IPv4 Address Sharing Technology in the IPv6 Era

We examine the characteristics of "stateful" and "stateless" address sharing technologies, and discuss the current state of IPv4 address sharing technology based on our experience with experimental implementation of 4rd using SEIL*[1] series routers that we presented in IIR Vol.13*[2].

3.1 A Post IPv4 Address Exhaustion World

As has already been announced, the pool of IPv4 addresses at the IANA (Internet Assigned Numbers Authority)*[3] was exhausted on February 3, 2011. Following this, addresses at the Asian RIR (Regional Internet Registry) APNIC were exhausted on April 15, 2011. The measures suggested by JPNIC*[4] in response to this consist of the following three pillars:

1. Promote the efficient use of allocated IPv4 addresses
2. Use NAT technology to accommodate new hosts without using global addresses
3. Implement IPv6 to accommodate new hosts

The third measure, migration to IPv6, is considered the ultimate solution. However, most business is currently conducted over IPv4, so the first and second measures are urgently required. Regarding the first measure, address space is being actively consolidated at organizations with a large number of addresses, and address blocks of a certain size can now be transferred between organizations. In cases where a global address is really required, it is likely that this framework will be used. This will require more time and money than in the past, but once an address is acquired there is little difference. For client use it may be possible to connect to the Internet while keeping consumption of global addresses to a minimum by applying the second measure.

3.2 Stateful vs. Stateless

CGN/LSN*[5] is the oldest form of IPv4 large-scale address sharing technology. With CGN/LSN an ISP can minimize IPv4 global address consumption by allocating private addresses after NAT conversion, instead of directly allocating IPv4 global addresses. The IPv4 access network-based "NAT444*[6]" and the IPv6 access network-based "DS-Lite*[7]" are becoming accepted as standard CGN/LSN usage models.

A number of "stateless" approaches to this CGN/LSN group of technologies have been proposed, and are discussed on a regular basis. I am sure many of you have heard of the broad categorization of methods as either stateful or stateless. Currently a large number of stateless methods have been proposed, and although the details of standardization have still not been hammered out, some form of standard will no doubt be agreed upon.

In this report we examine the characteristics of stateful methods including CGN/LSN and stateless methods such as 4rd based on experience gained through experimental implementation of 4rd using SEIL series routers that we presented in IIR Vol.13. We also discuss the current state of IPv4 address sharing technology from the perspective of a developer of routers.

*1 Portal site for the "SEIL" high-performance routers developed by IIJ using its expertise as an ISP (http://www.seil.jp/) (in Japanese).
*2 IIR Vol.13 "Internet Topics: 4rd Proof-of-Concept Tests for IIJ's Proprietary "SEIL" Routers" (http://www.iij.ad.jp/en/company/development/iir/pdf/iir_vol13_topic_EN.pdf).
*3 A faculty for managing and regulating the Internet resources operated by ICANN.
*4 "Regarding the exhaustion of IPv4 addresses" (http://www.nic.ad.jp/ja/ip/ipv4pool/) (in Japanese).
*5 CGN = Carrier Grade NAT, LSN = Large Scale NAT. A system for conducting the NAT conversion of IPv4 addresses at an ISP. CGN and LSN are two separate terms that refer to the same technology.
*6 "NAT444 addressing models draft-shirasaki-nat444-isp-shared-addr-07" (http://tools.ietf.org/html/draft-shirasaki-nat444-isp-shared-addr-07).
*7 "Dual-Stack Lite Broadband Deployments Following IPv4 Exhaustion" (http://tools.ietf.org/html/rfc6333).

3.3 An Attempt to Compare Methods

When comparing IPv4 address sharing technologies, methods are often categorized as either stateful or stateless. However, these categories are not always sufficient when comparing the details of each technology. For this reason it is common to also take into account the following factors when comparing technologies in detail.

• Where will the NAT device be placed?
• How will communicating entities be identified?
• What communication method will be used between customers?
• What packet format will be used?

3.3.1 Considering NAT Device Placement

NAT device placement (Figure 1) is the closest measure for the classification of stateless and stateful methods. NAT devices can be placed on the ISP side, on the customer's network, or both. When NAT devices are placed on the ISP side, the ISP must manage a vast amount of shared resources, but they are able to exert fine control. Placing the NAT device on the customer's network simplifies resource management for the ISP, but at the same time reduces flexibility.

