Sept. 2006, Vol.21, No.5, pp.723–731 *J. Comput. Sci. & Technol.*

Research on Next-Generation Internet Architecture

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Received April 19, 2006; revised June 20, 2006.

Abstract The primary problem during the evolvement of next-generation Internet is the contradiction between growing requirements for Internet and the insufficient development of network theory and technology. As the fundamental principles to guide the developing direction of Internet, the study of Internet architecture is always a focus in the research community. To address the core issue of network scalability, we propose multi-dimension scalable architecture of next-generation Internet, the main idea of which is to extend the single-dimension scalability of traditional Internet on interconnection to multi-dimension scalability of next-generation Internet. The multi-dimension scalability is composed of scale-scalability, performance-scalability, security-scalability, function-scalability, and service-scalability. We suggest five elements, namely, IPv6, authentic IPv6 addressing, scalable processing capacity of routers, end-to-end connectionless Quality-of-Service control, and 4over6 mechanism to realize the multi-dimension scalability. The current research results show that the multi-dimension scalable architecture composed of these five elements will bring great influence on next-generation Internet.

Keywords next-generation Internet, multi-dimension scalability, IPv6, authentic IPv6 addressing, 4over6

1 Introduction

Human society is going from industry era to information era, and information is the most important media and power in the society. Internet has been growing at such a fast speed that it already becomes a fundamental infrastructure in social production and daily life in the present era.

Along with the development of Internet, the primary contradiction to solve is the one between the growing requirements for next-generation Internet and the insufficient development of network theory and technology. As can be anticipated, the research fruits of extra-high speed optical communication, high speed wireless communication, grid computing, and biological computing will bring a flight to network technology in the next decade, toward a next-generation Internet signed by *larger, faster, more responsive, more convenient, more secure, more manageable, and more effective.*

The research on next-generation Internet and its applications has attracted attention by many countries, and there are a lot of research projects on next-generation Internet, such as NGI, Internet 2, NewArch, GENI, FIND, NSFCNET, etc. These projects will be introduced in Section 2.

Architecture is the key point for next-generation Internet research. Along with the growing requirements on many aspects of next-generation Internet, scalability of the next-generation Internet becomes the most important issue. Although it is regarded that Internet has good scalability based on end-to-end argument and best effort service, it only focuses on network interconnection. Internet shows more and more deficiency in supporting new applications. Traditional Internet architecture cannot scale well in addressing space, node processing performance, security, functions and services provided to upper layer users, etc. Although there are many research projects on next-generation Internet as described above, no satisfactory fruit is achieved on the architecture scalability of next-generation Internet until now.

We propose multi-dimension scalable architecture of next-generation Internet to meet the continuously growing requirements for Internet. The principal idea is to extend the single-dimension scalability on network connection of traditional Internet to multi-dimension scalability of next-generation Internet. The multi-dimension scalability is composed of scale-scalability, performance-scalability, security-scalability, function-scalability, and service-scalability. We suggest five elements, namely, IPv6, authentic IPv6 addressing, scalable processing capacity of routers, 4over6 mechanism, and end-to-end connectionless Quality-of-Service control to realize the multi-dimension scalability.

The remainder of this paper is organized as follows. Section 2 introduces related work. Section 3 discusses the design requirements of multi-dimension scalable architecture of next-generation Internet. The scalability elements are detailed in Section 4. We demonstrate the implementation and deployment of architecture in Section 5. Finally, Section 6 concludes the whole paper.

2 Related Work

2.1 Research Trends on Next-Generation Internet

The theory and technology of computer information network starts from the 60s of the 20th Century. D. Clark proposed the end-to-end argument as the primary

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This work is supported by the National Natural Science Foundation of China (Grant No. 90104002), the National Grand Fundamental Research 973 Program of China (Grant No. 2003CB314801).

design principle[1], which points out the developing direction of Internet. After 80s, standardization of network theory and technology is populated.

Internet is a successful example of computer information network. However, there is no theoretical model for such a complex huge system. As the continuously development of network service patterns, traditional mathematical models for network behavior such as poison process cannot reflect the actual network behavior. Recent researches mainly focus on establishing new mathematical models based on large amount of traffic data[2]. However, due to the burst property and random property of Internet traffic, there is no theory or model to completely reflect network state and network behavior until now.

As the requirements for Internet grow at fast speeds, many new ideas and technologies are introduced into the theory and practice of Internet. To overcome the problem of insufficient address space of current IPv4 protocol, IPv6 is propelled as the network layer protocol for next-generation Internet by IETF[3]. Nowadays, developed countries, such as USA, Europe, and Japan, are all energetically supporting the construction of IPv6 backbone. Constructed or constructing IPv6 network include Abilene in USA[4], GEANT in Europe[5], and APAN in Asia and Pacific[6].

