IPv4/IPv6 Translation Technology

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The ubiquitous network society in which anyone can connect to the Internet and enjoy services anytime, anywhere, and with any type of terminal is evolving at an increasing tempo. This evolution is proceeding together with the progress being made in high-speed broadband networks and the introduction of various types of information equipment such as mobile computers and electrical information appliances. The ubiquitous network society requires that the IPv6 network (or next-generation Internet Protocol), with its vast address space, be adapted as part of the infrastructure, because the IPv4 network currently used by the Internet cannot provide sufficient support. However, it is not practical to reconstruct the huge user properties built into the IPv4 network for migration to the IPv6 network. Migration to IPv6 involves two technical subjects: IPv4/IPv6 translation technology and gateway construction technology. IPv4/IPv6 translation technology involves address mapping between IPv4 and IPv6, and the methods used to translate protocols. Gateway construction technology involves reserving the necessary scalability and ensuring the required reliability. This paper describes an IPv4/IPv6 translation technology that fully utilizes the user properties built into the existing IPv4 network without any changes and standardizes new services on the IPv6 network that are compatible with the next-generation Internet. This paper also describes our newly developed IPv4/IPv6 address translator, application level gateway, and high-reliability technologies.

1. Introduction

The rapid diffusion of the Internet and development of high-speed broadband networks have posed the problem of inadequate IPv4 address space on the Internet. Moreover, this lack of address space has been made worse by the progress made toward the ubiquitous network society, in which various types of information equipment, mobile computers, and electrical information appliances communicate on the Internet. IPv6 was developed as a solution to this problem. The IPv4 address structure is based on a 32-bit address length. It can manage about 4 billion addresses, but cannot be assigned to everyone living in the world, which contains about 6.3 billion people. However, the IPv6 address structure is based on a 128-bit address length and therefore can be used to assign more than 5×10^{28} addresses to every person in the world, thus offering an almost infinite address space. In addition to extending the address space, IPv6 can be enhanced to, for example, concentrate routing information in the layering address structure, automatically set addresses, add the security feature offered by IPsec (IP Security), and add a QoS (Quality of Service) feature.

This background has already promoted IPv6 compatibility in various fields, with full-scale commercial use about to begin. In order to migrate the huge user properties (e.g., applications, network environments) built into IPv4 to IPv6, operating systems (OSs), middleware, and applications adapted for address length and IPv6 must be upgraded. These major changes pose a high risk, and many subjects remain to be resolved before a smooth migration from existing IPv4 properties to IPv6 can be achieved. Consequently, the authors have developed a reliable, large-scale IPv4/IPv6 translator that seamlessly enables new communication with the IPv6 network and devices for commercial use, without changing existing IPv4 user properties. This paper mainly introduces IPv4/IPv6 translation technology and gateway construction technology. IPv4/IPv6 translation technology involves address mapping, protocol translation, and cooperation between services. The gateway construction technology involves scalability and high reliability.

2. Development concept

The translator is a piece of equipment used to mutually translate IPv4 and IPv6 at the boundary between an IPv4 network and an IPv6 network. It can translate multimedia communications such as Internet/intranet communications involving the WWW, e-mail, and File Transfer Protocol (FTP) and mobile communications via Mobile-IP[1), note)] and IP telephone (VoIP) via Session Initiation Protocol (SIP).

The translator makes it possible to quickly and inexpensively achieve communication between IPv4 and IPv6 simply by installing a gateway (even when a part of a system, e.g., a server, client, or network, is replaced).

Figure 1 shows the positioning of the translator.

2.1 Basic concept

The translator was developed based on the concept of TRIOLE.[2)]

