The Future Internet: Towards Convergence of Cognition, Cooperation, Cross-layer, Virtualization and Cloud-computing

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Abstract—**In order to deal with the situation that current Internet cannot meet application requirements, we analyze the three features—pervasiveness, heterogeneity and intelligence that the future Internet possesses firstly. Secondly, we syncretize the technologies of cognition, cooperation, cross-layer, virtualization and cloud computing, and present a new architecture and thought to resolve the three features of future Internet. The architecture consists of Protocol Plane, Cognitive Plane and Control Plane, and involves some novel designed models such as layer protocol stack, three-layer cognitive rings and router cloud. Protocol plane mainly masks the lower layer heterogeneity of access networks and devices, and the upper layer diversity of application to achieve pervasiveness and heterogeneity of future Internet. Cognitive plane performs decision-making to achieve intelligence of future Internet based on perception, cross-layer, cooperation, machine learning, and so on. Control Plane deals with the implement problems of network adjustment through configurable components. The architecture and thought provide a useful reference for the researches of future Internet.**

Index Terms—**Future Internet, Network Architecture, Cognition, Cooperation, Cross-Layer, Virtualization, Cloud-computing**

I. 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 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 the 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] and FIND [5] plan were presented. 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

Manuscript received Mar.18, 2013; revised Apr. 19, 2013; accepted May 20, 2013.
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doi:10.4304/jcp.8.12.3134-3143

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 and our prior works [13-16], we consider that the problems of future Internet should be solved through converging current various networks and technologies, but not through designing a completely new network. 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 new future Internet architecture based on current various technologies to provide a helpful reference for the research of future Internet.

II. Description of Future Internet

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

A. 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 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.

B. 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.

C. 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.

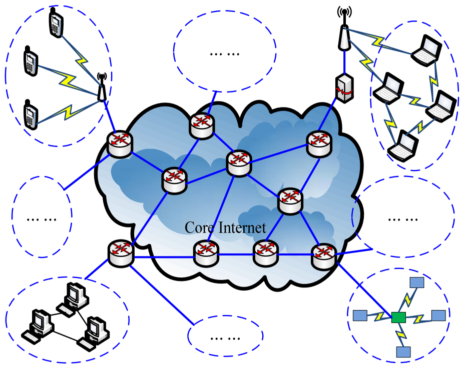


Fig. 1 Sketch map of topology for future Internet.

III. Challenges and Meeting Technologies for Future Internet

A. Challenges

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.

A) 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.

B) 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.

C) Intelligent Service

The future Internet is not only a data transmission network, but also a supporting 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.

B. Meeting Technologies

For these challenges, researchers put forward a great many solving technologies, such as cognitive theory, cooperative theory, virtual technology, cloud computing, autonomic computing, cross-layer, intelligent decision and machine learning. We can sum them up into five categories as follows.

A) Cognition

Cognitive theory [17] is introduced into information science deriving from cognitive radio and becomes a main technology of intelligent network by way of the development of cognitive radio network and cognitive network. The future Internet needs to employ cognitive theory to sense network conditions, analyze information acquired, make decisions, and perform adjustment actions. The sensing technology, intelligent decision, machine learning and autonomic computing are the research scope of cognitive theory which mainly resolves the intelligence of future Internet.

B) Cross-layer

Cross-layer design [18] is presented derives from performance optimization in wireless communication. With the development of research, it is used to pass parameters among layers of layered protocol stack to further assort with the works of each layer. We introduce cross-layer into network decision to optimize decision. It mainly resolves the pervasiveness, heterogeneity and intelligence of future Internet.

C) Cooperation

The concept of cooperation differs in different scopes. In future Internet, there are several applications of cooperation [19], such as cooperative communication, cooperative spectrum sensing, and cooperative decision. The modeling methods of cooperation include Petri network, Bayesian network, colony intelligence and game theory. Cooperation resolves the pervasiveness, heterogeneity and intelligence of future Internet.

D) Virtualization

Virtualization [20] is presented 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.

E) Cloud-computing

Cloud computing [20] 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 five technologies collaborate with each other to achieve the pervasiveness, heterogeneity and intelligence of future Internet. Their mergence will resolve the problems of current Internet and form a new generation Internet.