Secure and trustworthy service is an external requirement for Internet, and is also an important problem next-generation Internet faces. Although the design of traditional Internet has considered military security, it is not fully thought over since traditional Internet is used in a trusted environment. RFC 1287[7] points out the importance of the Internet security reference model, but there is not a systematical security architecture until now. RFC 2401[8] is only an IP layer security framework. Other related RFCs propose concrete solutions to concrete security problems, but these security technologies are not correlated and cannot satisfy the security requirements of the Internet in a global view. Trustworthy computing has also attracted attention of more and more researchers. Bill Gates thinks that trustworthy computing is the most important piece of work that Microsoft cooperation is carrying on. He defines trustworthy computing as a reliable, secure, easy-obtainable computing, similar to electric power and telephone. Trustworthy computing is not only the security and reliability of computing itself, but more a zoology environment.

The growing requirements for Internet are also embodied in the service diversity Internet should provide. Traditional static, unicast, and best effort architecture cannot satisfy many rising applications. Mobility, multicast and QoS are introduced into the Internet architecture. However, these new requirements are essentially conflict with traditional Internet architecture. And as a result, these new services are not widely deployed in Internet scale until now.

2.2 Representative Projects of Next-Generation Internet

Internet Architecture is the key point in research of next-generation Internet, and there are a lot of next-generation Internet projects. US government declared to launch the research plan of Next-Generation Internet (NGI) in October, 1996, focusing on studying the basic theory of computer information network in the 21st century and constructing completely new-concept Internet architecture[9]. As a complement to NGI, more than 100 universities and enterprises in USA cooperatively launched the research plan of Internet 2, trying to explore next-generation network applications on high-speed information network by use of current network technologies.

US department of defense also funded a research plan on next-generation Internet architecture named NewArch[10], which is cooperated by Computer Science Lab of MIT, International Computing Science Institute of UCB, and etc. In lately published papers of this project[11,12], authors rethought the current Internet, and proposed several design principles for next-generation Internet, such as design against variability, controllable transparency, and isolation of interest conflicts.

FIND[13] (Future Internet Network Design) is a long-term research program of NSFNETS. FIND asks two broad questions. What are the requirements for the global network of 15 years from now — what should that network look like and do? And how would we reconceive tomorrow's global network today, if we could design it from scratch? The FIND program solicits "clean slate process" research proposals in the broad area of network architecture, principles, and design, aimed at answering these questions.

GENI (Global Environment for Network Innovations) is a facility concept being explored by the US computing community[14]. The goal of GENI is to increase the quality and quantity of experimental research outcomes in networking and distributed systems, and to accelerate the transition of these outcomes into products and services that will enhance economic competitiveness and secure the future of USA.

There is a long history of the research on basic theory and application technology of computer information network in China. The policy of reform and open door brings forward a good developing opportunity for the construction of information infrastructure, such as telephone, cabled television, fiber transporting system, etc. As accounted by the Internet Information Center of China in Jan. 2003[15], there were 20,830,000 computers, 59,100,000 Internet users, 179,544 domain names under .CN, 371,600 web sites, and 9,380,000,000 Bytes of international line capacity in China. In recent years, the National Natural Science Foundation, 863 Program, 973 Program and other projects give energetically supports for the researches on basic theories and application technologies of Internet.

NSFCNET[16] is a program funded by the National Nature Science Foundation of China, co-completed by Tsinghua University, Computer Information Network Center of Chinese Academy of Sciences, Peking University, Beijing University of Post and Telecommunication, Beihang University, etc. The topology of NSFCNET is illustrated in Fig.1. The goal of this project is constructing the first DWDM fiber-based high speed computer network for academic in China, studying the basic theory and key technology of next-generation Internet, developing several important application systems, and providing the experimental environment for the research of next-generation Internet in China. With the effort of all the participating units, NSFCNET completed all the research plans and achieved the anticipated goal. In addition, the project realized the connection to international next-generation Internet, the performance factors reach the advanced next-generation Internet in the world, and obtains a lot of important research fruits.

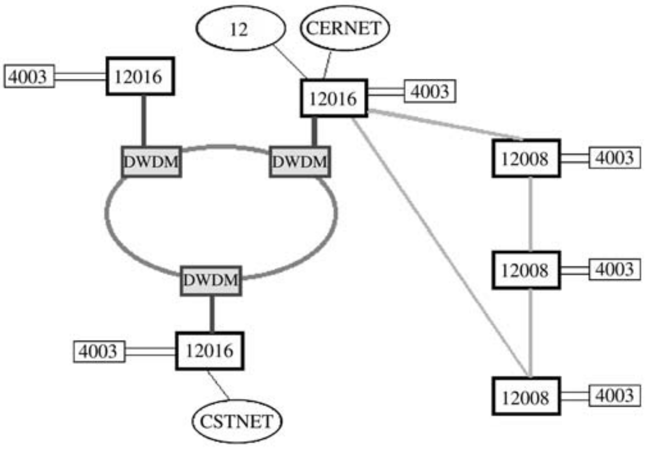


Fig.1. Topology of NSFCNET.