1) Virtualization

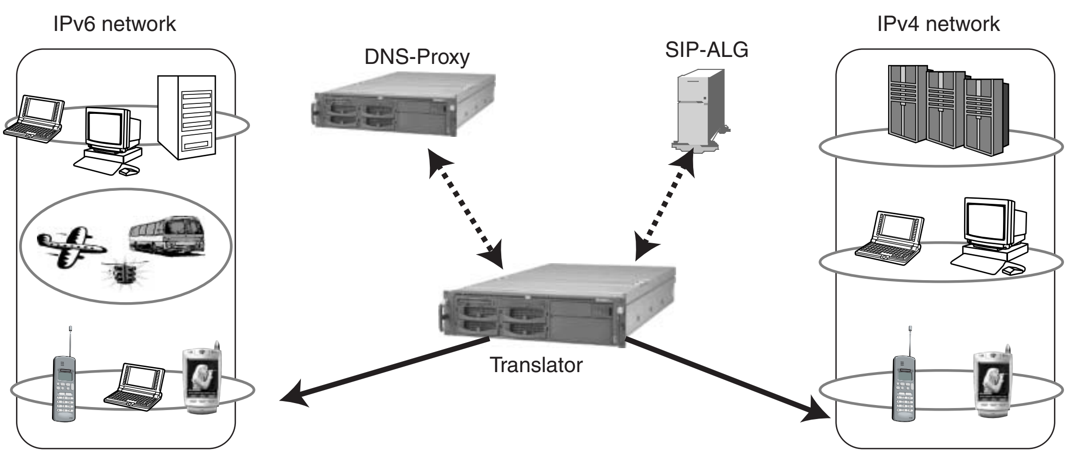
A system achieves translation in not only the IP layer, but also total mutual translation in higher layers. Seamless communication is realized by data-level translation and guaranteeing the transparency between IPv4 and IPv6 in services of a higher level (multi-layer translation).

Multi-layer translation achieves seamless communication independent of location and the connected network.

2) Automation

Automation autonomously adapts the system to changes in the communication load, failures, and other changes with scalability and high

note) Mobile-IP is the protocol of mobile computers in the IP network.



SIP: Session Initiation Protocol
SIP-ALG: Gateway server that performs the interconnection of IPv4/IPv6 networks by SIP (GeoServe)

Figure 1
Positioning of translator.

reliability.

3) Integration

Various types of communication functions are unified to handle various services of the ubiquitous age.

2.2 Requirements

The following four points are considered requirements for translation between an IPv4 network and an IPv6 network:

1) To perform seamless communication between an IPv4 network and an IPv6 network, communication must be conducted according to the differences between the IP headers and address space structures of IPv4 and IPv6. This is because the translator acts as a host node for each protocol.
2) When address information is handled in a higher-level protocol that is directly controlled by an application that makes a layer violation or the protocol specifications of a higher-level protocol differ between IPv4 and IPv6, address and protocol translation must be performed by complying with the higher-level protocol. For example, FTP[3] sets an IP address and port number as the payload part of TCP. Moreover, IPv6 extends the FTP protocol command and compatibility with lower parts is lost to IPv4.
3) Since a translator is installed between an IPv4 network and an IPv6 network, packets may be concentrated and the communication load increased. For this reason, we require a structure that can sufficiently support a system according to increases in the communication load without needing to stop the network.
4) Because the translator serves as a relay between an IPv4 network and IPv6 network, traffic may be concentrated on the translator. As a result, communication may be stopped, making services unavailable to users. Therefore, network devices must be highly reliable, especially in a network that provides real-time communication via VoIP.

3. IPv4/IPv6 translation technology

3.1 Address mapping

The 128-bit address space of IPv6 is much larger than the 32-bit address space of IPv4. It is characterized by the following:

- It is not possible to map all of the IPv6 addresses to IPv4 addresses on a one-to-one basis.
- An IPv4 address is written in the 32 low-order bits and combined with a prefix consisting of the 96 high-order bits to form a 128-bit IPv6 address.

Given these characteristics, IPv6 and IPv4 addresses are mapped in the translator as follows:

- The designated subnetworks for translation are assigned from inside the IPv4 network and managed as a pool of addresses included in subnetworks for the translator. Then, an IP address in the pool of IPv4 addresses (hereinafter called the pool addresses) is mapped to a designated IPv6 address and regarded as the IPv4 address of the IPv6 host node connecting to the IPv4 host node through the translator.
- The designated subnetworks for translation are assigned from inside the IPv6 network and managed using a 96-bit prefix assigned to the translator. The 128-bit IPv6 address (96-high-order-bits prefix and 32-low-order-bits IP address) of the connecting IPv4 host node is reported to the IPv6 host node.

Figure 2 shows the address mapping.

There are two methods of address mapping: static mapping and dynamic mapping. The method of address mapping must be selected according to the purpose of introducing the translator. Therefore, we implemented both methods of address mapping.