IV. Future Internet Architecture

According to the above analyses, we merge the intelligence into Internet and form three-dimensional architecture of future Internet in virtue of the technical kernel and successful experience of current Internet. The architecture is shown in Fig. 2.

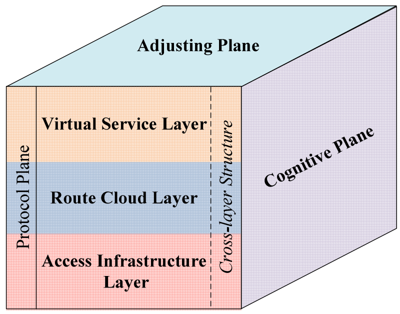


Fig. 2 Three-dimensional architecture for future Internet

The three-dimensional architecture is made up of three planes—Protocol Plane, Cognitive Plane and Control Plane. The Protocol Plane is constructed based on the traditional layer architecture. The Cognitive Plane performs the work related to cognition, such as information perception, data analyzing and decision-making, and generates the commands of actions. The control plane adjusts network states to achieve anticipant performance object according to the results of intelligent decision.

A. Protocol Plane

The Protocol Plane consists of layered protocol stack and cross-layer structure. We present a three-layer protocol stack which contains access infrastructure layer, router cloud layer and virtual service layer based on our early research results. The relationship of the layers is shown in Fig. 3 and the comparison of OSI model, TCP/IP model and our three-layer protocol stack is shown in Fig. 4. Cross-layer structure is proposed to pass more abundant parameters in each layer and assort with the works of each layer better.

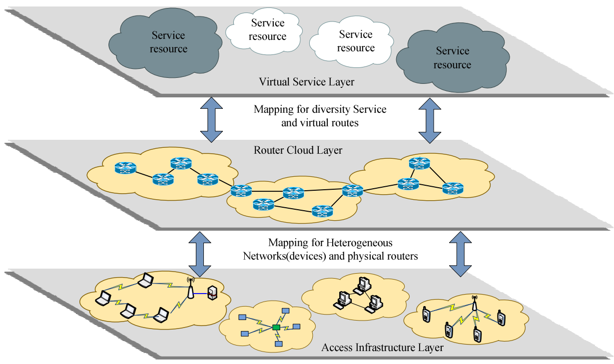


Fig. 3 Three-layer structure for protocol plane

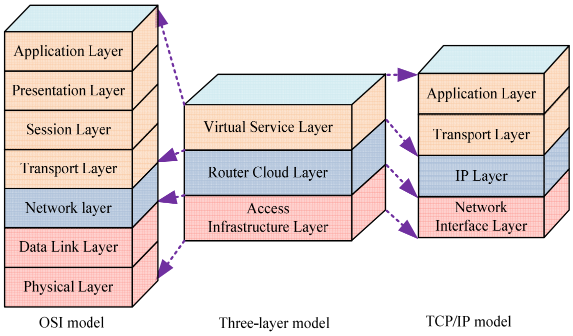


Fig. 4 Comparation for three kinds of network architecture

A) Access Infrastructure Layer

Access infrastructure layer corresponds to the network interface layer of TCP/IP model, and the physical layer and data link layer of OSI model. It provides a uniform communication platform for the business of data, voice and video to achieve the purpose of supporting ubiquitous access efficiently. It performs its basic operating principle through two mappings, which is shown as Fig. 5.

Virtual Access Mapping: Virtual access mapping maps various heterogeneous networks and devices into virtual access identifier to support network access.

Router Access Mapping: Router access mapping maps virtual access mapping into physical router identifier of to achieve router access of heterogeneous networks and devices.

B) Router Cloud Layer

Router cloud layer corresponds to the network layer of TCP/IP model and OSI model. 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 — router cloud layer based on virtual technology and cloud computing. The router cloud layer includes the following functions.

- Concealing the diversity of networks and devices of Access infrastructure layer downwards.
- Concealing the diversity of QoS of virtual service layer upwardly.
- Storing and transmitting data packets.
- Providing service for applications.