Although there are many researches and projects on next-generation Internet architecture both abroad and at home as described above, no satisfactory research fruit is achieved on the most important issue of architecture scalability of next-generation Internet. Traditional single-dimension scalability has already been the primary bottleneck for the development of Internet. The multi-dimension scalable architecture of next-generation Internet we propose can accurately and clearly reflect the growing requirements on next-generation Internet, and effectively solve the primary contradiction during the evolvement of next-generation Internet.

3 Design Demand of Multi-Dimension Scalable Architecture

With the development of next-generation Internet, the primary contradiction to solve is the contradiction between the growing requirements for Internet and the insufficient development of network theory and technology. This is also the fundamental problem the next-generation Internet faces.

On one hand, as human society enters the information era, Internet has become the nerve and blood of the society since it is the primary carrier for information storage and propagation. New demands are continuously brought forward to Internet. Internet is required to cover each corner of the society, realize more functions, provide more services, and ensure more secure information exchange. Therefore, Internet must develop towards the direction of larger, faster, more responsive, more convenient, more secure, more manageable, and more effective.

Larger indicates that next-generation Internet will adopt IPv6 as the basic network layer protocol, so as to solve the problem of insufficient address space in current IPv4. The use of IPv6 will also lay a foundation for the further development of next-generation Internet.

Faster means that the end-to-end performance in next-generation Internet will be greatly improved, at least more than 100Mbps.

More responsive means that next-generation Internet will support multicast and QoS, thus to provide more responsive real-time multimedia information to users.

More convenient means that next-generation Internet will provide more convenient access methods, supporting wireless terminal access and mobile communications.

More secure indicates that next-generation will provide more trustworthy network services, including object identification and network attack defense.

More manageable means that next-generation Internet will provide more convenient and more flexible managing methods, to conduct complete and effective management of networks.

On the other hand, traditional Internet technology can hardly satisfy the growing requirements, primarily because the scalability problem of the network architecture is not solved well. Although it is regarded that Internet has good scalability based on end-to-end argument and best effort service, it only focuses on network interconnection. Internet shows more and more deficiency in supporting new services, for instance, multicast, mobility and QoS. The underlying reason is just that best-effort based Internet only concerns single-dimension scalability in network interconnection, rather than multi-dimension scalability. Current Internet architecture cannot scale well in addressing space, router processing capacity, trust, functions and services provided to upper layer users. To effectively meet the growing requirements for Internet, multi-dimension scalable architecture is demanded for next-generation Internet.

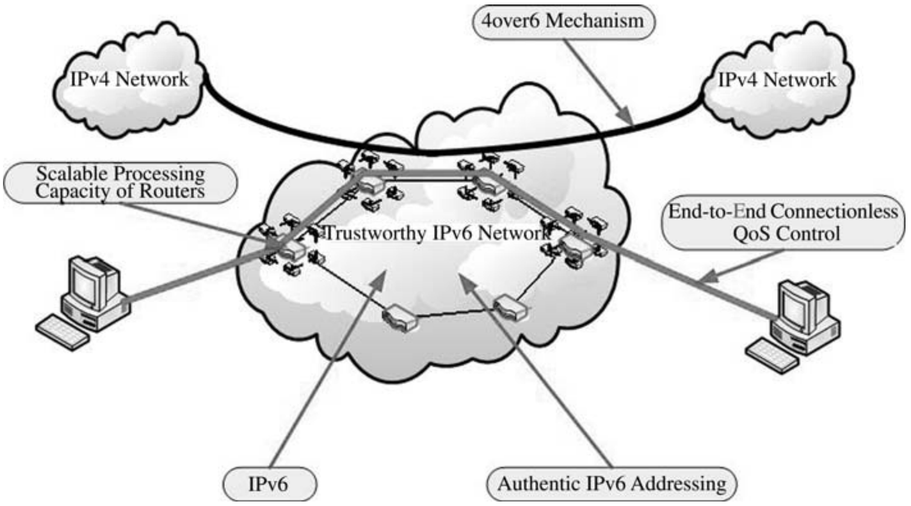


Fig.2. Relationship between the scalability elements.

4 Elements of Multi-Dimension Scalable Architecture of Next-Generation Internet

We design multi-dimension scalable architecture of next-generation Internet to solve the contradiction Internet faces, namely, scale-scalability, performance-scalability, function-scalability, security-scalability, and service-scalability, among which scale-scalability and performance-scalability are the two fundamental ones. We suggest five elements to realize the multi-dimension scalability.

1) IPv6. IPv6 becomes the defacto standard of the network layer protocol of next-generation Internet. It helps to realize the scale-scalability and security-scalability of next-generation Internet.

2) Authentic IPv6 addressing. A lot of security problems in traditional Internet come from non-authentication of source addresses. The authentic IPv6 addressing in next-generation Internet will help realize the security-scalability and service-scalability.

3) Scalable processing capacity of routers. As the number of users grows, the routers in next-generation Internet should have scalable processing capacity, which will help realize the performance-scalability and scale-scalability of next-generation Internet.