3.1.1 Static mapping

Each pool address of IPv4 is mapped one-to-

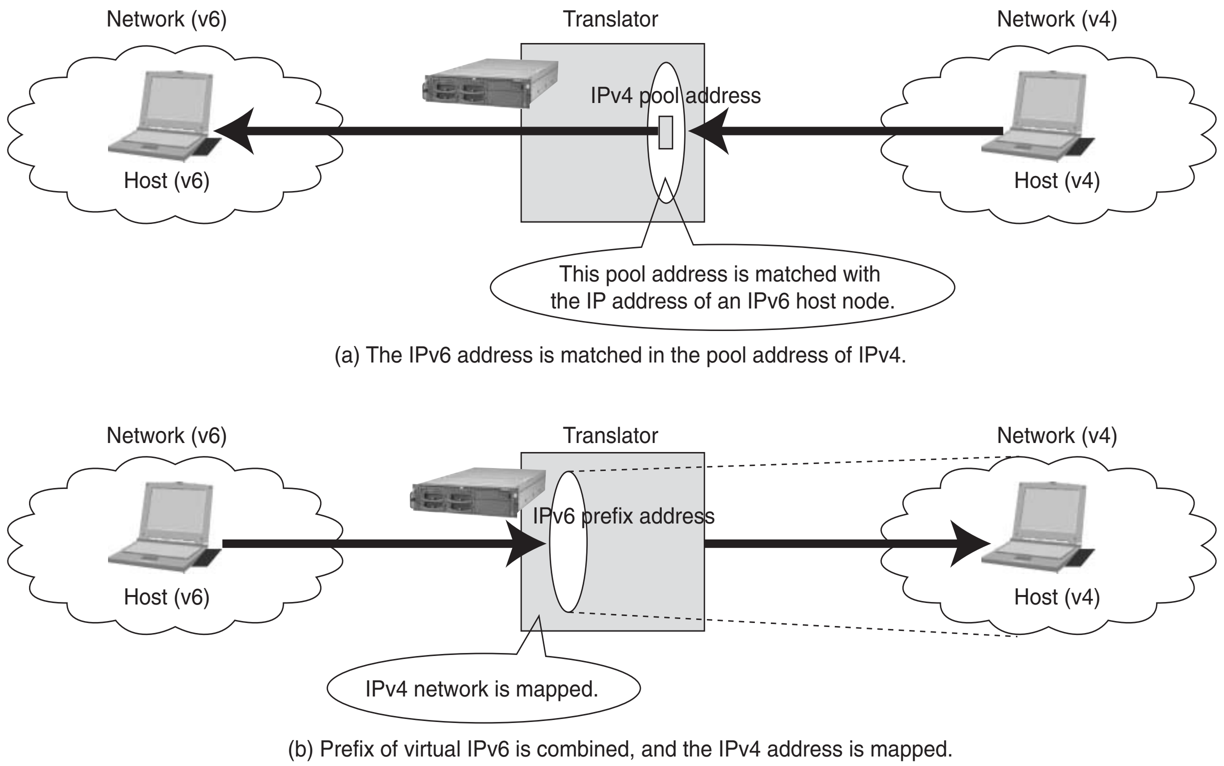


Figure 2
Address mapping.

one to an IP address of the IPv6 host node, and the translator is statically defined by these relationships. This is effective for a company intranet when sufficient private IP addresses can be assigned or an IP address can be fully secured or fixed based on the communication characteristics (e.g., the security and the direct address specification by IP address checking), because a pool address of IPv4 must match that of the IPv6 host node to be connected.

3.1.2 Dynamic mapping

When a client communicates with a connection partner by acquiring the connection partner's IP address via name resolution in DNS and by signaling control of SIP communication, and the versions of both IPs differ, the pool address of IPv4 and the IP address of the IPv6 host node are mapped dynamically. This mapping is released at the end of communication during a timeout.

This mapping is effective when an IP address must be used efficiently in large-scale networks (e.g., carrier networks) and Internet Database Connectors (IDCs) and when there are few IP addresses like global IP addresses that can be assigned. This is because IP addresses can be effectively used through dynamic mapping.

The following outlines name resolution by DNS that cooperates with DNS-Proxy.[4),5)] DNS-Proxy operates as the DNS server of a host node in name resolution by Fully Qualified Domain Name (FQDN). DNS-Proxy returns an IP address suitable for the demand type (a record indicating an IPv4 address or an AAAA record indicating an IPv6 address) of name resolution of a host node. **Figure 3** outlines the processing of name recognition by DNS-Proxy.

When an IPv4 host node requests the name resolution of, for example, "www.fujitsu.com" to DNS-Proxy at the start of communication with a Web server from an IPv4 host node (①), DNS-Proxy asks DNS for the applicable domain (②).

