: how to access Internet and ensure the performance of connection for many portable devices is another challenge of the future Internet.

(2) Data Transmission

Traditional Internet builds around the "narrow waist" of IP, which makes it hard to provide more abundant functional support for its upper and lower layers. Therefore, how to enhance the function of network layer to adapt the various access technologies of lower layer and support more luxuriant services of upper layer is an important challenge of the future Internet.

(3) Intelligent Service

The future Internet is not only data transmission network, but also support platform which merges various heterogeneous networks (e.g. wireless sensor network, vehicle network and Internet of things) and burdens a lot of new applications (e.g. cloud service, flow medium and mobile computing). How to provide more and better support for these new applications is another important challenge of the future Internet.

For these challenges, researchers put forward a great many solving technologies, such as virtual technology, cloud-computing, autonomic computing, intelligent decision and machine learning. We present the routing metric mainly based on the technology of virtualization and Cloud-computing.

(1) Virtualization

Virtualization[13, 14] is present to deal with the rigidity of traditional Internet and stimulate research innovation of future Internet. It is used to construct robust, creditable and manageable virtual circumstance of network and assign proper virtual resource for various virtual networks to share resources and improve the using ratio of network infrastructure. Virtualization can shield the lower layer heterogeneity of networks and devices and support the upper layer diversity of service. It resolves the pervasiveness and heterogeneity of future Internet.

(2) Cloud-computing

Cloud computing[15, 16] derives from "Google 101 Plan" and migrate storage and computing to "Cloud" to construct a "computing public service" and establish a new global resource share mode — "lease mode". It mainly resolves the pervasiveness of future Internet and supports heterogeneity and intelligence.

The new technologies (i.e. virtualization and cloud-computing) collaborate with each other to achieve the pervasiveness, pervasiveness and intelligence of future Internet. Their mergence will resolve the problems of current Internet and form a new generation Internet.

4. Proposed routing cloud metric

Routing cloud is a new layer to substitute the network layer of TCP/IP model and OSI model, the compare of station of which is shown in Fig. 2. In traditional networks, the main function of network layer is to transmit data packets. In order to extend the functions of network layer, we propose a new design blue print of network layer — routing cloud layer based on virtual technology and cloud computing. The Routing Cloud layer includes the following functions.

The routing cloud layer conceals the diversity of networks and devices of access infrastructure layer downwards.

The routing cloud layer conceals the diversity of QoS of service layer upwardly.

The routing cloud layer can store and transmit data packets.

The routing cloud layer can provide service for applications.

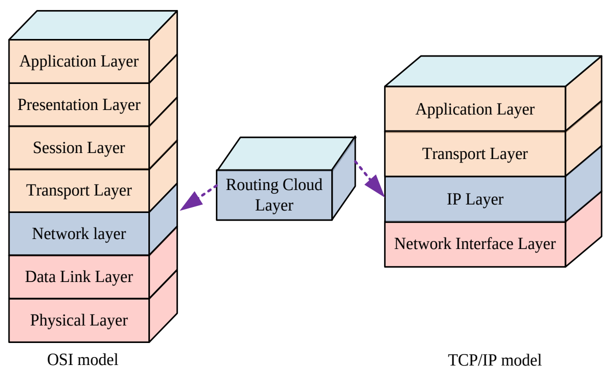


Fig. 2 Station of routing cloud layer

4.1 Architecture of Routing Cloud Layer

Routing cloud layer is made up of physical router sub-layer and virtual router sub-layer, which are closely related by mapping relationship and whose basic principle is shown in Fig. 3.

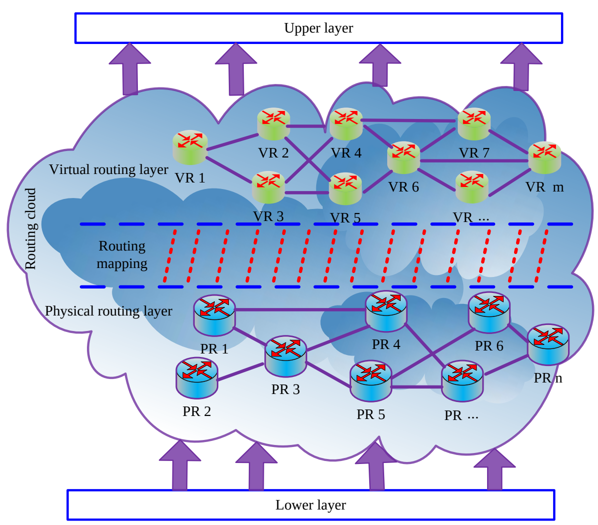


Fig. 3 Architecture of routing cloud

The routing cloud layer consists of physical routing layer, virtual routing layer and mapping relationship. The physical routing layer includes routers, link, topology etc. The virtual routing layer provides different service for different applications, which seems to a group of Virtual Private Networks. The routing mapping addresses the mapping between physical routing layer and virtual routing layer.