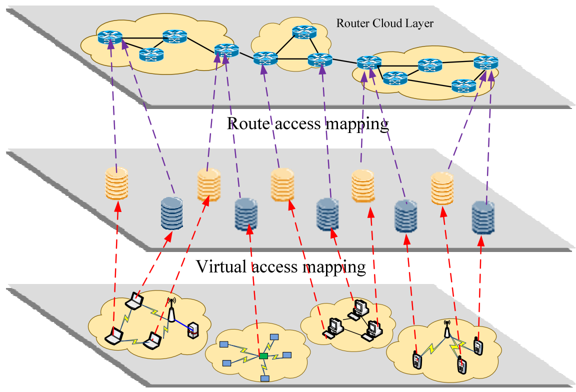


Fig. 5 Mapping for access infrastructure layer

Architecture of Router Cloud Layer: Router 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. 6.

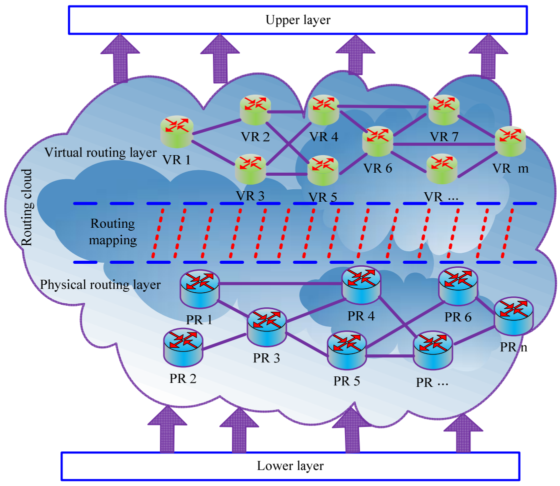


Fig. 6 Architecture of route cloud

Service Supply Mode of Router 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 router 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.

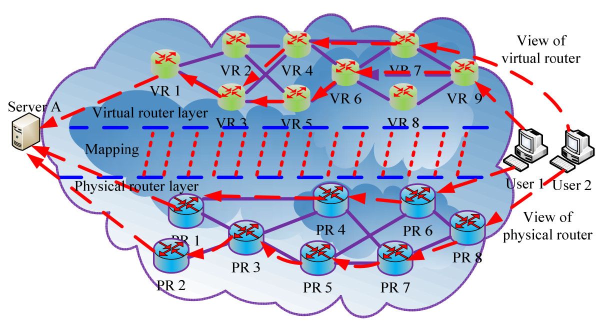
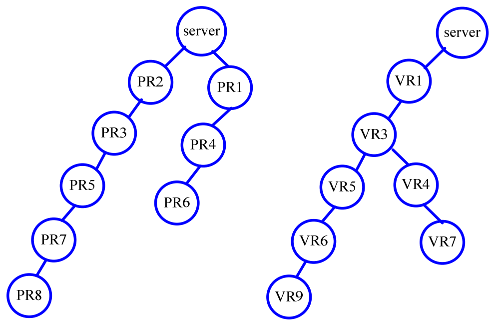


Fig. 7 Theory of service supply

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).



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

Fig. 8 Trees of Service supply

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). 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.

New Virtual Router: We present the new virtual router to adapt router 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.

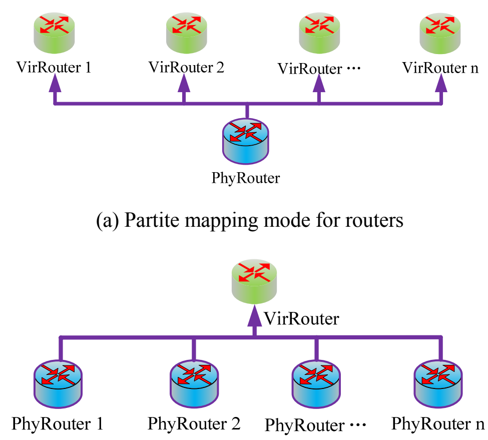
- Partite mapping: There is only one physical router and multiple virtual routers in partite mapping whose principle is illustrated in Fig. 9 (a). The partite mapping is applied to provide elaborate service, for example, assigning an individual virtual router for a specific kind of application.
- Convergent mapping: There are multiple physical routers and one virtual router in convergent mapping whose principle is illustrated in Fig. 9 (b). The convergent mapping is applied to provide high-powered service for application requiring high process capability.
- Mixed mapping: There are multiple physical routers and multiple virtual routers in convergent mapping whose principle is illustrated in Fig. 9 (c). The mixed mapping is applied to more complicated application.