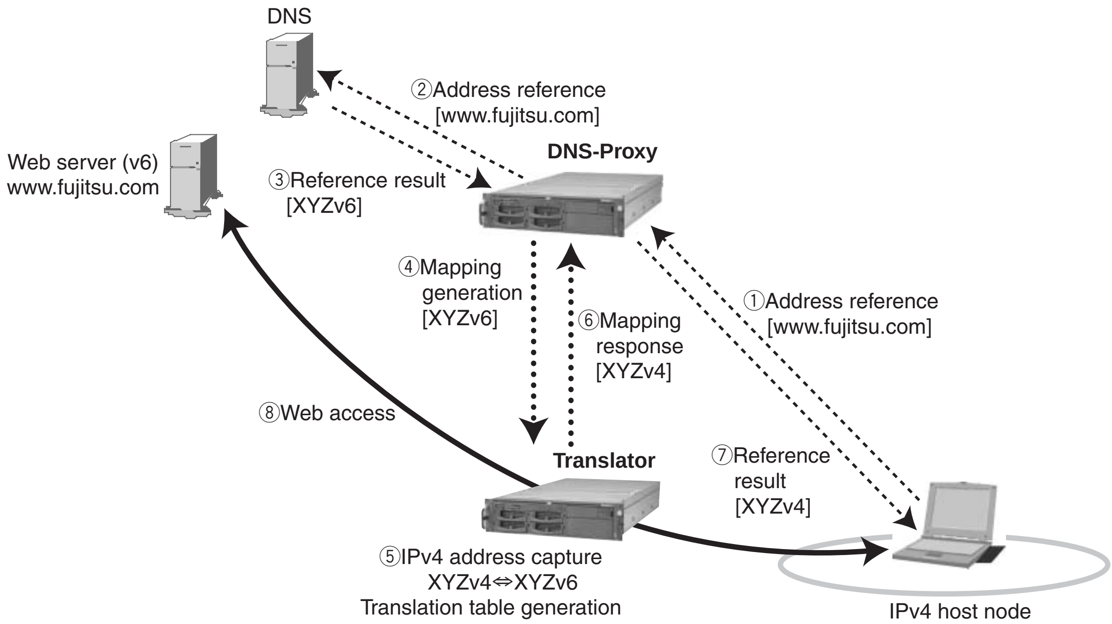


Figure 3
Name resolution by DNS-Proxy (IPv4→IPv6).

DNS returns the IP address of IPv6 as the name resolution result of "www.fujitsu.com" (③). DNS-Proxy requests mapping generation to the translator (④). After creating the translation table for the IP address of IPv6, the translator assigns the pool address of IPv4 to the IPv6 address reported by DNS-Proxy and sends the pool address to DNS-Proxy in response (⑤ and ⑥). DNS-Proxy returns a response for the pool address of IPv4 to the IPv4 host node as the name resolution result of "www.fujitsu.com" (⑦). The IPv4 host node initiates Web access using the pool address of IPv4, which is changed by the translator for translation (⑧).

No mapping generation request is sent to the translator from DNS-Proxy for name resolution from IPv6 to IPv4. This is because the result of name resolution (reported to the host node of IPv6) is generated by adding the IPv6 prefix of the translator to the IP address of IPv4 reported from the DNS IP address without completely corrupting the IPv4 address information. The translator can also perform translation of an IPv4 address by simply deleting the IPv6 prefix in the translation processing. Moreover, the source IPv4 address of the packet sent by the translator is dynamically assigned a vacant pool address when the translator receives a packet from the IPv6 host node.

3.2 Translation method

The translation technologies used to mutually connect the host node between IPv4 and IPv6 are listed below. Based on the applications and protocols to be relayed and the network composition, we considered it necessary to select a translation system and incorporate all three translation technologies.

1) Network Address Translation-Protocol Translation (NAT-PT)[6)]

According to the translation table in which the IP address of the IPv6 host node and the pool address in the translator match, the translation of an IP address and the IP header part was changed for both IPv4 and IPv6, along with the IP level relays. Moreover, to reserve a pool address for connection initiated in the IPv4 direction from IPv6, it is possible to use Network Address Port Translation (NAPT) that shares one source address between two or more IPv6 host nodes by changing the port number of each Transmission Control Protocol/User Datagram Protocol (TCP/UDP) connection.