4.2 Organizing Model of Physical Routers

Organizing model of physical routers uses Pearson correlativity principle to map discrete physical routers to a logical overall. Based on the characteristic information physical routers, we obtain

$$r = \frac{\sum_{i=1}^{n}(X_i - \overline{X})(Y_i - \overline{Y})}{\sqrt{\sum_{i=1}^{n}(X_i - \overline{X})^2}\sqrt{\sum_{I=1}^{n}(Y_i - \overline{Y})^2}} \quad (1)$$

where X_i, Y_i are the characteristic information of two physical routers in different time (the specific information is determined by the requirements of application). $\overline{X}, \overline{Y}$ are the average of X_i, Y_i. The domain is partitioned by calculating correlative coefficient r, and the routers whose correlative degree is high are partitioned into a domain. For domain i, its routers are described by $Z_i = \{L_1, L_2, ..., L_i, ..., L_n\}$. If we chose the router whose operating factor is the lowest as the reference point L_i, the difference degree of each router is calculated by

$$d_j = \begin{cases} \frac{\sqrt{(\overline{X_i} - \overline{X_j})^2 + (\overline{Y_i} - \overline{Y_j})^2}}{(\overline{X_i} - \overline{X_j})^2 + (\overline{Y_i} - \overline{Y_j})^2}, & \overline{X_i} \neq \overline{X_j}, \overline{Y_i} \neq \overline{Y_j} \\ 0, & \overline{X_i} = \overline{X_j}, \overline{Y_i} = \overline{Y_j} \end{cases} \quad (2)$$

Based on the domain i of router L_i, we map the different domains into one dimensional space by $P_{L_i} = i * c + d_i$, where c is a constant.

After mapping physical routers into one dimensional space, they can be denoted in uniform method, i.e. a physical router identifier (PhyRouterID) can only denotes a physical router.

4.3 Virtual Routers and Their Mapping Relationship

We present the new virtual router to adapt routing cloud layer. Besides traditional functions of router, the virtual router possesses two main new functions — service supply and virtualization which are introduced as follows.

The virtual router possesses high-powered CPU, MSF, effective queue, and so on. Apart from transmitting data packets, it can perform business process like servers. If the requirements of data packet can be met by a virtual router, it will directly respond to and serve the requirements to improve service efficiency without transmitting the data packet to server.

Virtualization is the foundation of realizing the isolation of applications of upper layer and hardware of lower layer. It refers to map physical routers into independent virtual logical routers, each of which possess independent bandwidth, CPU and cache. The mapping of virtualization includes partite mapping, convergent mapping and mixed mapping.

We assign unique physical router identifier PhyRouterID for each physical router. In one mapping, we also assign unique mapping identifier MappingID and unique virtual router identifier VirRouterID(s) for each virtual router. Thus, each virtual router can be ascertained by MappingID+VirRouter_ID. The three mappings are introduced as follows respectively.

(1) Partite mapping

There is only one physical router and multiple virtual routers in partite mapping whose principle is illustrated in Fig. 4. The partite mapping is applied to provide elaborate service, for example, assigning an individual virtual router for a specific kind of application. The virtual router possesses independent configuration, management authority, process, forwarding table, etc. The mapping relationship is maintained by physical router and virtual routers, respectively, and is shown as in Table I and Table II.

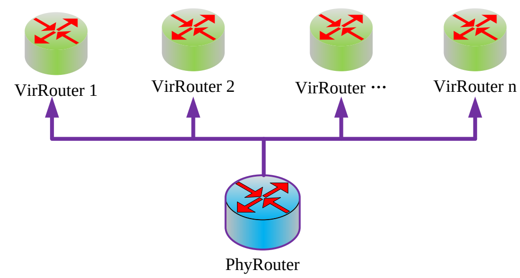


Fig. 4 Partite mapping mode for routers

Table I Partite mapping for physical router

number	field	meaning	Remark
1	MappingID	Identifier of mapping	There are one physical router and multiple virtual routers in the mapping.
2	PhyRouterID	Identifier of physical router	One physical router associate to multiple mappings and multiple virtual routers.
3	VirRouterIDs	List of identifier of virtual routers	One virtual router associate to one mapping and one physical router.
4	ServiceSupplyList	The provided service of the physical router.	
5	pfs	The packet forwarding speed of the physical router	
6	nocl	The number of concurrent link of the physical router	
7	nonlps	The number of new links per second of the physical router	