3.3.2 Considering Methods for Identifying Communicating Entities

When unauthorized access is detected, it is important for ISPs and server administrators to be able to identify the entity causing the issue from logs. When address sharing is used the communicating entity cannot be identified simply from IP address records, so a system that makes it possible to track who was using a specific port number is required.

When using a stateful method NAT session information is required for this process, while for a stateless method static allocation rules are all that is needed. This is one of the most significant differences between the two methods.

3.3.3 Considering Methods for Communications Between Customers

The methods available for communications between customers are of particular importance for P2P communications such as IP telephony. P2P communications technology is inherently incompatible with NAT, but its use has now been made practical due to various NAT bridging technology. If this existing NAT bridging technology can continue to be used, we can expect communications to become more efficient. Network usage efficiency and user comfort will change significantly based on whether a remote conference application operates in P2P communications mode or via an intermediate server.

3.3.4 Considering Packet Format

Broadly speaking, packet format options include transferring IPv4 packets as-is over an IPv4 network, translating them to IPv6 for transfer over an IPv6 network, or encapsulating them into IPv6 packets for transfer over an IPv6 network. When IPv6 is used, even if IPv4 addresses overlap, packets can be delivered to the right network based on IPv6 address information. This allows for more flexible placement of NAT devices.

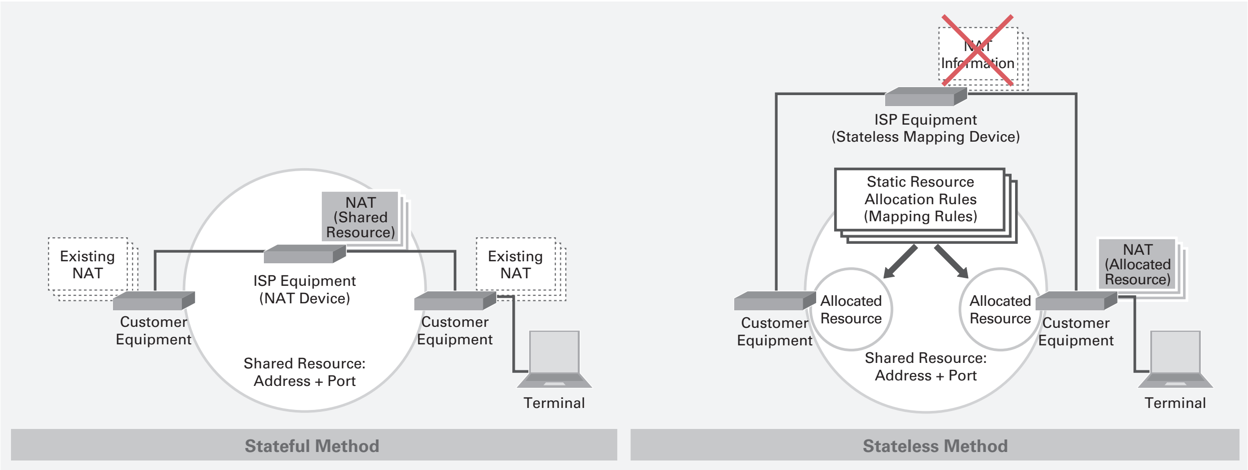

Figure 1: NAT Device Placement

3.4 An Overview of Stateful Methods

We have selected NAT444 and DS-Lite for comparison as examples of the address sharing methods categorized as stateful (Table 1).

3.4.1 Stateful Method Example: DS-Lite

DS-Lite is a technology based on CGN/LSM that uses an IPv6 access network. An ISP's CGN/LSN device and the CPE are connected using IPv4 over IPv6 tunneling. NAT conversion including the IPv6 global address is carried out as shown in Table 2.

Packets transferred from the CPE to the access network are encapsulated using IPv6, so there is no need for NAT at the CPE. Packets returned from the Internet are encapsulated inside IPv6 packets using the IPv6 global address recorded in the NAT session. The CPE can be identified by the IPv6 address, so the private address for the CPE can overlap within the ISP.

3.5 An Overview of the Stateless Method

Currently a large number of stateless methods have been proposed in parallel, and it is not known which will ultimately emerge as a standard. Here we examine the methods touched upon at IETF 82 in November 2011 (Table 3).