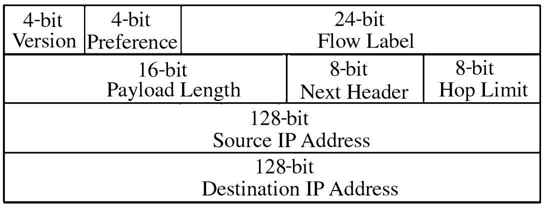
4) End-to-end connectionless Quality-of-Service control. The Quality-of-Service control capacity of Internet is always a hot topic. Realizing Quality-of-Service control based on hop-by-hop and connectionless routing will help achieve the performance-scalability and service-scalability of next-generation Internet.

5) IPv4 over IPv6 network transition policy. Next-generation Internet should cooperate with traditional Internet to provide services to users. However, current transition policies only suite to small-scale IPv6 network. The IPv4 over IPv6 transition policy when IPv6 network becomes the backbone of next-generation Internet will help achieve the function-scalability and service-scalability.

These elements are illustrated in Fig.2.

4.1 IPv6

The original users of Internet were members of the network research community. However, the pool of users has expanded in the recent years from network researcher to CS researcher to scholarly user to a broad cross section of worldwide society. Current Internet adopts IPv4 as the network layer protocol. Although technologies such as NAT, CIDR are introduced, IPv4 still has the problem of insufficient address space. IPv6 is propelled by IETF to replace IPv4 as the network layer protocol of next-generation Internet[3]. Except for larger address space, IPv6 also integrates IPSec to solve the network layer security problem to some extent. The packet header of IPv6 is illustrated in Fig.3.



<table>
<tr><td>4-bit
Version</td><td>4-bit
Preference</td><td colspan="3">24-bit
Flow Label</td></tr>
<tr><td colspan="3">16-bit
Payload Length</td><td>8-bit
Next Header</td><td>8-bit
Hop Limit</td></tr>
<tr><td colspan="5">128-bit
Source IP Address</td></tr>
<tr><td colspan="5">128-bit
Destination IP Address</td></tr>
</table>

Fig.3. IPv6 packet header.

Compared to IPv4, IPv6 has the following advantages.

- IPv6 extends the addressing space from 32 bits (IPv4) to 128 bits, and overcomes the problem of insufficient address space in IPv4. IPv6 supports hierarchical address structure and thus is more convenient for addressing. Multicast address and anycast address are also supported in IPv6, and packets can be sent to a group of nodes or one of a group of nodes.
- Stateless automatic address configuration is realized in IPv6. Therefore, IPv6 terminals can fast connect Internet. There is no need for manual configuration and plug-and-play is realized.
- The packet header is simplified and the processing cost of routers and switches is effectively reduced, which

is in favor of the hardware implementation.

- Extended header and option field are supported in IPv6, which not only makes forwarding more effective, but also supports the extension to new applications.
- Flow label in IPv6 can provide different network services to different classes of packets, and thus QoS assurance.
- IPSec must be supported in IPv6, ensuring the integration and confidentiality of end-to-end communication.
- There are also many improvements in mobility and real-time communication in IPv6.

Therefore, in the multi-dimension scalable architecture of next-generation Internet, we use IPv6 to help realize the scale-scalability and security-scalability.

4.2 Authentic IPv6 Addressing

The traditional Internet addressing architecture does not verify the source address of the packets received and forwarded, although RFC 1812[17] has mentioned that a router should implement the ability of validating source IP address. On the other hand, IPv4 address is limited, so Network Address Translation (NAT) is widely used. Because of these two facts, the current Internet addressing architecture using IPv4 is difficult to ensure the authenticity and global uniqueness of the source IP address of every packet forwarded in the network. Therefore, network security is threatened: attackers commonly forge source addresses to avoid responsibility for their malicious packets, and the defenders cannot easily trace their true source hosts from which these packets are sent, for example, DDoS attacks, TCP SYN flooding attacks, etc.

The deployment of IPv6 will give us the opportunity to implement an authentic addressing architecture. We propose a new addressing architecture for IPv6 network called "Authentic IPv6 Addressing Architecture" to ensure that every packet received and forwarded have to hold an authentic source address. Here the authentic source address has two meanings. First, the address must be authorized by Internet address authorization organization and not be forged. Second, the address must be globally unique and easy to be traced back. This will extend the traditional Internet routing architecture from destination address based to both source and destination addresses based. A router not only forwards the packet based on destination address, but also validates the source address to ensure whether the packet is eligible for forwarding.

The authentic IPv6 addressing architecture is divided into three subsystems: inter-AS, intra-AS, and access network. There are mainly six components of the architecture: ICMP6 Trace Validation Extension, AS Number to IPv6 Address Mapping, Inter-AS Filtering, Inter-AS Marking, Intra-AS Filtering, and Interface ID Management. The architecture of authentic IPv6 address is shown in Fig.4.