We assign unique physical router identifier PR_ID for each physical router. In one mapping, we also assign unique mapping identifier Mapping_ID and unique virtual router identifier VR_ID for each virtual router. Thus, each virtual router can be ascertained by Mapping_ID+VR_ID. The mapping relationship is shown in Table. I.

TABLE I

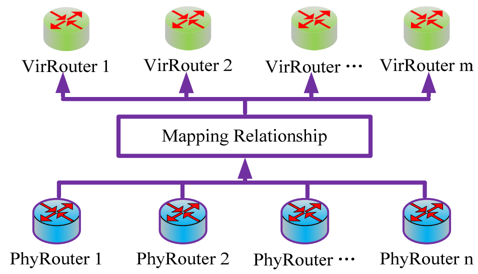
DESCRIPTION FOR THE MAPPING

field	meaning	Remark
Mapping_ID	Identifier of mapping	Physical router can belong to multiple mappings while virtual router only belongs to one mapping.
PhyRouterID s	List of identifier of physical routers	One physical router associate to multiple mappings and multiple virtual routers.
VirRouterIDs	List of identifier of virtual routers	The virtual router only associates to one mapping and multiple physical routers.
Features	Feature description of virtual router	E.g. packet transmission ratio, number of concurrent link, number of new links per second, service supply list.



(a) Partite mapping mode for routers

(b) Convergent mapping mode for routers



(c) Mixed mapping mode for routers

Fig. 9 Virtual router mapping

C) Virtual Service Layer

Virtual service layer migrate service to "Could" and establish a global resource supply mode like "public service". Its research contents mainly include the perception and aggregation of service resources, virtualization of service resources, and mapping of virtual service resource and virtual router.

Perception and Aggregation of Service Resources: The perception and aggregation of service resources are to process the large-scale original service resources through service perception, feature extraction, correlation analysis and clustering analysis to generate regular service resources and avail their virtualization. The whole process is shown in Fig. 10. Firstly, various service resources are sensed using perception technologies. Secondly, the eigenvector of service resources are distilled and regularized. Thirdly, the knowledge among service resources is dug and matched with the prior knowledge base to find the correlation and related network of service resources. Fourthly, the inherent information of service resources is dug by sample correlation analysis, time correlation analysis, cause and effect cause and effect analysis, and so on. Finally, the regular expresses of service resources are achieved by clustering analysis. The each process needs to interact with the prior knowledge base.

Virtualization of Service Resources: In order to visit service resources conveniently, it is necessary to establish uniform virtual service identifier which helps virtual service layer to manage service resources. Users can acquire the service needed through the uniform virtual service identifier not the data transmission process.

What the users care is QoS not the location and acquirement mode of service resources. Moreover, in order to support service supply of router cloud layer, Virtual Service Identifier (VSID) needs to be detailed to generate a group of service primitive (VSID_Primitive_1, VSID_ Primitive_2, …, VSID_Primitive_n) which are be visited independently. The sketch map of virtualization of service resources is shown in Fig. 11.