Table II Partite mapping for virtual router

number	field	meaning	Remark
1	MappingID	Identifier of mapping	There are one physical router and multiple virtual routers in the mapping.
2	PhyRouterID	Identifier of physical router	One physical router associate to multiple mappings and multiple virtual routers.
3	VirRouterID	List of identifier of virtual routers	One virtual router associate to one mapping and one physical router.
4	ServiceSupplyList	The provided service of the virtual router.	
5	pfs	The packet forwarding speed of the virtual router	
6	nocl	The number of concurrent link of the virtual router	
7	nonlps	The number of new links per second of the virtual router	

(2) Convergent mapping

There are multiple physical routers and one virtual router in convergent mapping whose principle is illustrated in Fig. 5. The convergent mapping is applied to provide high-powered service for application requiring high process capability. In convergent mapping, each physical router maintains the mapping relating to a virtual router, and the virtual router maintains the physical routers that it contains. The mapping relationship is shown as in Table III and Table IV.

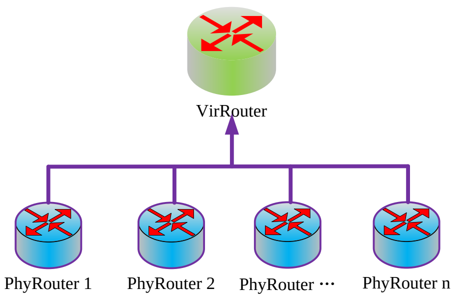


Fig. 5 Convergent mapping mode for routers

(3) Mixed mapping

There are multiple physical routers and multiple virtual routers in convergent mapping whose principle is illustrated in Fig. 6. The mixed mapping is applied to more complicated application and its mapping relationship is shown as in Table V and Table VI.

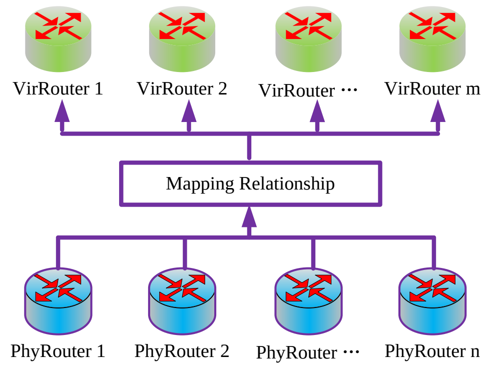


Fig. 6 Mixed mapping mode for routers

Table III Convergent mapping for physical router

number	field	meaning	Remark
1	MappingID	Identifier of mapping	There are multiple physical routers and one virtual router in the mapping.
2	PhyRouterID	Identifier of physical router	One physical router associate to multiple mappings and multiple virtual routers.
3	VirRouterID	Identifier of virtual router	The virtual router only associates to one mapping and one physical router.
4	ServiceSupplyList	The provided service of the physical router.	
5	pfs	The packet forwarding speed of the physical router	
6	nocl	The number of concurrent link of the physical router	
7	nonlps	The number of new links per second of the physical router	

Table IV Convergent mapping for physical router

number	field	meaning	Remark
1	MappingID	Identifier of mapping	There are multiple physical routers and one virtual router in the mapping.
2	PhyRouterIDs	List of identifier of physical routers	One physical router associate to multiple mappings and multiple virtual routers.
3	VirRouterID	Identifier of virtual router	The virtual router only associates to one mapping and one physical router.
4	ServiceSupplyList	The provided service of the physical router.	
5	pfs	The packet forwarding speed of the physical router	
6	nocl	The number of concurrent link of the physical router	
7	nonlps	The number of new links per second of the physical router	

Table V Mixed mapping for physical router

number	field	meaning	Remark
1	MappingID	Identifier of mapping	There are multiple physical routers and multiple virtual routers in the mapping.
2	PhyRouterID	Identifier of physical router	One physical router can include multiple mappings and multiple virtual routers.
3	VirRouterIDs	List of identifier of virtual routers	The virtual router only associates to one mapping and multiple physical routers.
4	ServiceSupplyList	The provided service of the physical router.	
5	pfs	The packet forwarding speed of the physical router	
6	nocl	The number of concurrent link of the physical router	
7	nonlps	The number of new links per second of the physical router	