When a host node transmits a large volume of data to another host node, the data is sent contiguously in the form of IP packets. For these IP packets, data should not be fragmented while it is sent from the source node to the destination node. However, the difference in IP header length of both protocols may exceed the Maximum Transmission Unit (MTU) of the translator due to the link on the boundary of an IPv4 network and IPv6 network. Therefore, although a relay node does not usually fragment IP packets in IPv6, the translator performs fragmentation instead of the source node.

Moreover, when the source node performs Path MTU Discovery,[7] exceeds MTU on the translator, and cannot transmit a packet to the following link, the translator returns Too Big messages of Internet Control Message Protocol (ICMP) Packet to the source node.

2) Transport Relay Translator (TRT)[8]

TRT establishes TCP connections with the client and host node on both sides (IPv4 and IPv6) and then serves as the termination of transport connection for each node. Unlike in the NAT-PT system, communication is managed according to the state of each transport connection.

TRT is required for the following reasons in a ubiquitous network that freely employs mobile communications, wireless LAN, and other radio-wave communication devices:

- TRT is not influenced by MTU.
- Communication parameters that suit the quality and performance of a given network can be selected.

3) Application Level Gateway (ALG)

For ALG, the specialized application process in the translator (gateway program) connects IPv4 with the host node of IPv6 in a higher level protocol. It also performs translation specific to the application.

In communications such as FTP communication and streaming, the IP address and port number information of the transport layer of a data session in the payload of a control session is conveyed. Since the translator must guarantee the permeability of an application level, it analyzes the data format of a payload and prepares an ALG that converts the IP address and port number information for all protocols.

Figure 4 shows the layers in which each translation method operates.

3.3 ICMP translation

To use network tools that use ICMP (e.g., Ping), protocol translation of IPv4 and IPv6 is also required. Although the same header format is used for ICMPv4 and ICMPv6,[9] the type and code information in the header that shows the packet classification are completely different. For this reason, this information is changed into values corresponding to the packet classification when each packet is translated. The Stateless IP/ICMP Translation Algorithm (SIIT)[10] prescribes the correspondence of values for type and code information.

3.4 VoIP translation coordinated with SIP-ALG

SIP[11] is the signaling control protocol used by Internet telephone (VoIP) types of communication that perform call control. The signaling control protocol is used (e.g., to call a partner and perform certification and codec negotiation for voice quality) as part of telephone call management, with voice data carried by data transmission protocols (e.g., RTP) for peer-to-peer communication between end nodes. In a telephone call via SIP, as in the case of calling connection from the calling side (UAC: User Agent Client) through an SIP server, the translator and nearby SIP-ALG (UAS: User Agent Server) cooperate to find a matching address. Consequently, it is possible to perform peer-to-peer communication between UAC and UAS when a voice telephone call is made.

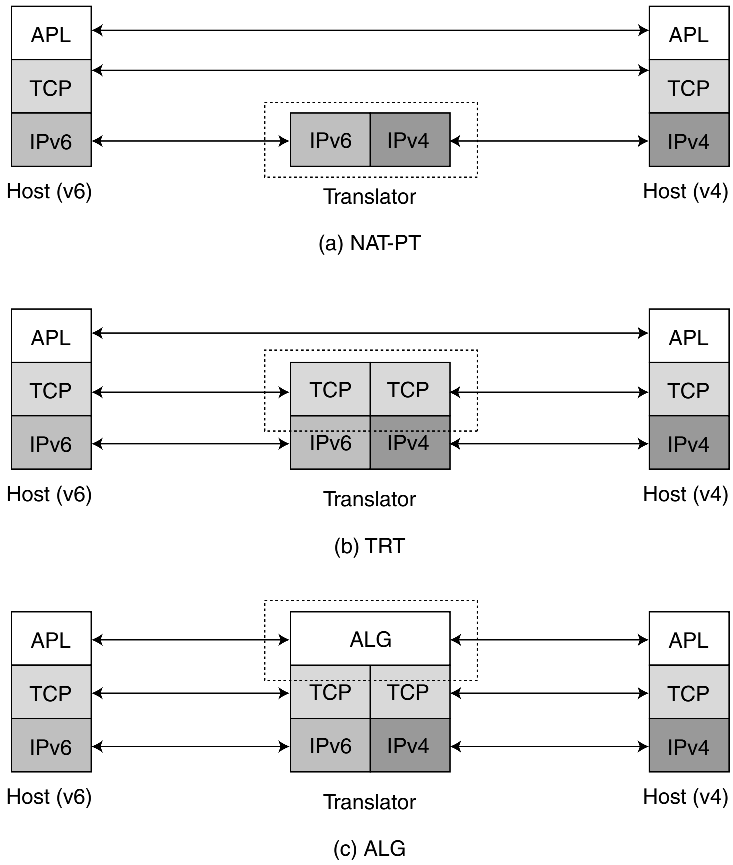


Figure 4
Translation methods.