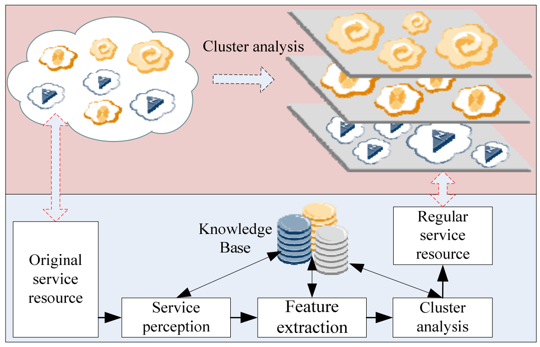


Fig. 10 Normalization process for service resource

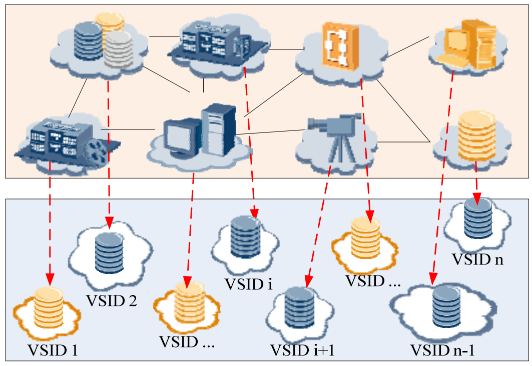


Fig. 11 Virtualization of service resource

Mapping of Virtual Service Resource and Virtual Router: In order to support service supply of router cloud layer, the mapping between virtual service resources and virtual routers is needed. The mapping implements the transform from VSID to Virtual Router Identifier (VRID). The mapping relationships include one-to-one, one-to-many and many-to-many, and its sketch map is shown in Fig. 12.

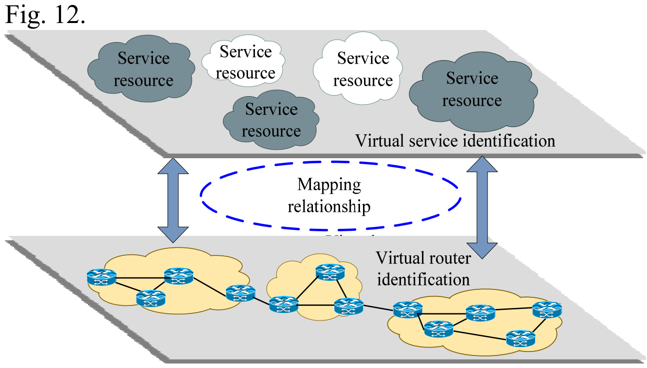


Fig. 12 Mapping between virtual service resource and virtual route

Cross-layer Structure: In communication field, cross-layer of is mainly used to pass more abundant parameters among layers of layered protocol stack to further assort with the works of each layer. The main purposes we introduce cross-layer are listed as follows.

- In protocol plane, we introduce cross-layer to enhance information transmission efficiency among layers.
- In cognitive plane, we construct information acquirement model and decision-making model using cross-layer to improve the efficiency of information perception and intelligent decision.

- In control plane, network adjust is implemented fast in virtue of cross-layer parameters transmission.

B. Cognitive Plane

The Cognitive Plane deals with intelligence of future Internet. It apperceives network condition, analyze the perceived information, make intelligent decisions, and perform adaptive adjusting actions, which aims to maximize network performance and meet the application requirement. We present the three-layer cognitive rings which is the core of cognitive plane and shown in Fig. 13 based on the OODA (Observe-Orient-Decide-Act) cognitive ring in the field of cognitive radio.

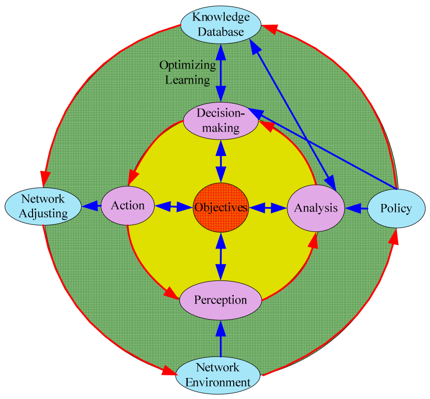


Fig. 13 Three-layer cognitive rings for future Internet

Firstly, the three-layer cognitive rings perceive a great deal of network conditions information. Secondly, the conditions information is analyzed and fused utilizing data fusion theory. Thirdly, the decision-making is performed based on the result of data fusion to achieve strategies of network behaviors, and machine learning theory is adopted to optimize future decision-making. Finally, network adjusting is executed according to strategies generated by decision-making. The four process run cooperatively to achieve the network performance objectives referring to policies, laws, and other prescripts etc.

From the three-layer cognitive rings, we can know that the decision-making is the most important link. Therefore, orienting decision-making, we present a Primary Decision-making Process (PDP) based on the three-layer cognitive rings. The PDP is a basic component for Cognitive Plane, which is usually used to build other more complicated decision-making process and shown in Fig. 14. In future Internet, each intelligent node at least maintains a PDP. If necessary, the node will cooperate with other nodes to acquire more valuable strategy.