- ICMP6 Trace Validation Extension is implemented by all the network devices supporting the Authentic IPv6 Addressing Architecture. It is used for actively measuring the deployment of the Authentic IPv6 Addressing Architecture. Just by this means, the loose coupling components can be combined as a whole architecture.
- AS Number to IPv6 Address Mapping is a component of inter-AS validation. It provides the common information of the AS and the IPv6 address prefixes belonging to it and predigests the creation of inter-AS validation rules.
- Inter-AS Filtering is a component of inter-AS validation. The validation rule creating of Inter-AS Filtering depends on the reachability information from routing system. It builds a filtering table that associates each incoming interface of the router with a set of valid source address blocks, and then uses it to filter spoofed packets. It achieves an authenticity of AS level granularity.

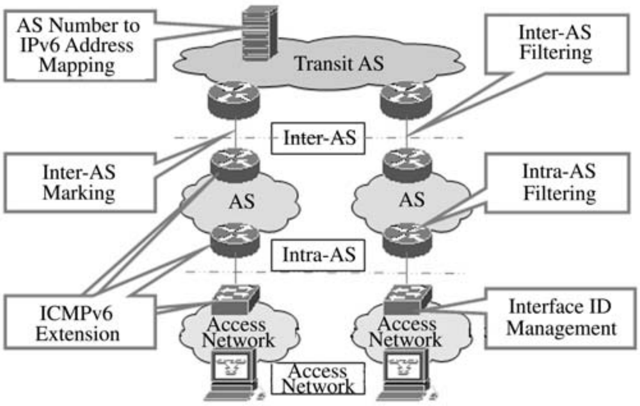


Fig.4. Architecture of authentic IPv6 addressing.

- Inter-AS Marking is a component of inter-AS validation. The validation rule creating of Inter-AS Marking is independent of the reachability information from routing system. It just uses the additional mark signed in each packet for validation. It achieves an authenticity of AS level granularity.
- Intra-AS Filtering belongs to intra-AS validation. It achieves an authenticity of address prefix granularity.
- Interface ID Management belongs to access network validation. It achieves an authenticity of Interface ID granularity.

The use of authentic IPv6 addressing will help realize the security-scalability and service-scalability of next-generation Internet.

4.3 Scalable Processing Capacity of Routers

It is well known that there are totally only three types of regular polygons which can cover the whole plane seamlessly: equilateral triangles, squares and regular hexagons. Square has been selected as the atomic structure of the k-ary n-cube topology. If we add a central point in each regular hexagon, we get a modified version of this topology as shown in Fig.5.

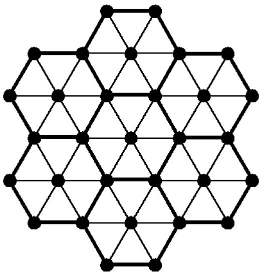


Fig.5. Modified regular hexagons.

If each line card in the router carries one node of this topology and data channels replace the edges, we can get a new architecture, called Cellular Router (CR), for scalable routers. As line cards are added, they may appear in only one single layer in one single rack, several layers in one single rack or several different racks. This architecture shows excellent scalability and can be easily packaged with short wires. Basic CR architecture shows poor fault tolerance. We can improve this by connecting the edge nodes. Fig.6(b) shows the improved multilayer scheme and Fig.7(b) shows the improved multi-rack scheme.

In Fig.7(a), we see that each edge node can find its connected edge node according to the axis AA' or BB'. Analogously we can find such axes AA', BB' and CC' as shown in Fig.5(b). The degree of a node n is the number of data channels which are connected to n. In 2-D case, the maximum degree of each node in CR architecture is 6. To ease the problem, we only consider the 2-D case. We can easily find that there are only two types of edge nodes in the regular CR architecture, nodes with degree of 3 and nodes with degree of 5. If one node happens to appear on one of the three axes AA', BB' and CC', its connected node can be found in the same axis. To each node with degree of 3, we can connect it to the three symmetric nodes according to the three axes. To each node with degree of 5, if it does not appear on any of the three axes, it chooses the axis with the longest distance. As shown in Fig.7(b), node 27 is connected to node 15, and node 29 is connected to nodes 26, 10 and 18. In this way, all the edge nodes have the same degree of 6. This can greatly improve the fault tolerance and reduce the average hop counts each node takes to arrive at its destination.

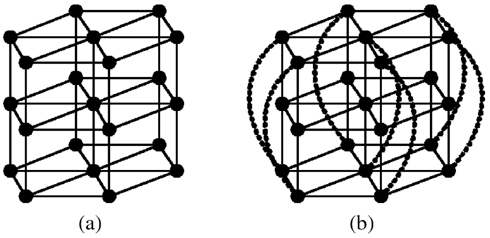


Fig.6. Improved multilayer scheme.

We also develop scalable software architectures on the cellular routers, realizing the load balance between controlling nodes, high reliability of software system and dynamic configuration of control plane. The scalable processing capacity of routers will help realize the performance-scalability and scale-scalability of next-generation Internet.