Figure 5 outlines the processing of VoIP translation cooperation with SIP-ALG (GeoServe).[12]

GeoServe is a Fujitsu server software for providing an IP telephone service in an SIP base and represents the core of network communication services.

4. Scalability

If a bottleneck occurs at the translator due to an increase in network traffic, the translator is extended and its load distributed. Because translators can be added to the network environment without stopping cooperation with DNS-Proxy and SIP-ALG, there is a high degree of extendibility. After being incorporated, a translator becomes a candidate for cooperation, with DNS-Proxy and SIP-ALG periodically monitoring for translator failures. If a translator failure is detected, the translator that failed is separated, thereby avoiding a failure in communication. Moreover, a malfunctioning translator is automatically returned to the network after being restored.

In addition, translators cooperate with DNS-Proxy or SIP-ALG to distribute their load. Load information such as the rate of CPU usage by each translator and the number of connections is periodically reported to DNS-Proxy or SIP-ALG. A DNS-Proxy or SIP-ALG selects translators for cooperation based on this load information to balance the translators' load. The pool address and IPv6 prefix (assigned at signaling control by SIP) and name resolution of DNS-Proxy are selected for a translator with a low load. In this way, the packet-passing load is equalized.

Figure 6 outlines the processing of the load balancing function.

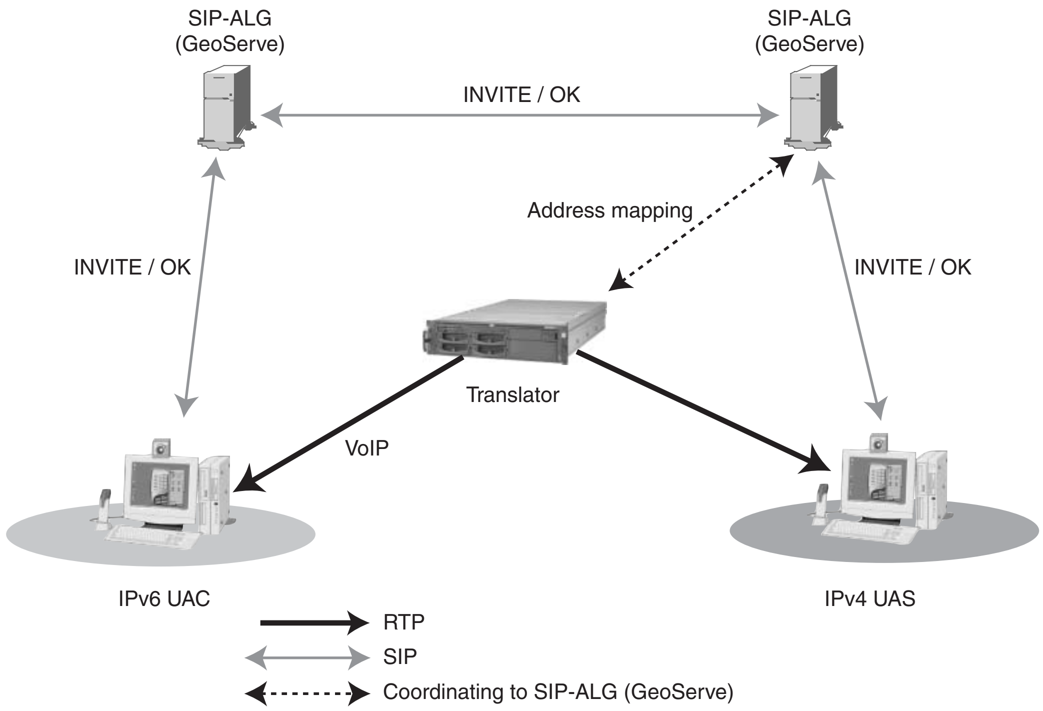


Figure 5
VoIP translation coordination with SIP-ALG.