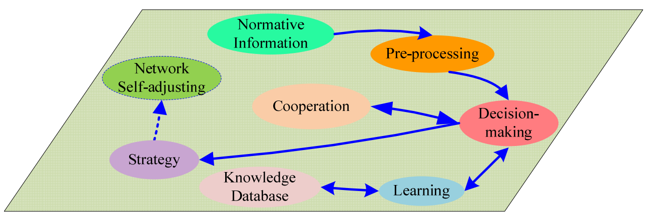


Fig. 14 Primary cognitive process

A) Information Perception

Information perception is the foundation of cognition. We propose the information perception model which is implemented by the nodes with perceptive capability and shown in Fig. 15. Firstly, the perception nodes acquire the network condition information through cross-layer channels, send to information queues, and store at local database. Then, the information is preprocessed, analyzed and regularized. Finally, the regular information is sent to domain database.

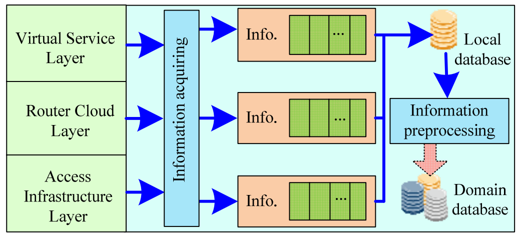


Fig. 15 Acquiring model of perception information

B) Intelligent Decision-making

Intelligence is the essential difference of traditional Internet and future Internet, while intelligent decision-making is the foundation of achieving intelligence of future Internet. In future Internet, all intelligent nodes will deploy one or more PDPs. For different network circumstance of application, intelligent nodes can independently perform decision-making and they can also cooperatively perform decision-making with other nodes.

The cross-layer decision-making is proposed based on PDP and used for independent decision-making of node. There are two meanings of the basic principle of cross-layer decision-making which is shown in Fig. 16. One is that each layer of protocol stack chooses the most appropriate decision process and algorithm based on its own characters and PDP to construct decision-making model of relevant layers. The other is that each layer needs to cooperate with others to optimize decision-making.

From horizontal view, there is a PDP in each layer to carry out the decision-making of relevant layer, which is connected to Cross-layer Adapter (CLA). From vertical view, the same link of each PDP (i.e. Deciding) realize the same function and represent a logical link (i.e. logistic Decision-making). From integrated view, the cross-layer model represents a logical intelligent node.

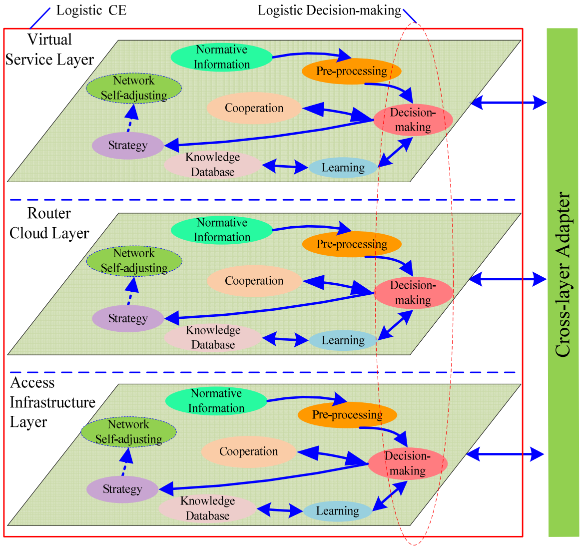


Fig. 16 Cross-layer decision-making model

Whether cross-layer is needed or not will be ascertained by Cross-layer Adapter which possesses control structure. Supposing that the set of cross-layer states is $S = \{S_1, S_2, \ldots, S_n\}$, each element S_i is a specific cross-layer state. For example, S_1 denotes that router cloud layer cooperates with virtual service layer and virtual service layer cooperates with access infrastructure layer, while router cloud layer and access infrastructure layer do not cooperate. The cross-layer states can be controlled by Boolean algebra, markov state transition, and so on.