Table 1: Address Sharing Methods (NAT444, DS-Lite)

Method	Access Network	NAT	Identification of Communicating Entity	Communication Between Customers	Packet Format
NAT444	IPv4	ISP, customer	Referencing NAT session information	Via ISP device*8	IPv4 native
DS-Lite	IPv6	ISP	Referencing NAT session information	Via ISP device*9	IPv4 over IPv6 tunnel*10

Table 2: NAT Conversion

Private Side (CPE)	Global Side (IPv4 Internet)
IPv6 global address IPv4 private address Port number	IPv4 global address Port number

Table 3: Stateless Methods

Method	Access Network	NAT	Identification of Communicating Entity		Communication Between Customers	Packet Format
4rd-E*11	IPv6	Customer	Static rules	• Prefix × 2 • Integer × 1	Connection possible	IPv4 over IPv6 tunnel
4rd-U*12	IPv6	Customer	Static rules	• Prefix × 2 • Integer × 1	Connection possible	IPV4 - IPv6 double translation w/ IPv6 option header
SA46T-AS*13	IPv6	Customer	Static rules	• Integer × 2	Connection possible	IPv4 over IPv6 tunnel
dIVI*14	IPv6	Customer	Static rules	• Integer × 2	Connection possible	IPv4-IPv6 double translation
SD-NAT*15	IPv4 IPv6	Customer (ISP)	Static rules	• Address × 2 • Integer × 2	Via ISP device	IPv4 native IPv4 over IPv6 tunnel
Stateless 4over6*16	IPv6	Customer	Static rules	• dIVI compliant	Via ISP device*17	IPv4 over IPv6 tunnel

*8 However, it is difficult to apply existing NAT bridging technology because multiple NAT layers are used.
*9 Extended specifications are also being standardized.
*10 A specific packet format is not assumed, but in typical cases a simple IPv4 over IPv6 tunnel is used.
*11 http://tools.ietf.org/html/draft-murakami-softwire-4rd-01
*12 http://tools.ietf.org/html/draft-despres-softwire-4rd-u-02
*13 http://tools.ietf.org/html/draft-matsuhira-sa46t-as-02
*14 http://tools.ietf.org/html/draft-xli-behave-divi-04
*15 http://tools.ietf.org/html/draft-penno-softwire-sdnat-01
*16 http://tools.ietf.org/html/draft-sun-softwire-stateless-4over6-00
*17 A route optimization device can also be added.

Stateless methods identify communicating entities by referencing rules statically determined by the ISP. This reduces operational costs because a record of NAT sessions is not needed. Currently the various methods are differentiated by their approach to defining rules, but there have also been moves to create a standard that is separate from individual methods.

3.5.1 Stateless Method Example: 4rd (4rd-E)

Here we take a quick look at the specific behavior of system operation using 4rd (4rd-E), stateless method, which is currently undergoing experimental implementation via SEIL.

When using 4rd, the CPE (CE in 4rd terms) is connected to an IPv6 access network, and an IPv6 global address is assigned. At the same time, the CPE is also assigned an IPv4 global address and a range of port numbers available for IPv4 communications. A customer identifier (EA-bits) is embedded in part of the IPv6 address that is assigned. Similarly, an identifier that covers the IPv4 global address and port numbers is also embedded. The static relationship between the identifier (EA-bits), the IPv6 global address, the IPv4 global address, and the port numbers serves as the mapping rules for 4rd. The IPv4 global address may be shared between different CPE, but when combined with the port numbers each unique CPE can be identified.

It is generally not possible to select a route by referencing port numbers on an IPv4 network. For this reason, IPv6 is used for packet delivery over 4rd. As mentioned above there is a static relationship between the CPE's combination of IPv4 address and port numbers and the IPv6 address, so by encapsulating packets using the post-conversion IPv6 address it is possible to perform route selection based on IPv4 packet port numbers.

■ **NAT with 4rd**

An IPv4 global address and port numbers are allocated to the CPE. NAT (NAPT) is used when sharing these resources between CPE terminals. Unlike standard IPv4 NAT, there are restrictions on the port numbers that can be allocated. Other than this point, there are no differences with existing NAT.

■ **Server Log Analysis**

To identify the communicating entity from the IP address and port numbers recorded on the server, the mapping rules and IPv6 allocation information are required. The former is a set value unique to the access network, and does not change dynamically. The latter can be determined by referring to the connection log for the access network. Connection logs can be managed using the same system as current IPv4 connection logs.

3.6 Conclusion

Here I have given a brief explanation of the distinguishing characteristics of IPv4 address sharing technology. There are likely to be many changes due to forthcoming standardization, but I hope that this report provides some food for thought regarding future IPv4 environments.

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