4.4 End-to-End Connectionless QoS Control

Traditional Internet can only provide best-effort services, which cannot meet the demands of the up-growing and heterogeneous applications. With the development

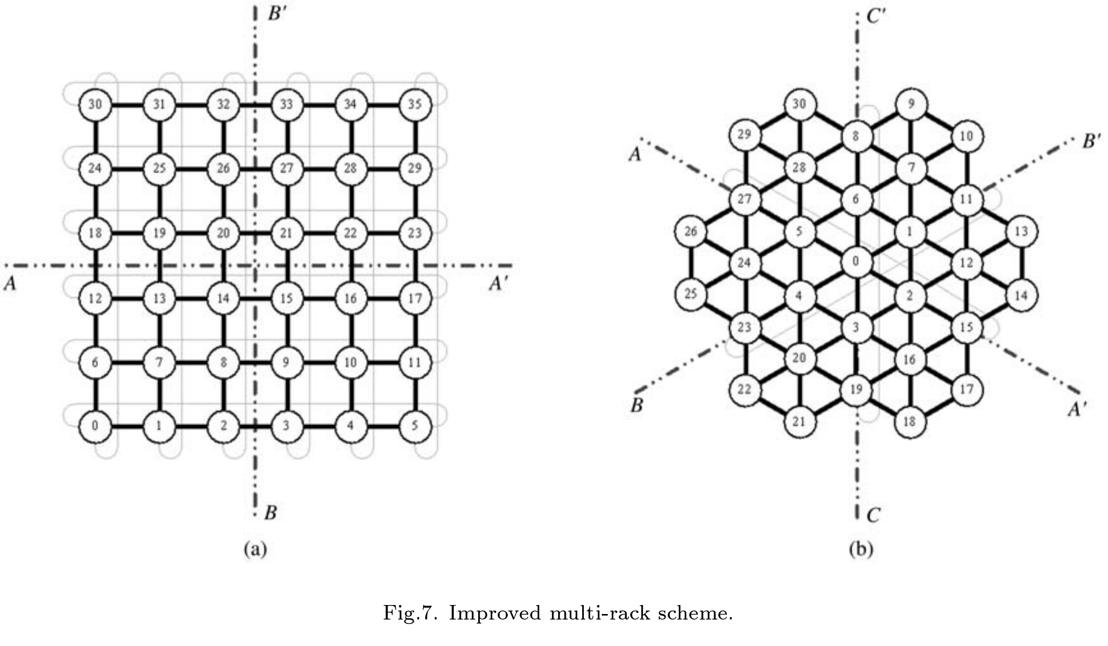


Fig.7. Improved multi-rack scheme.

of next-generation Internet and IPv6, how to provide different QoS control to upper layer applications becomes a constraint of the development of next-generation Internet. IntServ framework provides QoS assurance to every traffic flow, but it is hard to deploy in large-scale Internet due to scalability problem. DiffServ has better scalability, but it is unable to differentiate large amounts of heterogeneous applications, and cannot realize the independent control of different QoS metrics such as latency, dropping ratio, bandwidth, cost etc. Additionally, DiffServ cannot select different paths for applications with different QoS requirements. Therefore, DiffServ cannot realize the QoS control for data transmission in Internet essentially. Although packet schedule mechanisms can provide QoS control to some extent, there is not any overall consideration for the whole Internet. Therefore, the occasion may occur when some paths are congested while other paths are vacant.

We propose an end-to-end ConnectionLess QoS Routing (CLQoSR) framework[18,19], which is indicated in Fig.8. The advantage of CLQoSR includes:

- adaptation to network scale;
- support for multiple QoS parameters and constraints;
- support for multiple routing protocols;
- adaptation to QoS requests and packet arriving rates.

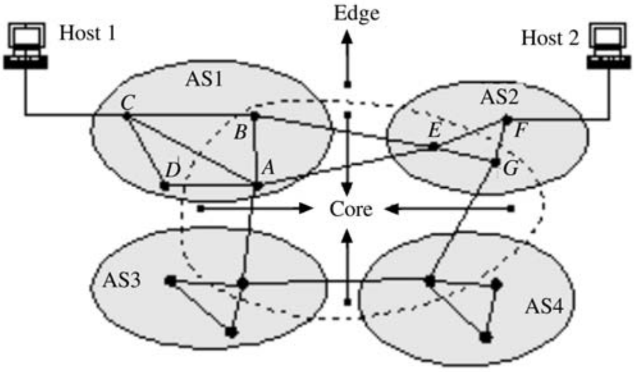


Fig.8. Architecture of end-to-end CLQoSR.

CLQoSR is composed of the following parts:

- local state measurement;
- intra-AS and inter-AS routing mechanism;
- link-state based multi-constrained QoSR core algorithm;
- end-to-end admission control mechanism;
- QoS packet forwarding mechanism.

Local state measurement obtains the local state information of network nodes (routers). Each network node gets the aggregated network state information through exchange of intra-AS and inter-AS routing protocols. The feasible packet forwarding paths are computed using the QoSR core algorithm. Finally, packets enter the network after end-to-end admission control, and are transmitted by network nodes.