In future Internet, the cooperative decision-making will be more important. The nodes will spontaneously form many autonomous domains according to physical, logical and other factors. The nodes (intelligent nodes and non-intelligent nodes) of each domain cooperate with each other to accomplish corporate tasks. The sketch map of multi-domain relationship is shown in Fig. 17.

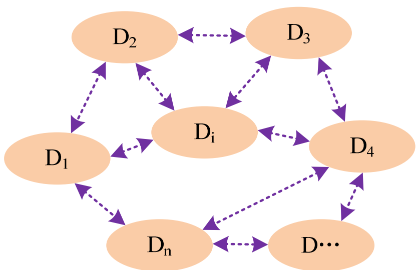


Fig. 17 Multi-domain relationship

In a particular period of time, if one intelligent node cannot meet the QoS of application, multiple nodes cooperation even multi-domain cooperation will be considered in broader network environment. In a domain, one or more intelligent nodes will be selected as governors to assort with the decision-making. They are also the agents to cooperate with agents of other domains. It is very difficult to find an “optimum solution” for the multi-domain cooperative decision-making because of complexity. Therefore, the target of multi-domain cooperative decision-making is to find an “acceptable solution” or suboptimal solution which can meet the QoS of application. The cooperative game theory is often used for modeling multi-domain cooperation to enhance efficiency of cooperative decision-making.

Thus, the basic thought of intelligent decision-making in future Internet can be described as follows: aiming at applications only relating to one intelligent node, it independently decides to find “acceptable solutions”; aiming at applications relating to multiple intelligent nodes in a domain, they cooperate with each other to find “acceptable solutions”; aiming at applications relating to multiple domains, the agents of multi-domain cooperate with each other to find “acceptable solutions”. That is to say, the intelligent decision-making of future Internet is a process to find “acceptable solutions” according to network conditions and QoS.

C. Control Plane

Control Plane focuses on the implement problems of future Internet. It consists of commands processor, commands queues, commands controller and commands transmission channel and its principle map is shown in Fig. 18. The basic thought of control plane can be illustrated as follows: 1) commands processor receives the results of decision-making in cognitive plane, processes the results to generate network control commands, and puts commands into commands queues of relevant layer; 2) commands controller chooses the front commands, analyzes the commands, and controls the configurable components to achieve the network states adjustment. The aim of whole process is to meet the anticipant network performance.

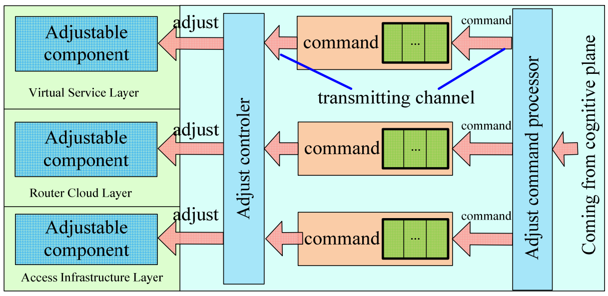


Fig. 18 Structure of adjusting plane

In order to fit in with the network states adjustment of control plane, the layered protocol stack of protocol plane needs to be constructed by configurable components. The commands controller changes the inner running states, parameters and process methods of protocol stack through the reserved interfaces of configurable components. That is to say, there are a state set of configurable components of protocol stack. Network states adjustment is in fact to assign proper state for configurable components. A group of states of configurable components which meet the anticipant network performance forms an optimized set of network states. The more abundant the optimized set is, the more flexible the network is, but the more complicated the network is.

V. Conclusions and Future Work

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 great 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.

In future work, there are still many topics that need to be further researched. Firstly, for the architecture, we only present the basic framework and simple solution thought of each plane but not their detailed solutions which are the focus of our next work. Secondly, how to integrate protocol plane, cognitive plane and control plane into an effective integration is also a focus of future work. Finally, how to construct test bed to validate the research result is another focus of future work.

ACKNOWLEDGMENT

This work is partially supported by the National Natural Science Foundation of China (NSFC) under Grant No. U1204614, No. 61142002 and No. 61003035, and in part by the Plan for Scientific Innovation Talent of Henan Province under Grant No. 124100510006, and in part by the Science and Technology Development Programs of Henan Province under Grant No. 112102210187.

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