Table VI Mixed mapping for physical router

number	field	meaning	Remark
1	MappingID	Identifier of mapping	There are multiple physical routers and multiple virtual routers in the mapping.
2	PhyRouterIDs	List of identifier of physical router	One physical router can include multiple mappings and multiple virtual routers.
3	VirRouterID	List of identifier of virtual routers	The virtual router only associates to one mapping and multiple physical routers.
4	ServiceSupplyList	The provided service of the physical router.	
5	pfs	The packet forwarding speed of the physical router	
6	nocl	The number of concurrent link of the physical router	
7	nonlps	The number of new links per second of the physical router	

4.3 Service Supply Mode of Routing Cloud Layer

Compared with traditional network layer, the main new function is supply application service which means that routers replace the partial/whole functions of application servers to realize application business. In order to achieve supply application service of routing cloud layer, it is needed to establish uniform identifiers for running applications, which is accomplished by virtual service layer. The main thought of supply application service is shown in Fig.7. We illustrate the basic principle of supply application service from the views of physical routers and virtual routers according to Fig.7 as follows.

(1) View of Physical Router

From the view of physical routers, user1 visits the application server A through physical routers PRL1 (PR6-PR4-PR1), and user2 visits the application server A through physical routers PRL2 (PR8-PR7-PR5-PR3-PR2). In the view of traditional router, the router PRL1 and PRL2 only achieve the storage and transmission of the data between server and user. In the view of our routers, a physical router downloads the corresponding service when transmitting data packets. If the same requirements pass by the physical router, it directly responds to the requirements by itself without transmitting to server A. It will form a supply service tree of server A shown in Fig. 8 (a).

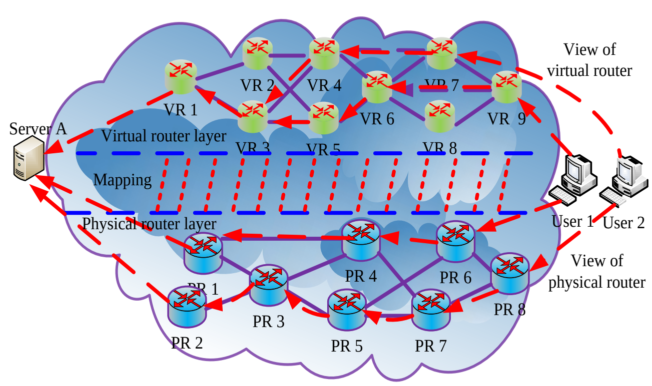
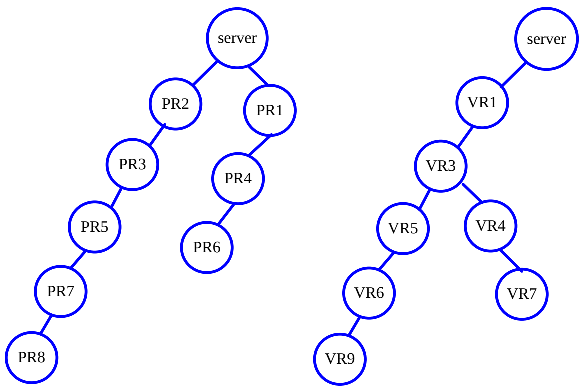


Fig. 7 Theory of Service supply

(2) View of Virtual Router

From the view of virtual routers, user1 visits the application server A through virtual routers VRL1 (VR9-VR6-VR5-VR3-VR1), and user2 visits the application server A through virtual routers VRL2 (VR7-VR4-VR3-VR1). In the view of traditional router, the router VRL1 and VRL2 only achieve the storage and transmission of the data between server and user. In the view of our routers, a virtual router downloads the corresponding service when transmitting data packets. If the same requirements pass by the virtual router, it directly responds to the requirements by itself without transmitting to server A. It will form a supply service tree of server A shown in Fig. 8 (b).



(a) Service supply tree of physical router (b) Service supply tree of virtual router

Fig. 8 Tree of Service supply

With time passing by, it will generate a gigantic supply service tree of the server A in whole network. Each router of the tree maintains a service supply table to ensure the coherence and validity of service between the router and server A.

6. Conclusions

The future Internet is regarded as an inevitable developmental trend to resolve the problems of traditional Internet. Compared with traditional Internet, future Internet will get improved greatly in performance and functions. Thus, the future Internet faces a good many challenges in network access, network transmission and network service. In this paper, we propose a thought of solution and relevant architecture for future Internet through converging cognition, cross-layer, cooperation, virtualization and cloud computing. The architecture consists of protocol plane, cognitive plane and control plane which collaborate with each other to achieve the performance and functions.

Acknowledgments

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