The use of end-to-end connectionless QoS control will help realize the performance-scalability and service-scalability of next-generation Internet.

4.5 4over6 Mechanism

IPv6 will be the network layer protocol of next-generation Internet since it can realize the scale-scalability of Internet. However, there is a long way to go for the transition from IPv4 to IPv6. The problem of how to communicate between IPv4 networks when IPv6 network becomes the Internet backbone is especially a key issue.

Although there are some related transition technologies, such as [20–22], most of them focus on the problem of IPv6 over IPv4, rather than the case when IPv6 network becomes the Internet backbone. There is also manual-configured tunnel technology to encapsulate IPv4 packets in IPv6 packets, but the insufferable burden of manual configuration prevents the wide deployment of such tunnels in large-scale IPv4/v6 interconnected networks. Therefore, new techniques need to be introduced to provide automatic tunneling mechanism for scalable IPv4 packet transmission over an IPv6 backbone.

We propose 4over6 Mechanism to solve this problem. Generally speaking, 4over6 mechanism concerns two aspects: the control plane and the data plane. The control plane needs to solve the problem of how to set up an IPv4 over IPv6 tunnel with proper method of tunnel end-point discovery. We extends BGP-MP[23] to carry the tunnel end information to the other side of the IPv6 backbone to setup of a stateless 4over6 tunnel on the dual-stack Provider Edge (PE) router. Based on the 4over6 tunnel, the data plane focuses on the data packet forwarding process with encapsulation and decapsulation.

The 4over6 mechanism is shown in Fig.9. In the IPv4/v6 interconnected network topology, a number of Provider (P) routers, only running the IPv6 network stack, compose a native IPv6 backbone. In order to provide IPv4 access to the current IPv4 users/applications, PE routers run both IPv6 and IPv4 stacks. The IPv6 backbone acts as a transit core to transport IPv4 packets over the IPv6 backbone. Therefore, each of IPv4 access islands can communicate with each other via the virtual softwires over the IPv6 transit core.

The IPv4 access island often uses default routing to a particular PE router on the IPv4 stack. However, since there are multiple PE routers connected to an IPv6 transit core, in order to forward the IPv4 packet directly to an egress PE router with encapsulation mechanism, the ingress PE router needs to know which PE should be the egress one. BGP-MP will be extended to carry the destination IPv4 networks over the IPv6 backbone.

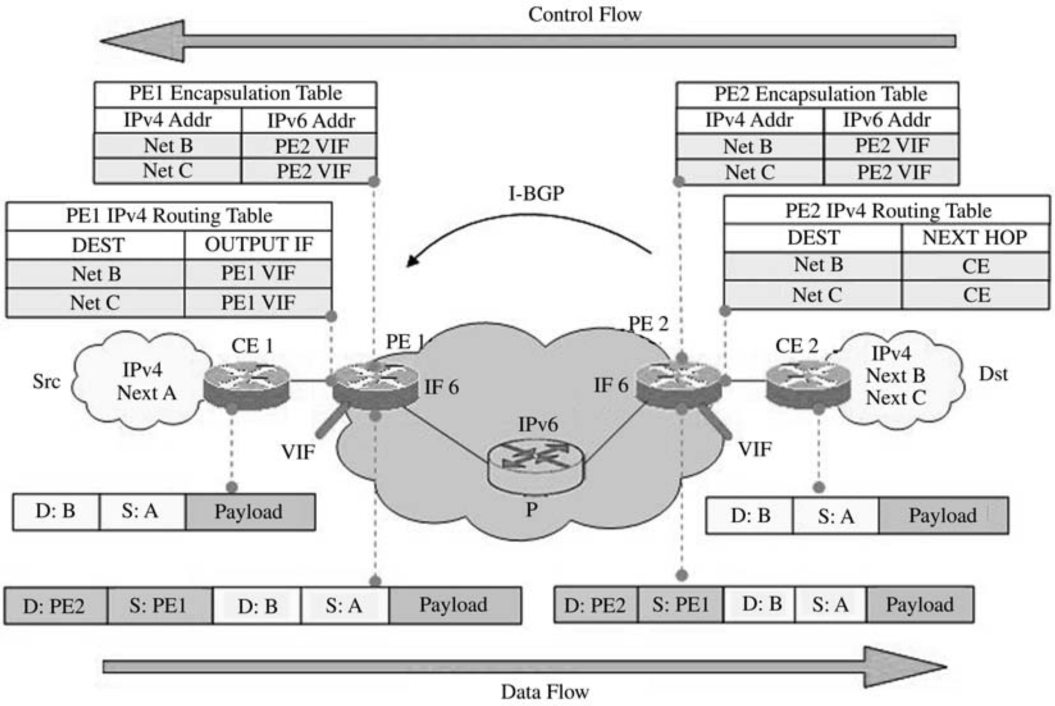


Fig.9. Overview of 4over6 mechanism.