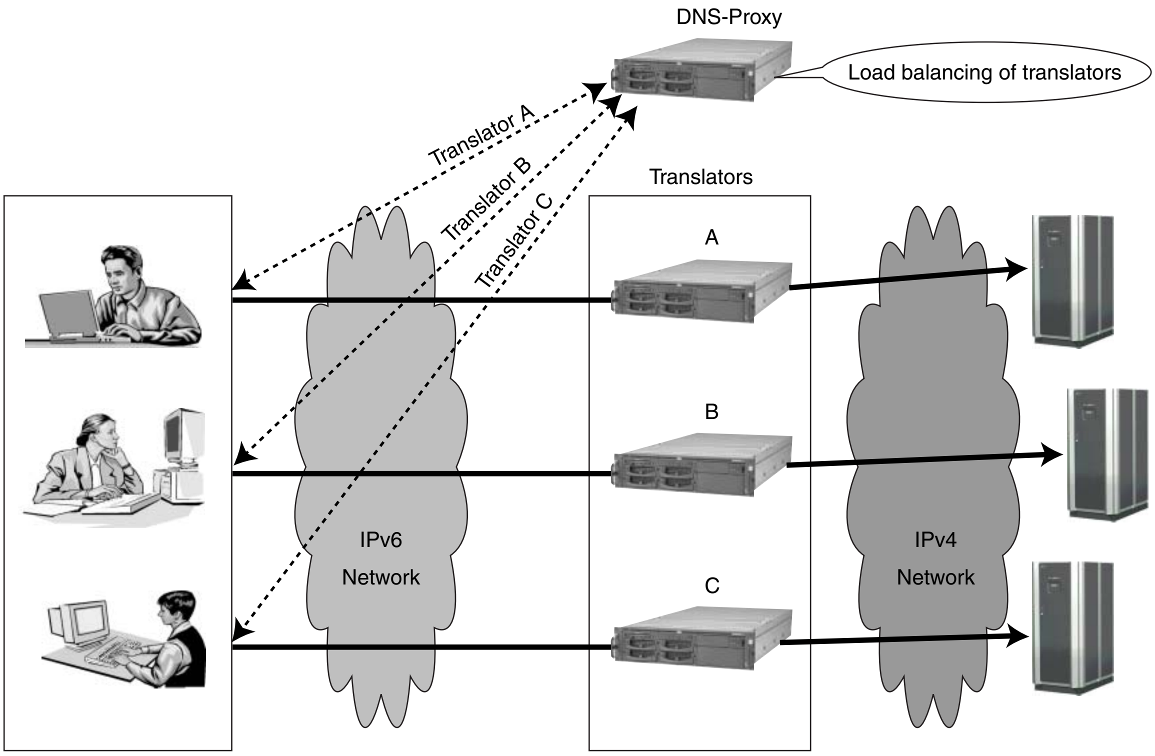


Figure 6
Load balancing function.

5. High reliability

When mutual surveillance performed with heartbeat messages between translators or self-surveillance detects a translation engine malfunction, the translator concerned is quickly switched to the standby system of the translator pair to allow processing to continue.

Figure 7 outlines hot-standby processing.

Thanks to the redundancy afforded by the Network Interface Card (NIC), if an NIC failure is detected, the NIC function is immediately switched to the standby system to allow communication to continue.

When the translation definition of a translator must be changed due to a system reconfiguration, it is unnecessary to stop the service, because the translators can be switched dynamically.

6. Translator components

The main components of a translator are the address management, translation engine, and high-reliance base (**Figure 8**).

1) Address management

This component matches the IPv6 address and IPv4 address and performs unitary management of the translation policy of various translation engines.