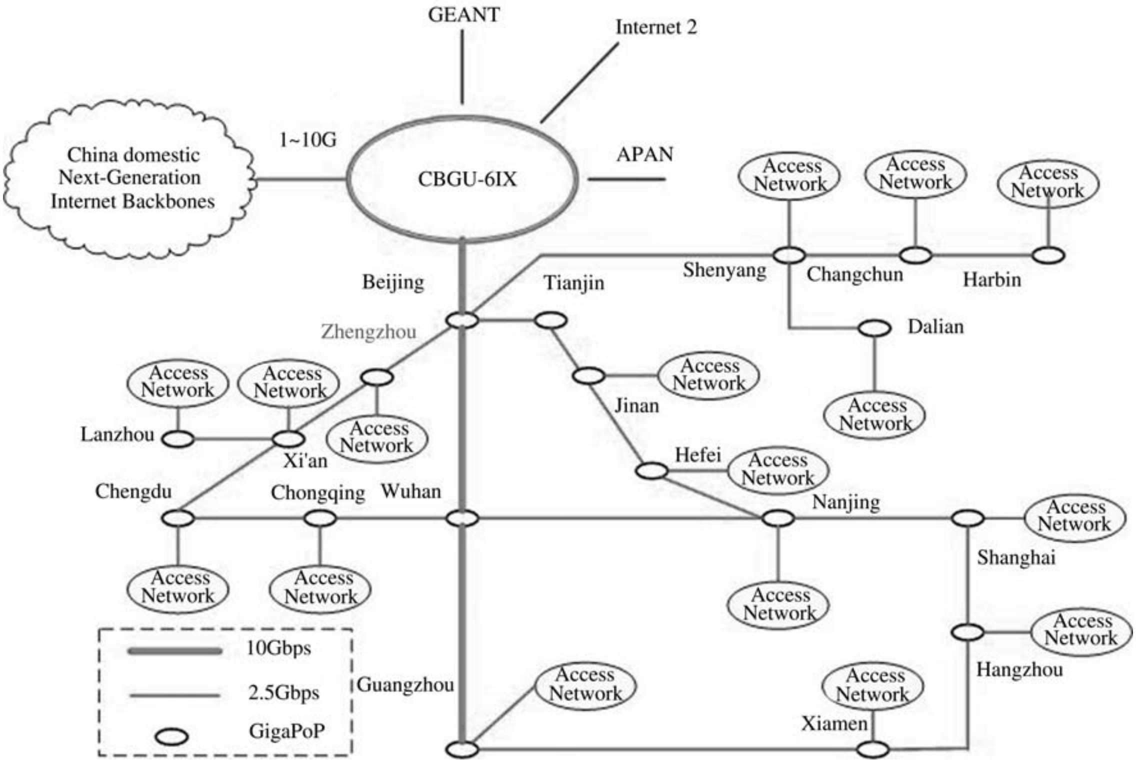


Fig.10. CERNET2.

After ingress PE router finds the exact egress PE router, the ingress one will use a particular encapsulation method to forward the original IPv4 packet over the IPv6 backbone. Receiving the encapsulated packet from the IPv6 transit core, the egress router will decapsulate the packet to its original IPv4 format and then forwards the packet to its final IPv4 destination.

4over6 mechanism provides network access to both IPv4 and IPv6 users. This mechanism will help realize the function-scalability and service-scalability of next-generation Internet.

5 Implementation and Deployment

Based on the theory of multi-dimension scalable architecture in next-generation Internet, we have implemented a testbed in CERNET2 including parts of our architecture such as IPv6, authentic IPv6 addressing and 4over6 mechanism. CERNET2 is the largest core network and the only academic network in the project of China Next Generation Internet Demonstration Project CNGI. CERNET2 is also so far the world's largest native IPv6 backbone. CERNET2 topology is shown as Fig.10.

In order to give a comprehensive evaluation of our testbed, we test some applications such as P2P application, multimedia streaming, and web application from views of scale-scalability, performance-scalability, security-scalability, function-scalability, and service-scalability. The results show that the multi-dimension scalable architecture composed of these five elements will surely bring great influence on next-generation Internet.

6 Conclusions

As more and more attention has been paid to the research of next-generation Internet and its application, many research projects were set up on this topic, such as NGI, Internet 2, NewArch, GENI, FIND, NSFCNET, etc. In this paper we focus on the primary problem in the architecture of Internet: the contradiction between the growing requirements for next-generation Internet and the insufficient development of network theory and technology.

To solve the key problem of scalability in the architecture of next-generation Internet, we propose multi-dimension scalable architecture in next-generation Internet instead of single-dimension scalability of traditional Internet on interconnection. There are five elements in our architecture realizing the multi-dimension scalability: IPv6, authentic IPv6 addressing, scalable processing capacity of routers, 4over6 mechanism, and end-to-end connectionless QoS control. We implement parts of our architecture in CERNET2 and show that the multi-dimension scalable architecture composes of these five elements will surely bring great influence on next-generation Internet.

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