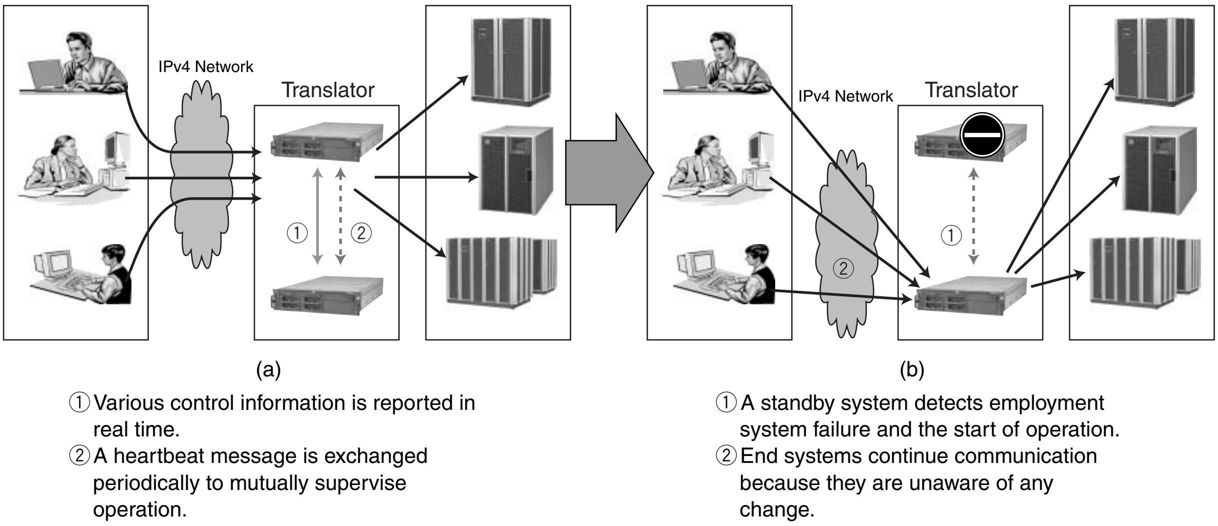


Figure 7
Hot standby.

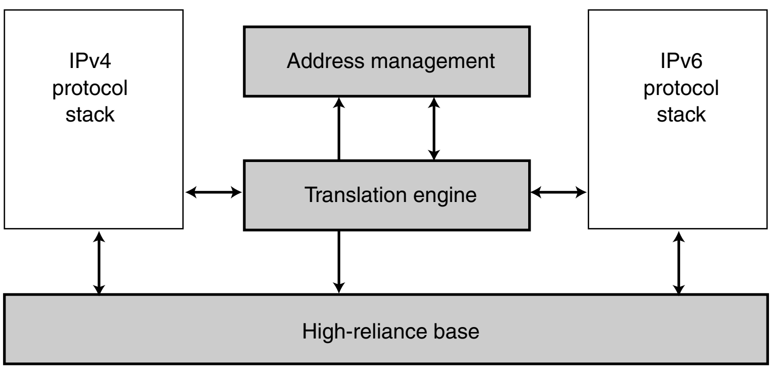


Figure 8
Components of translator.

2) Translation engine

This component performs translation control of various network protocols such as the IP header, transport header (UDP, TCP), and address information about a payload part.

3) High-reliance base

This component ensures the failure-proof nature of a translator and guarantees the continuity of service by hot standby and the NIC alternation function. The highly reliable engine of the IPCOM[13] series is used as the common base engine.

IPCOM provides various network functions (e.g., load balancing, bandwidth control, SSL) in cooperation with IP systems and points of contact between the Internet and intranets.

The translator implements the technology and functions described above, and also provides the fundamental translation function for correspondence between a low-level protocol and a higher level protocol, highly reliable functions, and employment/operation functions (**Table 1**).

7. Conclusion

The expected effects of introducing a translator are as follows:

1) The user can connect to an IPv4 network to use new services without being isolated from the ubiquitous world realized by IPv6.
2) Moreover, ubiquitous users can use the IPv6 network to access the abundant information accumulated in the IPv4 network and related services.

This paper described the technology for translating between an IPv4 network and an IPv6 network and the gateway construction involved in reserving scalability and reliability. The technology makes it possible to quickly provide compatibility with the next-generation network at low cost and low risk without needing to change the users' existing IPv4 properties, resulting in upgraded (modernized) user properties.

We took up the challenge of establishing a convergence technology for guaranteeing existing user assets and new services that are compatible with the key technologies and functions of a ubiquitous network.

The technology described in this paper incorporates some of the results from a sponsored research entitled "Research and Development of Large-Scale IPv4/IPv6 Mixture Network System Construction Technology" of the National Institute of Information and Communications Technology (NICT).

Table 1
Translator functions.

Item		Contents
Translation functions	Translation system	NAT, TRT, ALG
	Translation direction	IPv6→IPv4, IPv4→IPv6
	Standard protocol for translation	TCP, UDP, ICMP, http, ftp, telnet, etc.
	Optional function	VoIP, Streaming, Mobile-IP (Reverse tunnel)
	Cooperation with other equipment	DNS-Proxy, SIP-ALG
High-reliability functions/ scalability	Communication course change	NIC change
	Hot standby	Translator, DNS-Proxy
	Load distribution	DNS-Proxy cooperation, SIP-ALG cooperation
Employment operations	Definition	Dynamic change
	Operation	Command Line Interface (CLI)
	Maintenance	Log, Cooperation with network surveillance equipment

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